

# GMAT User Guide R2025a

general mission analysis tool

# **General Mission Analysis Tool (GMAT)**

## **User Guide**

**The GMAT Development Team**

**R2025a**

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## **General Mission Analysis Tool (GMAT): User Guide**

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# Documentation Overview

Welcome, and thank you for using GMAT! This User Guide contains a wealth of material to introduce you to GMAT and how it works. It also provides an extensive Reference Guide that contains data on every Resource, Command, and major subcomponent in the system.

## Using GMAT

The [Using GMAT](#) chapter contains high level and introductory information on the system. If you need information on how to install and run the system, would like a tour of the system, want know how to configure data files, or how GMAT is organized, start here.

The [Using GMAT](#) section provides general information on GMAT and how to use the software.

The [Welcome to GMAT](#) contains a brief project and software overview, including project status, licensing, and contributors.

The [Getting Started](#) section describes how to get and install GMAT, how to run the provided samples, and where to turn for further help.

The [Tour of GMAT](#) is an in-depth guide through some of the key interface features, including the Resources tree, Mission tree, Command Summary, and Script Editor.



### Note

We consider the [User Interfaces Overview](#) section to be essential reading, as it describes some fundamental aspects of how GMAT works.

## Tutorials

The [Tutorials](#) section contains in-depth tutorials that show you how to use GMAT for end-to-end analysis. The tutorials are designed to teach you how to use GMAT in the context of performing real-world analysis and are intended to take between 30 minutes and several hours to complete. Each tutorial has a difficulty level and an approximate duration listed with any prerequisites in its introduction, and are arranged in a general order of difficulty.

Here is a summary of selected Tutorials. For a complete list of tutorials see the [Tutorials](#) chapter.

The [Simulating an Orbit](#) tutorial is the first tutorial you should take to learn how to use GMAT to solve mission design problems. You will learn how to specify an orbit and propagate to orbit periapsis.

The [Mars B-Plane Targeting](#) tutorial shows how to perform targeting by application to a Mars transfer trajectory where you will target desired B-plane conditions at Mars.

The *Target Finite Burn to Raise Apogee* tutorial shows how to use finite maneuvers with an application to orbit apogee raising.

The *Finding Eclipses and Station Contacts* tutorial shows how to use GMAT to locate ellipses and station contacts.

The *Electric Propulsion* tutorial shows how to configure GMAT to model electric propulsion systems.

The *Mars B-Plane Targeting Using GMAT Functions* tutorial shows how to use GMAT functions to extend your analysis.

## Reference Guide

The *Reference Guide* contains individual topics that describe each of GMAT's resources and commands. When you need detailed information on syntax or application-specific examples for specific features, go here. It also includes system-level references that describe the script language syntax, parameter listings, external interfaces, and configuration files.



### Note

This document uses two typographical conventions throughout:

- Graphical user interface (GUI) elements and resource and command names are presented in **bold**.
- Filenames, script examples, and user input are presented in monospace.

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# Using GMAT

The [\*Using GMAT\*](#) chapter contains high level and introductory information on the system. If you need information on how to install and run the system, would like a tour of the system, want know how to configure data files, or how GMAT is organized, start here.

The [\*Welcome to GMAT\*](#) contains a brief project and software overview, including project status, licensing, and contributors.

The [\*Getting Started\*](#) section describes how to get and install GMAT, how to run the provided samples, and where to turn for further help.

The [\*Tour of GMAT\*](#) is an in-depth guide through some of the key interface features, including the Resources tree, Mission tree, Command Summary, and Script Editor.

The [\*Configuring GMAT\*](#) describes the contents of them GMAT installation directory tree and provides instructions on configuring GMAT to connect with MATLAB, Python, and custom user code.



## Note

We consider the [\*User Interfaces Overview\*](#) section to be essential reading, as it describes some fundamental aspects of how GMAT works.

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# Welcome to GMAT

The General Mission Analysis Tool (GMAT) is the world's only enterprise, multi-mission, open source software system for space mission design, optimization, and navigation. The system supports missions in flight regimes ranging from low Earth orbit to lunar, libration point, and deep space missions. GMAT is developed by a team of NASA, private industry, public, and private contributors and is used for real-world mission support, engineering studies, as a tool for education, and public engagement. See the release notes for a complete list of changes in this version.

## Features Overview

GMAT is a feature rich system containing high fidelity space system models, optimization and targeting, built in scripting and programming infrastructure, and customizable plots, reports and data products, to enable flexible analysis and solutions for custom and unique applications. GMAT can be driven from a fully featured, interactive GUI, from a custom script language or via API. Here are some of GMAT's key features broken down by feature group.

### Dynamics and Environment Modeling

- High fidelity dynamics models including harmonic gravity, drag, tides, attitude dependent drag and SRP, N-plate SRP, and relativistic corrections
- High fidelity spacecraft modeling
- Formations and constellations
- Impulsive and finite maneuver modeling and optimization of low and high thrust systems
- Propulsion system modeling including chemical and electric thrusters
- Solar System modeling including high fidelity ephemerides, custom celestial bodies, libration points, and barycenters
- Rich set of coordinate systems including J2000, ICRF, fixed, rotating, topocentric, and many others
- Propagation using CCSDS, SPICE, STK, and Code 500 ephemeris files
- Propagators that naturally synchronize epochs of multiple vehicles and avoid fixed step integration and interpolation

### Plotting, Reporting and Product Generation

- Interactive 3-D graphics
- Customizable data plots and reports
- Post computation animation
- CCSDS, SPK, and Code-500 ephemeris generation
- Eclipse and station contact location

### Optimization and Targeting

- Boundary value targeters
- Nonlinear, constrained optimization
- High order collocation

- Custom, scriptable cost functions
- Custom, scriptable nonlinear equality and inequality constraint functions
- Custom targeter controls and constraints

## Programming Infrastructure

- User defined variables, arrays, and strings
- User defined equations using MATLAB syntax. (i.e. overloaded array operation)
- Control flow such as If, For, and While loops for custom applications
- Matlab interface
- Python interface
- User-defined functions (sub-routines)
- Built in parameters and calculations in multiple coordinate systems

## Orbit Determination Infrastructure

- Batch estimator
- Extended Kalman Filter and Smoother
- Extensive statistical results reporting
- DSN, GN, TDRS, GPS point solution, and angle data types
- Measurement data editing
- Media corrections
- Process noise modeling
- Error modeling
- Initial Orbit determination (IOD) routines
- Covariance propagation using the **Propagate** command

## Interfaces

- Fully featured, interactive GUI that makes simple analysis quick and easy
- Custom scripting language that makes complex, custom analysis possible
- Matlab interface for custom external simulations and calculations
- Python interface for custom external simulations and calculations
- File interface for the TCOPS Vector Hold File format, for loading of initial spacecraft data
- Python, MATLAB, and JAVA APIs.
- Command line interface for batch analysis

## Heritage

GMAT has enabled and enhanced missions in nearly every NASA flight regime including enabling new mission types, extending the life of existing missions, and enabling new science observations. GMAT has supported in excess of 8 NASA missions and 10+ NASA proposal efforts. The system has experienced broad application and adoption around the world. To date, GMAT has been used by over 30 organizations, with 15 universities and 12 commercial firms publishing results in the open literature.

## Licensing

GMAT is licensed under the Apache License 2.0.

## Platform Support

GMAT has been rigorously tested on the Windows 11 platform and we perform nightly regression tests running more than 17,000 test cases for the system core and over 4000 test cases for the GUI interface. The Mac and Linux console versions are rigorously tested, but the GUI is provided in Beta form on those platforms.



### Note

GMAT on macOS is not a notarized application. The GMAT folder must be installed either to the system-wide /Applications folder or to the user's ~/Applications folder. The latter is useful for users without admin access to their Mac.

The following plugin modules do not run under this release of GMAT on Mac and Linux platforms:

- Optimizer libFmincon

and the Mac release does not support the following plugin:

- libMsise86

## Component Status

GMAT is distributed with production and Alpha/Beta components. Components that are in Alpha/Beta status are turned off by default. The status of plugin components is shown below.

Production quality plugin components:

- libDataInterface
- libEphemPropagator
- libEventLocator
- libFormation
- libGmatFunction
- libNewParameters
- libPythonInterface\_py39
- libStation
- libGmatEstimation
- libMatlabInterface
- libFminconOptimizer
- libProductionPropagators
- libScriptTools
- libYukonOptimizer
- libOpenFramesInterface
- libThrustFile
- libEKF
- libTLEPropagator

Alpha quality plugin components:

- libExtraPropagators
- libPolyhedronGravity
- libSaveCommand
- libExternalForceModel\_py39

Internal-only plugins (not included in public releases):

- proprietary/libMarsGRAM
- proprietary/libMsise86
- proprietary/libNRLMsise00
- proprietary/libSNOptimizer
- proprietary/libVF13Optimizer
- proprietary/libEMTGModels
- proprietary/libCSALTInterface

Third-party plugins (developed and maintained by external contributors):

- libOpenFramesInterface [Emergent Space Technologies, Inc.]

## Contributors

The Navigation and Mission Design Branch at NASA's Goddard Space Flight Center performs project management activities and is involved in most phases of the development process including requirements, algorithms, design, and testing. The Ground Software Systems Branch performs design, implementation, and integration testing. External participants contribute to design, implementation, testing and documentation. We use a collaborative development model that enables innovation and actively involves the public and private sector having seen contributions from 12 commercial firms. External participants for this release include:

- Thinking Systems, Inc. (system architecture and all aspects of development)
- Omitron Pearl River, Inc (testing, requirements, specifications, development)
- Emergent Space Technologies, Inc. (graphics, OD)

Past commercial and external contributors to GMAT include:

- Air Force Research Lab (all aspects of development)
- Omitron Inc. (algorithms and testing)
- Boeing (algorithms and testing)
- The Schafer Corporation (all aspects of development)
- Honeywell Technology Solutions (testing)
- Computer Sciences Corporation (requirements)
- Korea Aerospace Research Institute
- Chonbuk National University, South Korea
- Korea Advanced Institute of Science and Technology
- Yonsei University, South Korea

The NASA Jet Propulsion Laboratory (JPL) has provided funding for integration of the SPICE toolkit into GMAT. Additionally, the European Space Agency's (ESA) Ad-

vanced Concepts team has developed optimizer plug-ins for the Non-Linear Programming (NLP) solvers SNOPT (Sparse Nonlinear OPTimizer) and IPOPT (Interior Point OPTimizer).



# Getting Started

## Installation

Application bundles are available on the GMAT SourceForge project page, located at <https://sourceforge.net/projects/gmat>.

The following packages are available for the major platforms:

Operating System	Binary bundle	Source code
Windows	✓	✓
macOS	✓	✓
Linux	✓	✓

### Binary Bundle

A binary bundle is available on Windows as a .zip archive. To use it, unzip it anywhere in your file system, making sure to keep the folder structure intact. To run GMAT, run the bin\GMAT.exe executable in the extracted folder.

The MacOS binary bundle is available as a signed DMG file. To use it, install the image in either the global Applications folder (requires administrative access) or in your user account's Applications folder. To run the production quality GMAT console application, open a terminal, change directory to the GMAT bin/ folder, and run the GmatConsole application. To run the Beta level GMAT GUI, run the GMAT-R2025a\_Beta.app application in the bin/ folder.

The Linux builds for GMAT are packaged in compressed tarballs. Download either the Red Hat or Ubuntu tarball, extract the contents in a convenient location (preserving the file system structure), and GMAT will be available for use. To run the production quality console application, open a terminal, change directories to your release bin/ folder, and run the GmatConsole application. The beta quality GMAT GUI, GMAT\_Beta can also be run from this folder. (Note that the GMAT Linux builds follow the Linux custom of placing support libraries in a lib folder parallel to the bin folder. You may need to load that folder by setting LD\_LIBRARY\_PATH as part of your launch process.)

### Source Code

GMAT is available as a platform-independent source code bundle. See the [GMAT Wiki](#) for compiling instructions.

The release snapshot of the GMAT code is available from the Git repository at SourceForge:

<https://git.code.sf.net/p/gmat/git>

There are tags available in the repository for each release.

## Running GMAT

### Starting GMAT

If you installed GMAT from a .zip file or by compiling the system, locate the GMAT bin directory double-click GMAT.exe.

To start GMAT from the command line, run GMAT.exe. Various command-line parameters are available; see [Command-Line Usage](#) for details.



#### Note

GMAT on macOS is not a notarized application. The GMAT folder must be installed either to the system-wide /Applications folder or to the user's ~/Applications folder. The latter is useful for users without admin access to their Mac.

### Exiting GMAT

To end a GMAT session on Windows or Linux, in the menu bar, click **File**, then click **Exit**. On macOS, in the menu bar, click **GMAT**, then click **Quit GMAT**, or type **Command+Q**.

## Sample Missions

The GMAT distribution includes more than 30 sample missions. These samples show how to apply GMAT to problems ranging from the Hohmann transfer to libration point station-keeping to trajectory optimization. To locate and run a sample mission:

1. Open GMAT.
2. On the toolbar click **Open**.
3. Navigate to the samples folder located in the GMAT root directory.
4. Double-click a script file of your choice.
5. Click **Run** (▶).

Some optimization missions require MATLAB, the MATLAB optimization toolbox, the VF13 optimizer, or the Yukon optimizer. Some of these are proprietary libraries and are not distributed with GMAT. For sample missions employing optimizers that are not available to you, you may try substituting the Yukon optimizer which comes with GMAT. The MATLAB **fmincon** optimizer currently only works with GMAT on the Windows platform. See [MATLAB Interface](#) for details on configuring the MATLAB optimizer.

## Getting Help

This User Guide provides documentation and tutorials for all of GMAT's feature. But if you have further questions, or want to provide feedback, here are some additional resources:

- Wiki: <https://gmat.atlassian.net/wiki/spaces/GW/overview>

- 
- Downloads and source code: <http://sourceforge.net/projects/gmat>
  - Submit bug reports and feature requests: <https://gmat.atlassian.net/browse/GMT/issues/?filter=allissues>
  - Official contact: <[gmat-developers@lists.sourceforge.net](mailto:gmat-developers@lists.sourceforge.net)>



# Tour of GMAT

## User Interfaces Overview

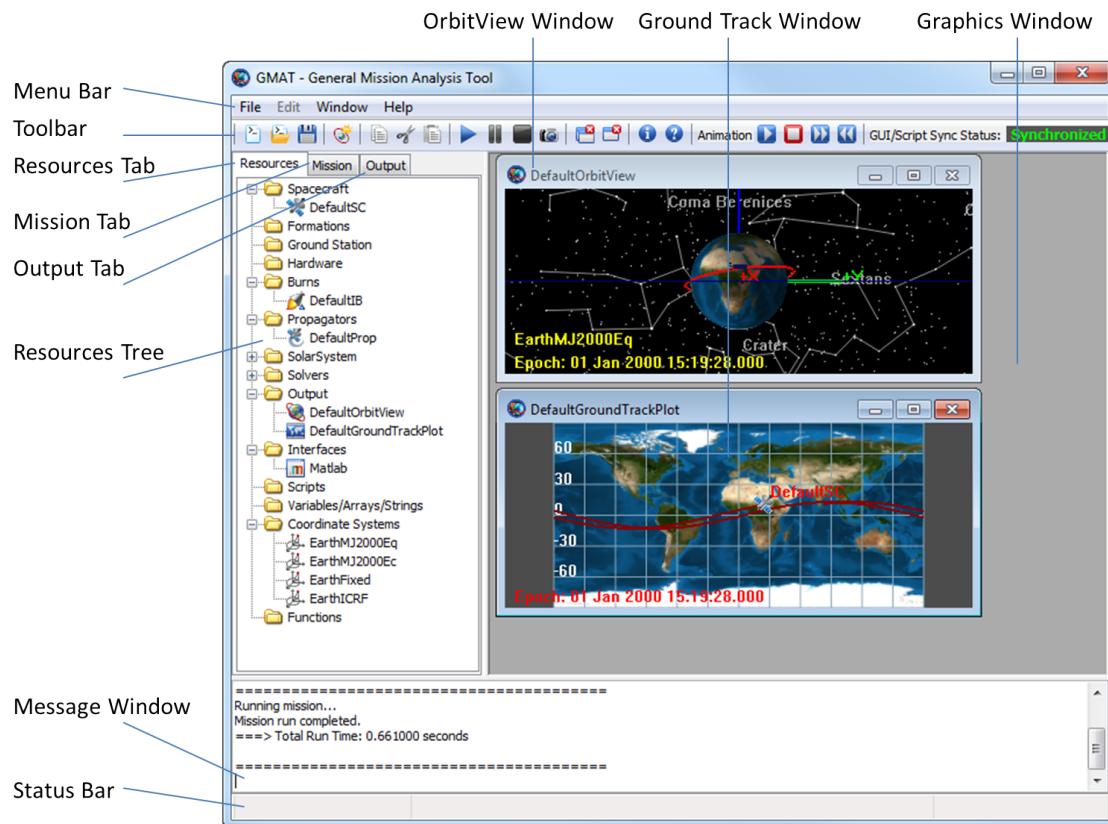
GMAT offers multiple ways to design and execute your mission. The two primary interfaces are the graphical user interface (GUI) and the script interface. These interfaces are interchangeable and each supports most of the functionality available in GMAT. When you work in the script interface, you are working in GMAT's custom script language. To avoid issues such as each of the two interfaces depending on the other (a circular dependency), there are some basic rules you must follow. Below, we discuss these interfaces and then discuss the basic rules and best practices for working in each interface.

### GUI Overview

When you start a session, the GMAT desktop is displayed with a default mission already loaded. The GMAT desktop has a native look and feel on each platform and most desktop components are supported on all platforms.

### Windows GUI

When you open GMAT on Windows and click **Run** in the Toolbar, GMAT executes the default mission as shown in the figure below. The tools listed below the figure are available in the GMAT desktop.



**Figure 1. GMAT Desktop (Windows)**

**Menu Bar**

The menu bar contains **File**, **Edit**, **Window** and **Help** functionality.

On Windows, the **File** menu contains standard **Open**, **Save**, **Save As**, and **Exit** functionality as well as **Open Recent**. The **Edit** menu contains functionality for script editing when the script editor is active. The **Window** menu contains tools for organizing graphics windows and the script editor within the GMAT desktop. Examples include the ability to **Tile** windows, **Cascade** windows and **Close** windows. The Help menu contains links to **Online Help**, **Tutorials**, and the **Report An Issue** option links to GMAT's defect reporting system, the **Welcome Page**, and a **Provide Feedback** link.

**Toolbar**

The toolbar provides easy access to frequently used controls such as file controls, **Run**, **Pause**, and **Stop** for mission execution, and controls for graphics animation. On Windows and Linux, the toolbar is located at the top of the GMAT window; on the Mac, it is located on the left of the GMAT frame. Because the toolbar is vertical on the Mac, some toolbar options are abbreviated.

GMAT allows you to simultaneously edit the raw script file representation of your mission and the GUI representation of your mission. It is possible to make inconsistent changes in these mission representations. The **GUI/Script Sync Status** indicator located in the toolbar shows you the state of the two mission representations. See the [the section called “GUI/Script Interactions and Synchronization”](#) section for further discussion.

**Resources Tab**

The **Resources** tab brings the **Resources** tree to the foreground of the desktop.

**Resources Tree**

The **Resources** tree displays all configured GMAT resources and organizes them into logical groups. All objects created in a GMAT script using a **Create** command are found in the **Resources** tree in the GMAT desktop.

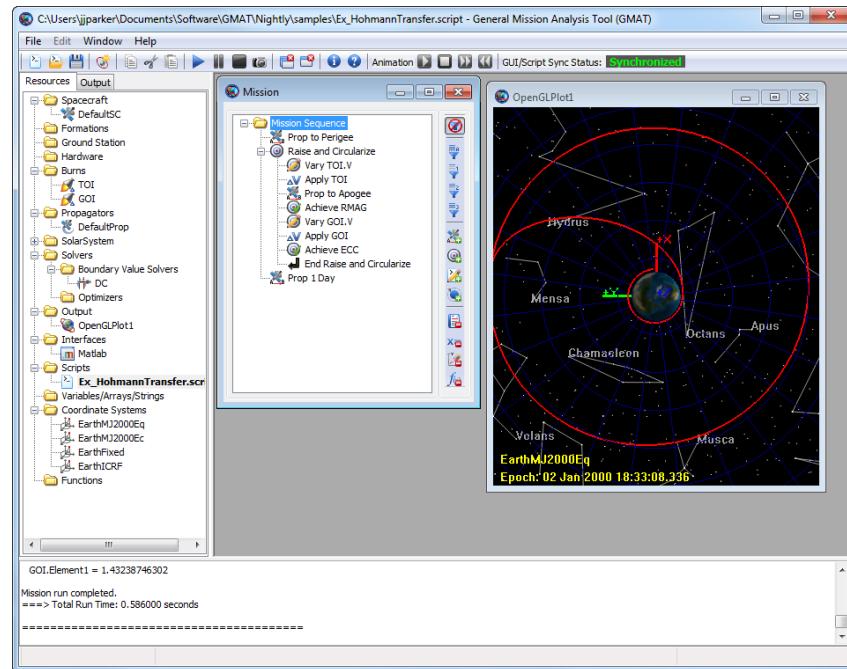
**Mission Tab**

The **Mission** tab brings the Mission Tree to the foreground of the desktop.

**Mission Tree**

The **Mission** tree displays GMAT commands that control the time-ordered sequence of events in a mission. The **Mission** tree contains all script lines that occur after the **BeginMissionSequence** command in a GMAT script. You can undock the **Mission** tree as shown in the figure below by right-clicking on the **Mission** tab and dragging it into the graphics window. You can also follow these steps:

1. Click on the **Mission** tab to bring the **Mission** Tree to the foreground.
2. Right-click on the **Mission Sequence** folder in the **Mission** tree and select **Undock Mission Tree** in the menu.



**Figure 2. Undocked Mission Tree**

#### Output Tab

The **Output** tab brings the Output Tree to the foreground of the desktop.

#### Output Tree

The **Output** tree contains GMAT output such as report files and graphical displays.

#### Message Window

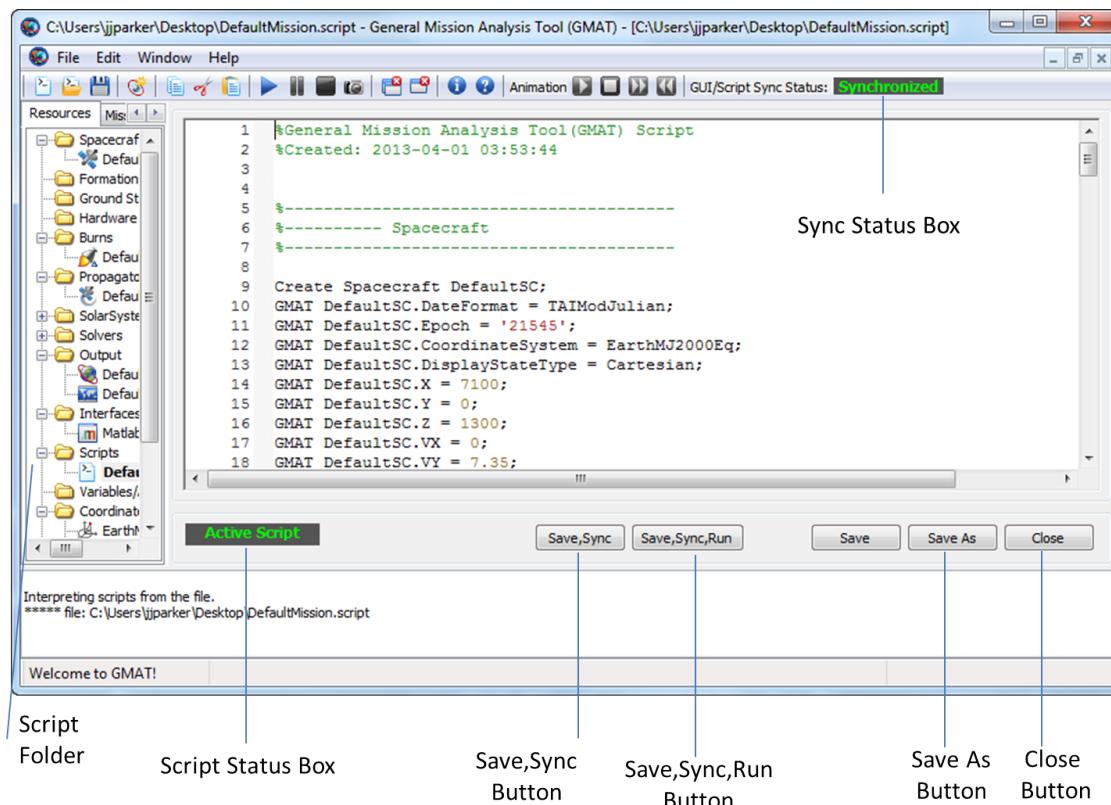
When you run a mission in GMAT, information including warnings, errors, and progress are written to the message window. For example, if there is a syntax error in a script file, a detailed error message is written to the message window.

#### Status Bar

The status bar contains various informational messages about the state of the GUI. When a mission is running, a **Busy** indicator will appear in the left pane. The center pane displays the latitude and longitude of the mouse cursor as it moves over a ground track window.

## Script Interface Overview

The GMAT script editor is a textual interface that lets you directly edit your mission in GMAT's built-in scripting language. In [Figure 3](#) below, the script editor is shown maximized in the GMAT desktop and the items relevant to script editing are labeled.



**Figure 3. GMAT Script Editor**

### Scripts Folder

The GMAT desktop allows you to have multiple script files open simultaneously. Open script files are displayed in the **Scripts** folder in the **Resources** tree. Double click on a script in the **Scripts** folder to open it in the script editor. The GMAT desktop displays each script in a separate script editor. GMAT indicates the script currently represented in the GUI with a boldface name. Only one script can be loaded into the GUI at a time.

### Script Status Box

The **Script Status** box indicates whether or not the script being edited is loaded in the GUI. The box says **Active Script** for the script currently represented in the GUI and **Inactive Script** for all others.

### Save,Sync Button

The **Save,Sync** button saves any script file changes to disk, makes the script active, and synchronizes the GUI with the script.

### Save,Sync,Run Button

The **Save,Sync,Run** button saves any script file changes to disk, makes the script active, synchronizes the GUI with the script, and executes the script.

### Save As Button

When you click **Save As**, GMAT displays the **Choose A File** dialog box and allows you to save the script using a new file name. After saving, GMAT loads the script into the GUI, making the new file the active script.

**Close**

The **Close** button closes the script editor.

## GUI/Script Interface Interactions and Rules

The GMAT desktop supports both a script interface and a GUI interface and these interfaces are designed to be consistent with each other. You can think of the script and GUI as different "views" of the same data: the resources and the mission command sequence. GMAT allows you to switch between views (script and GUI) and have the same view open in an editable state simultaneously. Below we describe the behavior, interactions, and rules of the script and GUI interfaces so you can avoid confusion and potential loss of data.

### GUI/Script Interactions and Synchronization

GMAT allows you to simultaneously edit both the script file representation and the GUI representation of your mission. It is possible to make inconsistent changes in these representations. The **GUI/Script Sync Status** window located in the toolbar indicates the state of the two representations. On the Mac, the status is indicated in abbreviated form in the left-hand toolbar. **Synchronized** (green) indicates that the script and GUI contain the same information. **GUI Modified** (yellow) indicates that there are changes in the GUI that have not been saved to the script. **Script Modified** (yellow) indicates that there are changes in the script that have not been loaded into the GUI. **Unsynchronized** (red) indicates that there are changes in both the script and the GUI.

**Caution**

GMAT will not attempt to merge or resolve simultaneous changes in the Script and GUI and you must choose which representation to save if you have made changes in both interfaces.

The **Save** button in the toolbar saves the GUI representation over the script. The **Save,Sync** button on the script editor saves the script representation and loads it into the GUI.

### How the GUI Maps to a Script

Clicking the **Save** button in the toolbar saves the GUI representation to the script file; this is the same file you edit when working in the script editor. GUI items that appear in the **Resources** tree appear before the **BeginMissionSequence** command in a script file and are written in a predefined order. GUI items that appear in the Mission Tree appear after the **BeginMissionSequence** command in a script file in the same order as they appear in the GUI.

**Caution**

If you have a script file that has custom formatting such as spacing and data organization, you should work exclusively in the script. If you load your script into the GUI, then click **Save** in the toolbar, you will lose the formatting of your script. (You will not, however, lose the data.)

## How the Script Maps to the GUI

Clicking the **Save,Sync** button on the script editor saves the script representation and loads it into the GUI. When you work in a GMAT script, you work in the raw file that GMAT reads and writes. Each script file must contain a command called **BeginMissionSequence**. Script lines that appear before the **BeginMissionSequence** command create and configure models and this data will appear in the **Resources** tree in the GUI. Script lines that appear after the **BeginMissionSequence** command define your mission sequence and appear in the **Mission** tree in the GUI. Here is a brief script example to illustrate:

```
Create Spacecraft Sat
Sat.X = 3000
BeginMissionSequence
Sat.X = 1000
```

The line `Sat.X = 3000` sets the x-component of the Cartesian state to 3000; this value will appear on the **Orbit** tab of the **Spacecraft** dialog box. However, because the line `Sat.X = 1000` appears after the **BeginMissionSequence** command, the line `Sat.X = 1000` will appear as an assignment command in the **Mission** tree in the GUI.

## Basic Script Syntax Rules

- Each script file must contain one and only one **BeginMissionSequence** command.
- GMAT commands are not allowed before the **BeginMissionSequence** command.
- You cannot use inline math statements (equations) before the **BeginMissionSequence** command in a script file. (GMAT considers in-line math statements to be an assignment command. You cannot use equations in the **Resources** tree, so you also cannot use equations before the **BeginMissionSequence** command.)
- In the GUI, you can only use in-line math statements in an assignment command. So, you cannot type `3000 + 4000` or `Sat.Y - 8` in the text box for setting a spacecraft's dry mass.
- GMAT's script language is case-sensitive.

For a more complete discussion of GMAT's script language, see the [Script Language](#) documentation.

## GUI Configuration File

The user is able to modify some GUI settings via the `MyGmat.ini` file. The `MyGMAT.ini` configuration file can be found in the `ROOT_PATH\data\gui_config` folder and contains several configurable keys to customize GMAT windows to the user's preferences.

- **Open:** The `Open` key, under the `ScriptEditor` header, tells GMAT if it should open the GMAT Script Editor upon opening the application. The default value is set to false.
- **ShowWelcomeOnStart:** The `ShowWelcomeOnStart` key, under the `Main` header, tells GMAT if it should open the Welcome window upon opening the application. The default value is set to true. This can also be modified by unchecking the "Show Welcome Page on Startup" box in the Welcome window.

- **DefaultConsoleHeight:** The DefaultConsoleHeight key, under the ConsoleWindow header, tells GMAT the default size of the console window upon opening the application. The default value is set to 100.
- **SetConsoleHeightToPrevious:** The SetConsoleHeightToPrevious key, under the ConsoleWindow header, tells GMAT if it should save the console window height from the previous session. If the user changes the console window height while using GMAT, GMAT will open the same size window next time GMAT is started. The default value is set to false.
- **PreviousConsoleHeight:** The PreviousConsoleHeight key, under the ConsoleWindow header, tells GMAT the height of the previous console window. GMAT will update this value for the user upon closing the application. This key is only used if SetConsoleHeightToPrevious is set to true.

## Resources Tree

The Resources tree displays GMAT resources and organizes them into logical groups and represents any objects that might be used or called in the Mission tree. This tree allows a user to add, edit, rename, or delete most available resources. The Resources tree can be edited either in the GMAT GUI or by loading or syncing a script file. All objects created in a GMAT script using a **Create** command are found in the Resources tree in the GMAT desktop. The default Resource tree is displayed below (Figure 4).

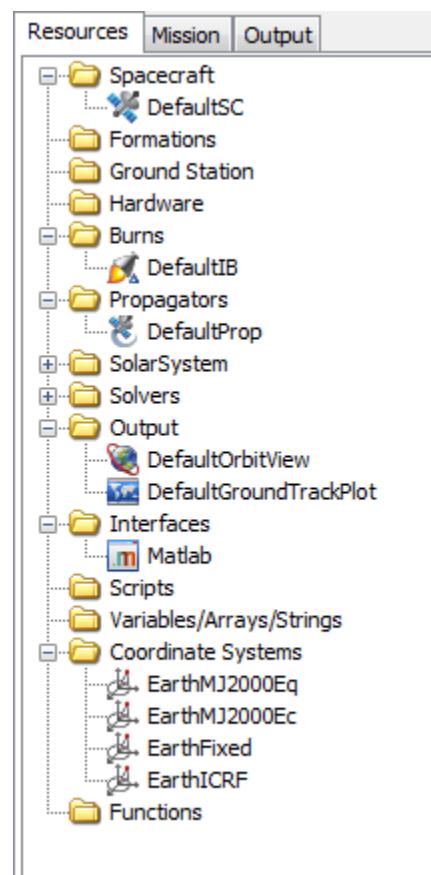


Figure 4. Default Resources tree

## Organization

The Resources tree displays created resources organized into folders by object category. The **SolarSystem** and **Solvers** folders contain more specific folders which can be found by clicking the expand (+) icon. Conversely, folders can be collapsed by clicking the minimize (-) icon.

## Folder Menus

Resources can be added by right clicking the folder of the resource and clicking the resource type from the available menu. Most folders have only one available resource type; for example if the **Spacecraft** folder is right-clicked, the user can only click “**Add Spacecraft**” (Figure 5). Other folders have multiple objects that can be added and the user must first select the “**Add**” menu before selecting the object; for example to add a **ChemicalTank**, right click the “**Hardware**” folder, select “**Add**”, then the list of available resource types is displayed and the user can click “**Fuel Tank**” (Figure 6). User-defined solar system resources are added by right-clicking either **Sun** or a default **Celestial-Body** resource. By right-clicking **Sun** the user can add a **Planet**, **Comet**, or **Asteroid** to the solar system. By right-clicking a **Planet** the user can add a **Moon** to that **Planet**.

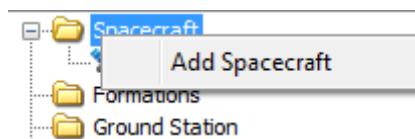


Figure 5. Folder menu for Spacecraft

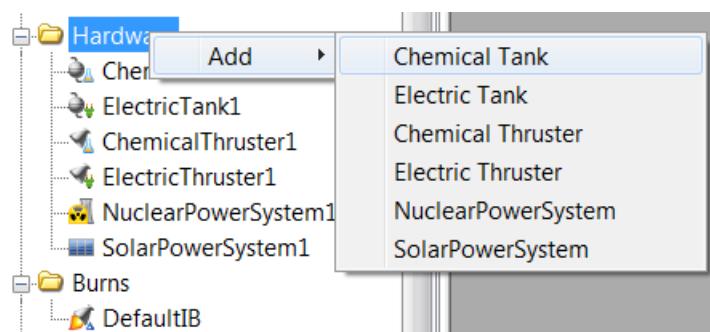
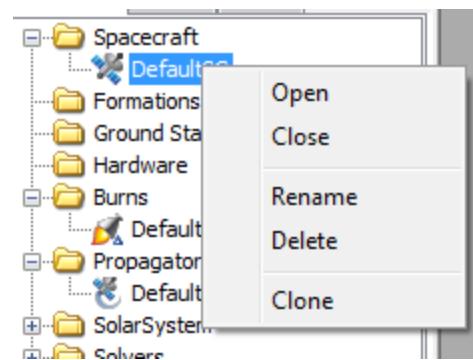


Figure 6. Folder menu for Hardware

## Resource Menus

Resources can be edited by right-clicking on the resources and selecting one of the options from the menu (Figure 7).



**Figure 7. Resource menu**

## Open/Close

To open a resource, you can either right-click the resource and select “**Open**”, or you can double click the resource. Conversely, the resource can be closed either by options in the resource properties window or selecting “**Close**” from the resource menu. When a resource is opened and the name is right-clicked in the Resource tree, the only options in the object menu are “**Open**” and “**Close**”.

## Rename

Once a resource has been created, the user can rename it to any valid name. Valid names must begin with a letter and may be followed by any combination of letters digits and underscores. Invalid names include:

- Folder names (eg, **Spacecraft**)
- Command names (eg, **Propagate**)
- Names already in use (eg, naming two variables “var”)
- Keywords (eg, “GMAT” or “function”)
- Names with spaces

## Delete

Resources can be deleted by right clicking the object and selecting “**Delete**”. Resources cannot be deleted if they are used by another resource or command and an error will be thrown. For example, a **Spacecraft** resource cannot be deleted if one of its properties (eg. **DefaultSC.A1ModJulian**) is being used by the **Report** command. Some default objects cannot be deleted. In such cases, the **Delete** menu item will not be shown. They include:

- Default coordinate systems
  - **EarthMJ2000Eq**
  - **EarthMJ2000Ec**
  - **EarthFixed**
  - **EarthICRF**
- Default planetary bodies

- Sun
- Mercury
- Venus
- Earth
- Luna
- Mars
- Jupiter
- Saturn
- Uranus
- Neptune
- Pluto

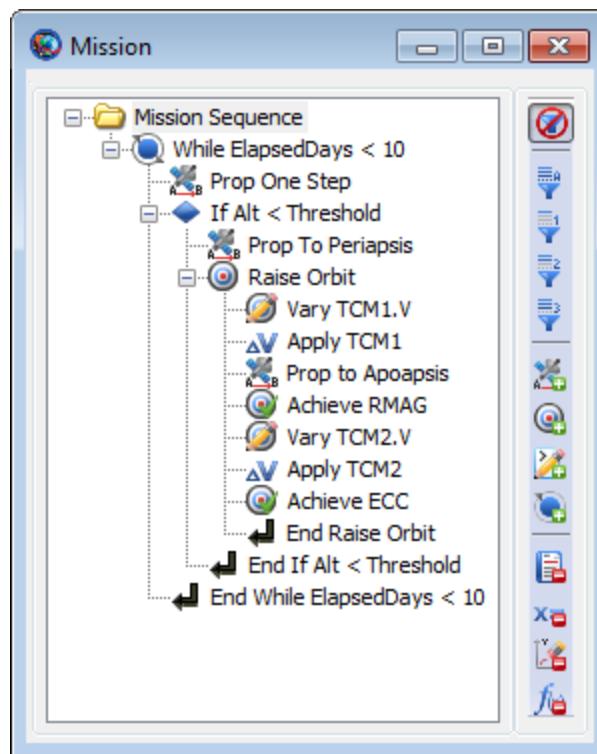
### Clone

Objects can be cloned by selecting the “**Clone**” option in the menu. A cloned object will be an exact copy of the original object with a different name. Some objects cannot be cloned. In such cases, the **Clone** menu item will not be available. The only objects that cannot be cloned are:

- Default coordinate systems (listed above)
- Default planetary bodies (listed above)
- Propagator resource objects

### Mission Tree

The Mission Tree is an ordered, hierarchical, display of your GMAT script command mission sequence (everything after the **BeginMissionSequence** in your script). It represents the ordered list of commands to be executed to model your mission. The hierarchical grouping in the mission tree represent commands that are executed inside a control logic command, e.g., **If**, **For**, **While**, etc. The mission tree allows you to add, edit, delete and rename commands. It allows you to configure or filter the display of the commands in the Mission Tree to make the command execution easier to understand or modify. An example Mission Tree screenshot is below. The Mission Tree window is made up of two elements: the Mission Sequence on the left and the view filters toolbar on the right.



### Warning



Edits to the Mission Tree will be reflected in your script after it is synchronized and vice-versa. If you edit the Mission Tree, you need to synchronize with the script to see it in the script editor. If you edit the script, you need to synchronize with the GUI to see your changes reflected in the Mission Tree.

### Mission Tree Display

The Mission Tree Display shows your hierarchical, ordered list of commands. Normally, the Mission Tree displays only the command name in the tree for each command node (more information such as command type, construction information, etc can be displayed using the **Show Detail** menu option). Commands are executed in the order they appear, e.g., GMAT executes commands from the top of the Mission Tree to the bottom. For control logic (**If**, **For**, and **While**) and the **Optimize** and **Target** commands, you can define a block of commands that execute as children of the parent command. These child commands of the control logic or the **Optimize** and **Target** commands appear indented. Use the plus (+) symbol to the left of the control logic command to show all the grouped commands and the minus (-) symbol to hide all the grouped commands. Commands that are grouped under control logic commands (e.g. **If**, **For**, and **While**) only execute if that control logic command is successfully executed (e.g., if the local expression evaluates to true for **If** command, or the loop condition evaluates to true for **For** and **While** commands).

In general, commands are executed only once. However, child commands grouped under the loop commands (e.g. **For** and **While**) may execute multiple times. These com-

mands will execute for each time the loop command evaluates to true. Commands under the **If** commands are only executed if the **If** condition evaluates to true; otherwise, they are skipped. For the **If-Else** command, child commands grouped under the **If** portion of the command execute if the conditional statement evaluates to true; otherwise, the child commands grouped under the **Else** portion of the command execute.



### Note

Note that all commands in the Mission Tree are grouped under a special **Mission Sequence** home item. This home item is always present as the first item in the Mission Tree and cannot be deleted.

## View Filters Toolbar

The Mission Tree may display a subset of the commands of the full mission sequence based on your view filter options. There are 3 basic filtering options available within GMAT:

- Filter by branch level: Control how many levels of nesting of commands are shown
- Filter by command types (inclusive): Identify types of commands to show on the mission tree display
- Filter by command types (exclusive): Identify types of commands not to show on the mission tree display.

The details of each filter are described in the immediately following sections.

The view filters activate by clicking one of the view filter buttons to the right of the Mission Tree. The pressed (pushed in) button indicates which filter is currently enabled. The four buttons on the top are the Filter by branch level buttons. The next four buttons in the middle are the inclusive filter-by-command-types buttons, and the four buttons on the bottom are the exclusive filter-by-command-types buttons. You cannot combine filter-by-branch-level filters with the filter-by-command-type filters nor combine inclusive and exclusive command type filters. However, multiple inclusive command type filters can be combined (e.g., filter both physics related and solver related commands) or multiple exclusive command type filters can be combined.



### Note

Note that all parents of a viewable command are displayed, even if the parent command is not part of the viewable command set.

Also note that the Mission Tree automatically reconfigures to show all commands when the user Appends or Inserts a new command.

## Filter by Branch Level

Filtering by branch level causes GMAT to not display commands in the mission tree that are below a certain level. To select the number of levels you wish to display, click the buttons on the top. The four buttons correspond to (from top to bottom):

- Show all branches
- Show one level of branching
- Show two levels of branching
- Show three levels of branching

Only one filter-by-branch-level button may be active at a time. The default GMAT behavior is to display all branches of a mission tree.

### Filter by Command Types

GMAT allows you to filter what commands are displayed by their command type. You may select to only display commands that are in a filter command type set (inclusive) or only display commands that are not in a filter command type set (exclusive). GMAT provides both pre-configured command type sets (e.g., physics related or output related) and custom command type sets that you define

The four middle buttons in the View Options toolbar are pre-configured inclusive command filters, e.g., only display commands that are in the desired command set. The four inclusive filter buttons correspond to (from top to bottom):

- Physics Related (**Propagate**, **Maneuver**, **BeginFiniteBurn**, and **EndFiniteBurn**)
- Solver Related (**Target**, **Optimize**, **Vary**, **Achieve**, **NonlinearConstraint**, **Minimize**, **EndTarget**, **EndOptimize**)
- **ScriptEvent** commands
- Control Flow (**If**, **If-Else**, **For**, and **While**)

Multiple inclusive command type filters can be active at once. For example, to filter both physics related and solver related commands, click both the physics-related and solver-related filter buttons so that they appear pressed down. This option will show all physics related and solver related commands and hide all other commands (except Parents of the viewable commands)).

The four buttons at the bottom in the View Options toolbar are pre-configured exclusive command filters, e.g., only display commands that are not in the command set. The four exclusive filter buttons correspond to (from top to bottom):

- **Report**
- **Equation**
- Output-related (**Report**, **Toggle**, **PenUp**, **PenDown**, **MarkPoint**, and **ClearPlot**)
- Function calls (**CallMatlabFunction**)

Multiple exclusive command type filters can be active at once. For example, to show everything but **Report** and output-related commands, click both the **Report** and output-related filter buttons so that they appear pressed down.

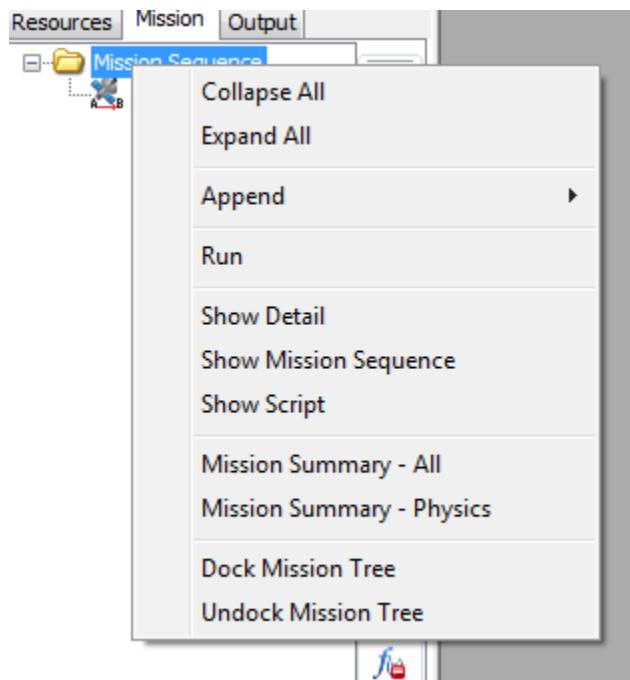


#### Note

Note that the Mission Tree shows an ellipsis (...) after a command name if the command is followed by items not graphically displayed in the tree because of filter options.

## Mission Sequence Menu

The Mission Tree has two context-sensitive popup menus, depending on whether you right-click the **Mission Sequence** home item or a command in the Mission Tree. The **Mission Sequence** popup menu primarily allows you to manipulate the Mission Tree window and the entire command sequence. It also enables appending (adding to the end) commands to the mission tree.



**Mission Sequence** menu options are always available and active in the menu list.

### Mission Sequence Menu Options:

#### Collapse All

This menu option collapses all the branches in the Mission Tree so that you only see the top-level commands. To show branches, click the plus (+) button next to a command or select **Expand All** from the **Mission Sequence** popup menu.

#### Expand All

This menu option expands all the branches and sub-branches in the Mission Tree so that you see every command in the mission sequence. To hide branches, click the minus (-) button next to a command or select **Collapse All** from the **Mission Sequence** popup menu.

#### Append

The **Append** menu option displays the submenu of commands that can be appended to the mission sequence. This menu is not available when the Mission Tree view is filtered.

## Run

The **Run** menu option executes the mission command sequence. This menu option is always available.

## Show Detail

The **Show Detail** menu option toggles an option to display the mission tree with short or verbose text. When the show detail menu option is checked, each command is displayed with the script line for the command (e.g. what appears in “**Show Script**” for the command). When the show detail menu option is unchecked, the mission tree shows only the label for the command which will be your custom label if you have provided one and a system provided label if you have not labelled the command. This menu option is always available.

## Show Mission Sequence

The **Show Mission Sequence** menu option displays a streamlined text view of the mission sequence in text window. This view shows a hierarchical view of every command (similar to a script view) in the mission sequence. Unlike the script editor, this view only includes the command names and labels. This menu option is always available.

## Show Script

The **Show Script** menu option displays the script associated with the GUI version of the current mission script. This is the complete script that would be saved to a file if you clicked the GUI save button. Note that when the GUI is unsynchronized with the script editor (please see [Script Editor](#) for more details), this mission script is different than the script displayed in the script editor. This menu option is always available

## Mission Summary - All

The **Mission Summary - All** menu option displays a mission simulation summary for the all commands in the mission sequence. This summary information includes spacecraft state information, spacecraft physical properties, time information, planetodetic properties, and other orbit data for each command. This information is only available after a mission simulation is run and the data shows state information after the execution of the command. Showing Mission Summary data for a **ScriptEvent** command is equivalent to showing summary data for the last command in that **ScriptEvent**. If commands are nested in control flow or solver branches, the summary data that is displayed is for the last pass through the sequence. This menu option is always available.

## Mission Summary - Physics

The **Mission Summary - Physics** menu option displays a mission simulation summary for physics related commands in the mission sequence. This summary information includes spacecraft state information, spacecraft physical properties, time information, planetodetic properties, and other orbit data for each command. This information is only available after a mission simulation is run and the data shows state information after the execution of the command. Note that if you have physics-based commands such as

**Propagate or Maneuver** inside a **ScriptEvent** command, then summary information for those commands, are not displayed. Showing Mission Summary data for a **ScriptEvent** is equivalent to showing summary data for the last command in that **ScriptEvent**. If commands are nested in control flow or solver branches, the summary data that is displayed is for the last pass through the sequence. This menu option is always available.

### Dock Mission Tree

The **Dock Mission Tree** menu option docks the Mission Tree window in the notebook containing the Resources tree and Output tree. This option is only selectable if the Mission Tree is currently floating or undocked. Please see the Docking/Undocking/Placement section for more information.

### Undock Mission Tree

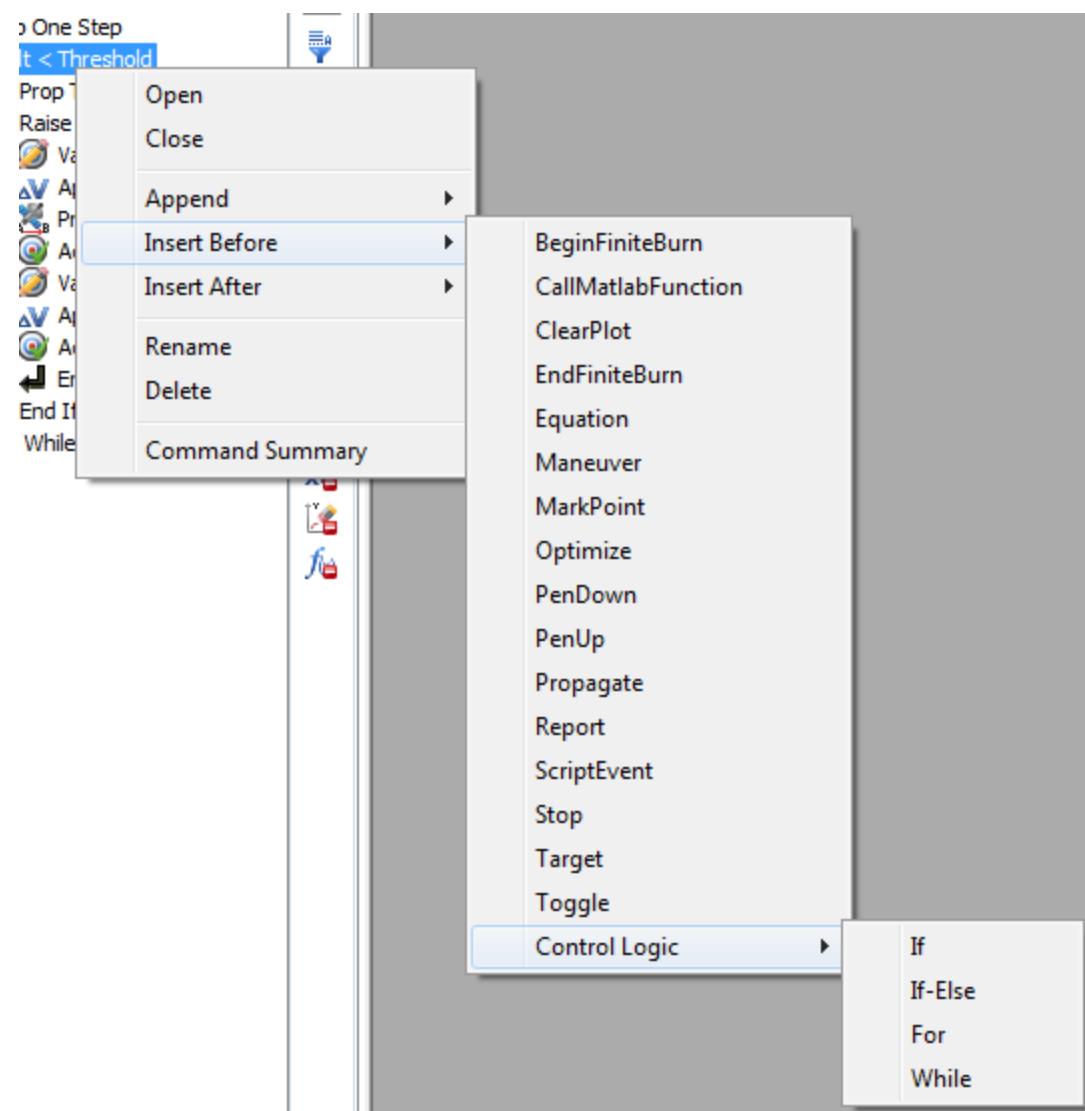
The **Undock Mission Tree** menu option undocks, or makes floating, the Mission Tree window from the Resources tree and Output tree. The undocked Mission Tree window may be resized, moved, maximized, minimized, and restored. This option is only selectable if the Mission Tree is currently docked. Please see the [the section called “Docking/Undocking/Placement”](#) section for more information.

### Command Menu

The Command popup menu allows you to add, edit, or delete the commands in the Mission Tree by using the right mouse button. This displays a context sensitive menu for adding and modifying commands as well as viewing your command sequence and command summary. To add commands to the Mission Tree, right click a command and select **Append**, **Insert Before**, or **Insert After**. To edit commands, double click the command name or right click and select **Open**.

Most commands in GMAT can appear anywhere in the mission sequence. However, there are some exceptions and the Command popup menu is context sensitive, meaning the options available under the menu change based on what command is selected and where in the tree the command occurs. Here is a complete list of context sensitivities:

- **Insert** and **Append** are not available unless the mission tree filter is set to show all levels.
- **Achieve** commands can only appear inside of a **Target** sequence.
- **Vary** commands can only appear in a **Target** or **Optimize** sequence,
- **NonlinearConstraint** and **Minimize** commands can only appear in an **Optimize** sequence.



## Command Menu Options

### Open

This menu option opens the command editor window for the selected command. The **Open** menu option is always active in the menu list. If the window is already open, the **Open** option brings the window to the front and makes it the active window.

### Close

This menu option closes the command editor window for the selected command. The **Close** menu option is always active in the menu list.

### Append

The **Append** menu option displays the submenu of commands that can be appended as the last sub-item of the selected command in the Mission Tree. As such, the Ap-

**pend** menu option only appears when the selected tree item can contain sub-items, e.g., the **Mission Sequence** home item, control logic commands, and **Optimize** and **Target** commands. Note that the **Append** submenu is context-sensitive and will only show commands that may be appended to the selected command. Finally, this menu is not available when the Mission Tree view is filtered.

### Insert After

The **Insert After** menu option displays the submenu of commands that can be inserted after the selected command (and any child commands, if any) in the Mission Tree. Nominally, the new command is inserted at the same level as the selected command. However, if the selected command is the “End” command of a control logic or **Optimize** or **Target** command (e.g., **End For**, **End If**, **End Optimize**, etc), the new command is inserted after the **End** command and on the same level (e.g., the next level up) as the parent command. The **Insert After** menu option is always active in the menu list except when the **Mission Sequence** home item is selected. Note that the **Insert After** submenu is context-sensitive and will only show commands that may be added after the selected command. Finally, this menu is not available when the Mission Tree view is filtered.

### Insert Before

The **Insert Before** menu option displays the submenu of commands that can be inserted before the selected command (and any child commands, if any) in the Mission Tree. The new command is always inserted at the same level as the selected command. The **Insert Before** menu option is always active in the menu list except when the **Mission Sequence Home** item is selected. Note that the **Insert Before** submenu is context-sensitive and will only show commands that may be added before the selected command. Finally, this menu is not available when the Mission Tree view is filtered.

### Rename

The **Rename** menu option displays a dialog box where you can rename the selected command. A command name may contain any characters except the single quote. Note that, unlike resources, command names do not have to be unique. The **Rename** menu option is always active in the menu list except when the **Mission Sequence** home item is selected.

### Delete

The **Delete** menu option deletes the selected command. GMAT does not confirm the option before deletion occurs. The **Delete** menu option is always active in the menu list except when the **Mission Sequence** home item is selected.

### Command Summary

The **Command Summary** menu option displays a mission simulation summary for the selected command, including spacecraft state information, time information, planetodetic properties, and other orbit data. This information is only available after a mission simulation run. This menu option is always available. However, command summary data is not available for **Propagate** command in single step mode. The button is available but no data is displayed.

## Docking/Undocking/Placement

The Mission Tree window may be used as a floating window or docked with the Resource tree. GMAT remembers the placement and docking status of the Mission Tree even after you quit. The undocked Mission Tree window may be resized, moved, or minimized. When the Mission Tree is undocked, and the user opens a dialog box for a GUI component, the dialog box does not cover the Mission Tree.

To undock the Mission Tree Display, either:

- Right click and drag the **Mission** tab out of the Resource Tree window.
- Right click the **Mission Sequence** home item and select **Undock Mission Tree**.

To dock the Mission Tree display, either:

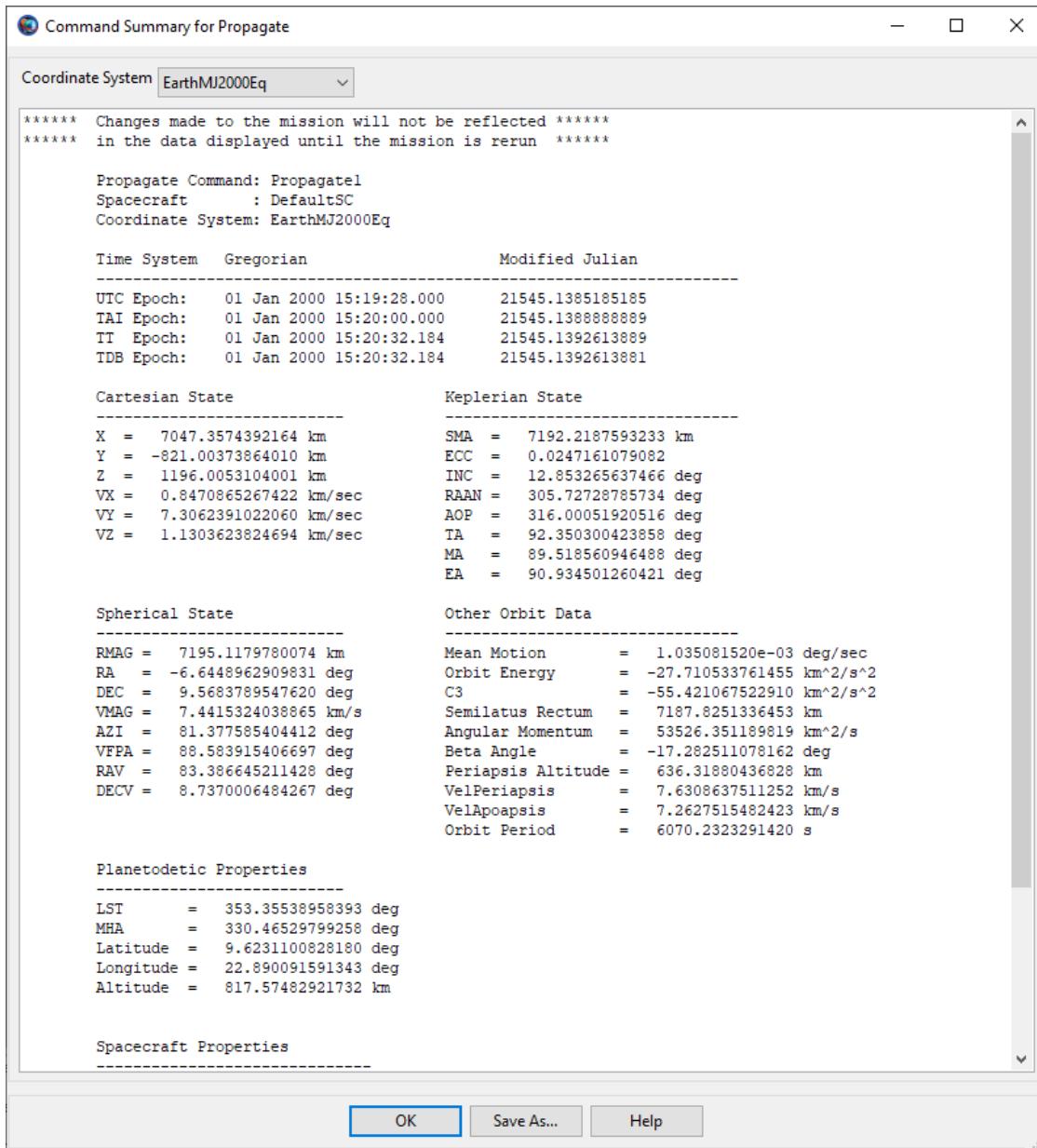
- Left click the close button (x) of the undocked Mission Tree window.
- Right click the **Mission Sequence** home item and select **Dock Mission Tree**.

## Command Summary

The **Command Summary** is a summary of orbit and spacecraft state information after execution of a command. For example, if the command is a **Propagate** command, the **Command Summary** contains state data after propagation is performed.

To view the **Command Summary**, right-click on the desired command, and select **Command Summary**. Or alternatively, double-click on the desired command, and click the **Command Summary** icon located near the lower left corner of the panel. You must run the mission before viewing **Command Summary** data.

Snapshot of a sample **Command Summary** is shown in the following figure.



## Data Availability

To view a **Command Summary**, you must first run the mission. If the mission has not been run during the current session, the **Command Summary** will be empty. If changes are made to your configuration, you must rerun the mission for those changes to take effect in the **Command Summary**.

## Data Contents

The **Command Summary** contains several types of data. Orbit state representations include Cartesian, spherical, and Keplerian. For hyperbolic orbits, B-Plane coordinates, DLA and RLA are provided. Planetodetic information includes Longitude and Latitude among others. For a **Maneuver** command, the **Maneuver** properties are displayed in

the CoordinateSystem specified on the **ImpulsiveBurn** resource. See the Coordinate Systems subsection below for more information on the command summary contents when some data is undefined.

In the event when the orbit is nearly singular conic section and/or any of the keplerian elements are undefined, an abbreviated **Command Summary** is displayed as shown in the Coordinate Systems subsection below.

You can save the data to a text file by clicking **Save As...** and specifying a file to save to.

## Supported Commands

For performance reasons, propagation in step mode does not write out a command summary. Additionally, if a command is nested in control logic and that command does not execute as a result, no command summary data is available.

# Coordinate Systems

The **Coordinate System** menu at the top of the **Command Summary** dialog allows you to select the desired coordinate system for the state data. When the **Coordinate System** has a celestial body at the origin, the **Command Summary** shows all supported data including Cartesian, Spherical, Keplerian, Other OrbitData, and Planetodetic properties as shown in the GUI screenshot above. When the **Coordinate System** does not have a celestial body at the origin, the **CommandSummary** contains an abbreviated command summary as shown below.

Note: GMAT currently requires that the selected **CoordinateSystem** cannot reference a spacecraft.

```

Propagate Command: Propagate1
Spacecraft          : DefaultSC
Coordinate System: EarthMJ2000Eq

Time System    Gregorian           Modified Julian
-----
UTC Epoch:    01 Jan 2000 15:19:28.000      21545.1385185185
TAI Epoch:    01 Jan 2000 15:20:00.000      21545.1388888889
TT Epoch:     01 Jan 2000 15:20:32.184      21545.1392613889
TDB Epoch:    01 Jan 2000 15:20:32.184      21545.1392613881

Cartesian State           Spherical State
-----
X   =  7047.3574396928 km      RMAG =   7195.1179781105 km
Y   = -821.00373455465 km     RA   =  -6.6448962577676 deg
Z   = 1196.0053110175 km      DEC  =   9.5683789596091 deg
VX  =  0.8470865225276 km/sec VMAG =   7.4415324037805 km/s
VY  =  7.3062391027010 km/sec AZI   =  81.377585410118 deg
VZ  =  1.1303623817297 km/sec VFPA =   88.583915406742 deg
                                         RAV   =  83.386645244484 deg
                                         DECV =  8.7370006427902 deg

Spacecraft Properties
-----
Cd              = 2.200000
Drag area       = 15.00000 m^2
Cr              = 1.800000
Reflective (SRP) area = 1.000000 m^2

```

Dry mass	=	850.0000000000 kg
Total mass	=	850.0000000000 kg

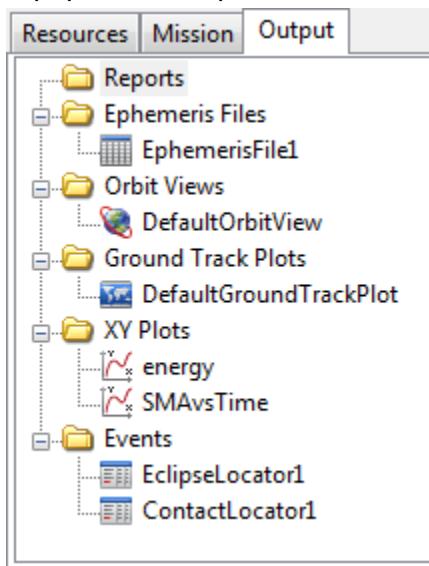
## Output Tree

The Output tree contains data files and plots after a mission is executed. Files consist of output from **ReportFile** and **EphemerisFile** resources. Plots consist of graphical **OrbitView**, **GroundTrackPlot**, and **XYPlots** windows.

To display the contents of an output file, double-click the name in the Output tree. A simple text display window will appear with the contents of the file.

Graphical output is automatically displayed during the mission run, but double-clicking the name of the output window in the Output tree will bring that display to the front. If you close the display window, however, you must rerun the mission to display it again.

A populated Output tree is shown in the following figure.



## Script Editor

A GMAT mission can be created in either the graphical user interface (GUI), or in a text script language. When a mission is loaded into the GUI from a script, or when it is saved from the GUI, there is a script file that can be accessed from the **Scripts** folder in the resources tree. When you open this script, it opens in a dedicated editor window called the **Script Editor**. While a GMAT script can be edited in any text editor, the GMAT script editor offers more features, such as:

- GUI/script synchronization
- Mission execution from the editor
- Syntax highlighting
- Comment/uncomment or indent blocks of text
- Standard features like copy/paste, line numbering, find-and-replace, etc.

The following figure shows a basic script editor session with the major features labeled.

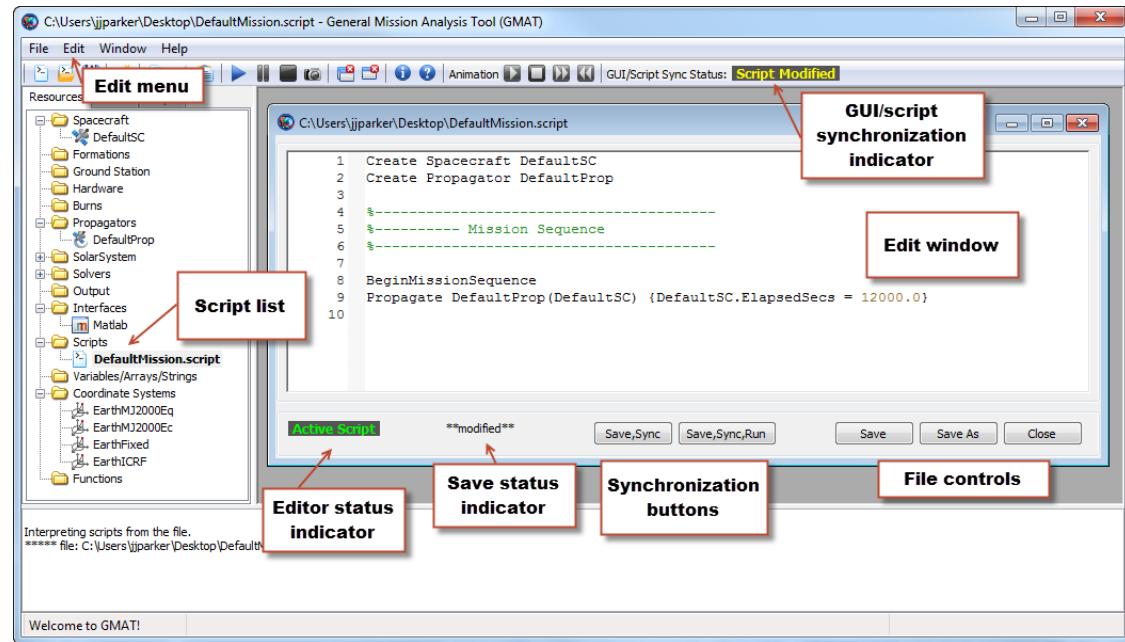


Figure 8. Parts of the script editor

## Active Script

When you load a script into the GMAT GUI, it is added to the script list in the resources tree. GMAT can have many scripts loaded at any one time, but only one can be synchronized with the GUI. This script is called the active script, and is distinguished by a bolded name in the script list. The editor status indicator in the script editor for the active script shows “**Active Script**” as well. All other scripts are inactive, but can be viewed and edited in the script editor.

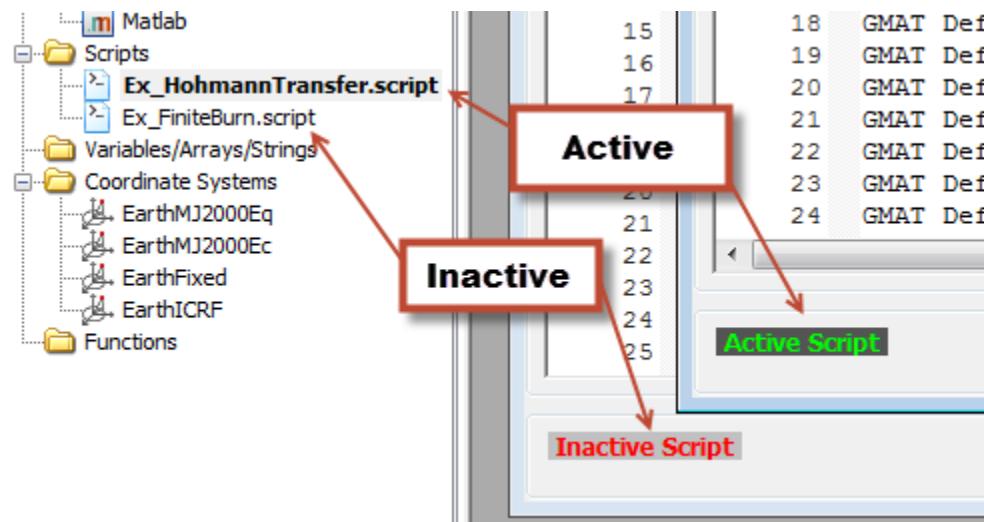


Figure 9. Active script indicators

To synchronize with the GUI, you must make an inactive script active by clicking either of the synchronization buttons (described in the next section). This will change the current

script to active, synchronize the GUI, and change the the previously active script to inactive. Alternately, you can right-click the script name in the resources tree and click Build.

## GUI/Script Synchronization

GMAT provides two separate representations of a mission: a script file and the GUI resources and mission trees. As shown in [Figure 8](#), you can have both representations open and active at the same time, and can make changes in both places. The **GUI/Script Sync Status** indicator shows the current status of the two representations relative to each other. The following states are possible:

<b>Synchronized</b>	The GUI and script representations are synchronized (they contain the same data).
<b>Script Modified</b>	The mission has been modified in the script representation, but has not been synchronized to the GUI. Use the synchronization buttons in the script editor to perform this synchronization. To revert the modifications, close the script editor without saving your changes.
<b>GUI Modified</b>	The mission has been modified in the GUI, but has not been synchronized to the script. To perform this synchronization, click the <b>Save</b> button in the GMAT toolbar. To revert the modifications, use the synchronization buttons in the script editor, or restart GMAT itself.
<b>Unsynchronized</b>	The mission has been modified both in the GUI and in the script. The changes cannot be merged; you have a choice of whether to save the modifications in either representations, or whether to revert either of them. See the notes above for instructions for either case.
<b>Script Error</b>	There is an error in the script. This puts the GUI in a minimal safe state. The error must be corrected before continuing.



### Warning

Saving modifications performed in the GUI will overwrite the associated script. The data will be saved as intended, but with full detail, including fields and settings that were not explicitly listed in the original script. A copy of the original script with the extension “.bak” will be saved alongside the new version.

The script editor provides two buttons that perform synchronization from the script to the GUI. Both the **Save,Sync** and the **Save,Sync,Run** buttons behave identically, except that the **Save,Sync,Run** button runs the mission after synchronization is complete. The following paragraphs describe the behavior of the **Save,Sync** button only, but the description applies to both buttons. If you right-click the name of a script in the resources tree, a context menu is displayed with the items **Save, Sync** and **Save, Sync, Run**. These are identical to the **Save,Sync** and **Save,Sync,Run** buttons in the script editor.

When pressed, the **Save,Sync** button performs the following steps:

1. Saves any modifications to the script
2. Closes all open windows (except the script editor itself)
3. Validates the script file
4. Refreshes the GUI by loading the saved script
5. Sets **GUI/Script Sync Status** to **Synchronized**.

If the GUI has existing modifications, a confirmation prompt will be displayed. If confirmed, the GUI modifications will be overwritten.

If the script is not active, a confirmation prompt will be displayed. If confirmed, the script will be made active before the steps above are performed.

If the script has errors, the GUI will revert to an empty base state until all errors are corrected and the script is synchronized successfully.

## Scripts List

The scripts folder in the Resources tree contains items for each script that has been loaded into GMAT. Individual scripts can be added to the list by right-clicking the **Scripts** folder and clicking **Add Script**.

The right-click menu for an individual script contains several options:

- **Open**: opens the script in the edit window
- **Close**: closes any open edit windows for this script
- **Save, Sync**: opens the script and synchronizes it with the GUI, making it the active script. This is identical to the **Save,Sync** button in the script editor.
- **Save, Sync, Run**: builds the script (see above), and also runs it. This is identical to the **Save,Sync,Run** button on the script editor.
- **Reload**: reloads the script from the last-saved version and refreshes the script editor
- **Remove**: removes the script from the script list

## Edit Window

The edit window displays the text of the loaded script and provides tools to edit it. The edit window provides the following features:

- Line numbering: Line numbers along the left side of the window
- Syntax highlighting: Certain elements of the GMAT script language are colored for immediate recognition.
- Folding: Script blocks (like **For** loops, **Target** sequences, etc.) can be collapsed by clicking the black downward-pointing triangle to the left of the command that begins the block.

If you right-click anywhere in the edit window, GMAT will display a context menu with the following options:

- **Undo/Redo**: Undo or redo any number of changes since the last time the script was saved
- **Cut/Copy/Paste**: Cut, copy, or paste over the current selection, or paste the current clipboard contents at the location of the cursor

- **Delete:** Delete the current selection
- **Select All:** Select the entire script contents

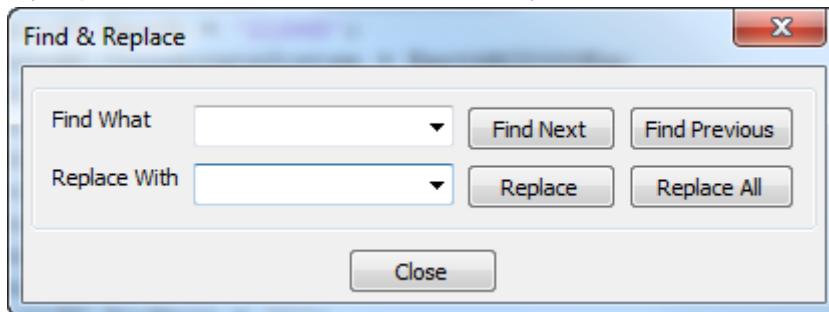
When the script editor is active in the GMAT GUI, the Edit menu is also available with the following options:

- **Undo/Redo:** Undo or redo any number of changes since the last time the script was saved
- **Cut/Copy/Paste:** Cut, copy, or paste over the current selection, or paste the current clipboard contents at the location of the cursor
- **Comment/Uncomment:** Add or remove a comment symbol (%) at the beginning of the current selection
- **Select All:** Select the entire script contents
- **Find/Replace:** Starts the **Find & Replace** utility (see below)
- **Show line numbers:** When selected (default), the editor window displays line numbering to the left of the script contents.
- **Goto:** Place the cursor on a specific line number
- **Indent more/less:** Adds or removes an indentation from the current line or selection. The default indentation is three space characters.

See the [Keyboard Shortcuts](#) reference page for the list of keyboard shortcuts that are available when working in the script editor:

## Find and Replace

On the **Edit** menu, if you click **Find** or **Replace** (or press **Ctrl+F** or **Ctrl+H**), GMAT displays the **Find & Replace** utility, which can be used to find text in the active script and optionally replace it with different text. The utility looks like the following figure.



To find text within the active script, type the text you wish to find in the **Find What** box and click **Find Next** or **Find Previous**. **Find Next** (F3) will start searching forward (below) the current cursor position, while **Find Previous** will start searching backward (above). If a match is found, the match will be highlighted. You can continue clicking **Find Next** or **Find Previous** to continue searching. The search text (in the **Find What** box) can be literal text only; wildcards are not supported. To replace found instances with different text, type the replacement text in the **Replace With** box. Click **Replace** to replace the currently-highlighted match and highlight the next match, or click **Replace All** to replace all matches in the file at once. The **Find & Replace** utility saves a history of text previously entered in the **Find What** and **Replace With** boxes in the current session. Click the down arrow in each box to choose a previously-entered value.

## File Controls

The **Save** button saves the current script without checking syntax or synchronizing with the GUI, and without switching the active script. The **Save As** button is identical, but allows you to save to a different file.

The **Close** button closes the script editor, and prompts you to save any unsaved changes.

## Save Status Indicator

When the contents of the script have been modified, the script editor displays “**\*\*modified\*\***” in the save status indicator. This is a visual indicator that there are unsaved changes in the script. Once the changes are saved or reverted, the indicator turns blank.

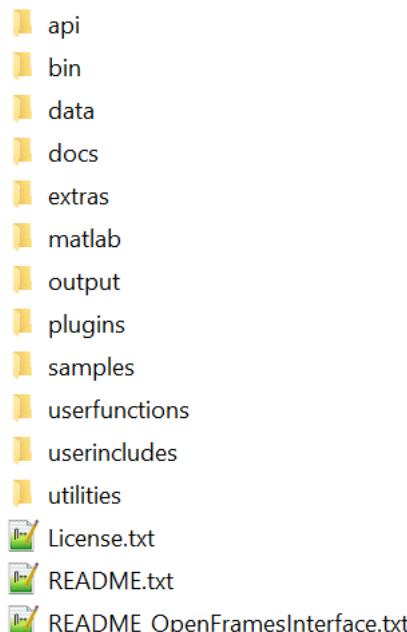


# Configuring GMAT

Below we discuss the files and data that are distributed with GMAT and are required for GMAT execution. GMAT uses many types of data files, including planetary ephemeris files, Earth orientation data, leap second files, and gravity coefficient files. This section describes how these files are organized and the controls provided to customize them.

## File Structure

The default directory structure for GMAT is broken into 12 main subdirectories, as shown in [Figure 10](#). These directories organize the files and data used to run GMAT, including binary libraries, data files, texture maps, and 3D models. Users are encouraged to review the README file located in the installation root directory. A summary of the contents of each subdirectory is provided in the sections below.



**Figure 10. GMAT Root Directory Structure**

### api

The `api` directory contains scripts that help the user configure and get started using the GMAT Application Programming Interface (API). The GMAT API allows the user to access GMAT functionality from other programming environments like Python and MATLAB. Sample scripts for both Python and MATLAB are provided in this folder. Follow the instructions in the `API_README.txt` file to get started with the GMAT API.

### bin

The `bin` directory contains all binary files required for the core functionality of GMAT. These libraries include the executable file (`GMAT.exe` on Windows, `GMAT.app` on the

Mac, and GMAT on Linux) and platform-specific support libraries. The `bin` directory also contains two text files: `gmat_startup_file.txt` and `gmat.ini`. The startup file is discussed in detail in a separate section below. The `gmat.ini` file is used to configure some GUI panels, set paths to external web links, and define GUI tooltip messages.

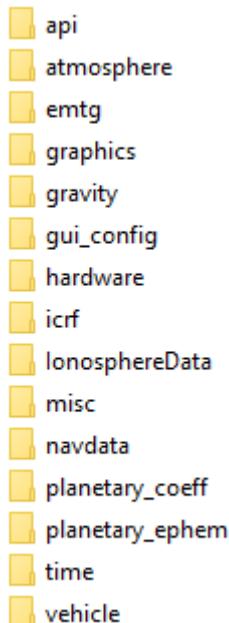


### Note

GMAT on macOS is not a notarized application. The GMAT folder must be installed either to the system-wide `/Applications` folder or to the user's `~/Applications` folder. The latter is useful for users without admin access to their Mac.

## data

The data directory contains all required data files to run GMAT and is organized according to data type, as shown in [Figure 11](#) and described below.



**Figure 11. GMAT Data Directory Structure**

The `api` directory contains a help file that GMAT will use to provide help in API interactive sessions.

The `atmosphere` directory contains data files required for modeling of planetary atmospheres. In particular, default files for modeling Earth's atmosphere are stored in the `atmosphere/earth` folder. The Earth atmosphere files may be updated in this directory manually, or by using the `utilities/python/GMATDataManager.py` tool. It is also possible to point to alternate paths for these files in your GMAT script.

The `emtg` folder contains files and scripts relevant to those using GMAT in combination with the Evolutionary Mission Trajectory Generator (EMTG) tool.

The `graphics` directory contains data files for GMAT's visualization utilities, as well as application icons and images. The `splash` directory contains the GMAT splash screen that is displayed briefly while GMAT is initializing. The `stars` directory contains a star catalogue used for displaying stars in 3D graphics. The `texture` folder contains texture maps used for the 2D and 3D graphics resources. The `icons` directory contains graphics files for icons and images loaded at run time, such as the GMAT logo and GUI icons.

The `gravity` directory contains gravity coefficient files for each body with a default non-spherical gravity model. Within each directory, the coefficient files are named according to the model they represent, and use the extension `.cof`.

The `gui_config` directory contains files for configuring some of the GUI dialog boxes for GMAT resources and commands. These files allow you to easily create a GUI panel for a user-provided plugin, and are also used by some of the built-in GUI panels.

The `hardware` folder contains a single sample clock cone angle file.

The `icrf` folder contains a data table required for ICRF coordinate transformations.

The `IonosphereData` directory contains files required for the Earth ionosphere model employed in the GMAT orbit determination tools. Two files in this directory require routine maintenance. The `ap.dat` file contains records of past and predicted Ap index observations. The `ig_rz.dat` file contains records of past and predicted solar flux observations. Those using the IRI ionosphere model for orbit determination should ensure that these files always contain sufficient data to cover processing spans. Both of these files can be updated manually or using the `utilities/python/GMATDataManager.py` tool. The remainder of the files in this directory should not be updated.

The `misc` directory contains files relevant to use of certain optimizers.

The `planetary_coeff` directory contains the Earth orientation parameters (EOP) provided by the International Earth Rotation Service (IERS) and nutation coefficients for different nutation theories.

The `planetary_ephem` directory contains planetary ephemeris data in both DE and SPK formats. The `de` directory contains the binary digital ephemeris DE405 files for the 8 planets, the Moon, and Pluto developed and distributed by JPL. The `spk` directory contains the DE421 SPICE kernel and kernels for selected comets, asteroids and moons. All ephemeris files distributed with GMAT are in the little-endian format.

The `time` directory contains the JPL leap second kernel `SPICELeapSecondKernel.tls` and the GMAT leap second file `tai-utc.dat`.

The `vehicle` directory contains ephemeris data and 3D models for selected spacecraft. The `ephem` directory contains SPK ephemeris files, including orbit, attitude, frame, and time kernels. The `models` directory contains 3D model files in 3DS or POV format for use by GMAT's **OrbitView** visualization resource.

## docs

The docs directory contains end-user documentation, including draft PDF versions of the Mathematical Specification, Architectural Specification, and Estimation Specification. The GMAT User's Guide is available in the help directory in PDF and HTML formats, and as a Windows HTML Help file.

## extras

The extras directory contains various extra convenience files that are helpful for working with GMAT but aren't part of the core codebase. The only file here so far is a syntax coloring file for the GMAT scripting language in the Notepad++ text editor.

## matlab

The matlab directory contains M-files required for GMAT's MATLAB interfaces, including the interface to the fmincon optimizer. All files in the matlab directory and its subdirectories must be included in your MATLAB path for the MATLAB interfaces to function properly.

## output

The output directory is the default location for file output such as ephemeris files and report files. If no path information is provided for reports or ephemeris files created during a GMAT session, then those files will be written to the output folder.

## plugins

The plugins directory contains optional plugins that are not required for use of GMAT. The proprietary directory is used for third-party libraries that cannot be distributed freely and is an empty folder in the open source distribution.

## samples

The samples directory contains sample missions and scripts, ranging from a Hohmann transfer to libration point station-keeping to Mars B-plane targeting. Example files begin with "Ex\_" and files that correspond to GMAT tutorials begin with "Tut\_". These files are intended to demonstrate GMAT's capabilities and to provide you with a potential starting point for building common mission types for your application and flight regime. Samples with specific requirements are located in subdirectories such as NeedMatlab and NeedVF13ad.

## userfunctions

The userfunctions directory contains MATLAB, Python, and GMAT functions that are included in the GMAT distribution. You can also store your own custom functions in the subdirectories named GMAT, Python, and MATLAB. GMAT includes those subdirectories in its search path to locate functions referenced in GMAT scripts and GMAT functions.

## userincludes

The userincludes directory provides a location where GMAT will by default automatically search for code files imported into scripts using the `#Include` macro. The user can change the search path for include files by modifying the `GMAT_INCLUDE_PATH` variable in the startup file, or by adding additional `GMAT_INCLUDE_PATH` assignments in the startup file. If multiple assignments are present, GMAT searches them in order of assignment to find any `#Include` files.

## utilities

The utilities directory contains some useful Python utilities. This directory includes the GMAT data file manager (`GMATDataFileManager.py`) which can be run to update many of the environmental data files (like space weather, EOP, and leap seconds files) that GMAT requires.

The navigation subdirectory contains some utilities that are useful for analysing the output of Extended Kalman Filter runs, but these scripts require use of the GMAT MATLAB interface. These scripts were built to be used with the GPS\_PosVec filter/smoker tutorial script and only currently work with the GPS\_PosVec data type.

The navigation subdirectory also contains scripts for conversion of CCSDS tracking data message (TDM), Deep Space Network TRK-2-34, and Universal Tracking Data Format (UTDF) binary files to GMAT GMD format. At this time, these scripts only convert a small subset of data types and are intended as examples and not for general purpose or operational use.

## Configuring Data Files

GMAT uses many empirical data files that are periodically updated. In some cases files are updated by the owning organization as often as every three hours. GMAT is distributed with a python script `\utilities\python\GMATDataFileManager.py` that automates file updates, logs changes, and optionally archives old versions of data files used by GMAT. See the help documentation contained in the Python class for detailed usage instructions. Below we describe the empirical data files used by GMAT, and which start-up file variables are used to define those files' locations on your system. The source of the data file and comments describe where the files are obtained and how they are used.

Startup File Variable	Data Source	Comments
EOP_FILE	<a href="ftp://hpiers.obspm.fr/iers/series/opa/eopc04_IAU2000/">ftp://hpiers.obspm.fr/iers/series/opa/eopc04_IAU2000/</a>	The EOP file used by GMAT's astrodynamics routines.
PLANETARY_PCK_FILE	<a href="https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/">https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/</a>	The SPICE planetary constants kernel containing orientation, size and shape data. As of release R2017a, the version is pck00010.pck. This can change and the file checks for new versions.

Startup File Variable	Data Source	Comments
LEAP_SECS_FILE	<a href="https://maia.usno.navy.mil/ser7/tai-utc.dat">https://maia.usno.navy.mil/ser7/tai-utc.dat</a>	The leap second file used by GMAT's astrodynamics routines.
LSK_FILE	<a href="https://naif.jpl.nasa.gov/pub/naif/generic_kernels/lsk/">https://naif.jpl.nasa.gov/pub/naif/generic_kernels/lsk/</a>	The leap second file used by SPICE's astrodynamics routines. As of release R2017a, the version is naif0012.tls. This can change and the file checks for new versions.
CSSI_FLUX_FILE	<a href="ftp://ftp.agi.com/pub/DynamicEarthData/SpaceWeather-All-v1.2.txt">ftp://ftp.agi.com/pub/DynamicEarthData/SpaceWeather-All-v1.2.txt</a>	The CSSI Space Weather File used for flux and geomagnetic indeces in drag modeling when a propagator is configured to use the CSSI file as the source for space weather modeling.
SCHATTEN_FILE	<a href="https://iswa.ccmc.gsfc.nasa.gov/iswa_data_tree/model/solar/FDF/SchattenSolarFluxPrediction/">https://iswa.ccmc.gsfc.nasa.gov/iswa_data_tree/model/solar/FDF/SchattenSolarFluxPrediction/</a>	The Schatten file is not currently updated by the data file manager utility. Users can manually download it from the data source. Note that after doing this BEGIN_DATA and END_DATA tags must be added to the data file as shown in the Schatten data file packaged with GMAT.
EARTH_LATEST_PCK	<a href="https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/earth_latest_high_prec.bpc">https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/earth_latest_high_prec.bpc</a>	The EOP file used by SPICE's astrodynamics routines.
EARTH_PCK_PREDICTED_FILE	<a href="https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/">https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/</a>	The SPICE kernel containing predicted, precession, nutation ,nutation corrections, UT1-TAI , and polar motion for the Earth. Used in SPICE's astrodynamic routines.
EARTH_PCK_CURRENT_FILE	<a href="https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/">https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/</a>	The SPICE kernel containing historical, precession, nutation ,nutation corrections, UT1-TAI , and polar motion for the Earth. Used in SPICE's astrodynamic routines.

Startup File Variable	Data Source	Comments
LUNA_PCK_CURRENT_FILE	<a href="https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/">https://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/</a>	Kernel providing orientation of Lunar Principal Axis (PA) reference frame. Used in SPICE's astrodynamic routines.
LUNA_FRAME_KERNEL_FILE	<a href="https://naif.jpl.nasa.gov/pub/naif/generic_kernels/fk/satellites/">https://naif.jpl.nasa.gov/pub/naif/generic_kernels/fk/satellites/</a>	This frame kernel contains the latest specifications of lunar reference frames realizing the Lunar Principal Axis (PA) and Mean Earth/Polar Axis (ME) reference systems. Used in SPICE's astrodynamical routines.

## Loading Custom Plugins

Custom plugins are loaded by adding a line to the startup file (bin/gmat\_startup\_file.txt) specifying the name and location of the plugin file. In order for a plugin to work with GMAT, the plugin library must be placed in the folder referenced in the startup file. For all details, see the [Startup File](#) reference.

## Configuring the MATLAB Interface

GMAT contains an interface to MATLAB. See the [MATLAB Interface](#) reference to configure the MATLAB interface.

## Configuring the Python Interface

GMAT contains an interface to Python. See the [Python Interface](#) reference to configure the Python interface.

## User-defined Function Paths

If you create custom MATLAB functions, you can provide the path to those files and GMAT will locate them at run time. The default startup file is configured so you can place MATLAB functions (with a .m extension) in the userfunctions/matlab directory. GMAT automatically searches that location at run time. You can change the location of the search path to your MATLAB functions by changing these lines in your startup file to reflect the location of your files with respect to the GMAT bin folder:

```
MATLAB_FUNCTION_PATH = ../userfunctions/matlab
```

If you wish to organize your custom functions in multiple folders, you can add multiple search paths to the startup file. For example,

```
MATLAB_FUNCTION_PATH = ../MyFunctions/utils
MATLAB_FUNCTION_PATH = ../MyFunctions/StateConversion
MATLAB_FUNCTION_PATH = ../MyFunctions/TimeConversion
```

GMAT will search the paths in the order specified in the startup file and will use the first function with a matching name.

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# Tutorials

The [Tutorials](#) section contains in-depth tutorials that show you how to use GMAT for end-to-end analysis. The tutorials are designed to teach you how to use GMAT in the context of performing real-world analysis and are intended to take between 30 minutes and several hours to complete. Each tutorial has a difficulty level and an approximate duration listed with any prerequisites in its introduction, and are arranged in a general order of difficulty.

Here is a summary of selected Tutorials. For a complete list of tutorials see the [Tutorials](#) chapter.

The [Simulating an Orbit](#) tutorial is the first tutorial you should take to learn how to use GMAT to solve mission design problems. You will learn how to specify an orbit and propagate to orbit periapsis.

The [Mars B-Plane Targeting](#) tutorial shows how to use GMAT to design a Mars transfer trajectory by targeting desired B-plane conditions at Mars.

The [Target Finite Burn to Raise Apogee](#) tutorial shows how to raise orbit apogee using finite maneuver targeting.

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# Simulating an Orbit

<b>Audience</b>	Beginner
<b>Length</b>	30 minutes
<b>Prerequisites</b>	None
<b>Script File</b>	Tut_SimulatingAnOrbit.script

## Objective and Overview



### Note

The most fundamental capability of GMAT is to propagate, or simulate the orbital motion of, spacecraft. The ability to propagate spacecraft is used in nearly every practical aspect of space mission analysis, from simple orbital predictions (e.g. When will the International Space Station be over my house?) to complex analyses that determine the thruster firing sequence required to send a spacecraft to the Moon or Mars.

This tutorial will teach you how to use GMAT to propagate a spacecraft. You will learn how to configure **Spacecraft** and **Propagator** resources, and how to use the **Propagate** command to propagate the spacecraft to orbit periapsis, which is the point of minimum distance between the spacecraft and Earth. The basic steps in this tutorial are:

1. Configure a **Spacecraft** and define its epoch and orbital elements.
2. Configure a **Propagator**.
3. Modify the default **OrbitView** plot to visualize the spacecraft trajectory.
4. Modify the **Propagate** command to propagate the spacecraft to periapsis.
5. Run the mission and analyze the results.

## Configure the Spacecraft

In this section, you will rename the default **Spacecraft** and set the **Spacecraft**'s initial epoch and classical orbital elements. You'll need GMAT open, with the default mission loaded. To load the default mission, click **New Mission** (💡) or start a new GMAT session.

### Rename the Spacecraft

1. In the **Resources** tree, right-click **DefaultSC** and click **Rename**.
2. Type **Sat**.
3. Click **OK**.

### Set the Spacecraft Epoch

1. In the **Resources** tree, double-click **Sat**. Click the **Orbit** tab if it is not already selected.

2. In the **Epoch Format** list, select **UTCGregorian**. You'll see the value in the **Epoch** field change to the UTC Gregorian epoch format.
3. In the **Epoch** box, type **22 Jul 2014 11:29:10.811**. This field is case-sensitive, and must be entered in the exact format shown.
4. Click **Apply** or press the **ENTER** key to save these changes.

## Set the Keplerian Orbital Elements

1. In the **StateType** list, select **Keplerian**. In the **Elements** list, you will see the GUI reconfigure to display the Keplerian state representation.
2. In the **SMA** box, type **83474.318**.
3. Set the remaining orbital elements as shown in the table below.

**Table 1. Sat Orbit State Settings**

Field	Value
ECC	0.89652
INC	12.4606
RAAN	292.8362
AOP	218.9805
TA	180

4. Click **OK**.
5. Click **Save** (💾). If this is the first time you have saved the mission, you'll be prompted to provide a name and location for the file.

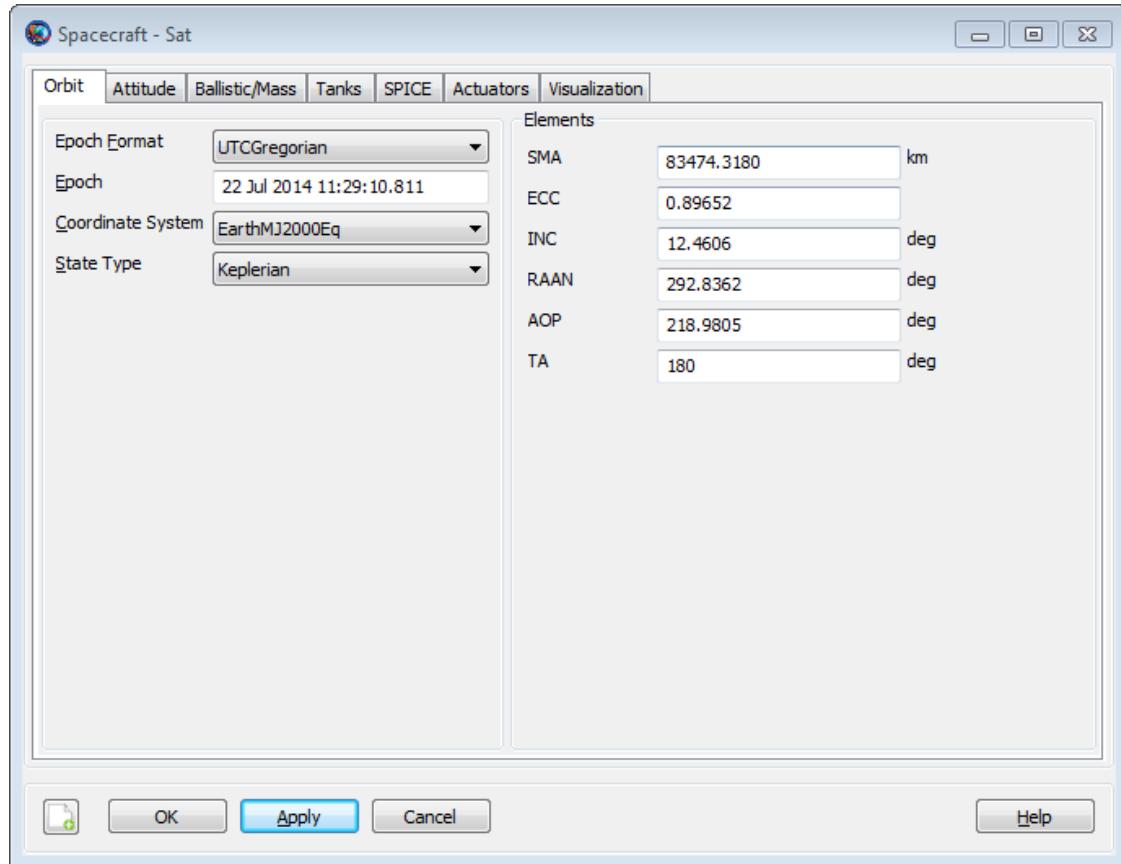


Figure 12. Spacecraft State Setup

## Configure the Propagator

In this section you'll rename the default **Propagator** and configure the force model.

### Rename the Propagator

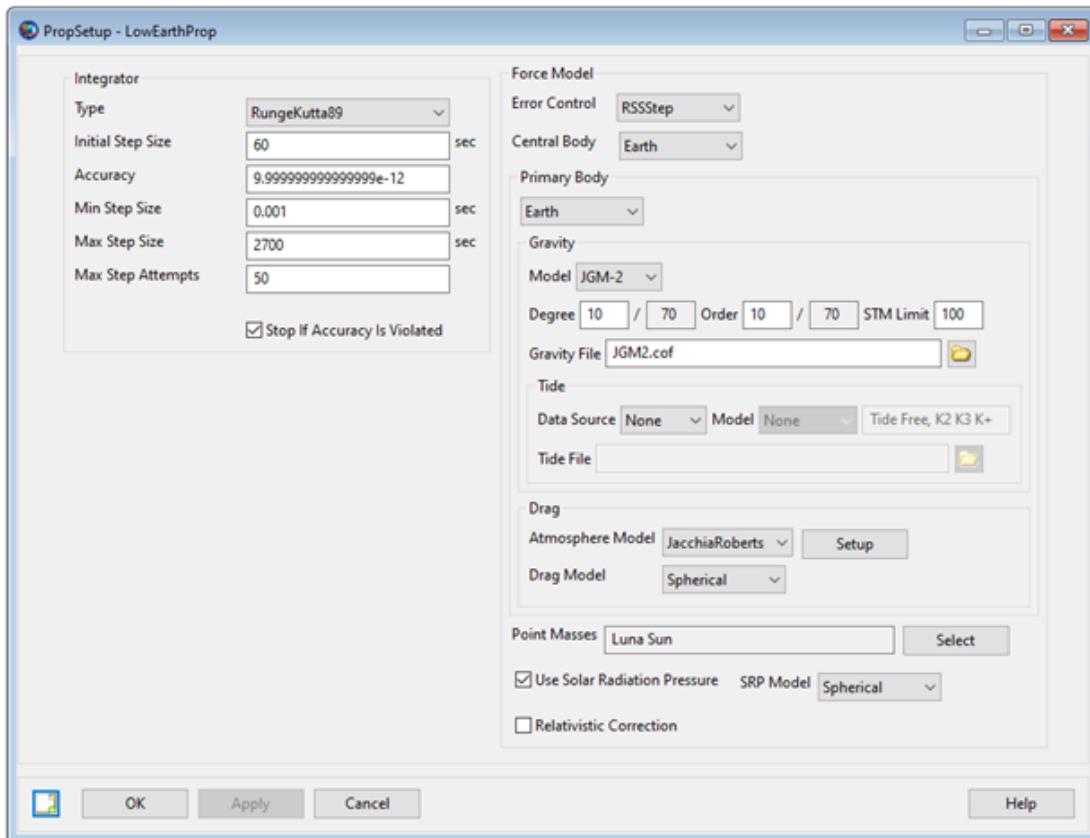
1. In the **Resources** tree, right-click **DefaultProp** and click **Rename**.
2. Type **LowEarthProp**.
3. Click **OK**.

### Configure the Force Model

For this tutorial you will use an Earth 10x10 spherical harmonic model, the Jacchia-Roberts atmospheric model, solar radiation pressure, and point mass perturbations from the Sun and Moon.

1. In the **Resources** tree, double-click **LowEarthProp**.
2. Under **Gravity**, in the **Degree** box, type **10**.
3. In the **Order** box, type **10**.
4. In **Atmosphere Model** list, click **JacchiaRoberts**.

5. Click the **Select** button next to the **Point Masses** box. This opens the **CelesBodySelectDialog** window.
6. In the **Available Bodies** list, click **Sun**, then click **->** to add **Sun** to the **Selected Bodies** list.
7. Add the moon (named **Luna** in GMAT) in the same way.
8. Click **OK** to close the **CelesBodySelectDialog**.
9. Select **Use Solar Radiation Pressure** to toggle it on. Your screen should now match [Figure 13](#).
10. Click **OK**.



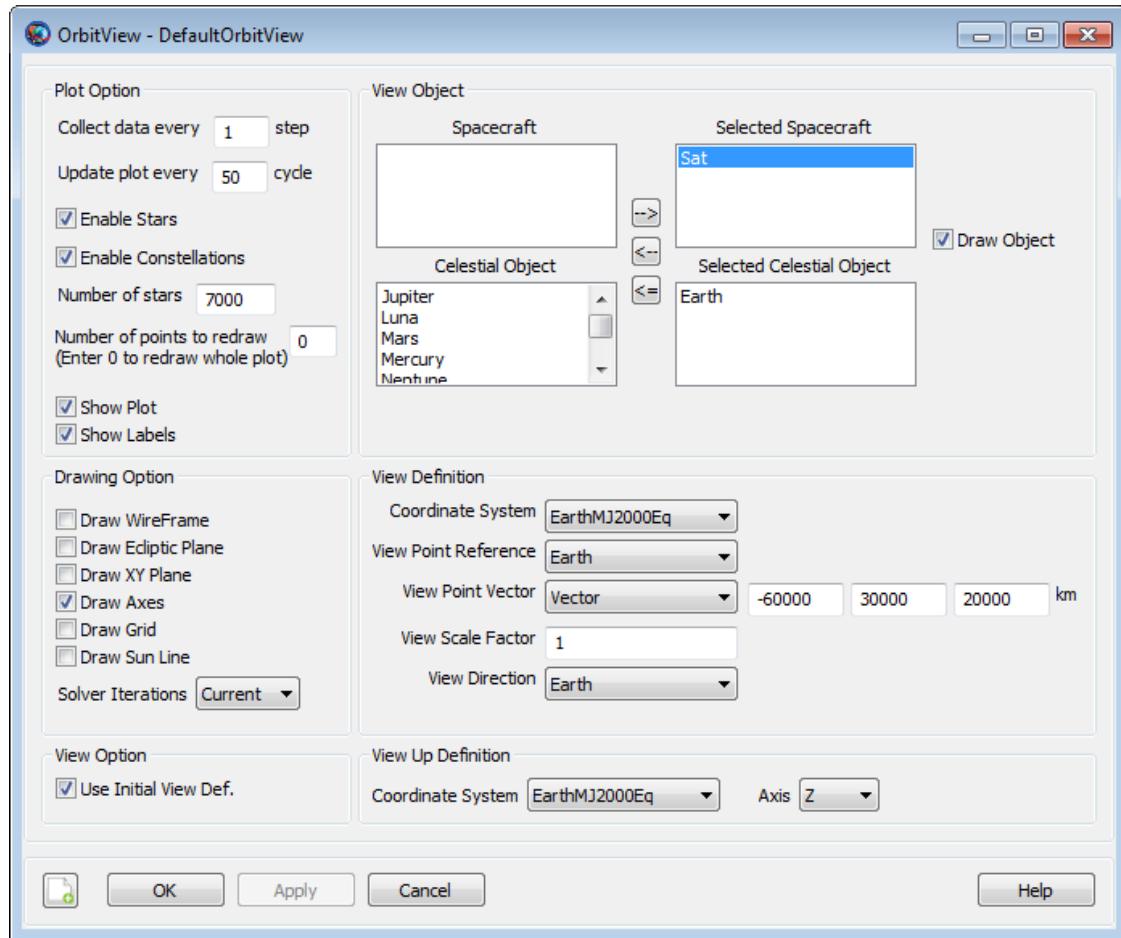
**Figure 13. Force Model Configuration**

## Configuring the Orbit View Plot

Now you will configure an **OrbitView** plot so you can visualize **Sat** and its trajectory. The orbit of **Sat** is highly eccentric. To view the entire orbit at once, we need to adjust the settings of **DefaultOrbitView**.

1. In the **Resources** tree, double-click **DefaultOrbitView**.
2. In the three boxes to the right of **View Point Vector**, type the values **-60000**, **30000**, and **20000** respectively.
3. Under **Drawing Option** to the left, clear **Draw XY Plane**. Your screen should now match [Figure 14](#).

4. Click **OK**.

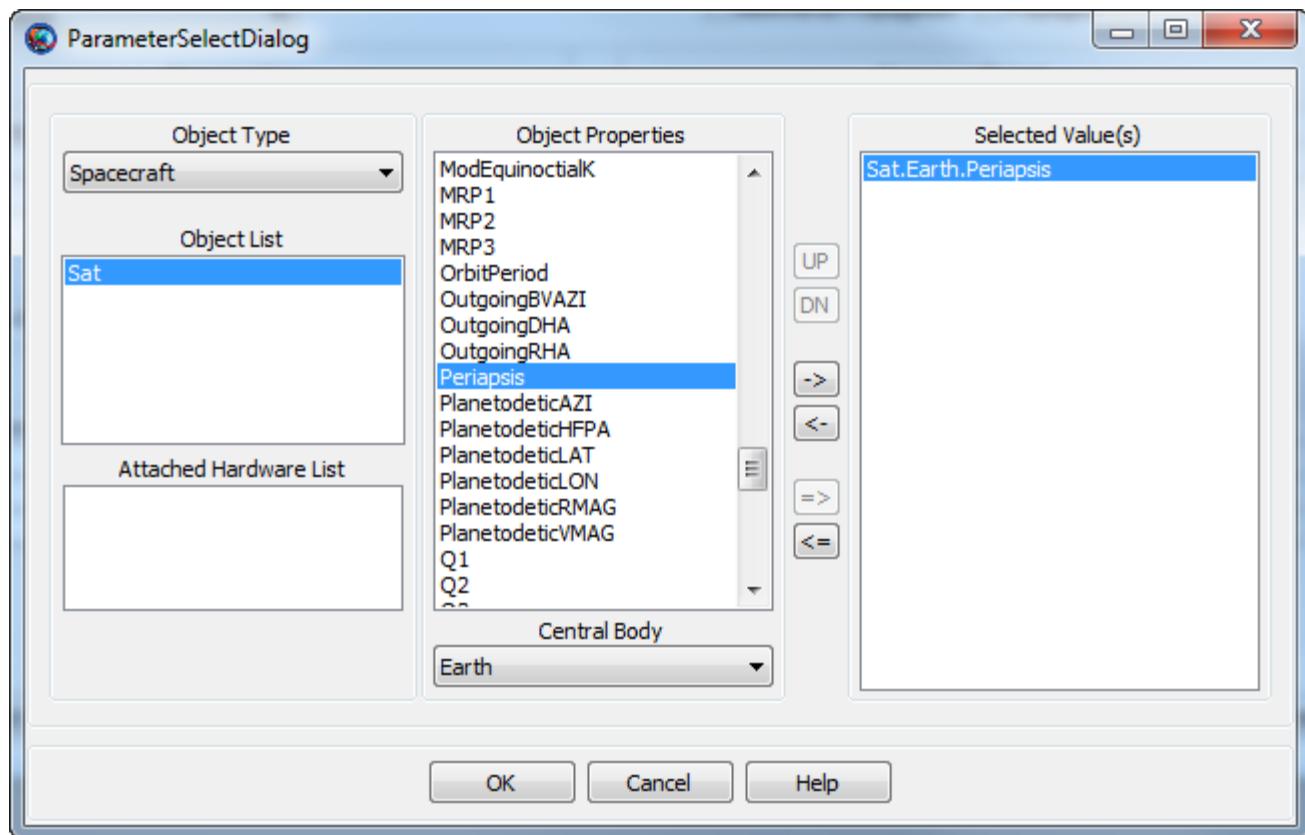


**Figure 14. DefaultOrbitView Configuration**

## Configure the Propagate Command

This is the last step before running the mission. Below you will configure a Propagate command to propagate (or simulate the motion of) **Sat** to orbit periapsis.

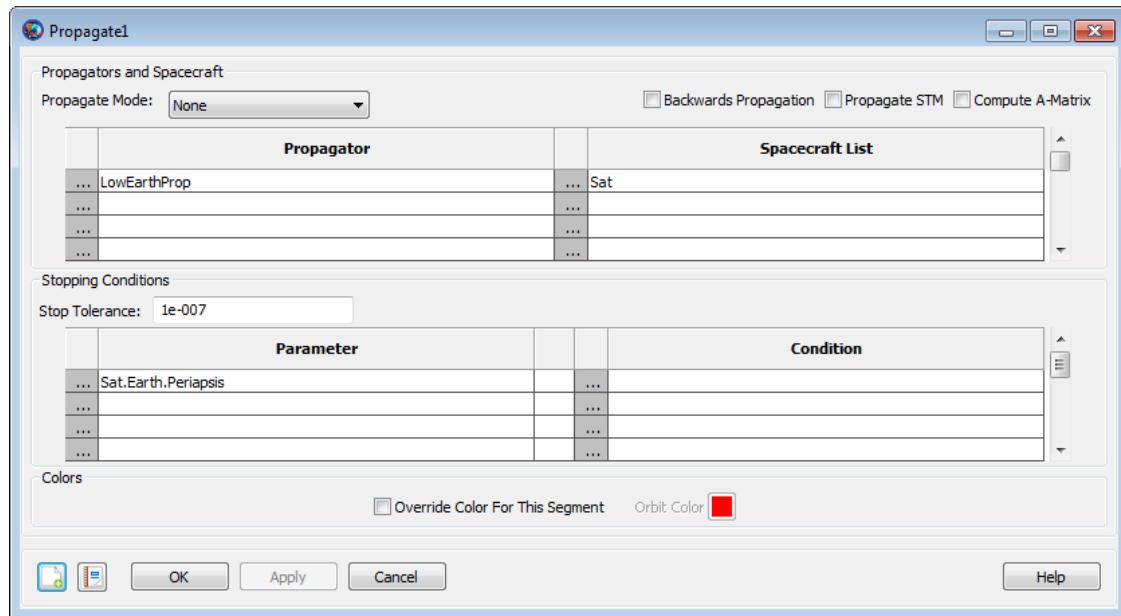
1. Click the **Mission** tab to display the **Mission** tree.
2. Double-click **Propagate1**.
3. Under **Stopping Conditions**, click the (...) button to the left of **Sat.ElapsedSecs**. This will display the **ParameterSelectDialog** window.
4. In the **Object List** box, click **Sat** if it is not already selected. This directs GMAT to associate the stopping condition with the spacecraft **Sat**.
5. In the **Object Properties** list, double-click **Periapsis** to add it to the **Selected Values** list. This is shown in **Figure 15**.



**Figure 15. Propagate Command  
ParameterSelectDialog Configuration**

6. Click **OK**. Your screen should now match [Figure 16](#).

7. Click **OK**.



**Figure 16. Propagate Command Configuration**

## Run and Analyze the Results

Congratulations, you have now configured your first GMAT mission and are ready to run the mission and analyze the results.

1. Click **Save** (disk icon) to save your mission.
2. Click the **Run** (▶).

You will see GMAT propagate the orbit and stop at orbit periapsis. [Figure 17](#) illustrates what you should see after correctly completing this tutorial. Here are a few things you can try to explore the results of this tutorial:

1. Manipulate the **DefaultOrbitView** plot using your mouse to orient the trajectory so that you can verify that at the final location the spacecraft is at periapsis. See the [OrbitView](#) reference for details.
2. Display the command summary:
  1. Click the **Mission** tab to display the **Mission** tree.
  2. Right-click **Propagate1** and select **Command Summary** to see data on the final state of **Sat**.
  3. Use the **Coordinate System** list to change the coordinate system in which the data is displayed.
3. Click **Start Animation** (play icon) to animate the mission and watch the orbit propagate from the initial state to periapsis.

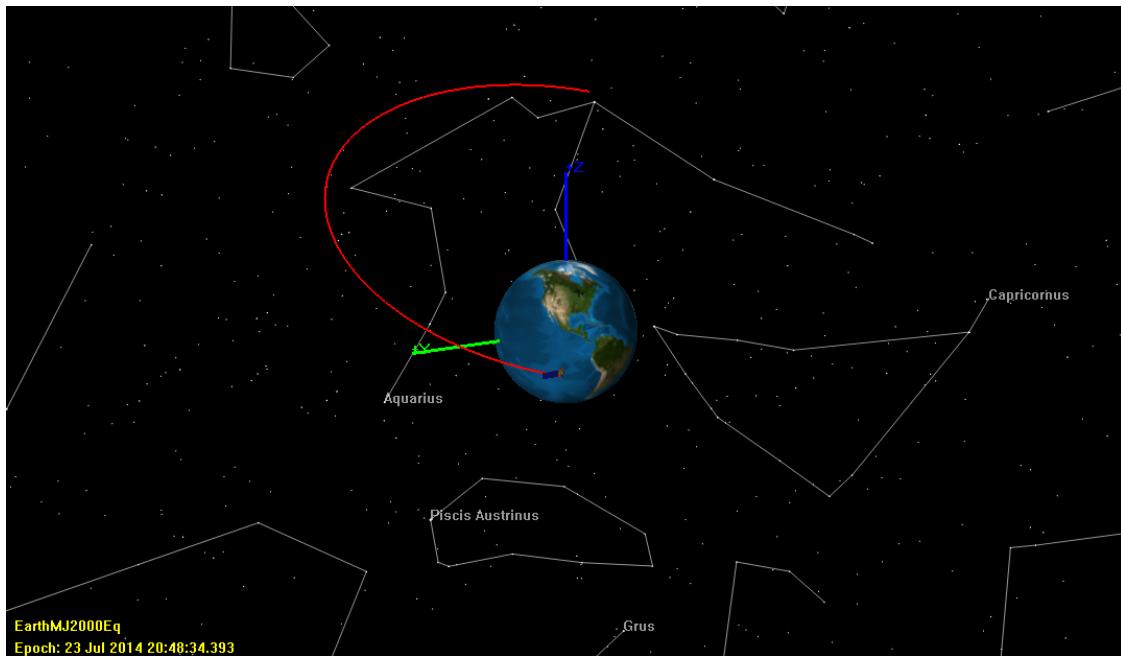


Figure 17. Orbit View Plot after Mission Run

# Simple Orbit Transfer

<b>Audience</b>	Beginner
<b>Length</b>	30 minutes
<b>Prerequisites</b>	Complete <i>Simulating an Orbit</i>
<b>Script File</b>	Tut_SimpleOrbitTransfer.script

## Objective and Overview



### Note

One of the most common problems in space mission design is to design a transfer from one circular orbit to another circular orbit that lie within the same orbital plane. Circular coplanar transfers are used to raise low-Earth orbits that have degraded due to the effects of atmospheric drag. They are also used to transfer from a low-Earth orbit to a geosynchronous orbit and to send spacecraft to Mars. There is a well known sequence of maneuvers, called the Hohmann transfer, that performs a circular, coplanar transfer using the least possible amount of fuel. A Hohmann transfer employs two maneuvers. The first maneuver raises the orbital apoapsis (or lowers orbital periapsis) to the desired altitude and places the spacecraft in an elliptical transfer orbit. At the apoapsis (or periapsis) of the elliptical transfer orbit, a second maneuver is applied to circularize the orbit at the final altitude.

In this tutorial, we will use GMAT to perform a Hohmann transfer from a low-Earth parking orbit to a geosynchronous mission orbit. This requires a targeting sequence to determine the required maneuver magnitudes to achieve the desired final orbit conditions. In order to focus on the configuration of the targeter, we will make extensive use of the default configurations for spacecraft, propagators, and maneuvers.

The target sequence employs two velocity-direction maneuvers and two propagation sequences. The purpose of the first maneuver is to raise orbit apoapsis to 42,165 km, the geosynchronous radius. The purpose of the second maneuver is to nearly circularize the orbit and yield a final eccentricity of 0.005. The basic steps of this tutorial are:

1. Create and configure a **DifferentialCorrector** resource.
2. Modify the **DefaultOrbitView** to visualize the trajectory.
3. Create two **ImpulsiveBurn** resources with default settings.
4. Create a **Target** sequence to (1) raise apoapsis to geosynchronous altitude and (2) circularize the orbit.
5. Run the mission and analyze the results.

## Configure Maneuvers, Differential Corrector, and Graphics

For this tutorial, you'll need GMAT open, with the default mission loaded. To load the default mission, click **New Mission** (➕) or start a new GMAT session. We will use the default configurations for the spacecraft (**DefaultSC**), the propagator (**DefaultProp**), and the two maneuvers. **DefaultSC** is configured by default to a near-circular orbit, and

**DefaultProp** is configured to use Earth as the central body with a nonspherical gravity model of degree and order 4. You may want to open the dialog boxes for these objects and inspect them more closely as we will leave them at their default settings.

## Create the Differential Corrector

The **Target** sequence we will create later needs a **DifferentialCorrector** resource to operate, so let's create one now. We'll leave the settings at their defaults.

1. In the **Resource tree**, expand the **Solvers** folder if it isn't already.
2. Right-click the **Boundary Value Solvers** folder, point to **Add**, and click **DifferentialCorrector**. A new resource called **DC1** will be created.

## Modify the Default Orbit View

We need to make minor modifications to **DefaultOrbitView** so that the entire final orbit will fit in the graphics window.

1. In the **Resource Tree**, double-click **DefaultOrbitView** to edit its properties.
2. Set the values shown in the table below.

**Table 2. DefaultOrbitView settings**

Field	Value
<b>Solver Iterations</b> , under <b>Drawing Option</b>	<b>Current</b>
<b>Axis</b> , under <b>View Up Definition</b>	<b>X</b>
<b>View Point Vector</b> boxes, under <b>View Definition</b> : 0, 0, and 120000 respectively	

3. Click **OK** to save these changes.

## Create the Maneuvers.

We'll need two **ImpulsiveBurn** resources for this tutorial, both using default values. Below, we'll rename the default **ImpulsiveBurn** and create a new one.

1. In the **Resources** tree, right-click **DefaultIB** and click **Rename**.
2. In the **Rename** box, type **TOI**, an acronym for Transfer Orbit Insertion, and click **OK**.
3. Right-click the **Burns** folder, point to **Add**, and click **ImpulsiveBurn**.
4. Rename the new **ImpulsiveBurn1** resource to **GOI**, an acronym for Geosynchronous Orbit Insertion.

## Configure the Mission Sequence

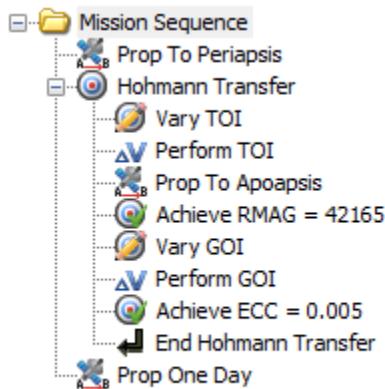
Now we will configure a **Target** sequence to solve for the maneuver values required to raise the orbit to geosynchronous altitude and circularize the orbit. We'll begin by creating an initial **Propagate** command, then the **Target** sequence itself, then the final **Propagate** command. To allow us to focus on the **Target** sequence, we'll assume you have already learned how to propagate an orbit to a desired condition by working through the *Simulating an Orbit* tutorial.

## Configure the Initial Propagate Command

1. Click on the **Mission** tab to show the **Mission** tree.
2. Configure **Propagate1** to propagate to **DefaultSC.Earth.Periapsis**.
3. Rename **Propagate1** to **Prop To Periapsis**.

## Create the Target Sequence

Now create the commands necessary to perform the **Target** sequence. [Figure 18](#) illustrates the configuration of the **Mission** tree after you have completed the steps in this section. We'll discuss the **Target** sequence after it has been created.



**Figure 18. Final Mission Sequence for the Hohmann Transfer**

To create the **Target** sequence:

1. In the **Mission** tree, right-click **Prop To Periapsis**, point to **Insert After**, and click **Target**. This will insert two separate commands: **Target1** and **EndTarget1**.
2. Right-click **Target1** and click **Rename**.
3. Type **Hohmann Transfer** and click **OK**.
4. Right-click **Hohmann Transfer**, point to **Append**, and click **Vary**.
5. Rename **Vary1** to **Vary TOI**.
6. Complete the **Target** sequence by appending the commands in [Table 3](#).

**Table 3. Additional Target Sequence Commands**

Command	Name
<b>Maneuver</b>	<b>Perform TOI</b>
<b>Propagate</b>	<b>Prop To Apoapsis</b>
<b>Achieve</b>	<b>Achieve RMAG = 42165</b>
<b>Vary</b>	<b>Vary GOI</b>
<b>Maneuver</b>	<b>Perform GOI</b>
<b>Achieve</b>	<b>Achieve ECC = 0.005</b>

**Note**



Let's discuss what the **Target** sequence does. We know that two maneuvers are required to perform the Hohmann transfer. We also know that for our current mission, the final orbit radius must be 42,165 km and the final orbital eccentricity must be 0.005. However, we don't know the size (or #V magnitudes) of the maneuvers that precisely achieve the desired orbital conditions. You use the **Target** sequence to solve for those precise maneuver values. You must tell GMAT what controls are available (in this case, two maneuvers) and what conditions must be satisfied (in this case, a specific orbital radius and eccentricity). You accomplish this using the **Vary** and **Achieve** commands. Using the **Vary** command, you tell GMAT what to solve for—in this case, the #V values for **TOI** and **GOI**. You use the **Achieve** command to tell GMAT what conditions the solution must satisfy—in this case, the final orbital conditions.

## Create the Final Propagate Command

We need a **Propagate** command after the **Target** sequence so that we can see our final orbit.

1. In the **Mission** tree, right-click **End Hohmann Transfer**, point to **Insert After**, and click **Propagate**. A new **Propagate3** command will appear.
2. Rename **Propagate3** to **Prop One Day**.
3. Double-click **Prop One Day** to edit its properties.
4. Under **Condition**, replace the value **12000.0** with **86400**, the number of seconds in one day.
5. Click **OK** to save these changes.

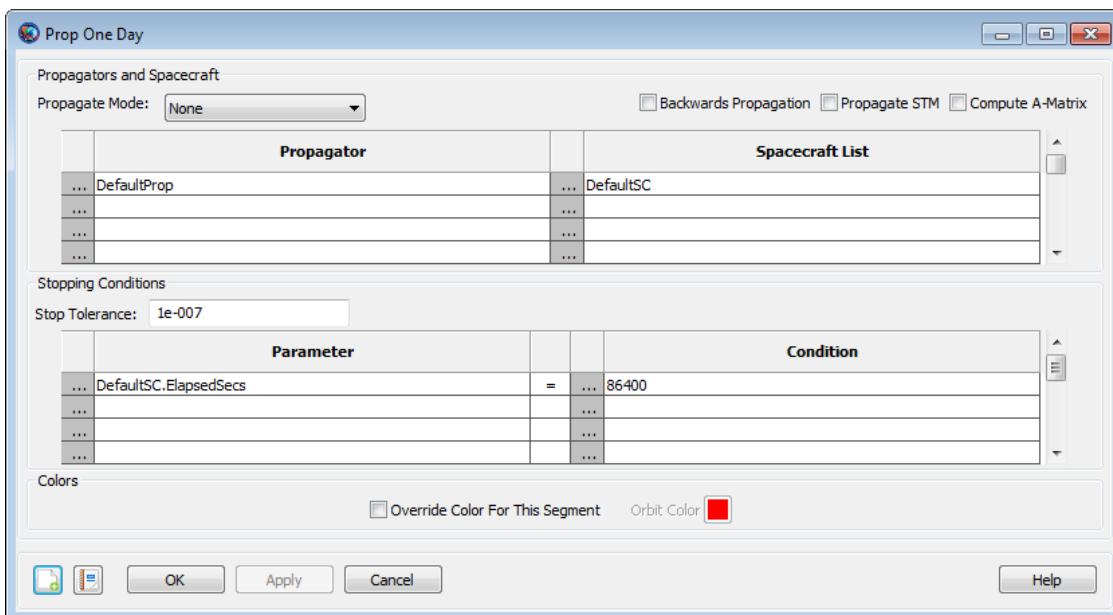


Figure 19. Prop One Day Command Configuration

## Configure the Target Sequence

Now that the structure is created, we need to configure the various parts of the **Target** sequence to do what we want.

### Configure the Vary TOI Command

1. Double-click **Vary TOI** to edit its properties. Notice that the variable in the **Variable** box is **TOI.Element1**, which by default is the velocity component of TOI in the local Velocity-Normal-Binormal (VNB) coordinate system. That's what we need, so we'll keep it.
2. In the **Initial Value** box, type **1.0**.
3. In the **Max Step** box, type **0.5**.
4. Click **OK** to save these changes.

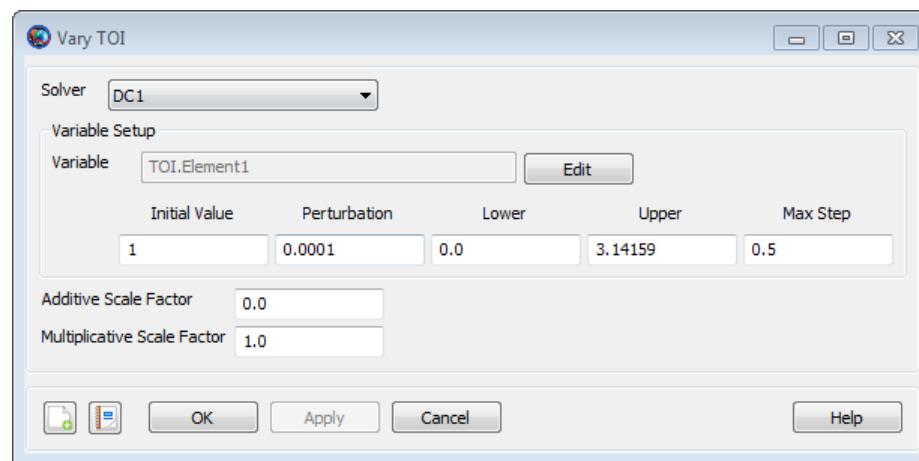


Figure 20. Vary TOI Command Configuration

### Configure the Perform TOI Command

1. Double-click **Perform TOI** to edit its properties. Notice that the command is already set to apply the **TOI** burn to the **DefaultSC** spacecraft, so we don't need to change anything here.
2. Click **OK**.

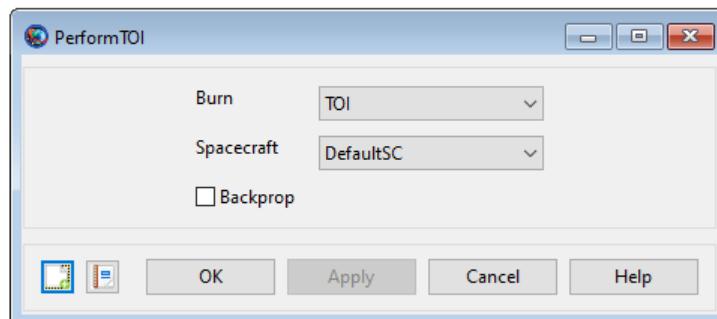
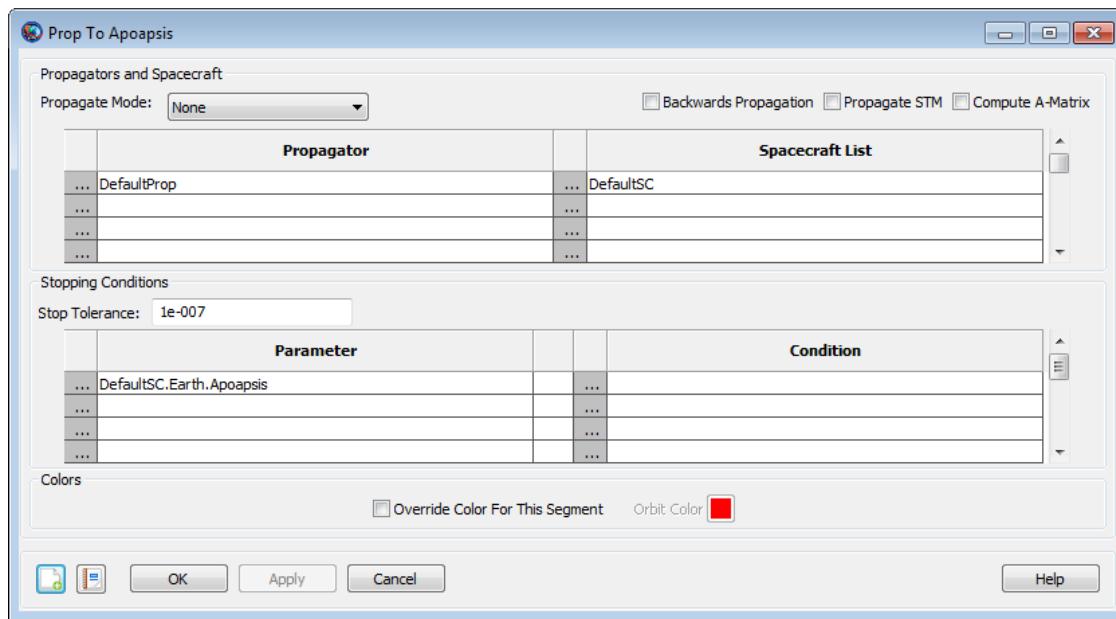


Figure 21. Perform TOI Command Configuration

## Configure the Prop to Apoapsis Command

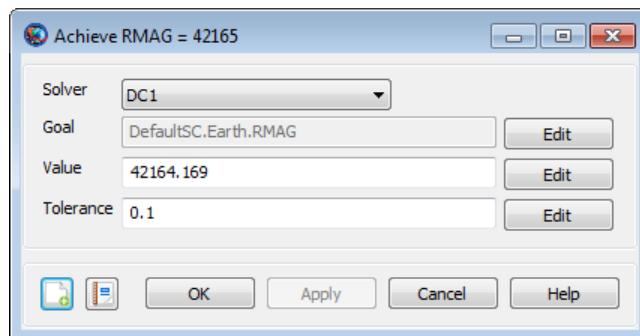
1. Double-click **Prop to Apoapsis** to edit its properties.
2. Under **Parameter**, replace **DefaultSC.ElapsedSecs** with **DefaultSC.Earth.Apoapsis**.
3. Click **OK** to save these changes.



**Figure 22. Prop to Apoapsis Command Configuration**

## Configure the Achieve RMAG = 42165 Command

1. Double-click **Achieve RMAG = 42165** to edit its properties.
2. Notice that **Goal** is set to **DefaultSC.Earth.RMAG**. This is what we need, so we make no changes here.
3. In the **Value** box, type **42164.169**, a more precise number for the radius of a geo-synchronous orbit (in kilometers).
4. Click **OK** to save these changes.



**Figure 23. Achieve RMAG = 42165 Command Configuration**

## Configure the Vary GOI Command

1. Double-click **Vary GOI** to edit its properties.
2. Next to **Variable**, click the **Edit** button.
3. Under **Object List**, click **GOI**.
4. In the **Object Properties** list, double-click **Element1** to move it to the **Selected Value(s)** list. See the image below for results.

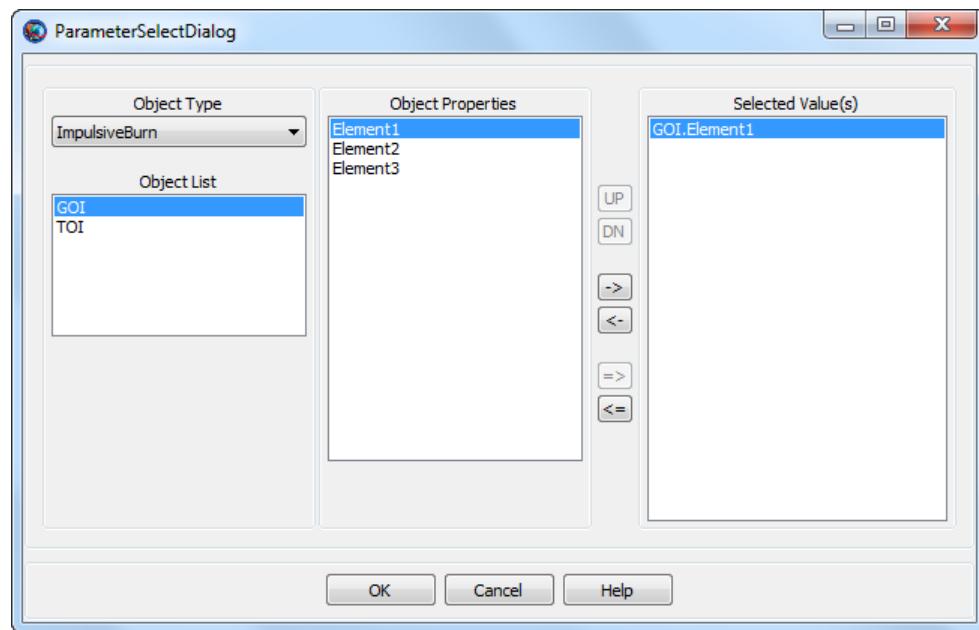


Figure 24. Vary GOI Parameter Selection

5. Click **OK** to close the **ParameterSelectDialog** window.
6. In the **Initial Value** box, type **1.0**.
7. Click **OK** to save these changes.

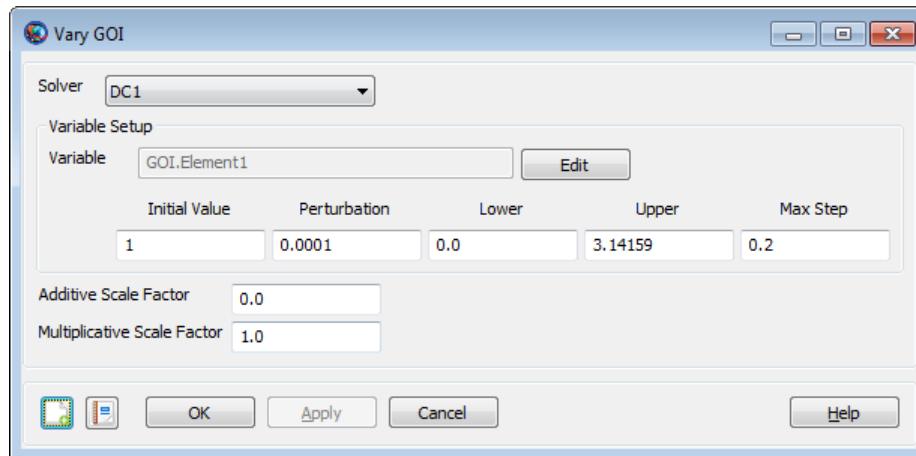


Figure 25. Vary GOI Command Configuration

## Configure the Perform GOI Command

1. Double-click **Perform GOI** to edit its properties.
2. In the **Burn** list, click **GOI**.
3. Click **OK** to save these changes.

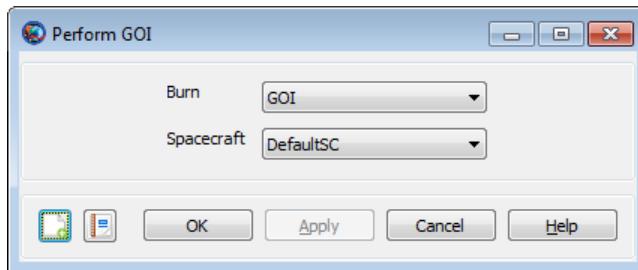


Figure 26. Perform GOI Command Configuration

## Configure the Achieve ECC = 0.005 Command

1. Double-click **Achieve ECC = 0.005** to edit its properties.
2. Next to **Goal**, click the **Edit** button.
3. In the **Object Properties** list, double-click **ECC**.
4. Click **OK** to close the **ParameterSelectDialog** window.
5. In the **Value** box, type **0.005**.
6. In the **Tolerance** box, type **0.0001**.
7. Click **OK** to save these changes.

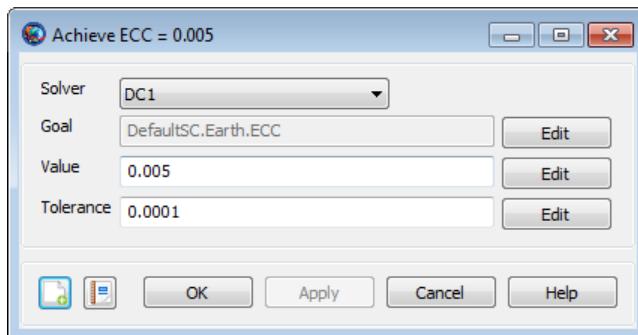
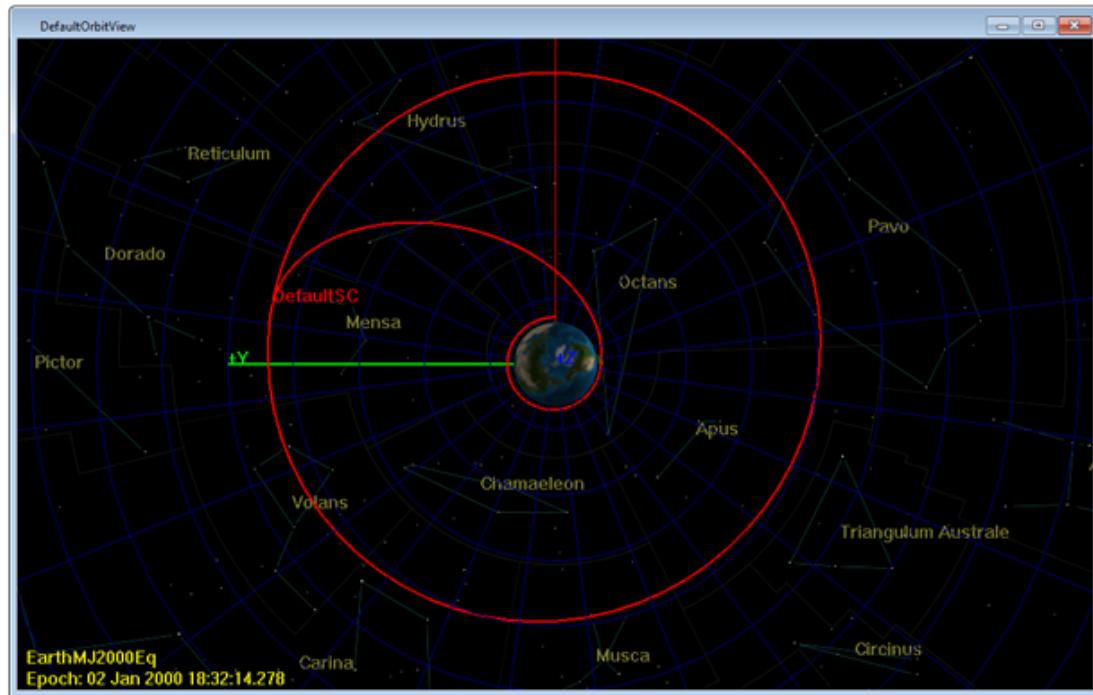


Figure 27. Achieve ECC = 0.005 Command Configuration

## Run the Mission

Before running the mission, click **Save** (💾) and save the mission to a file of your choice. Now click **Run** (▶). As the mission runs, you will see GMAT solve the targeting problem. Each iteration and perturbation is shown in **DefaultOrbitView** window in light blue, and the final solution is shown in red. After the mission completes, the 3D view should appear as in to the image shown below. You may want to run the mission several times to see the targeting in progress.



**Figure 28. 3D View of Hohmann Transfer**

If you were to continue developing this mission, you can store the final solution of the **Target** sequence as the initial conditions of the **TOI** and **GOI** resources themselves, so that if you make small changes, the subsequent runs will take less time. To do this, follow these steps:

1. In the **Mission** tree, double-click **Hohmann Transfer** to edit its properties.
2. Click **Apply Corrections**.
3. Now re-run the mission. If you inspect the results in the message window, you will see that the **Target** sequence converges in one iteration because you stored the solution as the initial condition.



# Target Finite Burn to Raise Apogee

<b>Audience</b>	Intermediate level
<b>Length</b>	45 minutes
<b>Prerequisites</b>	Complete Simulating an Orbit and Simple Orbit Transfer
<b>Script File</b>	Tut_Target_Finite_Burn_to_Raise_Apogee.script

## Objective and Overview



### Note

One of the most common operational problems in space mission design is the design of a finite burn that achieves a given orbital goal. A finite burn model, as opposed to the idealized impulsive burn model used for preliminary design, is needed to accurately model actual spacecraft maneuvers.

In this tutorial, we will use GMAT to perform a finite burn for a spacecraft in low Earth orbit. The goal of this finite burn is to achieve a certain desired apogee radius. Since the most efficient orbital location to affect apoapsis is at periapsis, the first step in this tutorial is to propagate the spacecraft to perigee.

To calculate the duration of the perigee burn needed to achieve a desired apogee radius of 12000 km, we must create the appropriate targeting sequence. The main portion of the target sequence employs a **Begin/End FiniteBurn** command pair, for a velocity direction maneuver, followed by a command to propagate the spacecraft to orbit apogee.

The basic steps of this tutorial are:

1. Create and configure the **Spacecraft** hardware and **FiniteBurn** resources
2. Create the **DifferentialCorrector** and Target Control Variable
3. Configure the Mission Sequence. To do this, we will
  - a. Create **Begin/End FiniteBurn** commands with default settings.
  - b. Create a **Target** sequence to achieve a 12000 km apogee radius.
4. Run the mission and analyze the results.

## Create and Configure Spacecraft Hardware and Finite Burn

For this tutorial, you'll need GMAT open with the default mission loaded. To load the default mission, click **New Mission** (➕) or start a new GMAT session. We will use the default configurations for the spacecraft (**DefaultSC**) and the propagator (**DefaultProp**). **DefaultSC** is configured by default to a near-circular orbit, and **DefaultProp** is configured to use Earth as the central body with a nonspherical gravity model of degree and order 4. You may want to open the dialog boxes for these objects and inspect them more closely as we will leave them at their default settings.

## Create a Thruster and a Fuel Tank

To model thrust and fuel use associated with a finite burn, we must create a **ChemicalThruster** and a **ChemicalTank** and then attach the newly created **ChemicalTank** to the **ChemicalThruster**.

1. In the **Resources** tree, right-click on the **Hardware** folder, point to **Add**, and click **ChemicalThruster**. A resource named **ChemicalThruster1** will be created.
2. In the **Resources** tree, right-click on the **Hardware** folder, point to **Add**, and click **ChemicalTank**. A resource named **ChemicalTank1** will be created.
3. Double-click **ChemicalThruster1** to edit its properties.
4. Select the **Decrement Mass** box so that GMAT will model fuel use associated with a finite burn.
5. Use the drop down menu to the right of the **Tank** field to select **ChemicalTank1** as the fuel source for **ChemicalThruster1**. Click **OK**.

Figure 29 below shows the default **ChemicalTank1** configuration that we will use and Figure 30 shows the finished **ChemicalThruster1** configuration.

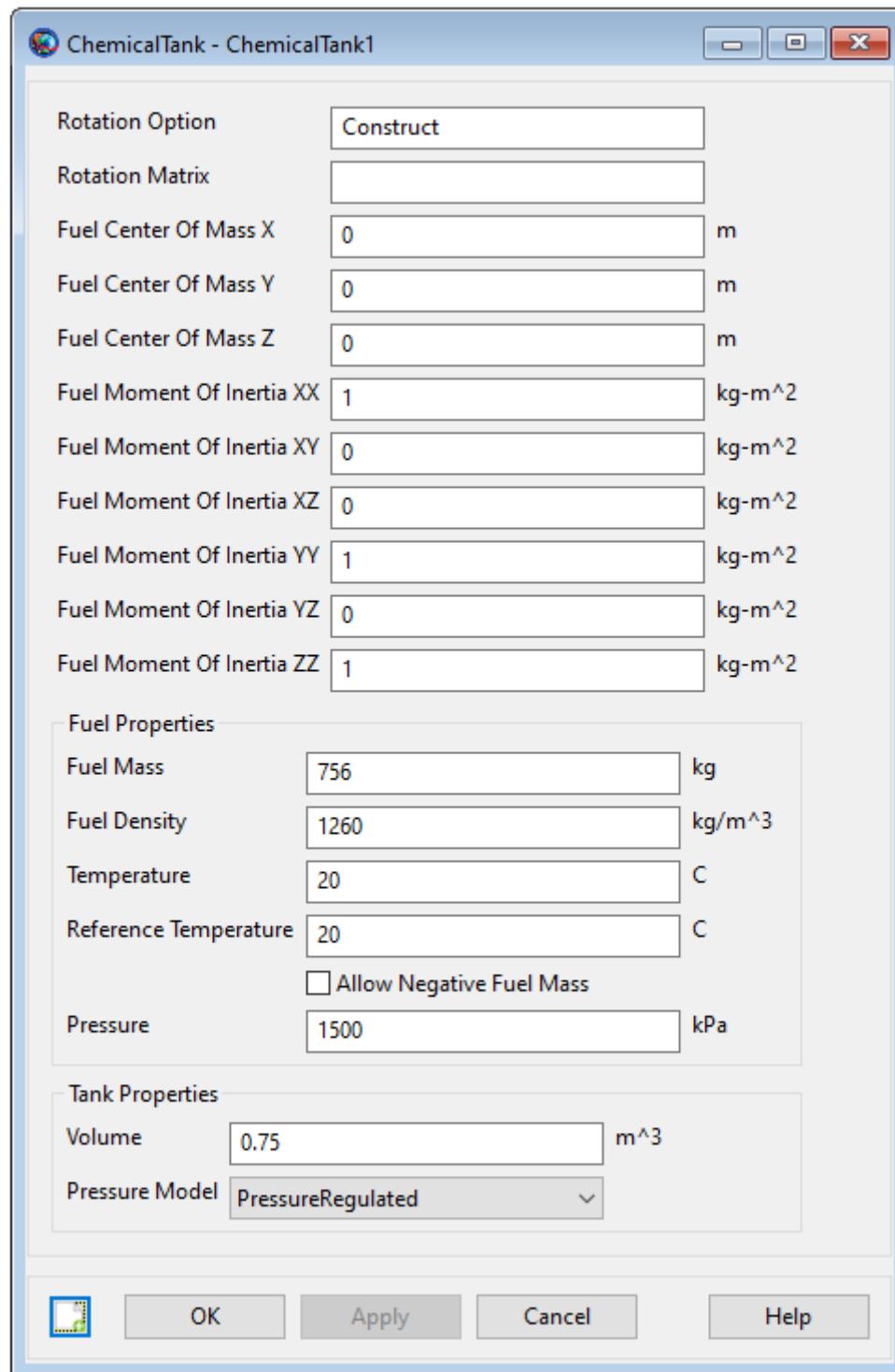
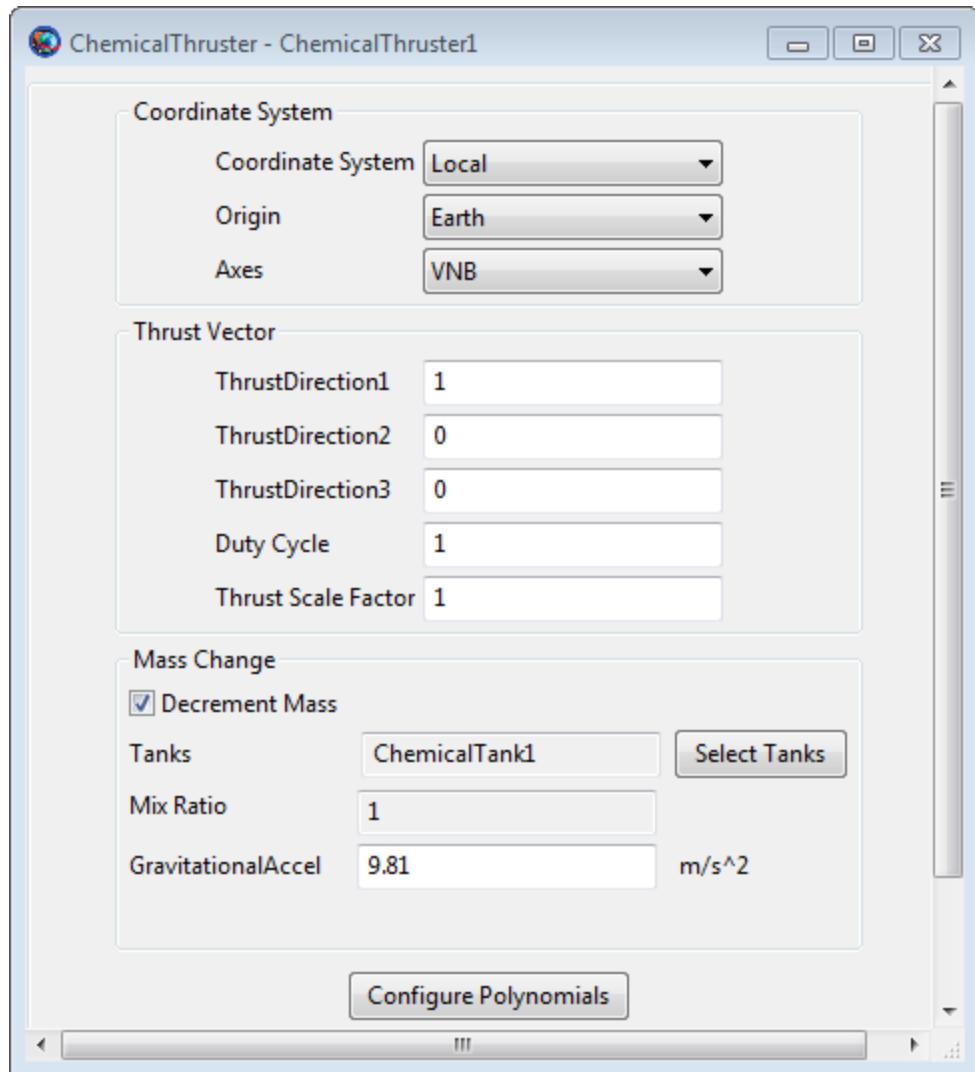


Figure 29. ChemicalTank1 Configuration



**Figure 30. ChemicalThruster1 Configuration**

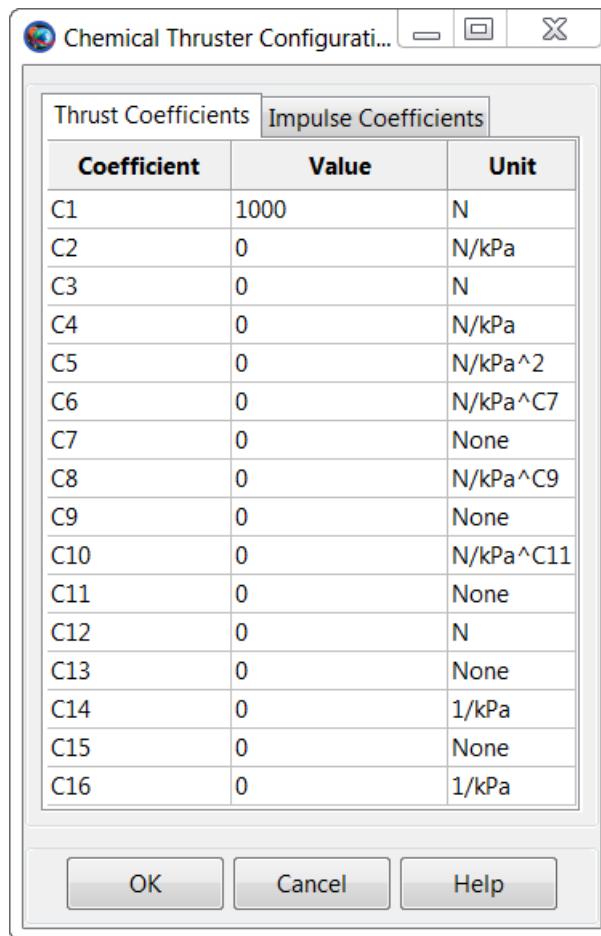
Note that the default **Thruster1 Coordinate System**, as shown in [Figure 30](#), is Earth-based Velocity, Normal, Bi-normal (VNB) and that the default **Thrust Vector** of (1,0,0) represents our desired velocity oriented maneuver direction.

For a general finite burn, if desired, we can specify how both the thrust and the fuel use depend upon fuel tank pressure. The user does this by inputting coefficients of certain pre-defined polynomials. To view the values for the thrust coefficients, click the **Edit Thruster Coef.** button and to view the ISP coefficients which determine fuel use, click the **Edit Impulse Coef.** button. For this tutorial, we will use the default ISP polynomial coefficient values but we will change the **ChemicalThruster1** polynomial coefficients as follows.

### Modify Thruster1 Thrust Coefficients

1. In the **Resources** tree, double-click **ChemicalThruster1** to edit its properties

2. Click the **Edit Thruster Coef.** button to bring up the **ThrusterCoefficientDialog** box, shown in [Figure 31](#). Replace the default **C1** coefficient value of 10 with 1000. Click **OK**.



**Figure 31. ChemicalThruster1 Thrust Coefficients**

The exact form of the pre-defined Thrust polynomial, associated with the coefficients above, are given in the **ChemicalThruster** help. We note that, by default, all of the Thrust coefficients associated with terms that involve tank pressure are zero. We have kept the default zero values for all of these coefficients. We simply changed the constant term in the Thrust polynomial from 10 to 1000 which is much larger than the thrust for a typical chemical thruster. The Thrust and ISP polynomials used in this tutorial are shown below.

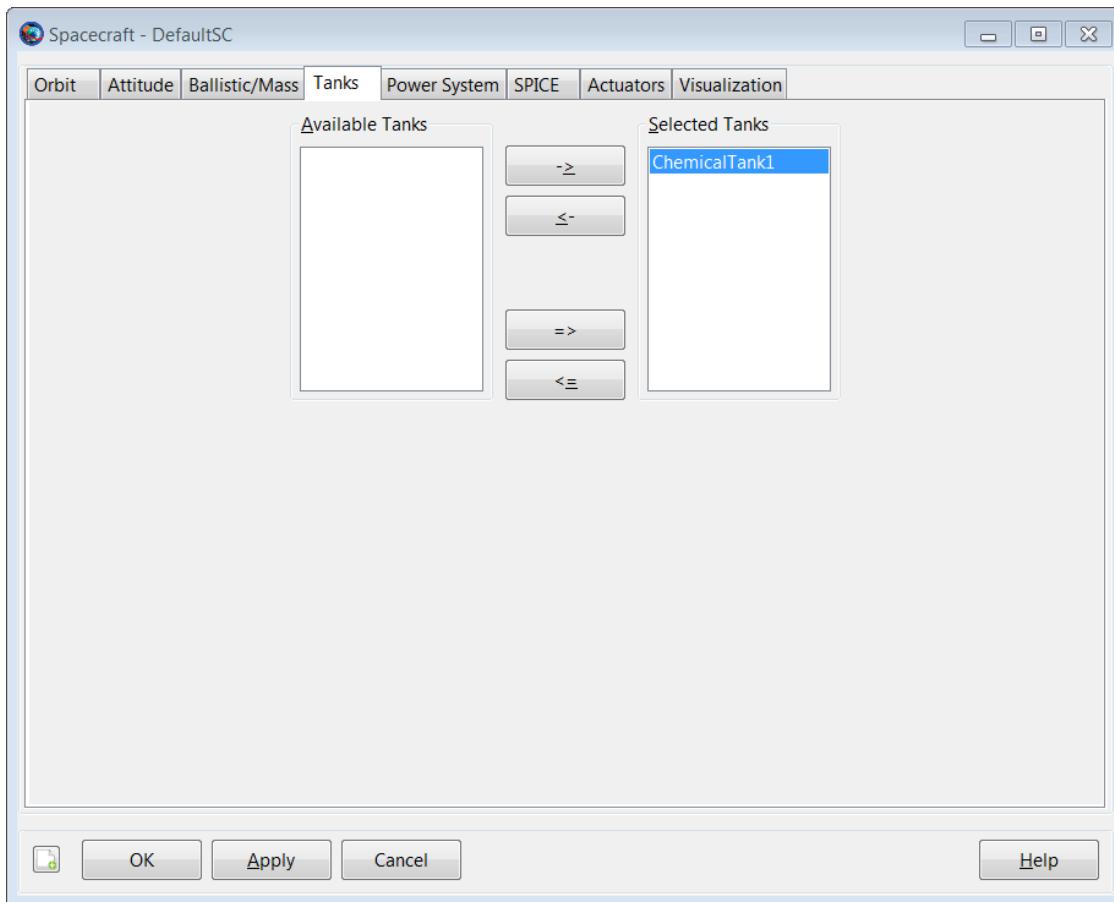
Thrust = 1000 (Newtons)

ISP = 300 (seconds)

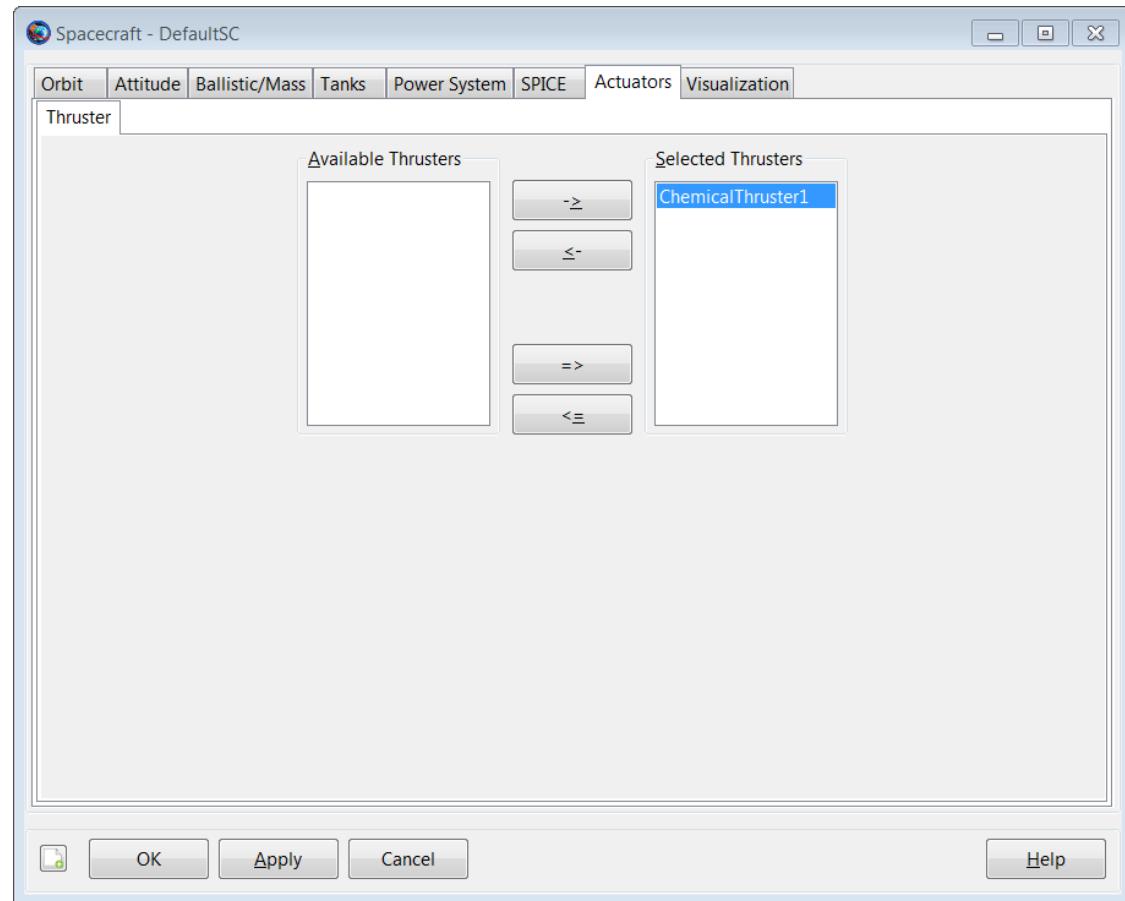
### Attach ChemicalTank1 and Thruster1 to DefaultSC

1. In the **Resources** tree, double-click **DefaultSC** to edit its properties.

2. Select the **Tanks** tab. In the **Available Tanks** column, select **ChemicalTank1**. Then click the right arrow button to add **ChemicalTank1** to the **SelectedTanks** list. Click **Apply**.
3. Select the **Actuators** tab. In the **Available Thrusters** column, select **ChemicalThruster1**. Then click the right arrow button to add **ChemicalThruster1** to the **SelectedThrusters** list. Click **OK**.



**Figure 32. Attach ChemicalTank1 to DefaultSC**

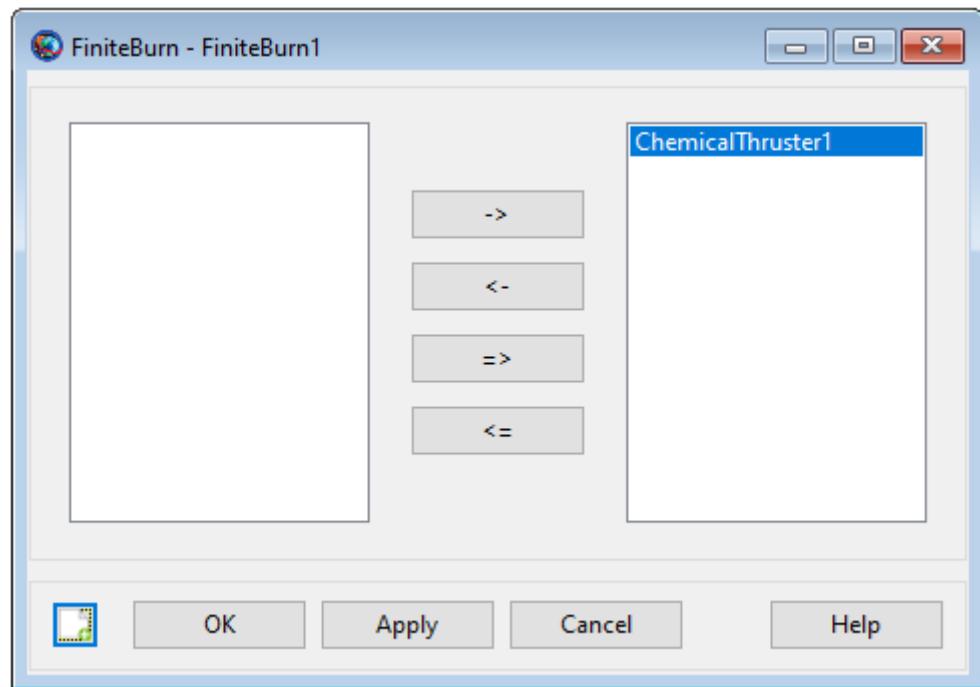


**Figure 33. Attach ChemicalThruster1 to DefaultSC**

### Create the Finite Burn Maneuver

We'll need a single **FiniteBurn** resource for this tutorial.

1. In the **Resources** tree, right-click the **Burns** folder and add a **FiniteBurn**. A resource named **FiniteBurn1** will be created.
2. Double-click **FiniteBurn1** to edit its properties.
3. In the left column, select **ChemicalThruster1**. Then click the right arrow button to add **ChemicalThruster1** as a thruster to be used by **FiniteBurn1**.



**Figure 34. Creation of FiniteBurn Resource FiniteBurn1**

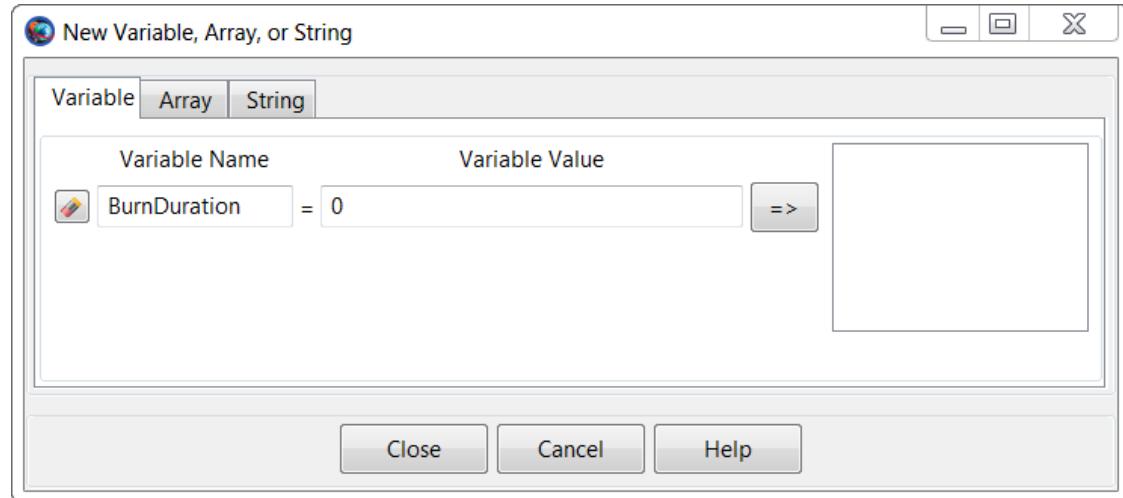
## Create the Differential Corrector and Target Control Variable

The **Target** sequence we will create later needs a **DifferentialCorrector** resource to operate, so let's create one now. We'll leave the settings at their defaults.

1. In the **Resources** tree, expand the **Solvers** folder if it isn't already.
2. Right-click the **Boundary Value Solvers** folder, point to **Add**, and click **DifferentialCorrector**. A new resource called **DC1** will be created.

The **Target** sequence we will later create uses the **Vary** command to adjust a user defined target control variable in order to achieve the desired orbital goal of raising apogee to 12000 km. We must first create this variable which we will name **BurnDuration**.

1. In the **Resources** tree, right-click the **Variables/Arrays/Strings** folder, point to **Add**, and click **Variable**. A new window will come up with two input fields, **Variable Name** and **Variable Value**. For **Variable Name**, input **BurnDuration** and for **Variable Value**, input **0**. Click the **=>** button to create the variable, then click **Close**.
2. To verify that we have created this new variable correctly, double-click **BurnDuration** to view its properties.



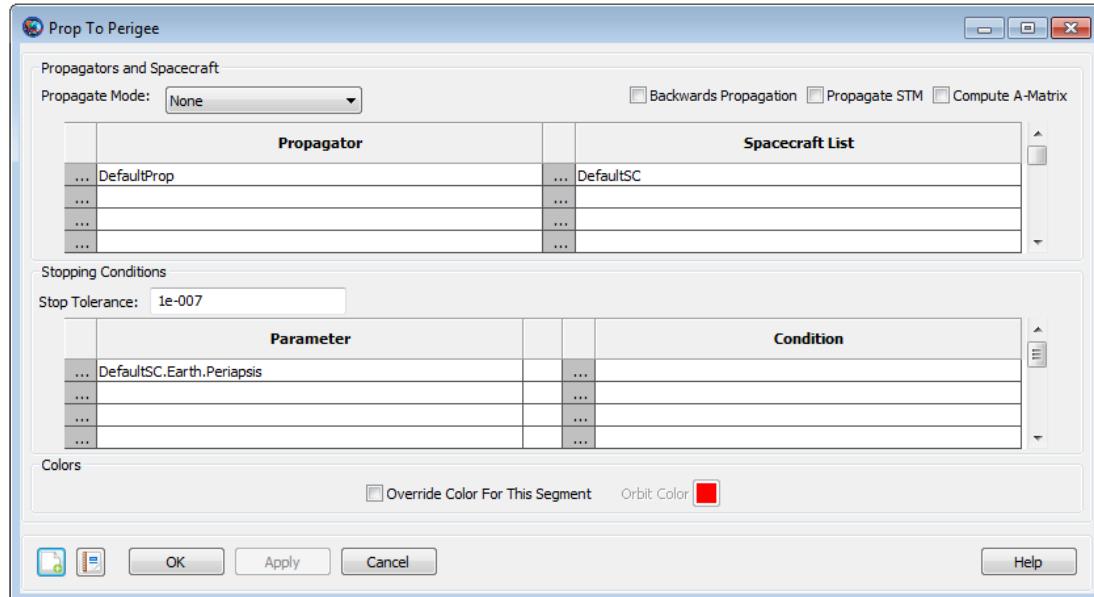
**Figure 35. Creation of Variable Resource, BurnDuration**

## Configure the Mission Sequence

Now we will configure a **Target** sequence to solve for the finite burn duration required to raise apogee to 12000 km. We'll begin by creating the initial **Propagate** command, then the **Target** sequence itself.

### Configure the Initial Propagate Command

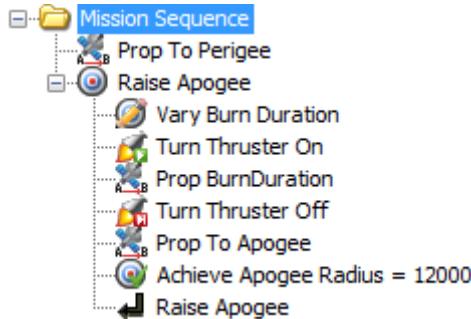
1. Click on the **Mission** tab to show the **Mission** tree.
2. Configure **Propagate1** to propagate to **DefaultSC.Earth.Periapsis**.
3. Rename **Propagate1** to **Prop To Perigee**.



**Figure 36. Prop To Perigee Command Configuration**

## Create the Target Sequence

Now create the commands necessary to perform the **Target** sequence. Figure 37 illustrates the configuration of the **Mission** tree after we have completed the steps in this section. We'll discuss the **Target** sequence after it has been created.



**Figure 37. Final Mission Sequence**

To create the **Target** sequence:

1. In the **Mission** tree, right-click **Prop To Perigee**, point to **Insert After**, and click **Target**. This will insert two separate commands: **Target1** and **EndTarget1**.
2. Right-click **Target1** and click **Rename**. Type **Raise Apogee** and click **OK**.
3. Right-click **Raise Apogee**, point to **Append**, and click **Vary**. Rename the newly created command as **Vary Burn Duration**.
4. Right-click **Vary Burn Duration**, point to **Insert After**, and click **BeginFiniteBurn**. Rename the newly created command as **Turn Thruster On**.
5. Complete the **Target** sequence by inserting the commands shown in Table 4.

**Table 4. Additional Target Sequence Commands**

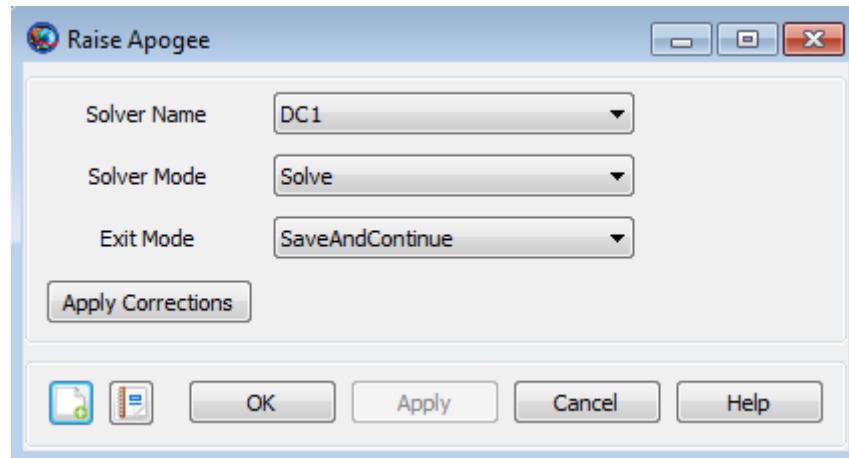
Command	Name
<b>Propagate</b>	<b>Prop BurnDuration</b>
<b>EndFiniteBurn</b>	<b>Turn Thruster Off</b>
<b>Propagate</b>	<b>Prop To Apogee</b>
<b>Achieve</b>	<b>Achieve Apogee Radius = 12000</b>

## Configure the Target Sequence

Now that the structure is created, we need to configure the various parts of the **Target** sequence to do what we want.

### Configure the Raise Apogee Command

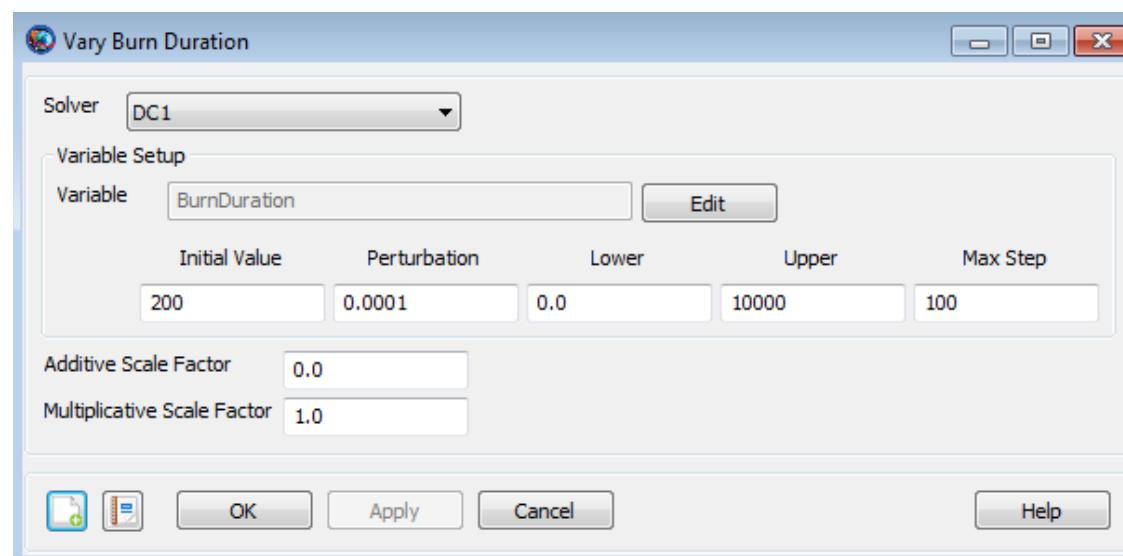
1. Double-click **Raise Apogee** to edit its properties.
2. In the **ExitMode** list, click **SaveAndContinue**. This instructs GMAT to save the final solution of the targeting problem after you run it.
3. Click **OK** to save these changes.



**Figure 38. Raise Apogee Command Configuration**

### Configure the Vary Burn Duration Command

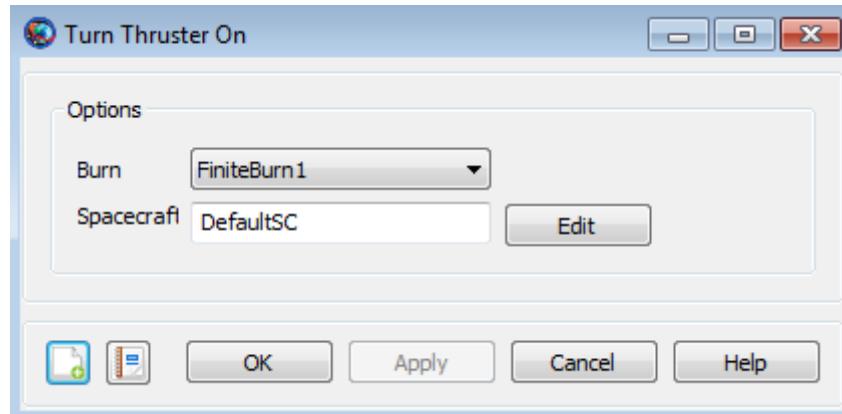
1. Double-click **Vary Burn Duration** to edit its properties. We want this command to adjust (or “Vary”) the finite burn duration represented by the previously created control variable, **BurnDuration**. To accomplish this, click on the **Edit** button to bring up the **ParameterSelectDialog**. Use the **ObjectType** menu to select the **Variable** object type. The **ObjectList** menu will then display a list of user defined variables. Double-click on the variable, **BurnDuration**, so that **BurnDuration** appears in the **SelectedValues(s)** menu. Click the **OK** button to save the changes and return to the **Vary Burn Duration** command menu.
2. In the **Initial Value** box, type 200
3. In the **Upper** box, type 10000
4. In the **Max Step** box, type 100.
5. Click **OK** to save these changes.



**Figure 39. Vary Burn Duration Command Configuration**

## Configure the Turn Thruster On Command

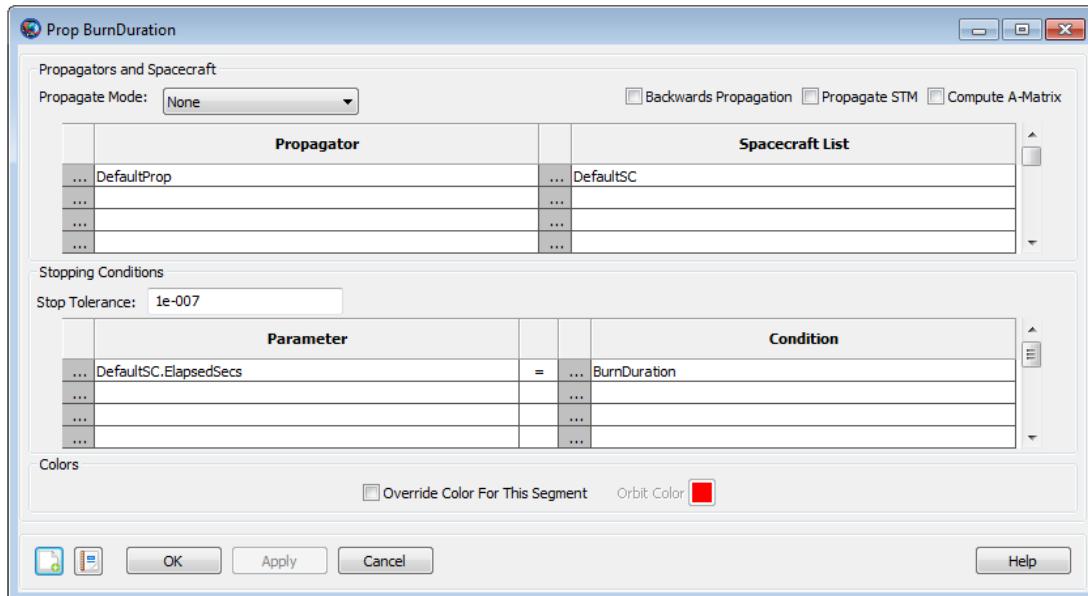
1. Double-click **Turn Thruster On** to edit its properties. Notice that the command is already set to apply **FiniteBurn1** to the **DefaultSC** spacecraft, so we don't need to change anything here.
2. Click **OK**.



**Figure 40. Turn Thruster On Command Configuration**

## Configure the Prop BurnDuration Command

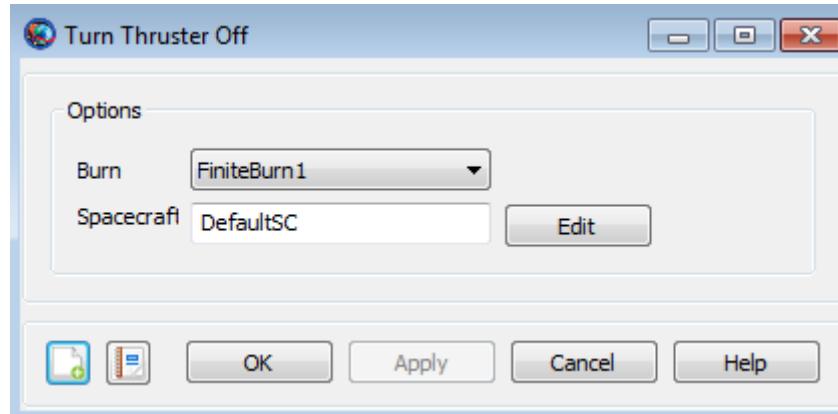
1. Double-click **Prop BurnDuration** to edit its properties.
2. We will use the default **Parameter** value of **DefaultSC.ElapsedSecs**.
3. Under **Condition**, replace the default value with **Variable**, **BurnDuration**.
4. Click **OK** to save these changes.



**Figure 41. Prop BurnDuration Command Configuration**

### Configure the Turn Thruster Off Command

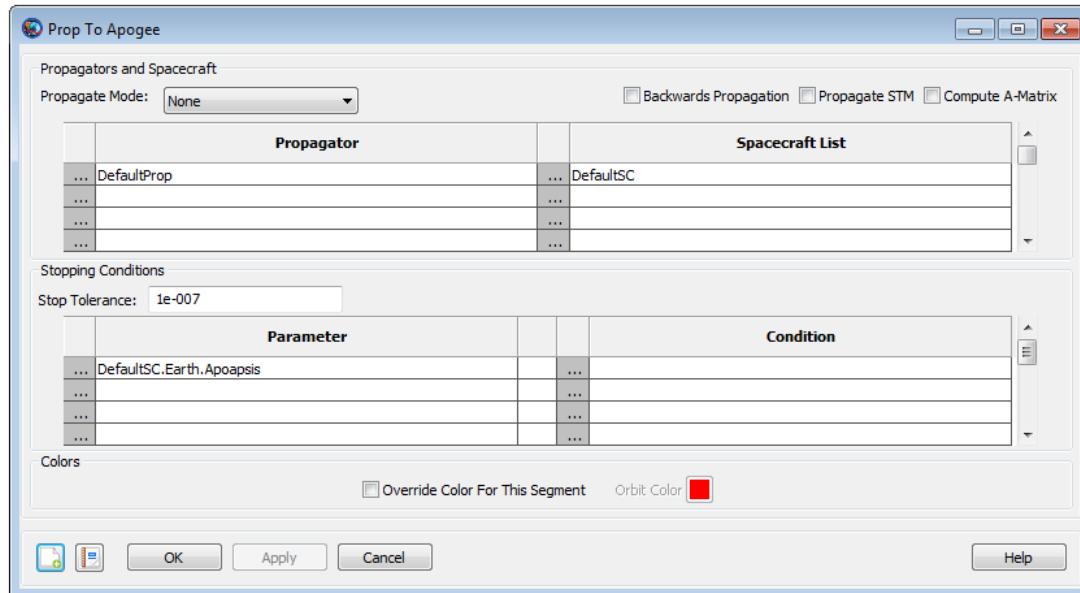
1. Double-click **Turn Thruster Off** to edit its properties. Notice that the command is already set to end **FiniteBurn1** as applied to the **DefaultSC** spacecraft, so we don't need to change anything here..
2. Click **OK**.



**Figure 42. Turn Thruster Off Command Configuration**

### Configure the Prop To Apogee Command

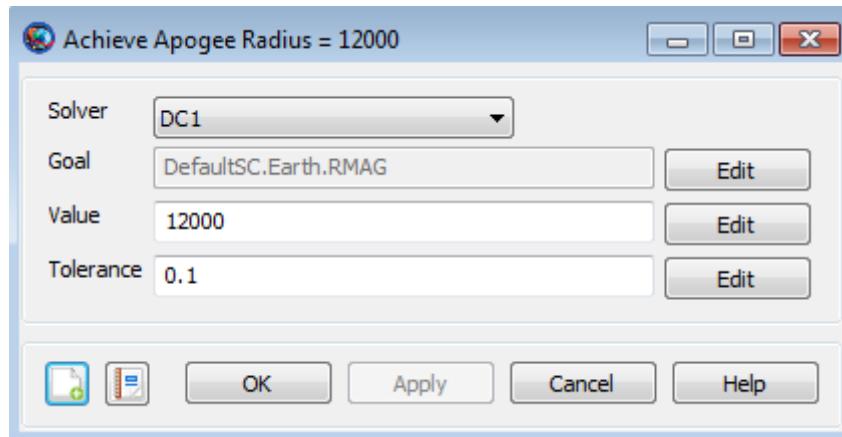
1. Double-click **Prop to Apogee** to edit its properties.
2. Under **Parameter**, replace **DefaultSC.ElapsedSecs** with **DefaultSC.Earth.Apoapsis**.
3. Click **OK** to save these changes.



**Figure 43. Prop To Apogee Command Configuration**

### Configure the Achieve Apogee Radius = 12000 Command

1. Double-click **Achieve Apogee Radius = 12000** to edit its properties.
2. Notice that **Goal** is set to **DefaultSC.Earth.RMAG**. This is what we need, so we make no changes here.
3. In the **Value** box, type 12000
4. Click **OK** to save these changes



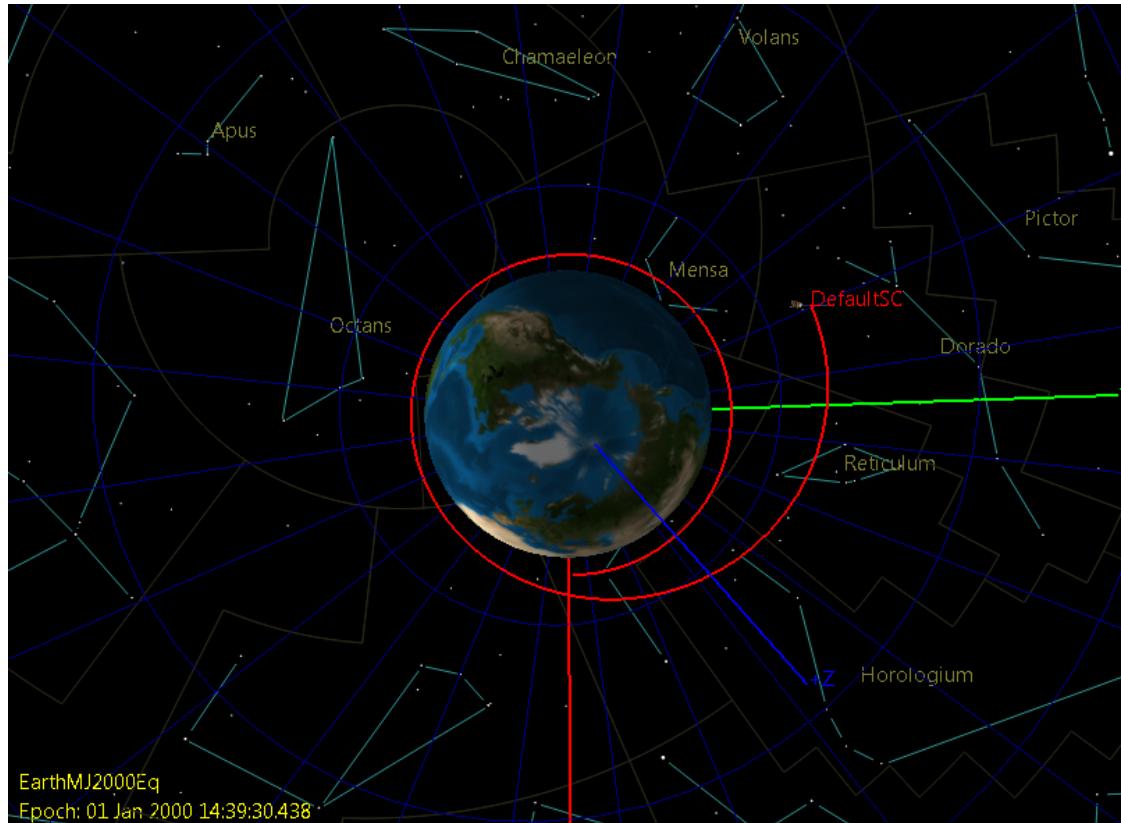
**Figure 44. Achieve Apogee Radius = 12000 Command Configuration**

### Run the Mission

Before running the mission, click **Save** to save the mission to a file of your choice. Now click **Run**. As the mission runs, you will see GMAT solve the targeting problem. Each iteration and perturbation is shown in **DefaultOrbitView** window in light blue, and the final solution is shown in red. After the mission completes, the 3D view should appear as shown in the image shown below. You may want to run the mission several times to see the targeting in progress.

### Inspect Orbit View and Message Window

Inspect the 3D DefaultOrbitView window. Manipulate the window as needed to view the orbit "face-on." Visually verify that apogee has indeed been raised.



**Figure 45. 3D View of Finite Burn to Raise Apogee**

As shown below, we inspect the output message window to determine the number of iterations it took the **DifferentialCorrector** to converge and the final value of the control variable, **BurnDuration**. Verify that you obtained a similar value for **BurnDuration**.

```
*** Targeting Completed in 13 iterations

Final Variable values:

BurnDuration = 1213.19316329
```

## Explore the Command Summary Reports

All of the commands in the **Mission** tree have associated **Command Summary** reports. As shown below, we review these reports to help verify that our script performed as expected.

1. In the **Mission** tree, select **Prop To Perigee**, then right-click to open the associated **Command Summary** which describes the state of **DefaultSC** after the **Prop To Perigee** command has been performed. We verify perigee has indeed been achieved by finding the mean anomaly value of **DefaultSC**. To do this, we look at the value of **MA** under the Keplerian State. As expected, the mean anomaly is zero.
2. View the **Turn Thruster On** command summary. Note that, as expected, prior to the start of the maneuver, the fuel mass is 756 kg.

3. View the **Turn Thruster Off** command summary.
  - a. Note that the mean anomaly at the end of the maneuver is 25.13 degrees. Thus, as the burn occurred, the mean anomaly increased from 0 to 25.13 degrees. By orbital theory, we know that an apogee raising burn is best performed at perigee. Thus, we may be able to achieve our orbital goal using less fuel if we “center” the burn. For example, we could try starting our burn at a mean anomaly of  $-(25.13/2)$  instead of 0 degrees.
  - b. Note that, at the end of the maneuver, the fuel mass is 343.76990815648 kg. Thus, this finite burn used approximately  $756 - 343.8 = 412.2$  kg of fuel.
4. View the **Prop To Apogee** command summary.
  - a. We note that the mean anomaly is 180 degrees which proves that we are indeed at apogee.
  - b. We note that the orbital radius (RMAG) is 11999.999998192 km which proves that we have achieved our desired 12000 km apogee radius to within our desired tolerance of 0.1 km.

# Mars B-Plane Targeting

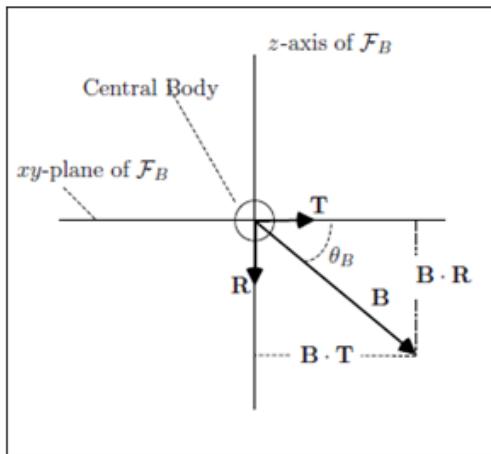
<b>Audience</b>	Advanced
<b>Length</b>	75 minutes
<b>Prerequisites</b>	Complete <i>Simulating an Orbit</i> , <i>Simple Orbit Transfer</i> and a basic understanding of B-Planes and their usage in targeting is required.
<b>Script File</b>	Tut_Mars_B_Plane_Targeting.script

## Objective and Overview

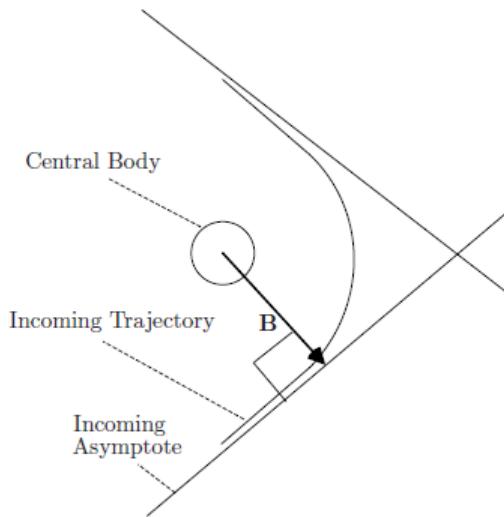


### Note

One of the most challenging problems in space mission design is to design an interplanetary transfer trajectory that takes the spacecraft within a very close vicinity of the target planet. One possible approach that puts the spacecraft close to a target planet is by targeting the B-Plane of that planet. The B-Plane is a planar coordinate system that allows targeting during a gravity assist. It can be thought of as a target attached to the assisting body. In addition, it must be perpendicular to the incoming asymptote of the approach hyperbola. [Figure 46](#) and [Figure 47](#) show the geometry of the B-Plane and B-vector as seen from a viewpoint perpendicular to orbit plane. To read more on B-Planes, please consult the GMATMathSpec document. A good example involving the use of B-Plane targeting is a mission to Mars. Sending a spacecraft to Mars can be achieved by performing a Trajectory Correction Maneuver (TCM) that targets Mars B-Plane. Once the spacecraft gets close to Mars, then an orbit insertion maneuver can be performed to capture into Mars orbit.



**Figure 46. Geometry of the B-Plane as seen from a viewpoint perpendicular to the B-Plane**



**Figure 47. The B-vector as seen from a viewpoint perpendicular to orbit plane**

In this tutorial, we will use GMAT to model a mission to Mars. Starting from an out-going hyperbolic trajectory around Earth, we will perform a TCM to target Mars B-Plane. Once we are close to Mars, we will adjust the size of the maneuver to perform a Mars Orbit Insertion (MOI) to achieve a final elliptical orbit with an inclination of 90 degrees. Meeting these mission objectives requires us to create two separate targeting sequences. In order to focus on the configuration of the two targeters, we will make extensive use of the default configurations for spacecraft, propagators, and maneuvers.

The first target sequence employs maneuvers in the Earth-based Velocity (V), Normal (N) and Bi-normal (B) directions and includes four propagation sequences. The purpose of the maneuvers in VNB directions is to target  $B_{dot}T$  and  $B_{dot}R$  components of the B-vector.  $B_{dot}T$  is targeted to 0 km and  $B_{dot}R$  is targeted to a non-zero value to generate a polar orbit that has inclination of 90 degrees.  $B_{dot}R$  is targeted to -7000 km to avoid having the orbit intersect Mars, which has a radius of approximately 3396 km.

The second target sequence employs a single, Mars-based anti-velocity direction (-V) maneuver and includes one propagation sequence. This single anti-velocity direction maneuver will occur at periapsis. The purpose of the maneuver is to achieve MOI by targeting position vector magnitude of 12,000 km at apoapsis. The basic steps of this tutorial are:

1. Modify the **DefaultSC** to define spacecraft's initial state. The initial state is an out-going hyperbolic trajectory that is with respect to Earth.
2. Create and configure a **Fuel Tank** resource.
3. Create two **ImpulsiveBurn** resources with default settings.
4. Create and configure three **Propagators**: NearEarth, DeepSpace and NearMars
5. Create and configure **DifferentialCorrector** resource.
6. Create and configure three **OrbitView** resources to visualize Earth, Sun and Mars centered trajectories.

7. Create and configure three **CoordinateSystems**: Earth, Sun and Mars centered.
8. Create first **Target** sequence to target BdotT and BdotR components of the B-vector.
9. Create second **Target** sequence to implement MOI by targeting position magnitude at apoapsis.
10. Run the mission and analyze the results.

## Configure Fuel Tank, Spacecraft properties, Maneuvers, Propagators, Differential Corrector, Coordinate Systems and Graphics

For this tutorial, you'll need GMAT open, with the default mission loaded. To load the default mission, click **New Mission** (➕) or start a new GMAT session. **DefaultSC** will be modified to set spacecraft's initial state as an out-going hyperbolic trajectory.

### Create Fuel Tank

We need to create a fuel tank in order to see how much fuel is expended after each impulsive burn. We will modify **DefaultSC** resource later and attach the fuel tank to the spacecraft.

1. In the **Resources** tree, right-click the **Hardware** folder, point to **Add** and click **ChemicalTank**. A new resource called **ChemicalTank1** will be created.
2. Right-click **ChemicalTank1** and click **Rename**.
3. In the **Rename** box, type **MainTank** and click **OK**.
4. Double click on **MainTank** to edit its properties.
5. Set the values shown in the table below.

**Table 5. MainTank settings**

Field	Value
<b>Fuel Mass</b>	<b>1718</b>
<b>Fuel Density</b>	<b>1000</b>
<b>Pressure</b>	<b>5000</b>
<b>Volume</b>	<b>2</b>

6. Click **OK** to save these changes.

### Modify the DefaultSC Resource

We need to make minor modifications to **DefaultSC** in order to define spacecraft's initial state and attach the fuel tank to the spacecraft.

1. In the **Resources** tree, under **Spacecraft** folder, right-click **DefaultSC** and click **Rename**.
2. In the **Rename** box, type **MAVEN** and click **OK**.

3. Double-click on **MAVEN** to edit its properties. Make sure **Orbit** tab is selected.
4. Set the values shown in the table below.

**Table 6. MAVEN settings**

Field	Value
<b>Epoch Format</b>	<b>UTCGregorian</b>
<b>Epoch</b>	<b>18 Nov 2013 20:26:24.315</b>
<b>Coordinate System</b>	<b>EarthMJ2000Eq</b>
<b>State Type</b>	<b>Keplerian</b>
<b>SMA under Elements</b>	<b>-32593.21599272796</b>
<b>ECC under Elements</b>	<b>1.202872548116185</b>
<b>INC under Elements</b>	<b>28.80241266404142</b>
<b>RAAN under Elements</b>	<b>173.9693759331483</b>
<b>AOP under Elements</b>	<b>240.9696529532764</b>
<b>TA under Elements</b>	<b>359.9465533778069</b>

5. Click on **Tanks** tab now.
6. Under **Available Tanks**, you'll see **MainTank**. This is the fuel tank that we created earlier.
7. We attach **MainTank** to the spacecraft **MAVEN** by bringing it under **Selected Tanks** box. Select **MainTank** under **Available Tanks** and bring it over to the right-hand side under the **Selected Tanks**.
8. Click **OK** to save these changes.

## Create the Maneuvers

We'll need two **ImpulsiveBurn** resources for this tutorial. Below, we'll rename the default ImpulsiveBurn and create a new one. We'll also select the fuel tank that was created earlier in order to access fuel for the burns.

1. In the **Resources** tree, under the **Burns** folder, right-click **DefaultIB** and click **Rename**.
2. In the **Rename** box, type **TCM**, an acronym for Trajectory Correction Maneuver and click **OK** to edit its properties.
3. Double-Click **TCM** to edit its properties to edit its properties.
4. Check **Decrement Mass** under **Mass Change**.
5. For **Tank** field under **Mass Change**, select **MainTank** from drop down menu.
6. Click **OK** to save these changes.
7. Right-click the**Burns** folder, point to **Add**, and click **ImpulsiveBurn**. A new resource called **ImpulsiveBurn1** will be created.
8. **Rename** the new **ImpulsiveBurn1** resource to **MOI**, an acronym for Mars Orbit Insertion and click **OK**.
9. Double-click **MOI** to edit its properties.

10. For **Origin** field under **Coordinate System**, select **Mars**.
11. Check **Decrement Mass** under **Mass Change**.
12. For **Tank** field under **Mass Change**, select **MainTank** from the drop down menu.
13. Click **OK** to save these changes.

## Create the Propagators

We'll need to add three propagators for this tutorial. Below, we'll rename the default **DefaultProp** and create two more propagators.

1. In the **Resources** tree, under the **Propagators** folder, right-click **DefaultProp** and click **Rename**.
2. In the **Rename** box, type **NearEarth** and click **OK**.
3. Double-click on **NearEarth** to edit its properties.
4. Set the values shown in the table below.

**Table 7. NearEarth settings**

Field	Value
<b>Initial Step Size</b> under <b>Integrator</b>	600
<b>Accuracy</b> under <b>Integrator</b>	1e-013
<b>Min Step Size</b> under <b>Integrator</b>	0
<b>Max Step Size</b> under <b>Integrator</b>	600
<b>Model</b> under <b>Gravity</b>	JGM-2
<b>Degree</b> under <b>Gravity</b>	8
<b>Order</b> under <b>Gravity</b>	8
<b>Atmosphere Model</b> under <b>Drag</b>	None
<b>Point Masses</b> under <b>Force Model</b>	Add <b>Luna</b> and <b>Sun</b>
<b>Use Solar Radiation Pressure</b> under <b>Force Model</b>	<input checked="" type="checkbox"/> Check this field

5. Click on **OK** to save these changes.
6. Right-click the **Propagators** folder and click **Add Propagator**. A new resource called **Propagator1** will be created.
7. **Rename** the new **Propagator1** resource to **DeepSpace** and click **OK**.
8. Double-click **DeepSpace** to edit its properties.
9. Set the values shown in the table below.

**Table 8. DeepSpace settings**

Field	Value
Type under Integrator	PrinceDormand78
Initial Step Size under Integrator	600
Accuracy under Integrator	1e-012
Min Step Size under Integrator	0
Max Step Size under Integrator	864000
Central Body under Force Model	Sun
Primary Body under Force Model	None
Point Masses under Force Model	Add Earth, Luna, Sun, Mars, Jupiter, Neptune, Saturn, Uranus, Venus
Use Solar Radiation Pressure under Force Model	Check this field

10. Click **OK** to save these changes.
11. Right-click the **Propagators** folder and click **Add Propagator**. A new resource called **Propagator1** will be created.
12. Rename the new **Propagator1** resource to **NearMars** and click **OK**.
13. Double-click on **NearMars** to edit its properties.
14. Set the values shown in the table below.

**Table 9. NearMars settings**

Field	Value
Type under Integrator	PrinceDormand78
Initial Step Size under Integrator	600
Accuracy under Integrator	1e-012
Min Step Size under Integrator	0
Max Step Size under Integrator	86400
Central Body under Force Model	Mars
Primary Body under Force Model	Mars
Model under Gravity	Mars-50C
Degree under Gravity	8
Order under Gravity	8
Atmosphere Model under Drag	None
Point Masses under Force Model	Add Sun
Use Solar Radiation Pressure under Force Model	Check this field

15. Click **OK** to save the changes.

## Create the Differential Corrector

Two **Target** sequences that we will create later need a **DifferentialCorrector** resource to operate, so let's create one now. We'll leave the settings at their defaults.

1. In the **Resources** tree, expand the **Solvers** folder if it isn't already.
2. Right-click the **Boundary Value Solvers** folder, point to **Add**, and click **DifferentialCorrector**. A new resource called **DC1** will be created.
3. **Rename** the new **DC1** resource to **DefaultDC** and click **OK**.

## Create the Coordinate Systems

The BdotT and BdotR constraints that we will define later under the first **Target** sequence require us to create a coordinate system. Orbit View resources that we will create later also need coordinate system resources to operate. We will create Sun and Mars centered coordinate systems. So let's create them now.

1. In the **Resources** tree, right-click the **Coordinate Systems** folder and click **Add Coordinate System**. A new Dialog box is created with a title **New Coordinate System**.
2. Type **SunEcliptic** under **Coordinate System Name** box.
3. Under **Origin** field, select **Sun**.
4. For **Type** under **Axes**, select **MJ2000Ec**.
5. Click **OK** to save these changes. You'll see that a new coordinate system **SunEcliptic** is created under **Coordinate Systems** folder.
6. Right-click the **Coordinate Systems** folder and click **Add Coordinate System**. A new Dialog Box is created with a title **New Coordinate System**.
7. Type **MarsInertial** under **Coordinate System Name** box.
8. Under **Origin** field, select **Mars**.
9. For **Type** under **Axes**, select **BodyInertial**.
10. Click **OK** to save these changes. You'll see that a new coordinate system **MarsInertial** is created under **Coordinate Systems** folder.

## Create the Orbit Views

We'll need three **OrbitView** resources for this tutorial. Below, we'll rename the default **OrbitView** and create two new ones. We need three graphics windows in order to visualize spacecraft's trajectory centered around Earth, Sun and then Mars

1. In the **Resources** tree, under **Output** folder, right-click **DefaultOrbitView** and click **Rename**.
2. In the **Rename** box, type **EarthView** and click **OK**.
3. In the **Output** folder, delete **DefaultGroundTrackPlot**.
4. Double-click **EarthView** to edit its properties.
5. Set the values shown in the table below.

**Table 10. EarthView settings**

Field	Value
<b>View Scale Factor</b> under <b>View Definition</b>	4
<b>View Point Vector</b> boxes, under <b>View Definition</b>	0, 0, 30000

6. Click **OK** to save these changes.
7. Right-click the **Output** folder, point to **Add**, and click **OrbitView**. A new resource called **OrbitView1** will be created.
8. **Rename** the new **OrbitView1** resource to **SolarSystemView** and click **OK**.
9. Double-click **SolarSystemView** to edit its properties.
10. Set the values shown in the table below.

**Table 11. SolarSystemView settings**

Field	Value
From <b>Celestial Object</b> under <b>View Object</b> , add following objects to <b>Selected Celestial Object</b> box	<b>Mars, Sun</b> (Do not remove <b>Earth</b> )
<b>Coordinate System</b> under <b>View Definition</b>	<b>SunEcliptic</b>
<b>View Point Reference</b> under <b>View Definition</b>	<b>Sun</b>
<b>View Point Vector</b> boxes, under <b>View Definition</b>	0, 0, 5e8
<b>View Direction</b> under <b>View Definition</b>	<b>Sun</b>
<b>Coordinate System</b> under <b>View Up Definition</b>	<b>SunEcliptic</b>

11. Click **OK** to save these changes.
12. Right-click the **Output** folder, point to **Add**, and click **OrbitView**. A new resource called **OrbitView1** will be created.
13. **Rename** the new **OrbitView1** resource to **MarsView** and click **OK**.
14. Double-click **MarsView** to edit its properties.
15. Set the values shown in the table below.

**Table 12. MarsView settings**

Field	Value
From <b>Celestial Object</b> under <b>View Object</b> , add following object to <b>Selected Celestial Object</b> box	<b>Mars</b> (You don't have to remove <b>Earth</b> )
<b>Coordinate System</b> under <b>View Definition</b>	<b>MarsInertial</b>
<b>View Point Reference</b> under <b>View Definition</b>	<b>Mars</b>
<b>View Point Vector</b> boxes, under <b>View Definition</b>	22000, 22000, 0
<b>View Direction</b> under <b>View Definition</b>	<b>Mars</b>
<b>Coordinate System</b> under <b>View Up Definition</b>	<b>MarsInertial</b>

16. Click **OK** to save the changes.

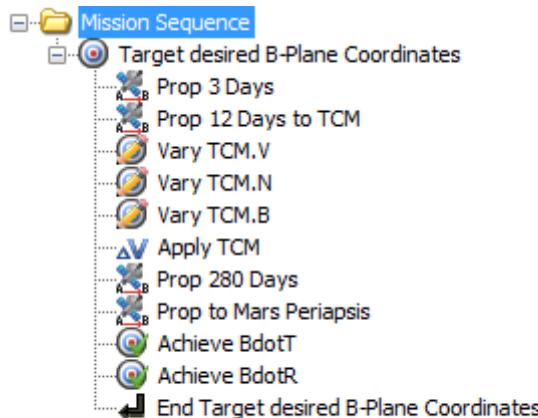
## Configure the Mission Sequence

Now we will configure first **Target** sequence to solve for the maneuver values required to achieve BdotT and BdotR components of the B-vector. BdotT will be targeted to 0 km and BdotR is targeted to a non-zero value in order to generate a polar orbit that will have an inclination of 90 degrees. To allow us to focus on the first **Target** sequence, we'll assume you have already learned how to propagate an orbit by having worked through *Simulating an Orbit* tutorial.

The second **Target** sequence will perform the MOI maneuver so that the spacecraft can orbit around Mars, but that sequence will be created later.

### Create the First Target Sequence

Now create the commands necessary to perform the first **Target** sequence. Figure 48 illustrates the configuration of the **Mission** tree after you have completed the steps in this section. We'll discuss the first **Target** sequence after it has been created.



**Figure 48. Mission Sequence for the First Target sequence**

To create the first **Target** sequence:

1. Click on the **Mission** tab to show the **Mission** tree.
2. You'll see that there already exists a **Propagate1** command. We need to delete this command
3. Right-click on **Propagate1** command and click **Delete**.
4. Right-click on **Mission Sequence** folder, point to **Append**, and click **Target**. This will insert two separate commands: **Target1** and **EndTarget1**.
5. Right-click **Target1** and click **Rename**.
6. Type **Target desired B-plane Coordinates** and click **OK**.
7. Right-click **Target desired B-plane Coordinates**, point to **Append**, and click **Propagate**. A new command called **Propagate1** will be created.
8. Right-click **Propagate1** and click **Rename**.

9. In the **Rename** box, type **Prop 3 Days** and click **OK**.
10. Complete the **Target** sequence by appending the commands in [Table 13](#).

**Table 13. Additional First Target Sequence Commands**

Command	Name
<b>Propagate</b>	<b>Prop 12 Days to TCM</b>
<b>Vary</b>	<b>Vary TCM.V</b>
<b>Vary</b>	<b>Vary TCM.N</b>
<b>Vary</b>	<b>Vary TCM.B</b>
<b>Maneuver</b>	<b>Apply TCM</b>
<b>Propagate</b>	<b>Prop 280 Days</b>
<b>Propagate</b>	<b>Prop to Mars Periapsis</b>
<b>Achieve</b>	<b>Achieve BdotT</b>
<b>Achieve</b>	<b>Achieve BdotR</b>



### Note

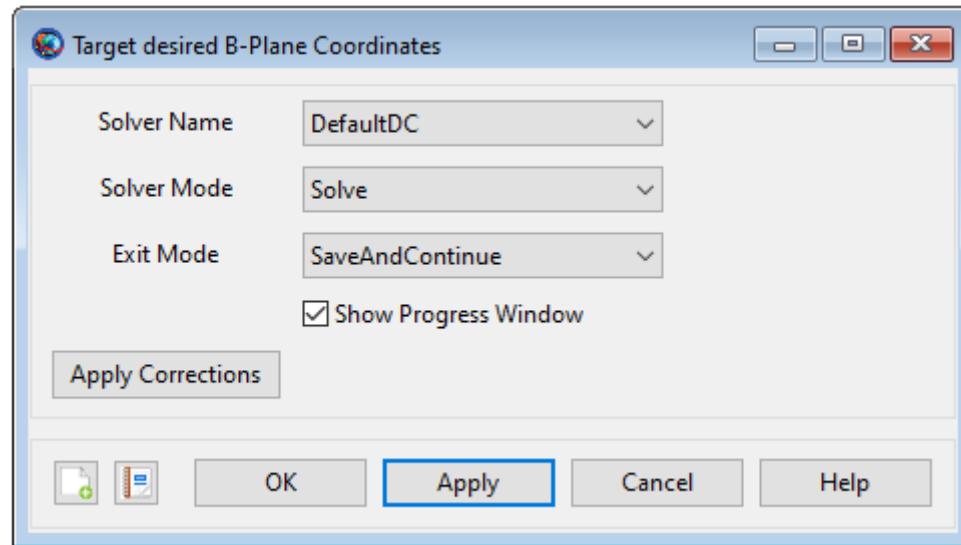
Let's discuss what the first **Target** sequence does. We know that a maneuver is required to perform the B-Plane targeting. We also know that the desired B-Plane coordinate values for BdotT and BdotR are 0 and -7000 km, resulting in a polar orbit with 90 degree inclination. However, we don't know the size (or #V magnitude) and direction of the **TCM** maneuver that will precisely achieve the desired orbital conditions. We use the **Target** sequence to solve for those precise maneuver values. We must tell GMAT what controls are available (in this case, three controls associated with three components of the TCM maneuver) and what conditions must be satisfied (in this case, BdotT and BdotR values). You accomplish this by using the **Vary** and **Achieve** commands. Using the **Vary** command, you tell GMAT what to solve for—in this case, the #V value and direction for **TCM**. You use the **Achieve** command to tell GMAT what conditions the solution must satisfy—in this case, BdotT and BdotR values that result in a 90 degree inclination.

## Configure the First Target Sequence

Now that the structure is created, we need to configure various parts of the first **Target** sequence to do what we want.

### Configure the Target desired B-plane Coordinates Command

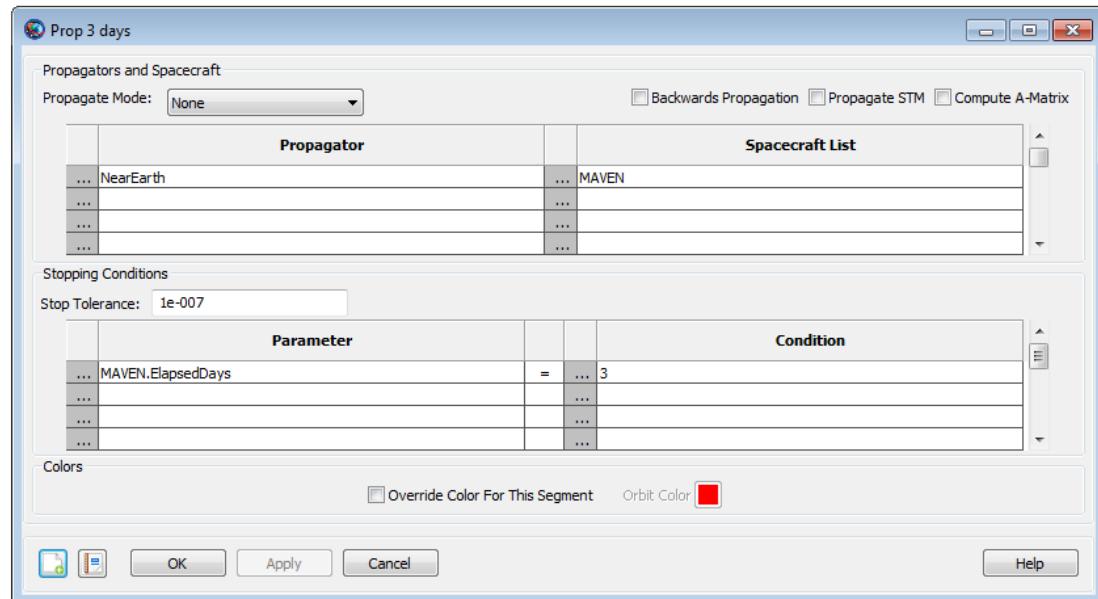
1. Double-click **Target desired B-plane Coordinates** to edit its properties.
2. In the **ExitMode** list, click **SaveAndContinue**. This instructs GMAT to save the final solution of the targeting problem after you run it.
3. Click **OK** to save these changes.



**Figure 49. Target desired B-plane Coordinates Command Configuration**

### Configure the Prop 3 Days Command

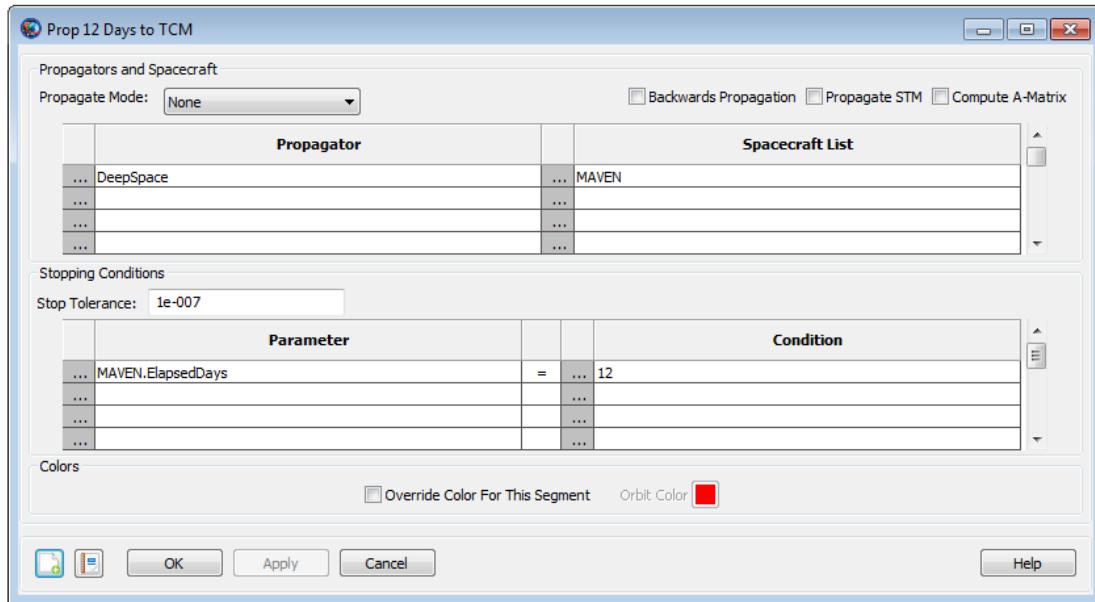
1. Double-click **Prop 3 Days** to edit its properties.
2. Under **Propagator**, make sure that **NearEarth** is selected
3. Under **Parameter**, replace **MAVEN.ElapsedSeconds** with **MAVEN.ElapsedDays**.
4. Under **Condition**, replace **12000.0** with **3**.
5. Click **OK** to save these changes.



**Figure 50. Prop 3 Days Command Configuration**

## Configure the Prop 12 Days to TCM Command

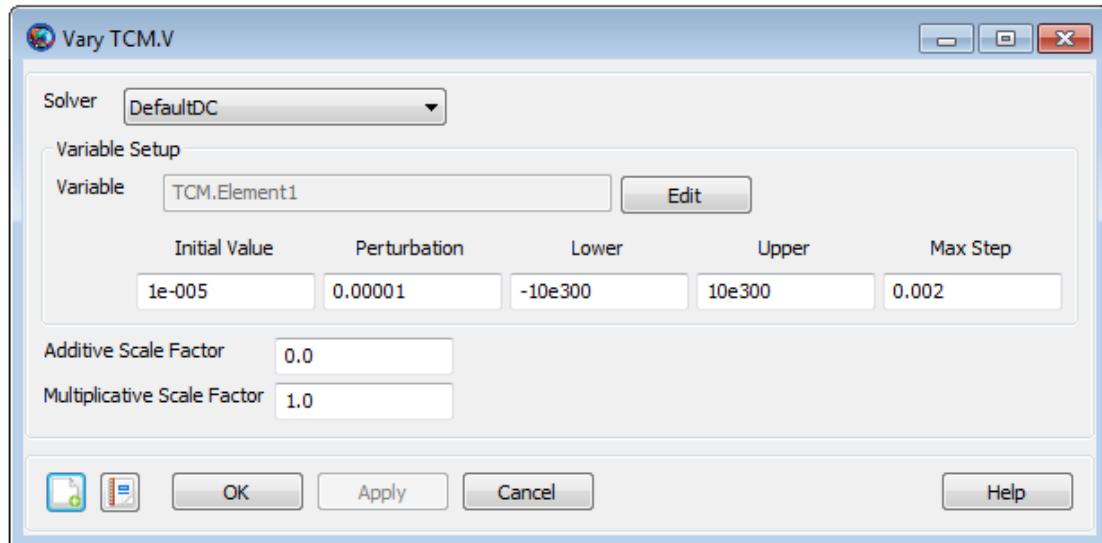
1. Double-click **Prop 12 Days to TCM** to edit its properties.
2. Under **Propagator**, replace **NearEarth** with **DeepSpace**.
3. Under **Parameter**, replace **MAVEN.ElapsedSeconds** with **MAVEN.ElapsedDays**.
4. Under **Condition**, replace **12000.0** with **12**.
5. Click **OK** to save these changes.



**Figure 51. Prop 12 Days to TCM Command Configuration**

## Configure the Vary TCM.V Command

1. Double-click **Vary TCM.V** to edit its properties. Notice that the variable in the **Variable** box is **TCM.Element1**, which by default is the velocity component of **TCM** in the local Velocity-Normal-Binormal (VNB) coordinate system. That's what we need, so we'll keep it.
2. In the **Initial Value** box, type **1e-005**.
3. In the **Perturbation** box, type **0.00001**.
4. In the **Lower** box, type **-10e300**.
5. In the **Upper** box, type **10e300**.
6. In the **Max Step** box, type **0.002**.
7. Click **OK** to save these changes.



**Figure 52. Vary TCM.V Command Configuration**

### Configure the Vary TCM.N Command

1. Double-click **Vary TCM.N** to edit its properties. Notice that the variable in the **Variable** box is still **TCM.Element1**, which by default is the velocity component of TCM in the local VNB coordinate system. We need to insert **TCM.Element2** which is the normal component of TCM in the local VNB coordinate system. So let's do that.
2. Next to **Variable**, click the **Edit** button..
3. Under **Object List**, click **TCM**.
4. In the **Object Properties** list, double-click **Element2** to move it to the **Selected Value(s)** list. See the image below for results.
5. Click **OK** to close the **ParameterSelectDialog** window.
6. Notice that the variable in the **Variable** box is now **TCM.Element2**.
7. In the **Initial Value** box, type **1e-005**.
8. In the **Perturbation** box, type **0.00001**.
9. In the **Lower** box, type **-10e300**.
10. In the **Upper** box, type **10e300**.
11. In the **Max Step** box, type **0.002**.
12. Click **OK** to save these changes.

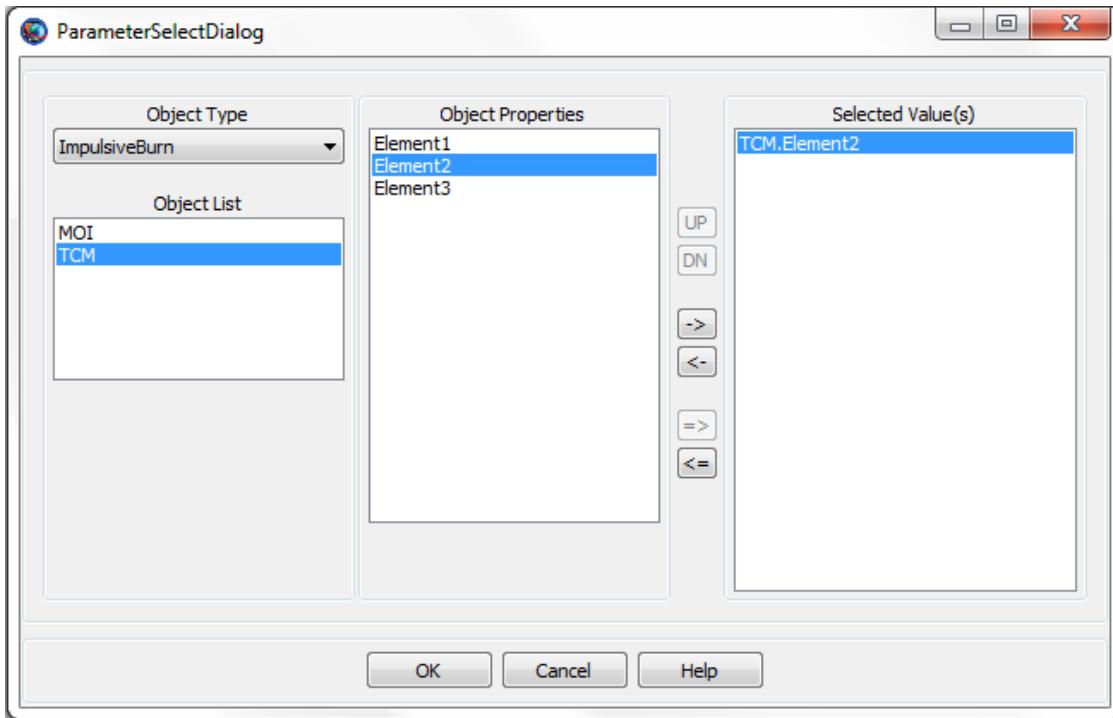


Figure 53. Vary TCM.N Parameter Selection

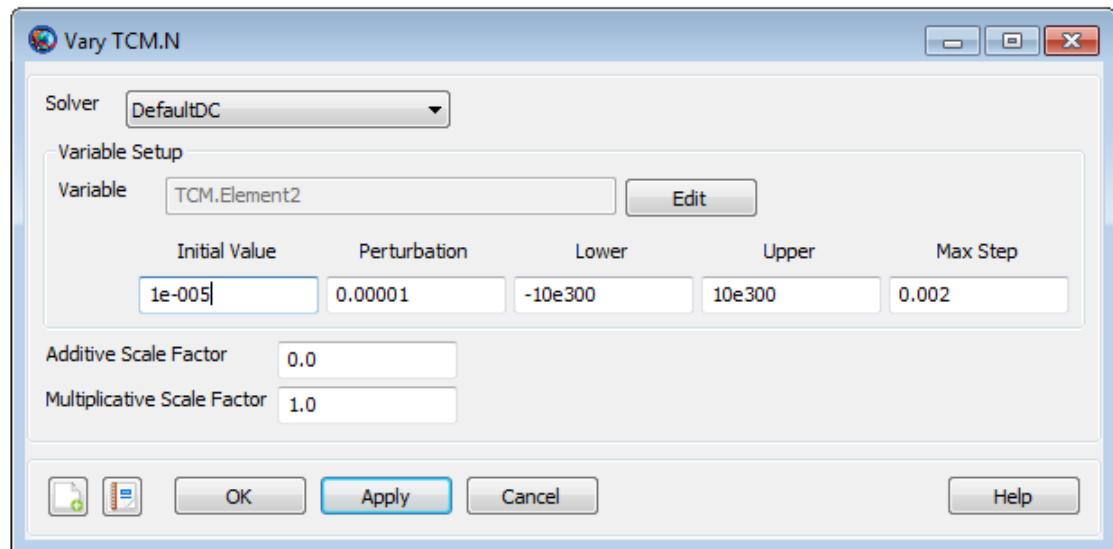
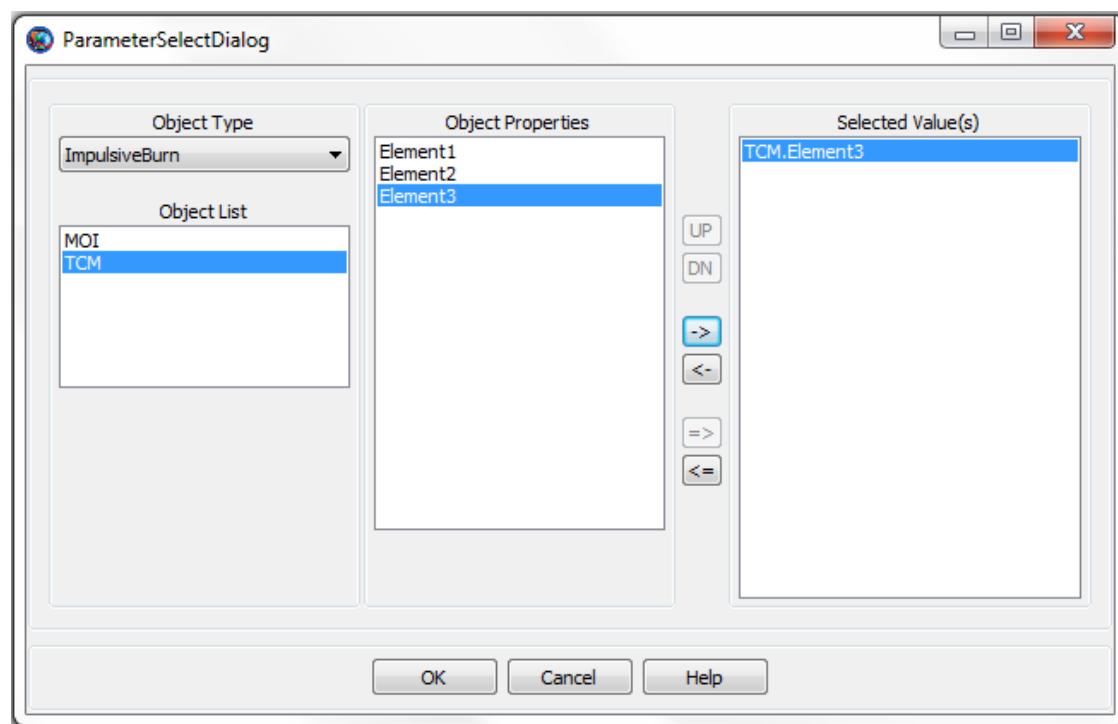


Figure 54. Vary TCM.N Command Configuration

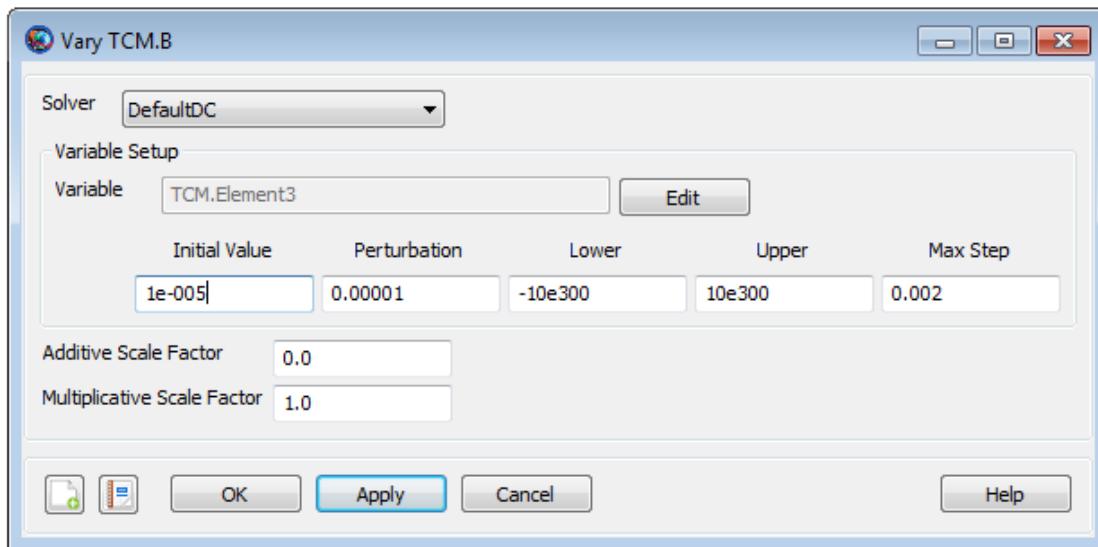
### Configure the Vary TCM.B Command

1. Double-click **Vary TCM.B** to edit its properties. Notice that the variable in the **Variable** box is still **TCM.Element1**, which by default is the velocity component of TCM. We need to insert **TCM.Element3** which is the bi-normal component of TCM in the local VNB coordinate system. So let's do that.

2. Next to **Variable**, click the **Edit** button.
3. Under **Object List**, click **TCM**.
4. In the **Object Properties** list, double-click **Element3** to move it to the **Selected Value(s)** list. See the image below for results.
5. Click **OK** to close the **ParameterSelectDialog** window.
6. Notice that the variable in the **Variable** box is now **TCM.Element3**.
7. In the **Initial Value** box, type **1e-005**.
8. In the **Perturbation** box, type **0.00001**.
9. In the **Lower** box, type **-10e300**.
10. In the **Upper** box, type **10e300**.
11. In the **Max Step** box, type **0.002**.
12. Click **OK** to save these changes.



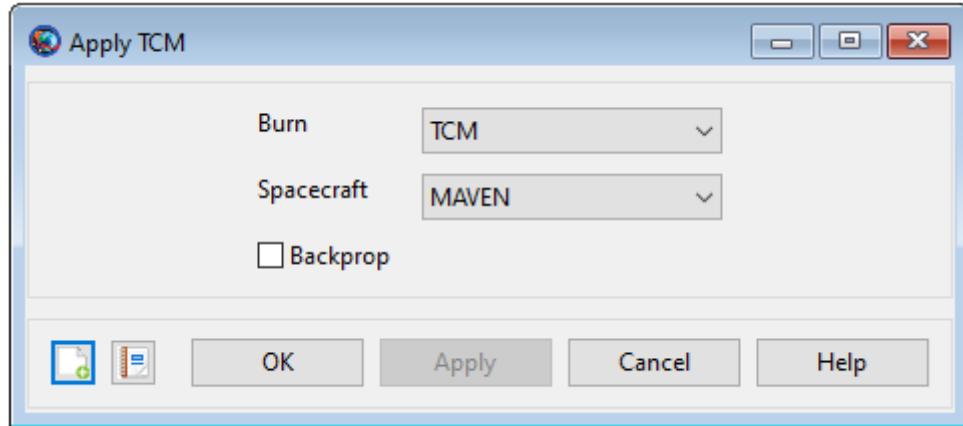
**Figure 55. Vary TCM.B Parameter Selection**



**Figure 56. Vary TCM.N Command Configuration**

### Configure the Apply TCM Command

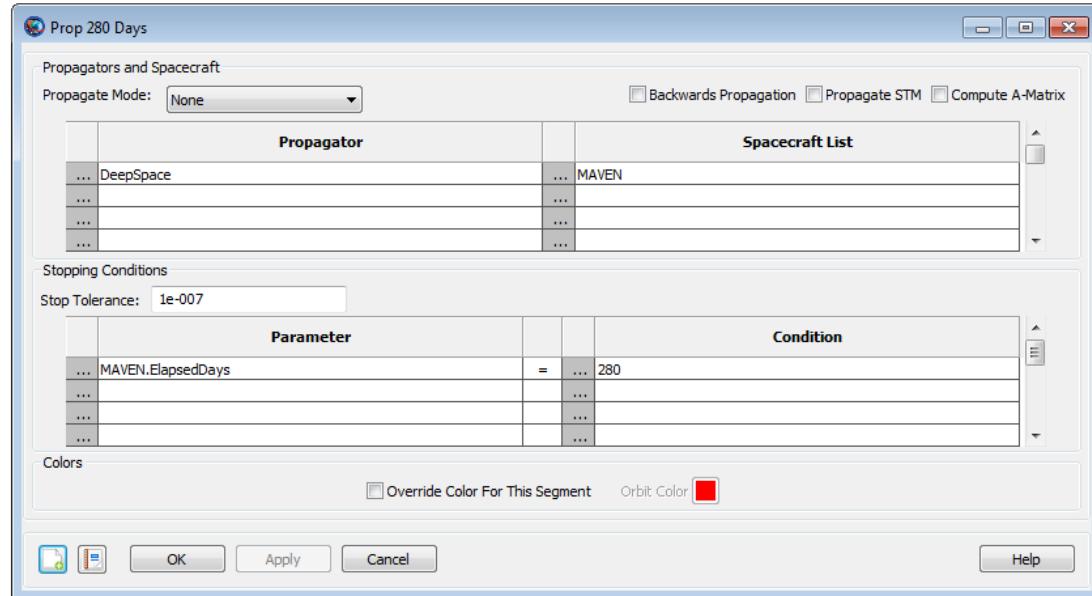
- Double-click **Apply TCM** to edit its properties. Notice that the command is already set to apply the **TCM** burn to the **MAVEN** spacecraft, so we don't need to change anything here.



**Figure 57. Apply TCM Command Configuration**

### Configure the Prop 280 Days Command

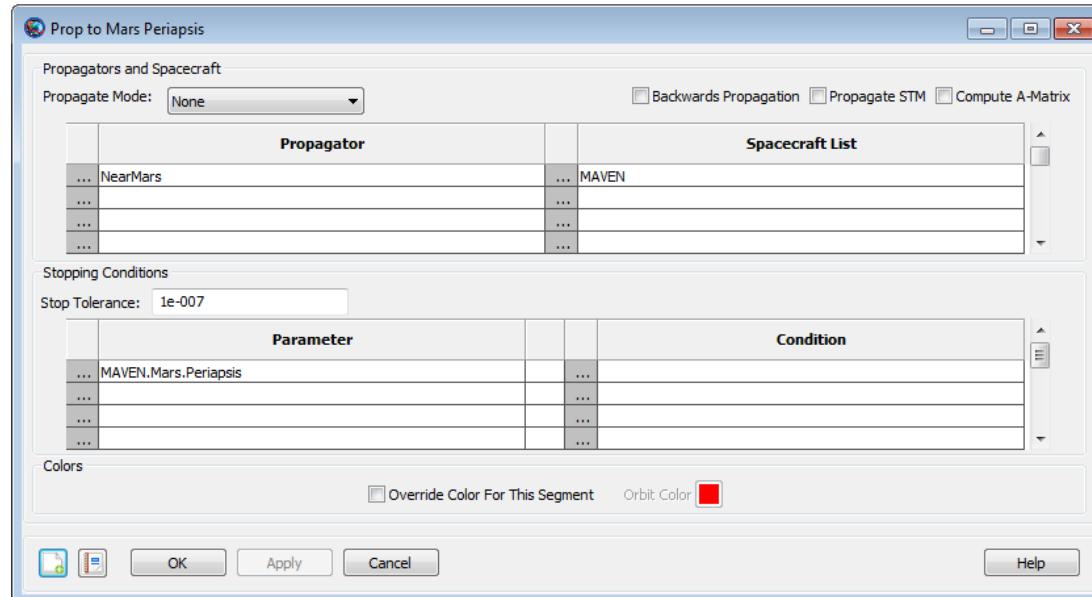
- Double-click **Prop 280 Days** to edit its properties.
- Under **Propagator**, replace **NearEarth** with **DeepSpace**.
- Under **Parameter**, replace **MAVEN.ElapsedSeconds** with **MAVEN.ElapsedDays**.
- Under **Condition**, replace **12000.0** with **280**.
- Click **OK** to save these changes.



**Figure 58. Prop 280 Days Command Configuration**

### Configure the Prop to Mars Periapsis Command

1. Double-click **Prop to Mars Periapsis** to edit its properties.
2. Under **Propagator**, replace **NearEarth** with **NearMars**.
3. Under **Parameter**, replace **MAVEN.ElapsedSeconds** with **MAVEN.Mars.Periapsis**.
4. Click **OK** to save these changes.



**Figure 59. Prop to Mars Periapsis Command Configuration**

## Configure the Achieve BdotT Command

1. Double-click **Achieve BdotT** to edit its properties.
2. Next to **Goal**, click the **Edit** button.
3. In the **Object Properties** list, click **BdotT**.
4. Under **Coordinate System**, select **MarsInertial** and double-click on **BdotT**.
5. Click **OK** to close the **ParameterSelectDialog** window.
6. In the **Value** box, type **0**.
7. In the **Tolerance** box, type **0.00001**.
8. Click **OK** to save these changes.

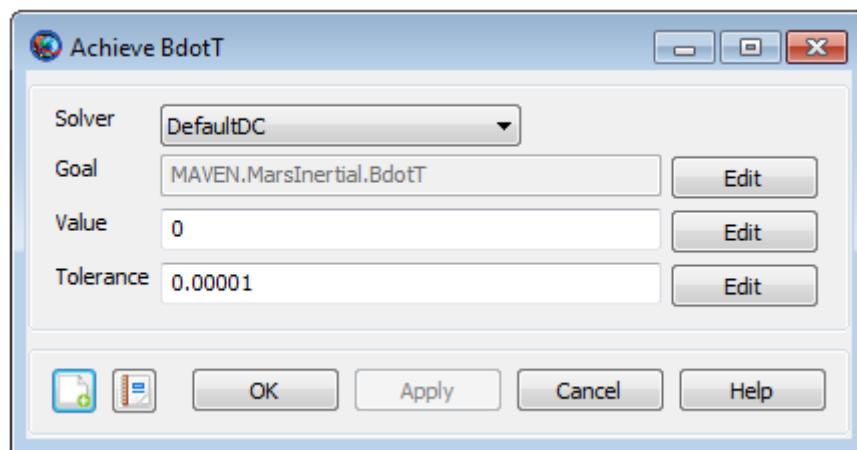
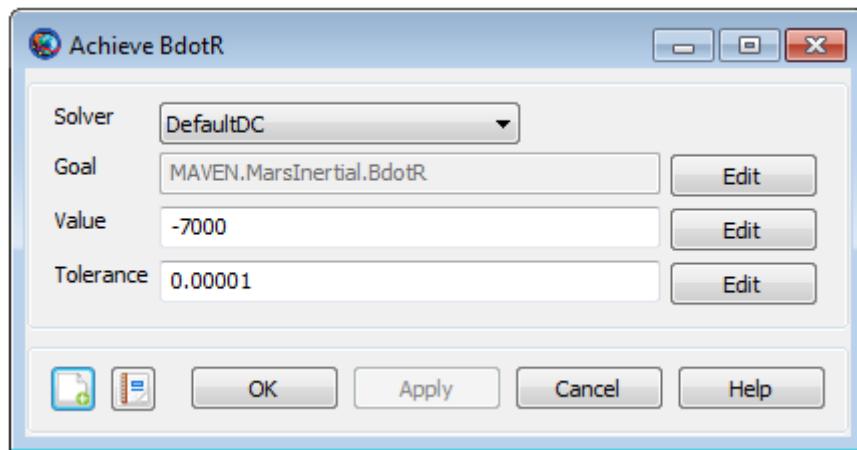


Figure 60. Achieve BdotT Command Configuration

## Configure the Achieve BdotR Command

1. Double-click **Achieve BdotR** to edit its properties.
2. Next to **Goal**, click the **Edit** button.
3. In the **Object Properties** list, click **BdotR**.
4. Under **Coordinate System**, select **MarsInertial** and double-click on **BdotR**.
5. Click **OK** to close the **ParameterSelectDialog** window.
6. In the **Value** box, type **-7000**.
7. In the **Tolerance** box, type **0.00001**.
8. Click **OK** to save these changes.



**Figure 61. Achieve BdotR Command Configuration**

### Run the Mission with first Target Sequence

Before running the mission, click **Save** (💾) and save the mission to a file of your choice. Now click **Run** (▶). As the mission runs, you will see GMAT solve the targeting problem. Each iteration and perturbation is shown in **EarthView**, **SolarSystemView** and **MarsView** windows in light blue, and the final solution is shown in red. After the mission completes, the 3D views should appear as in the images shown below. You may want to run the mission several times to see the targeting in progress.

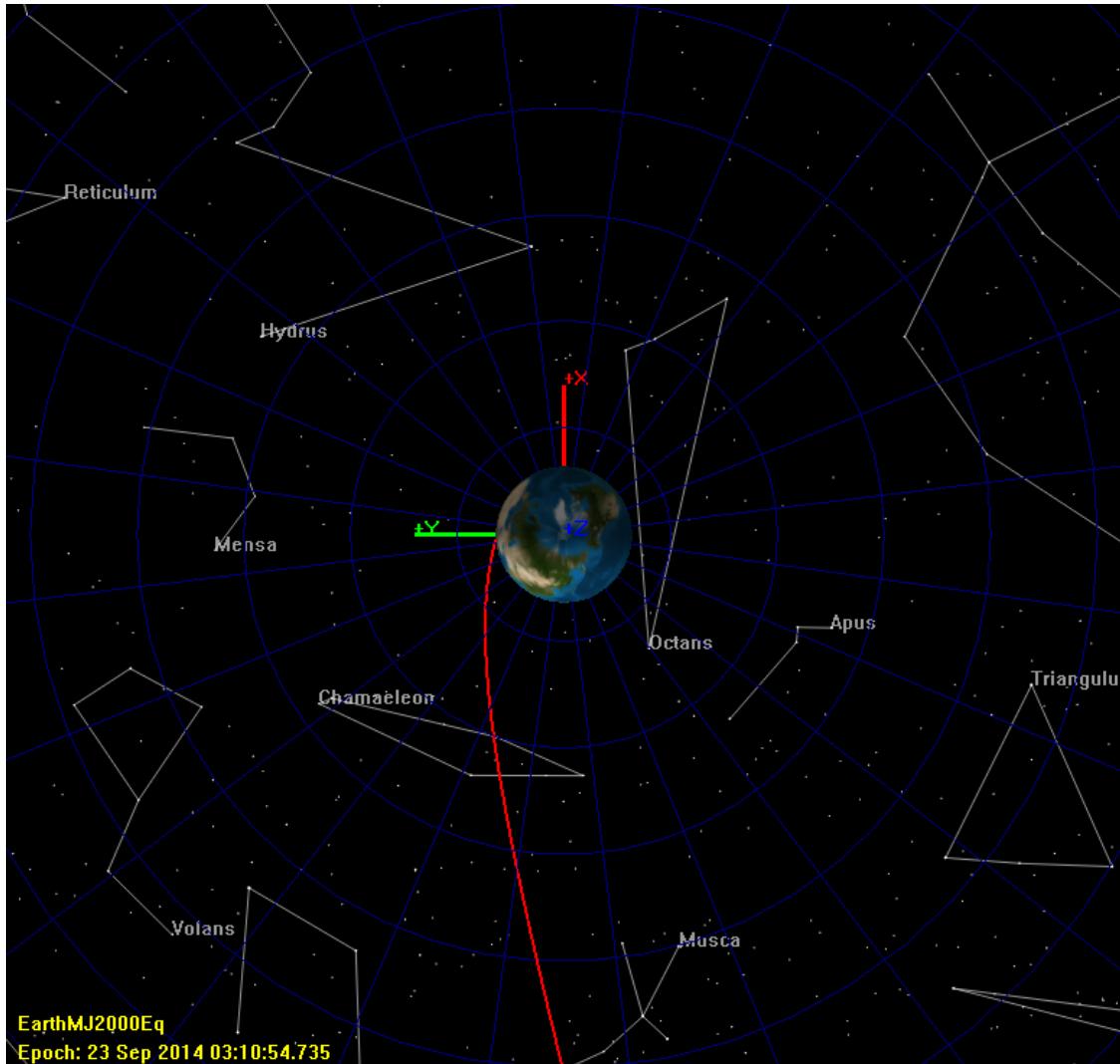
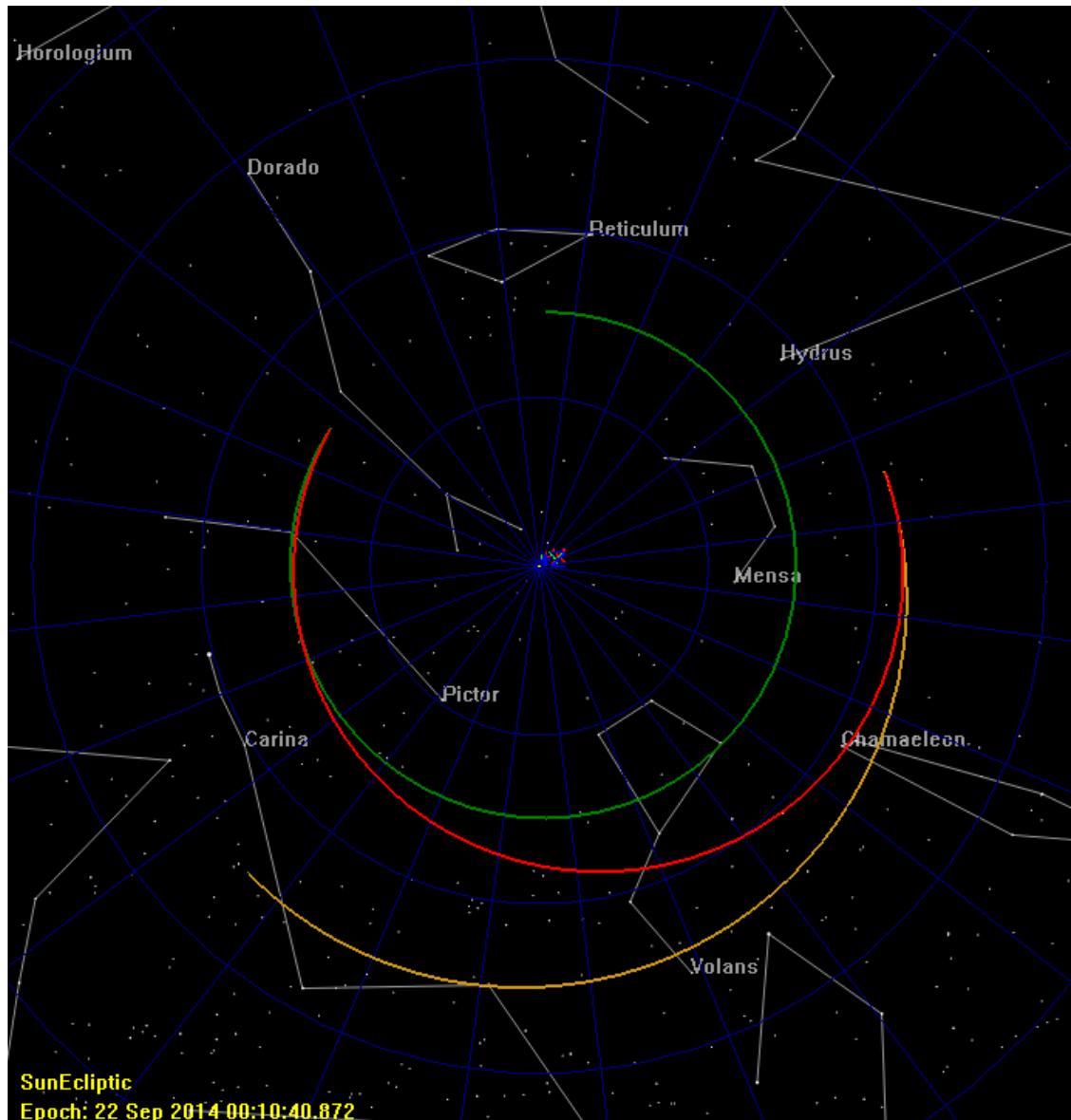
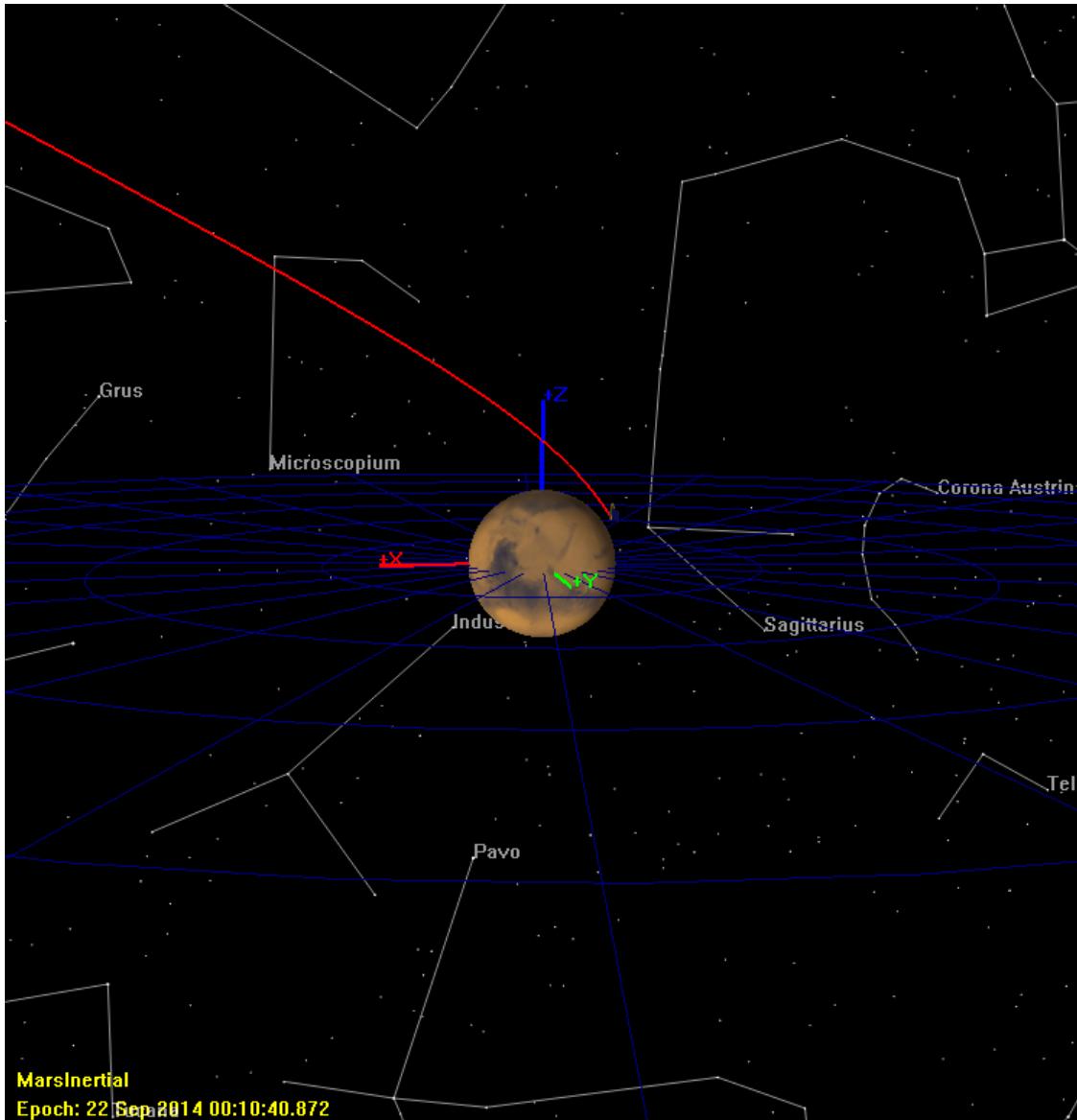


Figure 62. 3D View of departure hyperbolic trajectory (EarthView)



**Figure 63. 3D View of heliocentric transfer trajectory (SolarSystemView)**



**Figure 64. 3D View of approach hyperbolic trajectory. MAVEN stopped at periapsis (MarsView)**

Since we are going to continue developing the mission tree by creating the second **Target** sequence, we will store the final solution of the first **Target** sequence as the initial conditions of the **TCM** resource. This is so that when you make small changes, the subsequent runs will take less time. To do this, follow these steps:

1. In the **Mission** tree, double-click **Target desired B-plane Coordinates** to edit its properties.
2. Click **Apply Corrections**.
3. Click **OK** to save these changes.
4. Now re-run the mission. If you inspect the results in the message window, you will see that the first **Target** sequence converges in one iteration. This is because you stored the solution as the initial conditions.

5. In the **Mission** tree, double-click **Vary TCM.V**, **Vary TCM.N** and **Vary TCM.B**, you will notice that the values in Initial Value box have been updated to the final solution of the first **Target** sequence.

If you want to know TCM maneuver's delta-V vector values and how much fuel was expended during the maneuver, do the following steps:

1. In the **Mission** tree, right-click **Apply TCM**, and click on **Command Summary**.
2. Scroll down and under **Maneuver Summary** heading, values for delta-V vector are:

**Delta V Vector:**

Element 1: 0.0039376963731 km/s

Element 2: 0.0060423170483 km/s

Element 3: -0.0006747125434 km/s

3. Scroll down and under **Mass depletion** from **MainTank** heading, **Delta V** and **Mass Change** tells you TCM maneuver's magnitude and how much fuel was used for the maneuver:

**Delta V:** 0.0072436375569 km/s

**Mass change:** -6.3128738639690 kg

4. Click **OK** to close **Command Summary** window.

Just to make sure that the goals of first **Target** sequence were met successfully, let us access command summary for **Prop to Mars Periapsis** command by doing the following steps:

1. In the **Mission** tree, right-click **Prop to Mars Periapsis**, and click on **Command Summary**.
2. Under **Coordinate System**, select **MarsInertial**.
3. Under **Hyperbolic Parameters** heading, see the values of **BdotT** and **BdotR**. Under **Keplerian State**, see the value for **INC**. You can see that the desired B-Plane coordinates were achieved which result in a 90 degree inclined trajectory:

**BdotT** = -0.0000053320678 km

**BdotR** = -7000.0000019398 km

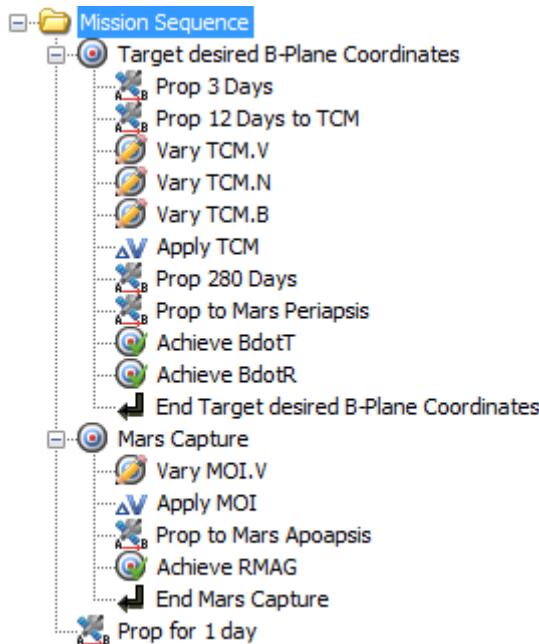
**INC** = 90.00000039301 deg

## Create the Second Target Sequence

Recall that we still need to create second **Target** sequence in order to perform Mars Orbit Insertion maneuver to achieve the desired capture orbit. In the **Mission** tree, we will create the second **Target** sequence right after the first **Target** sequence.

Now let's create the commands necessary to perform the second **Target** sequence. Figure 65 illustrates the configuration of the **Mission** tree after you have completed the

steps in this section. Notice that in [Figure 65](#), the second **Target** sequence is created after the first **Target** sequence. We'll discuss the second **Target** sequence after it has been created.



**Figure 65. Mission Sequence showing first and second Target sequences**

To create the second **Target** sequence:

1. Click on the **Mission** tab to show the **Mission** tree.
2. In the **Mission** tree, right-click on **Mission Sequence** folder, point to **Append**, and click **Target**. This will insert two separate commands: **Target2** and **EndTarget2**.
3. Right-click **Target2** and click **Rename**.
4. Type **Mars Capture** and click **OK**.
5. Right-click **Mars Capture**, point to **Append**, and click **Vary**. A new command called **Vary4** will be created.
6. Right-click **Vary4** and click **Rename**.
7. In the **Rename** box, type **Vary MOI.V** and click **OK**.
8. Complete the **Target** sequence by appending the commands in [Table 14](#).

**Table 14. Additional Second Target Sequence Commands**

Command	Name
<b>Maneuver</b>	<b>Apply MOI</b>
<b>Propagate</b>	<b>Prop to Mars Apoapsis</b>
<b>Achieve</b>	<b>Achieve RMAG</b>



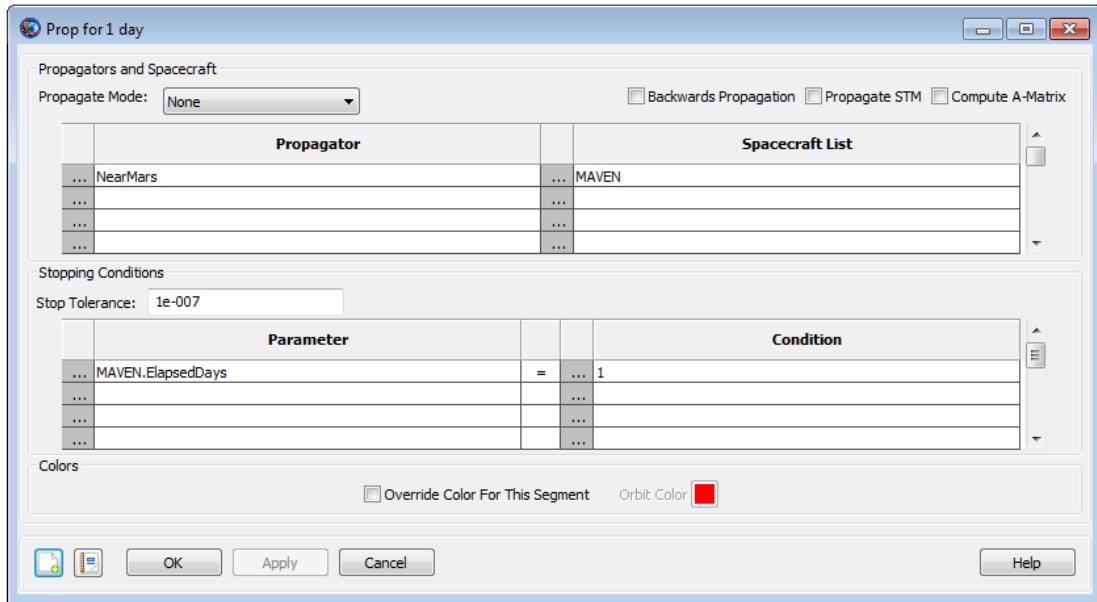
### Note

Let's discuss what the second **Target** sequence does. We know that a maneuver is required for the Mars capture orbit. We also know that the desired radius of capture orbit at apoapsis must be 12,000 km. However, we don't know the size (or #V magnitude) of the **MOI** maneuver that will precisely achieve the desired orbital conditions. You use the second **Target** sequence to solve for that precise maneuver value. You must tell GMAT what controls are available (in this case, a single maneuver) and what conditions must be satisfied (in this case, radius magnitude value). Once again, just like in the first **Target** sequence, here we accomplish this by using the **Vary** and **Achieve** commands. Using the **Vary** command, you tell GMAT what to solve for—in this case, the #V value for **MOI**. You use the **Achieve** command to tell GMAT what conditions the solution must satisfy—in this case, RMAG value of 12,000 km.

## Create the Final Propagate Command

We need a **Propagate** command after the second **Target** sequence so that we can see our final orbit.

1. In the **Mission** tree, right-click **End Mars Capture**, point to **Insert After**, and click **Propagate**. A new **Propagate6** command will appear.
2. Right-click **Propagate6** and click **Rename**.
3. Type **Prop for 1 day** and click **OK**.
4. Double-click **Prop for 1 day** to edit its properties.
5. Under **Propagator**, replace **NearEarth** with **NearMars**.
6. Under **Parameter**, replace **MAVEN.ElapsedSeconds** with **MAVEN.ElapsedDays**.
7. Under **Condition**, replace the value **12000.0** with **1**.
8. Click **OK** to save these changes



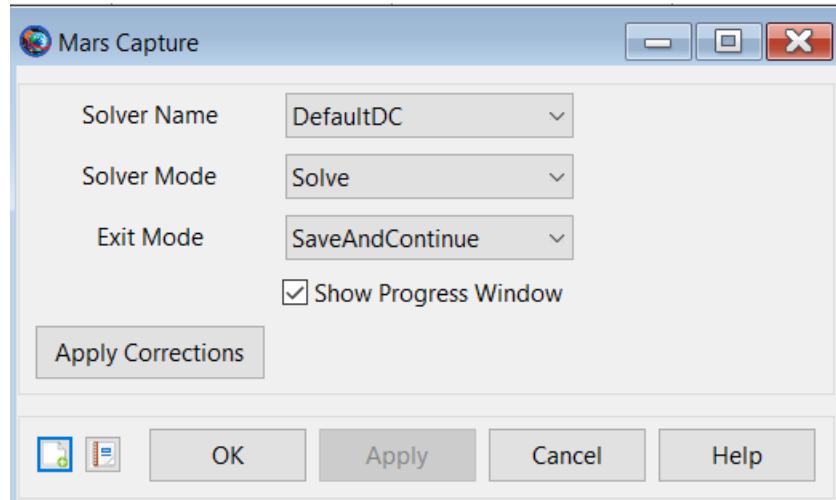
**Figure 66. Prop for 1 day Command Configuration**

### Configure the second Target Sequence

Now that the structure is created, we need to configure various parts of the second **Target** sequence to do what we want.

### Configure the Mars Capture Command

1. Double-click **Mars Capture** to edit its properties.
2. In the **ExitMode** list, click **SaveAndContinue**. This instructs GMAT to save the final solution of the targeting problem after you run it.
3. Click **OK** to save these changes



**Figure 67. Mars Capture Command Configuration**

## Configure the Vary MOI.V Command

1. Double-click **Vary MOI.V** to edit its properties. Notice that the variable in the **Variable** box is **TCM.Element1**. We want **MOI.Element1** which is the velocity component of **MOI** in the local VNB coordinate system. So let's change that.
2. Next to **Variable**, click the **Edit** button.
3. Under **Object List**, click **MOI**.
4. In the **Object Properties** list, double-click **Element1** to move it to the **Selected Value(s)** list. See the image below for results.
5. Click **OK** to close the **ParameterSelectDialog** window.
6. In the **Initial Value** box, type **-1.0**.
7. In the **Perturbation** box, type **0.00001**.
8. In the **Lower** box, type **-10e300**.
9. In the **Upper** box, type **10e300**.
10. In the **Max Step** box, type **0.1**.
11. Click **OK** to save these changes.

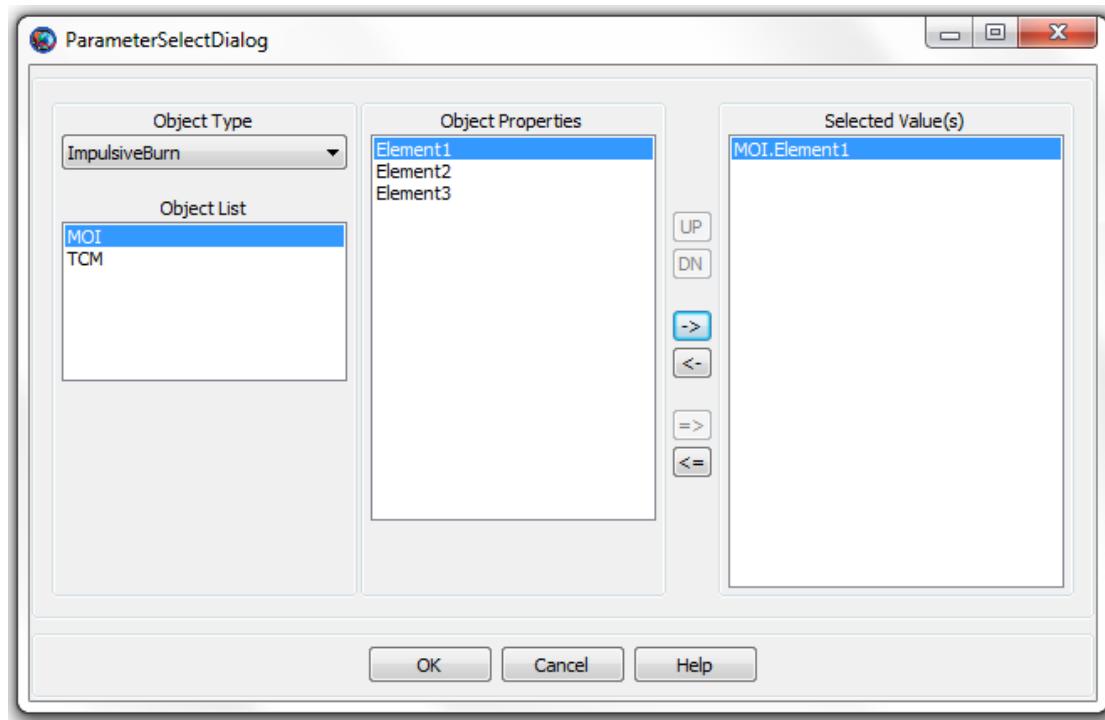


Figure 68. Vary MOI Parameter Selection

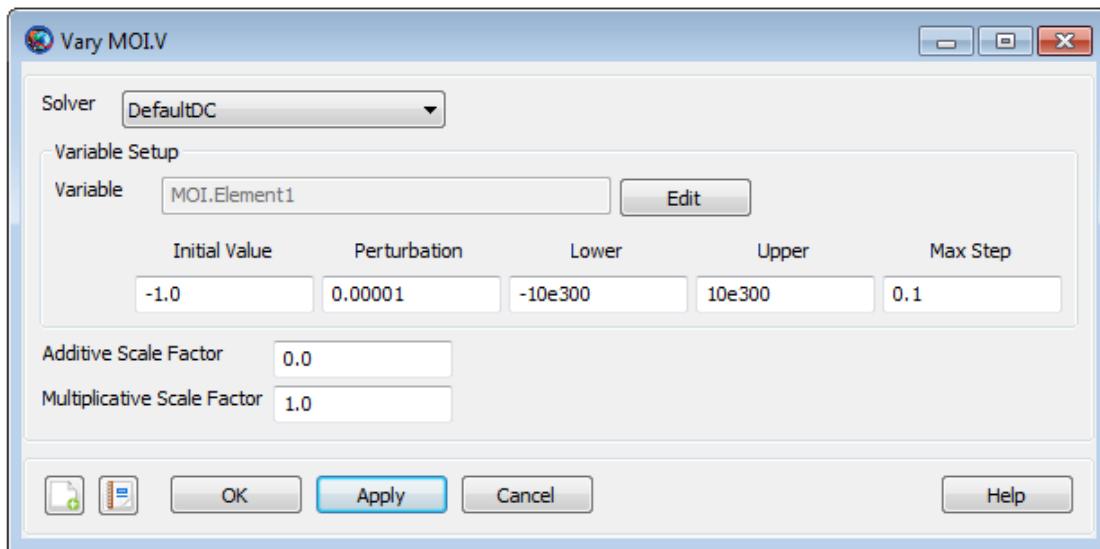


Figure 69. Vary MOI Command Configuration

### Configure the Apply MOI Command

1. Double-click **Apply MOI** to edit its properties.
2. In the **Burn** list, click **MOI**.
3. Click **OK** to save these changes.

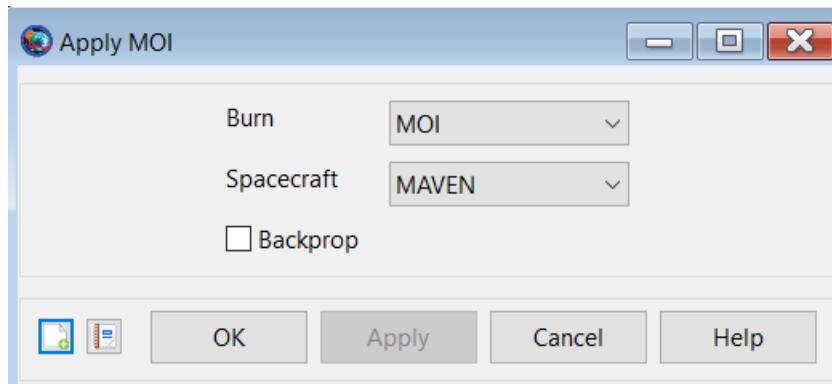
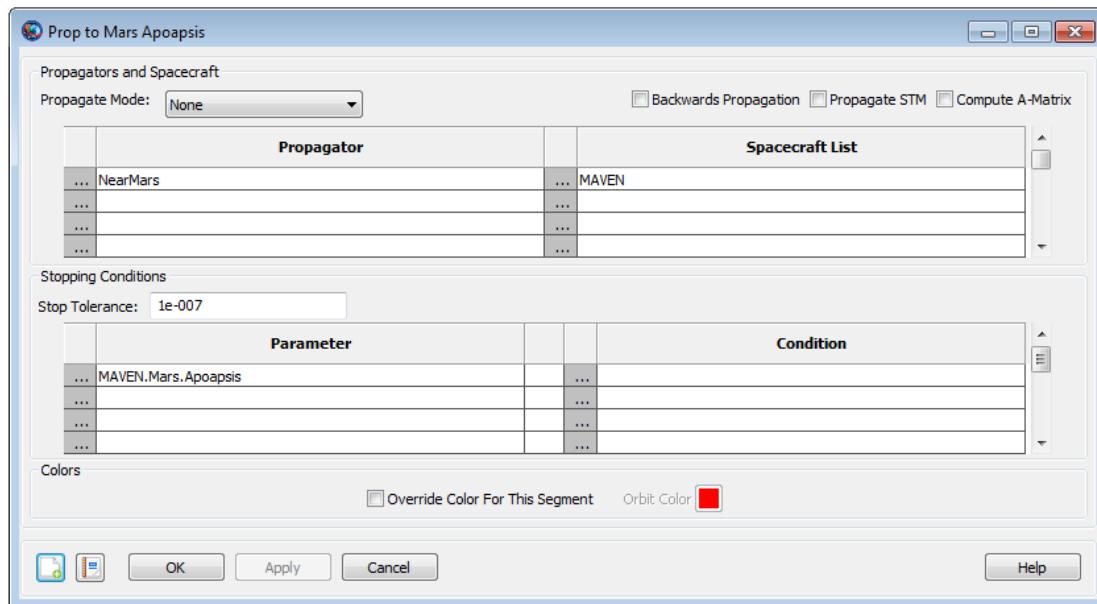


Figure 70. Apply MOI Command Configuration

### Configure the Prop to Mars Apoapsis Command

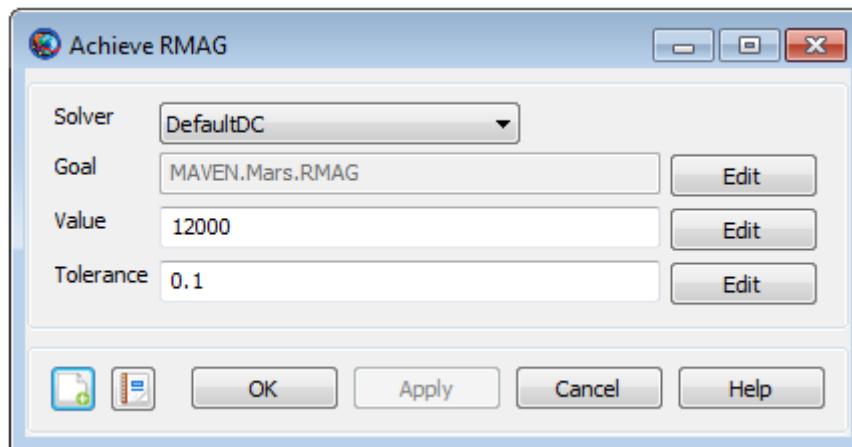
1. Double-click **Prop to Mars Apoapsis** to edit its properties.
2. Under **Propagator**, replace **NearEarth** with **NearMars**.
3. Under **Parameter**, replace **MAVEN.ElapsedSeconds** with **MAVEN.Mars.Apoapsis**.
4. Click **OK** to save these changes.



**Figure 71. Prop to Mars Apoapsis Command Configuration**

### Configure the Achieve RMAG Command

1. Double-click **Achieve RMAG** to edit its properties.
2. Next to **Goal**, click the **Edit** button.
3. In the **Object Properties** list, click **RMAG**.
4. Under **Central Body**, select **Mars** and double-click on **RMAG**.
5. Click **OK** to close the **ParameterSelectDialog** window.
6. In the **Value** box, type **12000**.
7. Click **OK** to save these changes.

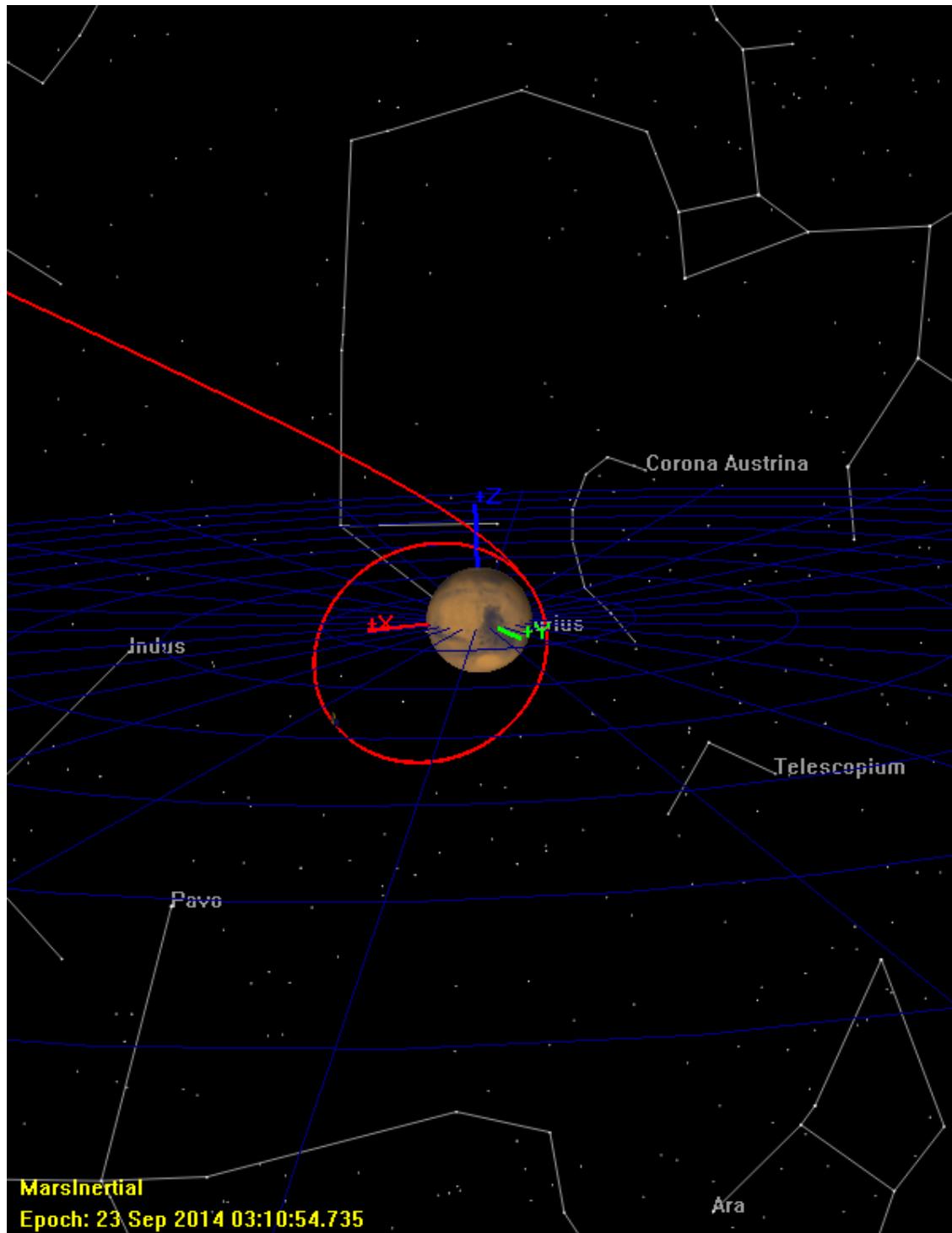


**Figure 72. Achieve RMAG Command Configuration**

## Run the Mission with first and second Target Sequences

Before running the mission, click **Save** (💾). This will save the additional changes that we implemented in the **Mission** tree. Now click **Run** (▶). The first **Target** sequence will converge in one-iteration. This is because earlier, we stored the solution as the initial conditions. The second **Target** sequence may converge after 10 to 11 iterations.

As the mission runs, you will see GMAT solve the second **Target** sequence's targeting problem. Each iteration and perturbation is shown in **MarsView** windows in light blue, and the final solution is shown in red. After the mission completes, the **MarsView** 3D view should appear as in the image shown below. **EarthView** and **SolarSystemView** 3D views are same as before. You may want to run the mission several times to see the targeting in progress.



**Figure 73. 3D view of Mars Capture orbit after MOI maneuver (MarsView)**

If you were to continue developing this mission, you can store the final solution of the second **Target** sequence as the initial condition of **MOI** resource. This is so that when

you make small changes, the subsequent runs will take less time. To do this, follow these steps:

1. In the **Mission** tree, double-click **Mars Capture** to edit its properties.
2. Click **Apply Corrections**.
3. Now re-run the mission. If you inspect the results in the message window, you will see that now the second **Target** sequence also converges in one iteration. This is because you stored the solution as the initial condition. Now whenever you re-run the mission, both first and second Target sequences will converge in just one iteration.
4. In the **Mission** tree, double-click **Vary MOI.V**, you will notice that the values in **Initial Value** box have been updated to the final solution of the second **Target** sequence.

If you want to know MOI maneuver's delta-V vector values and how much fuel was expended during the maneuver, do the following steps:

1. In the **Mission** tree, right-click **Apply MOI**, and click on **Command Summary**.
2. Scroll down and under **Maneuver Summary** heading, values for delta-V vector are:

Delta V Vector:

Element 1: -1.6034665169868 km/s

Element 2: 0.000000000000 km/s

Element 3: 0.000000000000 km/s

3. Scroll down and under **Mass depletion** from **MainTank** heading, **Delta V** and **Mass Change** tells you MOI maneuver's magnitude and how much fuel was used for the maneuver:

Delta V: 1.6034665169868 km/s

Mass change: -1076.0639629424 kg

Just to make sure that the goal of second **Target** sequence was met successfully, let us access command summary for **Achieve RMAG** command by doing the following steps:

1. In the **Mission** tree, right-click **Achieve RMAG**, and click on **Command Summary**.
2. Under **Coordinate System**, select **MarsInertial**.
3. Under **Keplerian State** and **Spherical State** headings, see the values of **TA** and **RMAG**. You can see that the desired radius of the capture orbit at apoapsis was achieved successfully:

TA = 180.0000241484 deg

RMAG = 12000.019889021 km

# Optimal Lunar Flyby using Multiple Shooting

<b>Audience</b>	Advanced
<b>Length</b>	90 minutes
<b>Prerequisites</b>	Complete Simulating an Orbit, Simple Orbit Transfer, Mars B-Plane Targeting tutorial and take GMAT Fundamentals training course or watch videos
<b>Script File</b>	Tut_MultipleShootingTutorial_Step1.script, Tut_MultipleShootingTutorial_Step2.script,... Tut_MultipleShootingTutorial_Step5.script

## Objective and Overview



### Note

For highly elliptic earth orbits (HEO), it is often cheaper to use the Moon's gravity to raise periapsis or to perform plane changes, than it is to use the spacecraft's propulsion resources. However, designing lunar flybys to achieve multiple specific mission constraints is non-trivial and requires modern optimization techniques to minimize fuel usage while simultaneously satisfying trajectory constraints. In this tutorial, you will learn how to design flyby trajectories by writing a GMAT script to perform multiple shooting optimization. As the analyst, your goal is to design a lunar flyby that provides a mission orbit periapsis of 15 Earth radii and changes the inclination of the mission orbit to 10 degrees. (Note: There are other mission constraints that will be discussed in more detail below.)

To efficiently solve the problem, we will employ the Multiple Shooting Method to break down the sensitive boundary value problem into smaller, less sensitive problems. We will employ three trajectory segments. The first segment will begin at Transfer Orbit Insertion (TOI) and will propagate forward; the second segment is centered at lunar periapsis and propagates both forward and backwards. The third segment is centered on Mission Orbit Insertion (MOI) and propagates forwards and backwards. See figures 1 and 2 that illustrate the final orbit solution and the "Control Points" and "Patch Points" used to solve the problem.

To begin this tutorial we start with a several views of the solution to provide a physical understanding of the problem. In Fig. 1, an illustration of a lunar flyby is shown with the trajectory displayed in red and the Moon's orbit displayed in yellow. The Earth is at the center of the frame. We require that the following constraints are satisfied at TOI:

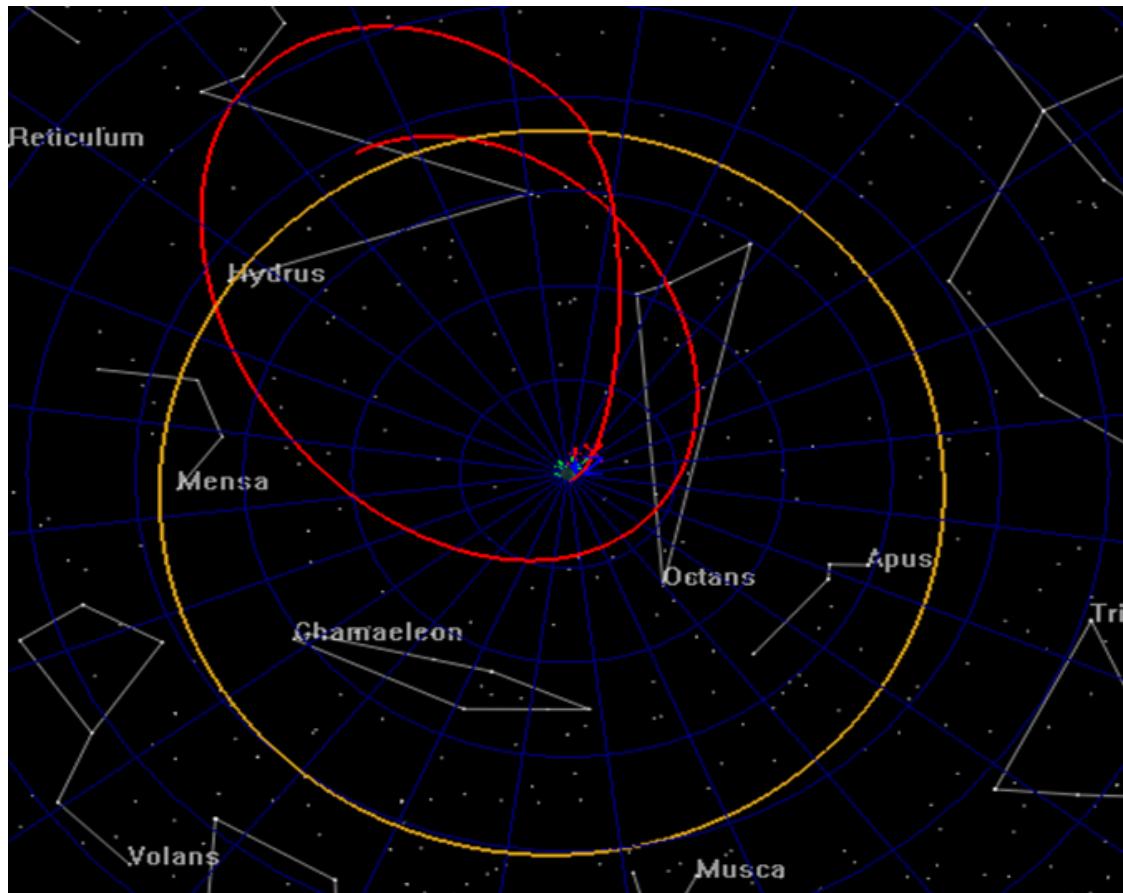
1. The spacecraft is at orbit perigee,
2. The spacecraft is at an altitude of 285 km.

3. The inclination of the transfer orbit is 28.5 degrees.

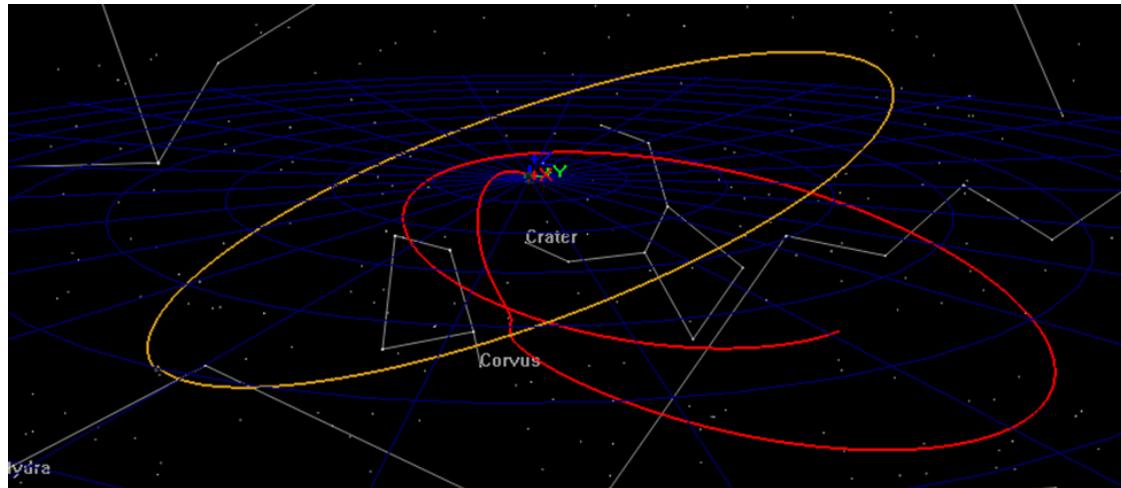
At lunar flyby, we only require that the flyby altitude is greater than 100 km. This constraint is satisfied implicitly so we will not explicitly script this constraint. An insertion maneuver is performed at earth perigee after the lunar fly to insert into the mission orbit. The following constraints must be satisfied after MOI.

1. The mission orbit perigee is 15 Earth radii.
2. The mission orbit apogee is 60 Earth radii.
3. The mission orbit inclination is 10 degrees.

Note: (Phasing with the moon is important for these orbits but design considerations for lunar phasing are beyond the scope of this tutorial)

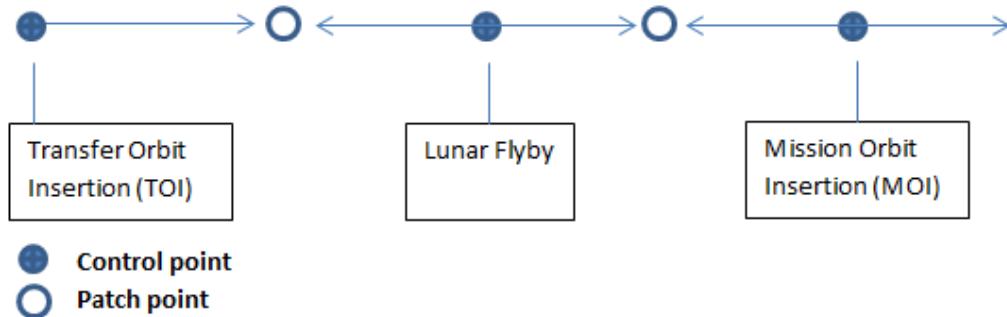


**Figure 74. View of Lunar Flyby from Normal to Earth Equator**



**Figure 75. View of Lunar Flyby Geometry**

The figure below illustrates the mission timeline and how control points and patch points are defined. Control points are drawn using a solid blue circle and are defined as locations where the state of the spacecraft is treated as an optimization variable. Patch points are drawn with an empty blue circle and are defined as locations where position and/or velocity continuity is enforced. For this tutorial, we place control points at TOI, the lunar flyby and MOI. At each control point, the six Cartesian state elements, and the epoch are varied for a total of 18 optimization variables. At the MOI control point, there is an additional optimization variable for the delta V (in the velocity direction) to insert into the mission orbit.



**Figure 76. Definition of Control and Patch Points**

Notice that while there are only three control points, we have 5 segments (which will result in 5 spacecraft). The state at the lunar flyby, which is defined as a control point, is propagated backwards to a patch point and forwards to a patch point. The same occurs for the MOI control point. To design this trajectory, you will need to create the following GMAT resources.

1. Create a Moon-centered coordinate system.
2. Create 5 spacecraft required for modeling segments.
3. Create an Earth-centered and a Moon-centered propagator.

4. Create an impulsive maneuver.
5. Create many user variables for use in the script.
6. Create A VF13ad optimizer.
7. Create plots for tracking the optimization process.

After creating the resources using script snippets you will construct the optimization sequence using GMAT script. Pseudo-code for the optimization sequence is shown below.

```
Define optimization initial guesses
Initialize variables
Optimize
    Loop initializations
    Vary control point epochs
    Set epochs on spacecraft
    Vary control point state values
    Configure/initialize spacecraft
    Apply constraints on initial control points (i.e before propagation)
    Propagate spacecraft
    Apply patch point constraints
    Apply constraints on mission orbit
    Apply cost function
EndOptimize
```

After constructing the basic optimization sequence we will perform the following steps:

1. Run the sequence and analyze the initial guess.
2. Run the optimizer satisfying only the patch point constraints.
3. Turn on the mission orbit constraints and find a feasible solution.
4. Use the feasible solution as the initial guess and find an optimal solution.
5. Apply an altitude constraint at lunar orbit periapsis

## Configure Coordinate Systems, Spacecraft, Optimizer, Propagators, Maneuvers, Variables, and Graphics

For this tutorial, you'll need GMAT open, with a blank script editor open. To open a blank script editor, click the **New Script** button in the toolbar.

### Create a Moon-centered Coordinate System

You will need a Moon-centered **CoordinateSystem** for the lunar flyby control point so we begin by creating an inertial system centered at the moon. Use the **MJ2000Eq** axes for this system.

```
%-----
% Configure coordinate systems
%-----
Create CoordinateSystem MoonMJ2000Eq
MoonMJ2000Eq.Origin = Luna
```

```
MoonMJ2000Eq.Axes      = MJ2000Eq
```

## Create the Spacecraft

You will need 5 **Spacecraft** for this mission design. The epoch and state information will be set in the mission sequence and here we only need to configure coordinate systems for the **Spacecraft**. The **Spacecraft** named **satTOI** models the transfer orbit through the first patch point. Use the **EarthMJ2000Eq CoordinateSystem** for **satTOI**. **satFlyBy\_Foward** and **satFlyBy\_Backward** model the trajectory from the flyby backwards to patch point 1 and forward to patch point 2 respectively. Use the **MoonMJ2000Eq CoordinateSystem** for **satFlyBy\_Foward** and **satFlyBy\_Backward**. Similarly, **satMOI\_Foward** and **satMOI\_Backward** model the trajectory on either side of the MOI maneuver. Use the **EarthMJ2000Eq CoordinateSystem** for **satMOI\_Foward** and **satMOI\_Backward**.

```
%-----
% Configure spacecraft
%-----

% The TOI control point
Create Spacecraft satTOI
satTOI.DateFormat          = TAIModJulian
satTOI.CoordinateSystem    = EarthMJ2000Eq

% Flyby control point
Create Spacecraft satFlyBy_Foward
satFlyBy_Foward.DateFormat = TAIModJulian
satFlyBy_Foward.CoordinateSystem = MoonMJ2000Eq

% Flyby control point
Create Spacecraft satFlyBy_Backward
satFlyBy_Backward.DateFormat = TAIModJulian
satFlyBy_Backward.CoordinateSystem = MoonMJ2000Eq

% MOI control point
Create Spacecraft satMOI_Backward
satMOI_Backward.DateFormat = TAIModJulian
satMOI_Backward.CoordinateSystem = EarthMJ2000Eq

% MOI control point
Create Spacecraft satMOI_Foward
satMOI_Foward.DateFormat = TAIModJulian
satMOI_Foward.CoordinateSystem = EarthMJ2000Eq
```

## Create the Propagators

Modeling the motion of the spacecraft when near the earth and near the moon requires two propagators; one Earth-centered, and one Moon-centered. The script below configures the **ForceModel** named **NearEarthForceModel** to use JGM-2 8x8 harmonic gravity model, with point mass perturbations from the Sun and Moon, and the SRP pertur-

bation. The **ForceModel** named **NearMoonForceModel** is similar but uses point mass gravity for all bodies. Note that the integrators are configured for performance and not for accuracy to improve run times for the tutorial. There are times when integrator accuracy can cause issues with optimizer performance due to noise in the numerical solutions.

```
%-----
% Configure propagators and force models
%-----

Create ForceModel NearEarthForceModel
NearEarthForceModel.CentralBody          = Earth
NearEarthForceModel.PrimaryBodies        = {Earth}
NearEarthForceModel.PointMasses         = {Luna, Sun}
NearEarthForceModel.SRP                 = On
NearEarthForceModel.GravityField.Earth.Degree = 8
NearEarthForceModel.GravityField.Earth.Order   = 8

Create ForceModel NearMoonForceModel
NearMoonForceModel.CentralBody          = Luna
NearMoonForceModel.PointMasses         = {Luna, Earth, Sun}
NearMoonForceModel.Drag                = None
NearMoonForceModel.SRP                 = On

Create Propagator NearEarthProp
NearEarthProp.FM = NearEarthForceModel
NearEarthProp.Type          = PrinceDormand78
NearEarthProp.InitialStepSize = 60
NearEarthProp.Accuracy      = 1e-11
NearEarthProp.MinStep       = 0.0
NearEarthProp.MaxStep       = 86400

Create Propagator NearMoonProp
NearMoonProp.FM          = NearMoonForceModel
NearMoonProp.Type          = PrinceDormand78
NearMoonProp.InitialStepSize = 60
NearMoonProp.Accuracy      = 1e-11
NearMoonProp.MinStep       = 0
NearMoonProp.MaxStep       = 86400
```

## Create the Maneuvers

We will require one **ImpulsiveBurn** to insert the spacecraft into the mission orbit. Define the maneuver as **MOI** and configure the maneuver to be applied in the **VNB** (Earth-referenced) **Axes**.

```
%-----
% Configure maneuvers
%-----

Create ImpulsiveBurn MOI
```

MOI.CoordinateSystem	= Local
MOI.Origin	= Earth
MOI.Axes	= VNB

## Create the User Variables

The optimization sequence requires many user variables that will be discussed in detail later in the tutorial when we define those variables. For now, we simply create the variables (which initializes them to zero). The naming convention used here is that variables used to define constraint values begin with “con”. For example, the variable used to define the constraint on TOI inclination is called **conTOIIInclination**. Variables beginning with “error” are used to compute constraint variances. For example, the variable used to define the error in MOI inclination is called **errorTOIIInclination**.

```
%-----
% Create user data: variables, arrays, strings
%-----

% Variables for defining constraint values
Create Variable conTOIPeriapsis conMOIPeriapsis conTOIIInclination
Create Variable conLunarPeriapsis conMOIApoapsis conMOIIInclination
Create Variable launchRdotV finalPeriapsisValue

% Variables for computing constraint violations
Create Variable errorPos1 errorVel1 errorPos2 errorVel2
Create Variable errorMOIRadApo errorMOIRadPer errorMOIIInclination

% Variables for managing time calculations
Create Variable patchTwoElapsedDays patchOneEpoch patchTwoEpoch refEpoch
Create Variable toiEpoch flybyEpoch moiEpoch patchOneElapsedDays
Create Variable deltaTimeFlyBy

% Constants and miscellaneous variables
Create Variable earthRadius earthMu launchEnergy launchVehicleDeltaV
Create Variable toiDeltaV launchCircularVelocity loopIdx Cost
```

## Create the Optimizer

The script below creates a **VF13ad** optimizer provided in the Harwell Subroutine Library. **VF13ad** is an Sequential Quadratic Programming (SQP) optimizer that uses a line search method to solve the Non-linear Programming Problem (NLP). Here we configure the optimizer to use forward differencing to compute the derivatives, define the maximum iterations to 200, and define convergence tolerances.

```
%-----
% Configure solvers
%-----

Create VF13ad NLPopt
NLPopt.ShowProgress = true
```

```
NLPOpt.ReportStyle      = Normal
NLPOpt.ReportFile       = 'VF13adVF13ad1.data'
NLPOpt.MaximumIterations = 200
NLPOpt.Tolerance        = 1e-004
NLPOpt.UseCentralDifferences = false
NLPOpt.FeasibilityTolerance = 0.1
```

## Create the 3-D Graphics

You will need an **OrbitView** 3-D graphics window to visualize the trajectory and especially the initial guess. Below we configure an orbit view to view the entire trajectory in the **EarthMJ2000Eq** coordinate system. Note that we must add all five **Spacecraft** to the **OrbitView**. Updating an **OrbitView** during optimization can dramatically slow down the optimization process and they are best used to check initial configuration and then use XY plots to track numerical progress. Later in the tutorial, we will toggle the **ShowPlot** field to **false** once we have verified the initial configuration is correct.

```
%-----
% Configure plots, reports, etc.
%-----

Create OrbitView EarthView
EarthView.ShowPlot          = true
EarthView.SolverIterations   = All
EarthView.UpperLeft         = ...
[ 0.4960127591706539 0.00992063492063492 ];
EarthView.Size               = ...
[ 0.4800637958532695 0.5218253968253969 ];
EarthView.RelativeZOrder     = 501
EarthView.Add                = ...
{satTOI, satFlyBy_Forward, satFlyBy_Backward, satMOI_Backward, ...
Earth, Luna, satMOI_Forward}
EarthView.CoordinateSystem    = EarthMJ2000Eq
EarthView.DrawObject          = [ true true true true true]
EarthView.OrbitColor          = ...
[ 255 32768 1743054 16776960 32768 12632256 14268074 ]
EarthView.TargetColor         = ...
[ 65280 124 4227327 255 12345 9843 16711680 ];
EarthView.DataCollectFrequency = 1
EarthView.UpdatePlotFrequency = 50
EarthView.NumPointsToRedraw   = 300
EarthView.ViewScaleFactor     = 35
EarthView.ViewUpAxis          = X
EarthView.UseInitialView      = On
```

## Create XYPlots and Reports

Below we create several **XYPlots** and a **ReportFile**. We will use **XYPlots** to monitor the progress of the optimizer in satisfying constraints. **PositionError1** plots the position error at the first patch point... **VelocityError2** plots the velocity error at the second patch

point, and so on. **OrbitDimErrors** plots the errors in the periapsis and apoapsis radii for the mission orbit. When optimization is proceeding as expected, these plots should show errors driven to zero.

```
Create XYPlot PositionError
PositionError.SolverIterations = All
PositionError.UpperLeft      = [ 0.02318840579710145 0.4358208955223881 ];
PositionError.Size           = [ 0.4594202898550724 0.5283582089552239 ];
PositionError.RelativeZOrder = 378
PositionError.XVariable     = loopIdx
PositionError.YVariables   = {errorPos1, errorPos2}
PositionError.ShowGrid       = true
PositionError.ShowPlot      = true

Create XYPlot VelocityError
VelocityError.SolverIterations = All
VelocityError.UpperLeft      = [ 0.02463768115942029 0.01194029850746269 ];
VelocityError.Size           = [ 0.4565217391304348 0.4208955223880597 ];
VelocityError.RelativeZOrder = 410
VelocityError.XVariable     = loopIdx
VelocityError.YVariables   = {errorVel1, errorVel2}
VelocityError.ShowGrid       = true
VelocityError.ShowPlot      = true

Create XYPlot OrbitDimErrors
OrbitDimErrors.SolverIterations = All
OrbitDimErrors.UpperLeft      = [ 0.4960127591706539 0.5337301587301587 ];
OrbitDimErrors.Size           = [ 0.481658692185008 0.4246031746031746 ];
OrbitDimErrors.RelativeZOrder = 347
OrbitDimErrors.XVariable     = loopIdx
OrbitDimErrors.YVariables   = {errorMOIRadApo, errorMOIRadPer}
OrbitDimErrors.ShowGrid       = true
OrbitDimErrors.ShowPlot      = true

Create XYPlot IncError
IncError.SolverIterations = All
IncError.UpperLeft          = [ 0.4953586497890296 0.01306240928882438 ];
IncError.Size                = [ 0.479324894514768 0.5079825834542816 ];
IncError.RelativeZOrder     = 382
IncError.YVariables         = {errorMOIIInclination}
IncError.XVariable          = loopIdx
IncError.ShowGrid            = true
IncError.ShowPlot            = true
```

Create a **ReportFile** to allow reporting useful information to a text file for review after the optimization process is complete.

```
Create ReportFile debugData
debugData.SolverIterations = Current
debugData.Precision        = 16
```

```

debugData.WriteHeader      = Off
debugData.LeftJustify     = On
debugData.ZeroFill        = Off
debugData.ColumnWidth     = 20
debugData.WriteReport      = false

```

## Configure the Mission Sequence

### Overview of the Mission Sequence

Now that the resources are created and configured, we will construct the optimization sequence. Pseudo-script for the optimization sequence is shown below. We will start by defining initial guesses for the control point optimization variables. Next, selected variables are initialized. Take some time and study the structure of the optimization loop before moving on to the next step.

```

Define optimization initial guesses
Initialize variables
Optimize
    Loop initializations
    Vary control point epochs
    Set epochs on spacecraft
    Vary control point state values
    Set state values on spacecraft
    Apply constraints on control points (i.e before propagation)
    Propagate spacecraft
    Apply patch point constraints (i.e. after propagation)
    Apply constraints on mission orbit
    Apply cost function
EndOptimize

```

### Define Initial Guesses

Below we define initial guesses for the optimization variables. Initial guesses are often difficult to generate and to ensure you can take this tutorial we have provided a reasonable initial guess for this problem. You can use GMAT to produce initial guesses and the sample script named `Ex_GivenEpochGoToTheMoon` distributed with GMAT can be used for that purpose for this tutorial.

The time variables **launchEpoch**, **flybyEpoch** and **moiEpoch** are the TAI modified Julian epochs of the launch, flyby, and MOI. It is not obvious yet that these are TAI modified Julian epochs, but later we use statements like this to set the epoch: `satTOI.Epoch.TAIModJulian = launchEpoch`. Recall that we previously set up the spacecraft to used coordinate systems appropriate to the problem. Setting **satTOI.X** sets the quantity in **EarthMJ2000Eq** and **satFlyBy\_Forward.X** sets the quantity in **MoonMJ2000Eq** because of the configuration of the spacecraft.

```

BeginMissionSequence

% Define initial guesses for optimization variables

```

```
BeginScript 'Initial Guess Values'

    % Robust intial guess but not feasible
    toiEpoch = 27698.1612435
    flybyEpoch = 27703.7658714
    moiEpoch = 27723.305398
    satTOI.X = -6659.70273964
    satTOI.Y = -229.327053112
    satTOI.Z = -168.396030559
    satTOI.VX = 0.26826479315
    satTOI.VY = -9.54041067213
    satTOI.VZ = 5.17141415746
    satFlyBy_Forward.X = 869.478955662
    satFlyBy_Forward.Y = -6287.76679557
    satFlyBy_Forward.Z = -3598.47087228
    satFlyBy_Forward.VX = 1.14619150302
    satFlyBy_Forward.VY = -0.73648611256
    satFlyBy_Forward.VZ = -0.624051812914
    satMOI_Backward.X = -53544.9703742
    satMOI_Backward.Y = -68231.6310266
    satMOI_Backward.Z = -1272.76362793
    satMOI_Backward.VX = 2.051823425
    satMOI_Backward.VY = -1.91406286218
    satMOI_Backward.VZ = -0.280408526046
    MOI.Element1 = -0.0687322937282

EndScript
```

## Initialize Variables

The script below is used to define some constants and to define the values for various constraints applied to the trajectory. Pay particular attention to the constraint values and time values. For example, the variable **conTOIPerapsis** defines the perapsis radius at launch constraint to be at about 285 km (geodetics will cause altitude to vary slightly). The variable **conMOIApoapsis** defines the mission orbit apoapsis to be 60 earth radii. The variables **patchOneElapsedDays**, **patchTwoElapsedDays**, and **refEpoch** are particularly important as they define the epochs of the patch points later in the script using lines like this **patchOneEpoch = refEpoch + patchOneElapsedDayspatchOneEpoch**. The preceding line defines the epoch of the first patch point to be one day after **refEpoch** (**refEpoch** is set to **launchEpoch**). Similarly, the epoch of the second patch point is defined as 13 days after **refEpoch**. Note, the patch point epochs can be treated as optimization variables but that was not done to reduce complexity of the tutorial.

```
% Define constants and configuration settings
BeginScript 'Constants and Init'

    % Some constants
    earthRadius      = 6378.1363
```

```
% Define constraint values and other constants
conTOIPeriapsis = 6378 + 285 % constraint on launch periapsis
conTOIIInclination = 28.5 % constraint launch inclination
conLunarPeriapsis = 8000 % constraint on flyby altitude
conMOIApoapsis = 60*earthRadius % constraint on mission apoapsis
conMOIIInclination = 10 % constraint on mission inc.
conMOIPeriapsis = 15*earthRadius % constraint on mission periapsis
patchOneElapsedDays = 1 % define epoch of patch 1
patchTwoElapsedDays = 13 % define epoch of patch 2
refEpoch = toiEpoch % ref. epoch for time quantities

EndScript

% The optimization loop
Optimize 'Optimize Flyby' NLPOpt ...
{SolveMode = Solve, ExitMode = DiscardAndContinue}

% Loop initializations
loopIdx = loopIdx + 1

EndOptimize
```



### Caution

In the above script snippet, we have included the EndOptimize command so that your script will continue to build while we construct the optimization sequence. You must paste subsequence script snippets inside of the optimization loop.

## Vary and Set Spacecraft Epochs

Now we will write the commands that vary the control point epochs and apply those epochs to the spacecraft. The first three script lines below define **launchEpoch**, **flybyEpoch**, and **moiEpoch** to be optimization variables. It is important to note that when a **Vary** command is written like this

```
Vary NLPOpt(launchEpoch = launchEpoch, . . .
```

that you are telling the optimizer to vary **launchEpoch** (the RHS of the equal sign), and to use as the initial guess the value contained in **launchEpoch** when the command is first executed. This will allow us to easily change initial guess values and perform “Apply Corrections” via the script interface which will be shown later. Continuing with the script explanation, the last five lines below set the epochs of the spacecraft according to the optimization variables and set up the patch point epochs.

```
% Vary the epochs
Vary NLPOpt(toiEpoch = toiEpoch, {Perturbation = 0.0001, MaxStep = 0.5})
Vary NLPOpt(flybyEpoch = flybyEpoch, {Perturbation=0.0001,MaxStep=0.5})
```

```
Vary NLPOpt(moiEpoch = moiEpoch, {Perturbation = 0.0001,MaxStep=0.5})  
  
% Configure epochs and spacecraft  
satTOI.Epoch.TAIModJulian = toiEpoch  
satMOI_Backward.Epoch.TAIModJulian = moiEpoch  
satFlyBy_Forward.Epoch.TAIModJulian = flybyEpoch  
patchOneEpoch = refEpoch + patchOneElapsedDays  
patchTwoEpoch = refEpoch + patchTwoElapsedDays
```

## Vary Control Point States

The script below defines the control point optimization variables and defines the initial guess values for each optimization variable. For example, the following line

```
Vary NLPOpt(satTOI.X = satTOI.X, {Perturbation = 0.00001, MaxStep = 100})
```

tells GMAT to vary the X Cartesian value of **satTOI** using as the initial guess the value of **satTOI.X** at initial command execution. The **Perturbation** used to compute derivatives is 0.00001 and the optimizer will not take steps larger than 100 for this variable. Note: units of settings like **Perturbation** are the same as the unit for the optimization variable.

Notice the lines at the bottom of this script snippet that look like this:

```
satFlyBy_Backward = satFlyBy_Forward
```

This line assigns an entire **Spacecraft** to another **Spacecraft**. Because we are varying one control point in the middle of a segment, this assignment allows us to conveniently set the second **Spacecraft** without independently varying its state properties.

```
% Vary the states and delta V  
Vary NLPOpt(satTOI.X = ...  
satTOI.X, {Perturbation = 0.00001, MaxStep = 100})  
Vary NLPOpt(satTOI.Y = ...  
satTOI.Y, {Perturbation = 0.00001, MaxStep = 100})  
Vary NLPOpt(satTOI.Z = ...  
satTOI.Z, {Perturbation = 0.00001, MaxStep = 100})  
Vary NLPOpt(satTOI.VX = ...  
satTOI.VX, {Perturbation = 0.00001, MaxStep = 0.05})  
Vary NLPOpt(satTOI.VY = ...  
satTOI.VY, {Perturbation = 0.00001, MaxStep = 0.05})  
Vary NLPOpt(satTOI.VZ = ...  
satTOI.VZ, {Perturbation = 0.00001, MaxStep = 0.05})  
Vary NLPOpt(satFlyBy_Forward.X = ...  
satFlyBy_Forward.MoonMJ2000Eq.X, {Perturbation = 0.00001, MaxStep = 100})  
Vary NLPOpt(satFlyBy_Forward.Y = ...  
satFlyBy_Forward.MoonMJ2000Eq.Y, {Perturbation = 0.00001, MaxStep = 100})  
Vary NLPOpt(satFlyBy_Forward.Z = ...  
satFlyBy_Forward.MoonMJ2000Eq.Z, {Perturbation = 0.00001, MaxStep = 100})  
Vary NLPOpt(satFlyBy_Forward.VX = ...  
satFlyBy_Forward.MoonMJ2000Eq.VX, {Perturbation = 0.00001, MaxStep = 0.1})
```

```

Vary NLPOpt(satFlyBy_Front.VY = ...
satFlyBy_Front.MoonMJ2000Eq.VY, {Perturbation = 0.00001, MaxStep = 0.1})
Vary NLPOpt(satFlyBy_Front.VZ = ...
satFlyBy_Front.MoonMJ2000Eq.VZ, {Perturbation = 0.00001, MaxStep = 0.1})
Vary NLPOpt(satMOI_Backward.X = ...
satMOI_Backward.X, {Perturbation = 0.000001, MaxStep = 40000})
Vary NLPOpt(satMOI_Backward.Y = ...
satMOI_Backward.Y, {Perturbation = 0.000001, MaxStep = 40000})
Vary NLPOpt(satMOI_Backward.Z = ...
satMOI_Backward.Z, {Perturbation = 0.000001, MaxStep = 40000})
Vary NLPOpt(satMOI_Backward.VX = ...
satMOI_Backward.VX, {Perturbation = 0.00001, MaxStep = 0.1})
Vary NLPOpt(satMOI_Backward.VY = ...
satMOI_Backward.VY, {Perturbation = 0.00001, MaxStep = 0.1})
Vary NLPOpt(satMOI_Backward.VZ = ...
satMOI_Backward.VZ, {Perturbation = 0.00001, MaxStep = 0.1})
Vary NLPOpt(MOI.Element1 = ...
MOI.Element1, {Perturbation = 0.0001, MaxStep = 0.005})

% Initialize spacecraft and do some reporting
satFlyBy_Backward = satFlyBy_Front
satMOI_Front = satMOI_Backward
deltaTimeFlyBy = flybyEpoch - toiEpoch

```

## Apply Constraints at Control Points

Now that the control points have been set, we can apply constraints that occur at the control points (i.e. before propagation to the patch point). Notice below that the **NonlinearConstraint** commands are commented out. We will uncomment those constraints later. The commands below, when uncommented, will apply constraints on the launch inclination, the launch periapsis radius, the mission orbit periapsis, and the last constraint ensures that TOI occurs at periapsis of the transfer orbit.

```

% Apply constraints on initial states
%NonlinearConstraint NLPOpt(satTOI.INC=conTOIIInclination)
%NonlinearConstraint NLPOpt(satTOI.RadPer=conTOIPeriapsis)
%NonlinearConstraint NLPOpt(satMOI_Backward.RadPer = conMOIPeriapsis)
errorMOIRadPer = satMOI_Backward.RadPer - conMOIPeriapsis

% This constraint ensures that satTOI state is at periapsis at injection
launchRdotV = (satTOI.X *satTOI.VX + satTOI.Y *satTOI.VY + ...
satTOI.Z *satTOI.VZ)/1000
%NonlinearConstraint NLPOpt(launchRdotV=0)

```

## Propagate the Segments

We are now ready to propagate the spacecraft to the patch points. We must propagate **satTOI** forward to **patchOneEpoch**, propagate **satFlyBy\_Backward** backwards to **patchOneEpoch**, propagate **satFlyBy\_Front** to **patchTwoEpoch**, and propagate **satMOI\_Backward** to **patchTwoEpoch**. Notice that some **Propagate** commands are

applied inside of **If** statements to ensure that propagation is performed in the correct direction.

```
% DO NOT PASTE THESE LINES INTO THE SCRIPT, THEY ARE
% INCLUDED IN THE COMPLETE SNIPPET LATER IN THIS SECTION
If satFlyBy_Forward.TAIModJulian > patchTwoEpoch
    Propagate BackProp NearMoonProp(satFlyBy_Forward) . . .
Else
    Propagate NearMoonProp(satFlyBy_Forward) . . .
EndIf
```

In the script below, you will notice lines like this:

```
% DO NOT PASTE THESE LINES INTO THE SCRIPT, THEY ARE
% INCLUDED IN THE COMPLETE SNIPPET LATER IN THIS SECTION
Propagate NearEarthProp(satTOI) {satTOI.TAIModJulian = patchOneEpoch, ...
PenUp EarthView % The next three lines handle plot epoch discontinuity
Propagate BackProp NearMoonProp(satFlyBy_Backward)
PenDown EarthView
```

These lines are used to clean up discontinuities in the **OrbitView** that occur because we are making discontinuous changes to time in this complex script.

```
% Propagate the segments
Propagate NearEarthProp(satTOI) {satTOI.TAIModJulian = ...
patchOneEpoch, StopTolerance = 1e-005}
PenUp EarthView % The next three lines handle discontinuity in plots
Propagate BackProp NearMoonProp(satFlyBy_Backward)
PenDown EarthView
Propagate BackProp NearMoonProp(satFlyBy_Backward)... .
{satFlyBy_Backward.TAIModJulian = patchOneEpoch, StopTolerance = 1e-005}

% Propagate FlybySat to Apogee and apply apogee constraints
PenUp EarthView % The next three lines handle discontinuity in plots
Propagate NearMoonProp(satFlyBy_Forward)
PenDown EarthView
Propagate NearMoonProp(satFlyBy_Forward) ...
{satFlyBy_Forward.Earth.Apoapsis, StopTolerance = 1e-005}
Report debugData satFlyBy_Forward.RMAG

% Propagate FlybSat and satMOI_Backward to patchTwoEpoch
If satFlyBy_Forward.TAIModJulian > patchTwoEpoch
    Propagate BackProp NearMoonProp(satFlyBy_Forward)...
{satFlyBy_Forward.TAIModJulian = patchTwoEpoch, StopTolerance = 1e-005}
Else
    Propagate NearMoonProp(satFlyBy_Forward)...
{satFlyBy_Forward.TAIModJulian = patchTwoEpoch, StopTolerance = 1e-005}
EndIf
PenUp EarthView % The next three lines handle discontinuity in plots
Propagate BackProp NearMoonProp(satMOI_Backward)
```

```

PenDown EarthView
Propagate BackProp NearMoonProp(satMOI_Backward)...
{satMOI_Backward.TAIModJulian = patchTwoEpoch, StopTolerance = 1e-005}

```

## Compute Some Quantities and Apply Patch Constraints

The variables **errorPos1** and others below are used in **XYPlots** to display position and velocity errors at the patch points.

```

% Compute constraint errors for plots
errorPos1 = sqrt((satTOI.X - satFlyBy_Backward.X)^2 + ...
(satTOI.Y - satFlyBy_Backward.Y)^2 + (satTOI.Z - satFlyBy_Backward.Z)^2)
errorVel1 = sqrt((satTOI.VX - satFlyBy_Backward.VX)^2 + ...
(satTOI.VY-satFlyBy_Backward.VY)^2+(satTOI.VZ-satFlyBy_Backward.VZ)^2)
errorPos2 = sqrt((satMOI_Backward.X - satFlyBy_Forward.X)^2 + ...
(satMOI_Backward.Y - satFlyBy_Forward.Y)^2 + ...
(satMOI_Backward.Z - satFlyBy_Forward.Z)^2)
errorVel2 = sqrt((satMOI_Backward.VX - satFlyBy_Forward.VX)^2 + ...
(satMOI_Backward.VY - satFlyBy_Forward.VY)^2 + ...
(satMOI_Backward.VZ - satFlyBy_Forward.VZ)^2)

```

## Apply Patch Point Constraints

The **NonlinearConstraint** commands below apply the patch point constraints.

```

% Apply the collocation constraints constraints on final states
NonlinearConstraint NLPOpt(satTOI.EarthMJ2000Eq.X=...
satFlyBy_Backward.EarthMJ2000Eq.X)
NonlinearConstraint NLPOpt(satTOI.EarthMJ2000Eq.Y=...
satFlyBy_Backward.EarthMJ2000Eq.Y)
NonlinearConstraint NLPOpt(satTOI.EarthMJ2000Eq.Z=...
satFlyBy_Backward.EarthMJ2000Eq.Z)
NonlinearConstraint NLPOpt(satTOI.EarthMJ2000Eq.VX=...
satFlyBy_Backward.EarthMJ2000Eq.VX)
NonlinearConstraint NLPOpt(satTOI.EarthMJ2000Eq.VY=...
satFlyBy_Backward.EarthMJ2000Eq.VY)
NonlinearConstraint NLPOpt(satTOI.EarthMJ2000Eq.VZ=...
satFlyBy_Backward.EarthMJ2000Eq.VZ)
NonlinearConstraint NLPOpt(satMOI_Backward.EarthMJ2000Eq.X=...
satFlyBy_Forward.EarthMJ2000Eq.X)
NonlinearConstraint NLPOpt(satMOI_Backward.EarthMJ2000Eq.Y=...
satFlyBy_Forward.EarthMJ2000Eq.Y)
NonlinearConstraint NLPOpt(satMOI_Backward.EarthMJ2000Eq.Z=...
satFlyBy_Forward.EarthMJ2000Eq.Z)
NonlinearConstraint NLPOpt(satMOI_Backward.EarthMJ2000Eq.VX=...
satFlyBy_Forward.EarthMJ2000Eq.VX)
NonlinearConstraint NLPOpt(satMOI_Backward.EarthMJ2000Eq.VY=...
satFlyBy_Forward.EarthMJ2000Eq.VY)

```

```
NonlinearConstraint NLPOpt(satMOI_Backward.EarthMJ2000Eq.VZ=...
satFlyBy_Forward.EarthMJ2000Eq.VZ)
```

## Apply Constraints on Mission Orbit

We can now apply constraints on the final mission orbit that cannot be applied until after propagation. The script snippet below applies the inclination constraint on the final mission orbit, and applies the apogee radius constraint on the final mission orbit after **MOI** is applied.

```
% Apply mission orbit constraints/others on segments after propagation
errorMOIIInclination = satMOI_Forward.INC - conMOIIInclination
%NonlinearConstraint NLPOpt(satMOI_Forward.EarthMJ2000Eq.INC = ...
% conMOIIInclination)
    % Propagate satMOI_Forward to apogee
PenUp EarthView    % The next three lines handle discontinuity in plots
Propagate NearEarthProp(satMOI_Forward)
PenDown EarthView
If satMOI_Forward.Earth.TA > 180
    Propagate NearEarthProp(satMOI_Forward){satMOI_Forward.Earth.Periapsis}
Else
    Propagate BackProp NearEarthProp(satMOI_Forward)...
    {satMOI_Forward.Earth.Periapsis}
EndIf
Maneuver MOI(satMOI_Forward)
Propagate NearEarthProp(satMOI_Forward) {satMOI_Forward.Earth.Apoapsis}
%NonlinearConstraint NLPOpt(satMOI_Forward.RadApo=conMOIApoapsis)
errorMOIRadApo = satMOI_Forward.Earth.RadApo - conMOIApoapsis
```

## Apply Cost Function

The last script snippet applies the cost function and a Stop command. The **Stop** command is so that we can QA your script configuration and make sure the initial guess is providing reasonable results before attempting optimization.

```
% Apply cost function and
Cost = sqrt( MOI.Element1^2 + MOI.Element2^2 + MOI.Element3^2)
%Minimize NLPOpt(Cost)

% Report stuff at the end of the loop
Report debugData MOI.Element1
Report debugData satMOI_Forward.RMAG conMOIApoapsis conMOIIInclination

Stop
```

## Design the Trajectory

### Overview

We are now ready to design the trajectory. We'll do this in a couple of steps:

1. Run the script configuration and verify your configuration.
2. Run the mission applying only the patch point constraints to provide a smooth trajectory.
3. Run the mission with all constraints applied generating an optimal solution.
4. Run the mission with an alternative initial guess.
5. Add a new constraint and rerun the mission.

## Step 1: Verify Your Configuration

If your script is configured correctly, when you click **Save-Sync-Run** in the bottom of the script editor, you should see an **OrbitView** graphics window display the initial guess for the trajectory as shown below. In the graphics, **satTOI** is displayed in green, **satFlyBy\_Backward** is displayed in orange, **satFlyBy\_Foward** is displayed in dark red, and **satMOI\_Backward** is displayed in bright red, and **satMOI\_Foward** is displayed in blue.

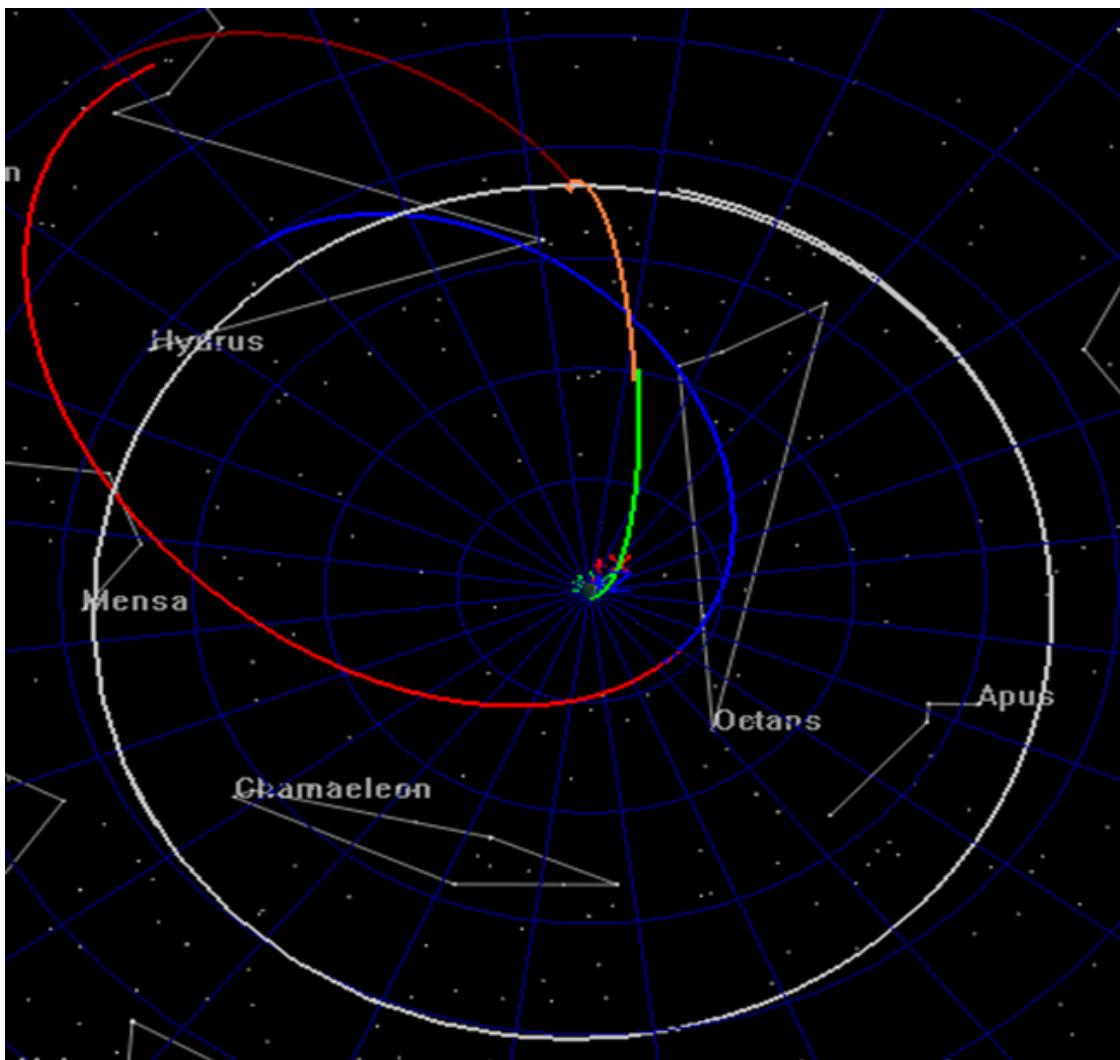
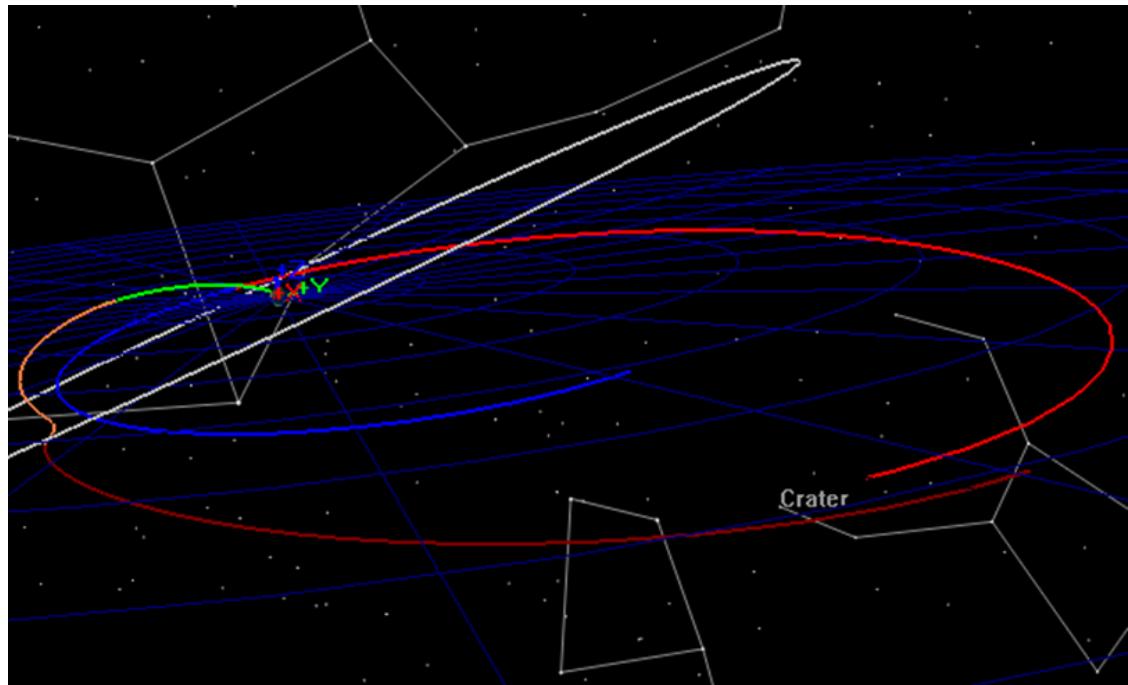
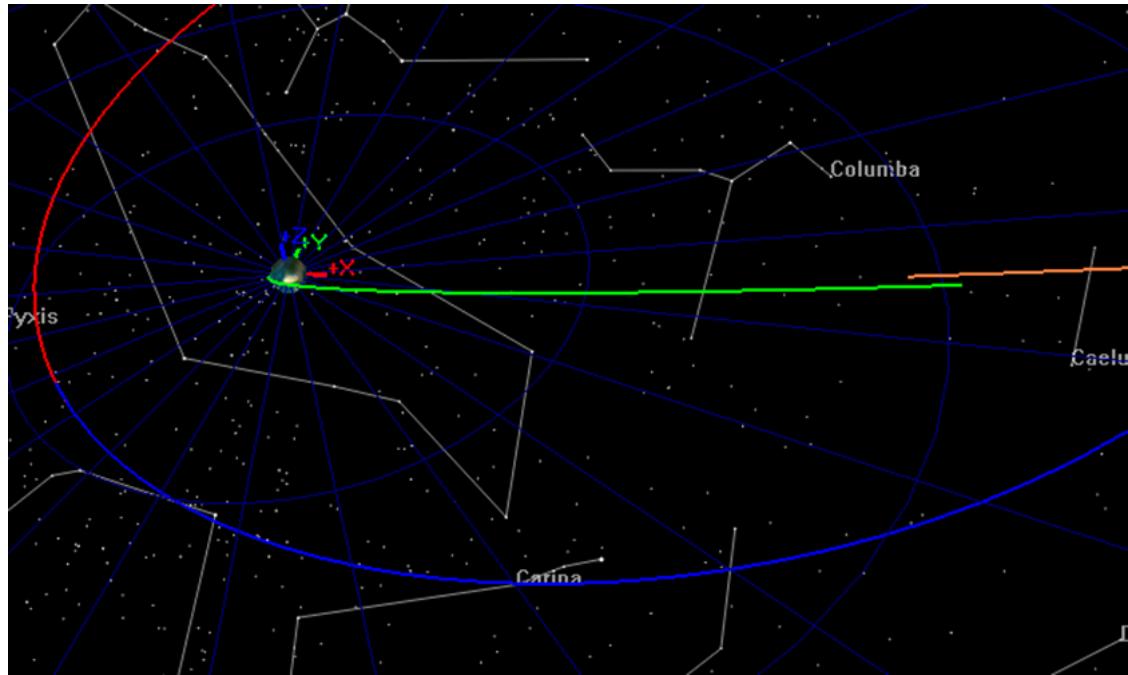


Figure 77. View of Discontinuous Trajectory

You can use the mouse to manipulate the **OrbitView** to see that the patch points are indeed discontinuous for the initial guess as shown below in the two screen captures. If your configuration does not provide you with similar graphics, compare your script to the one provided for this tutorial and address any differences.



**Figure 78. Alternate View (1) of Discontinuous Trajectory**



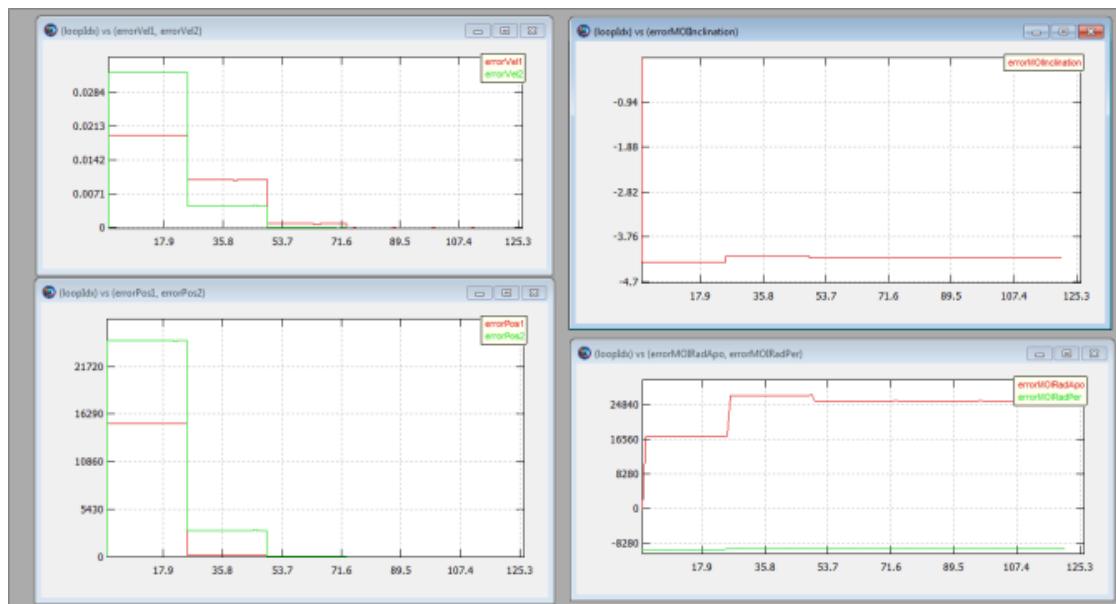
**Figure 79. Alternate View (2) of Discontinuous Trajectory**

## Step 2: Find a Smooth Trajectory

At this point in the tutorial, your script is configured to eliminate the patch point discontinuities but does not apply mission constraints. We need to make a few small modifications before proceeding. We will turn off the **OrbitView** to improve the run time, and we will remove the **Stop** command so that the optimizer will attempt to find a solution.

1. Near the bottom of the script, comment out the **Stop** command.
2. In the configuration of **EarthView**, change **ShowPlot** to **false**.
3. Click **Save Sync Run**.

After a few optimizer iterations you should see "NLPOpt converged to within target accuracy" displayed in the GMAT message window and your XY plot graphics should appear as shown below. Let's discuss the content of these windows. The upper left window shows the RSS history of velocity error at the two patch points during the optimization process. The lower left window shows the RSS history of the position error. The upper right window shows error in mission orbit inclination, and the lower right window shows error in mission orbit apogee and perigee radii. You can see that in all cases the patch point discontinuities were driven to zero, but since other constraints were not applied there are still errors in some mission constraints.



**Figure 80. Smooth Trajectory Solution**

Before proceeding to the next step, go to the message window and copy and paste the final values of the optimization variables to a text editor for later use:

## Step 3: Find an Optimal Trajectory

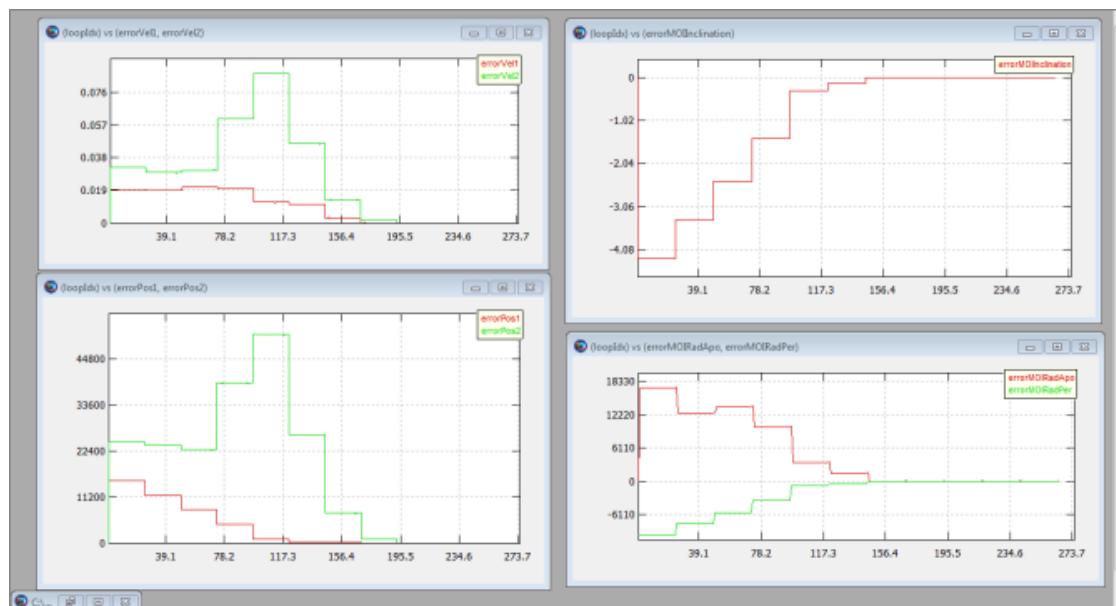
At this point in the tutorial, your script is configured to eliminate the patch point discontinuities but does not apply constraints. We need to make a few small modifications to the script to find an solution that meets the constraints.

1. Remove the “%” sign from the all **NonlinearConstraint** commands and the **Minimize** command:

```
NonlinearConstraint NLPOpt(satTOI.INC=conTOIIInclination)
NonlinearConstraint NLPOpt(satTOI.RadPer=conTOIPeriapsis)
NonlinearConstraint NLPOpt(satMOI_Backward.RadPer = conMOIPeriapsis)
NonlinearConstraint NLPOpt(launchRdotV=0)
NonlinearConstraint NLPOpt(satMOI_Forward.EarthMJ2000Eq.INC =. . .
NonlinearConstraint NLPOpt(satMOI_Forward.RadApo=conMOIApoapsis)
Minimize NLPOpt(Cost)
```

2. Click **Save Sync Run**.

The screen capture below shows the plots after optimization has been completed. Notice that the constraint errors have been driven to zero in the plots



**Figure 81. Optimal Trajectory Solution**

Another way to verify that the constraints have been satisfied is to look in the message window where the final constraint variances are displayed as shown below. We could further reduce the variances by lowering the tolerance setting on the optimizer.

#### Equality Constraint Variances:

```
Delta satTOI.INC = 1.44773082411e-011
Delta satTOI.RadPer = 7.08496372681e-010
Delta satMOI_Backward.RadPer = -3.79732227884e-007
Delta launchRdotV = -1.87725390788e-014
Delta satTOI.EarthMJ2000Eq.X = 0.00037122167123
Delta satTOI.EarthMJ2000Eq.Y = 2.79954474536e-005
Delta satTOI.EarthMJ2000Eq.Z = 2.78138068097e-005
Delta satTOI.EarthMJ2000Eq.VX = -3.87579257577e-009
```

```

Delta satTOI.EarthMJ2000Eq.VY = 1.5329883335e-009
Delta satTOI.EarthMJ2000Eq.VZ = -6.84140494256e-010
Delta satMOI_Backward.EarthMJ2000Eq.X = 0.0327844279818
Delta satMOI_Backward.EarthMJ2000Eq.Y = 0.0501471919124
Delta satMOI_Backward.EarthMJ2000Eq.Z = 0.0063349630509
Delta satMOI_Backward.EarthMJ2000Eq.VX = -7.5196416871e-008
Delta satMOI_Backward.EarthMJ2000Eq.VY = -7.48570442854e-008
Delta satMOI_Backward.EarthMJ2000Eq.VZ = -6.01668809219e-009
Delta satMOI_Forward.EarthMJ2000Eq.INC = -1.25488952563e-010
Delta satMOI_Forward.RadApo = -0.000445483252406

```

Finally, let's look at the delta-V of the solution. In this case the delta-V is simply the value of **MOI.Element1** which is displayed in the message window with a value of -0.09171 km/s.

#### Step 4: Use a New Initial Guess

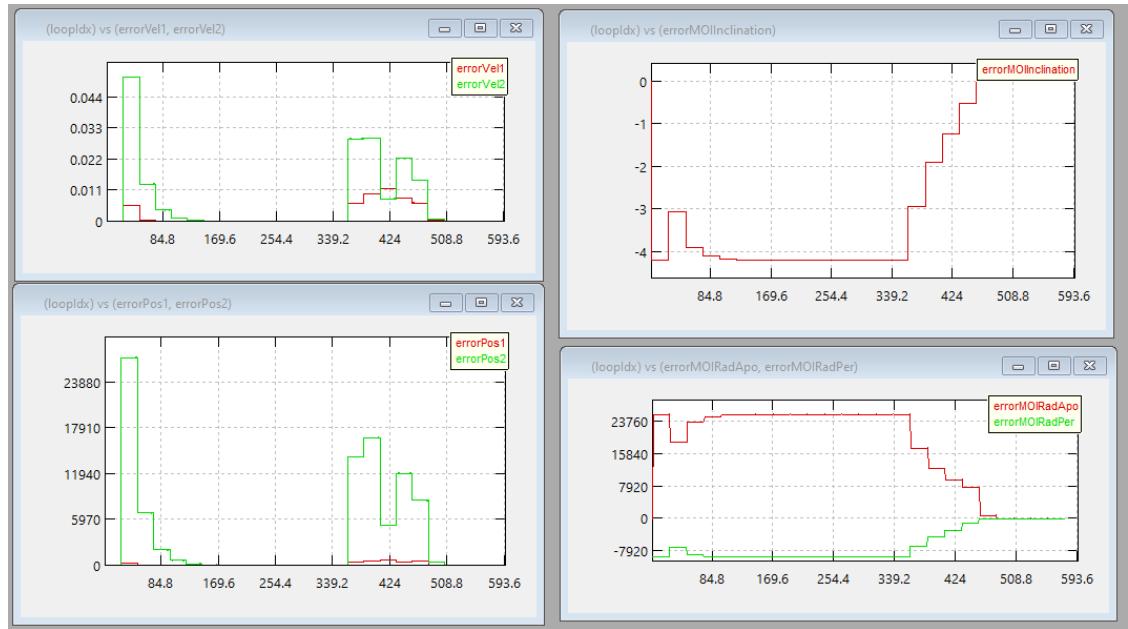
In Step 2 above, you saved the final solution for the smooth trajectory run. Let's use those values as the initial guess and see if we find a similar solution as found in the previous step. In the **ScriptEvent** that defines the initial guess, paste the values below, below the values already there. (don't overwrite the old values!). Once you have changed the guess, run the mission again.

```

toiEpoch = 27698.256145
flybyEpoch = 27703.7770684
moiEpoch = 27723.6701715
satTOI.X = -6659.13341885
satTOI.Y = -229.783192179
satTOI.Z = -169.250174918
satTOI.VX = 0.242540691605
satTOI.VY = -9.53977126847
satTOI.VZ = 5.14567942624
satFlyBy_Forward.X = 868.52380217
satFlyBy_Forward.Y = -6285.90491392
satFlyBy_Forward.Z = -3602.43285625
satFlyBy_Forward.VX = 1.14637334169
satFlyBy_Forward.VY = -0.725846851005
satFlyBy_Forward.VZ = -0.617742623057
satMOI_Backward.X = -53544.9839991
satMOI_Backward.Y = -68231.6263522
satMOI_Backward.Z = -1272.86527093
satMOI_Backward.VX = 2.08018507078
satMOI_Backward.VY = -1.89056552755
satMOI_Backward.VZ = -0.284892404787

```

We see in this case the optimization converged and found essentially the same solution of -0.091532 km/s



**Figure 82. Solution Using New Guess**

### Step 5: Apply a New Constraint

We leave it as an exercise, to apply a constraint that the lunar flyby periapsis radius must be greater than or equal to 5000 km.



# Mars B-Plane Targeting Using GMAT Functions

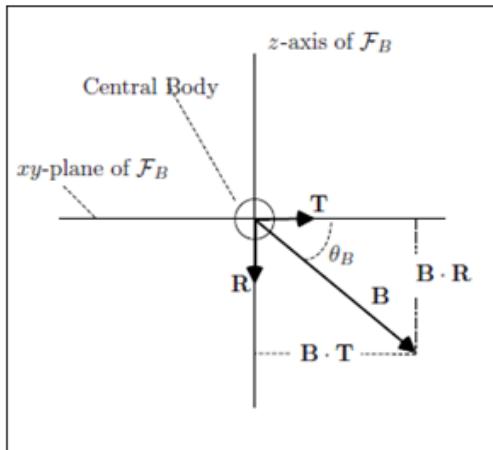
<b>Audience</b>	Advanced
<b>Length</b>	75 minutes
<b>Prerequisites</b>	Complete <i>Simulating an Orbit</i> , <i>Simple Orbit Transfer</i> , <i>Mars B-Plane Targeting</i> and a basic understanding of B-Planes and their usage in targeting is required.
<b>Script and function Files</b>	<code>Tut_UsingGMATFunctions.script</code> , <code>TargeterInsideFunction.gmf</code>

## Objective and Overview

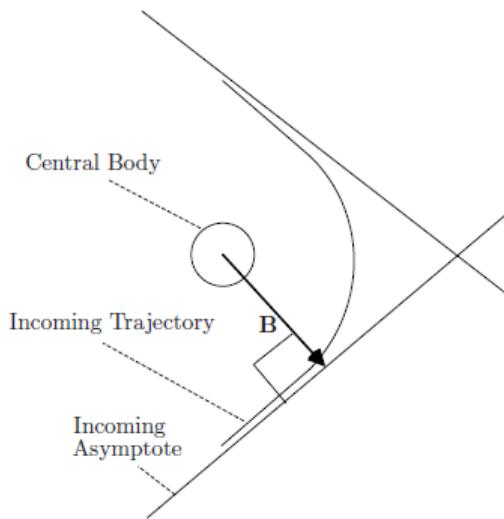


### Note

One of the most challenging problems in space mission design is to design an interplanetary transfer trajectory that takes the spacecraft within a very close vicinity of the target planet. One possible approach that puts the spacecraft close to a target planet is by targeting the B-Plane of that planet. The B-Plane is a planar coordinate system that allows targeting during a gravity assist. It can be thought of as a target attached to the assisting body. In addition, it must be perpendicular to the incoming asymptote of the approach hyperbola. [Figure 83](#) and [Figure 84](#) show the geometry of the B-Plane and B-vector as seen from a viewpoint perpendicular to orbit plane. To read more on B-Planes, please consult the GMATMathSpec document. A good example involving the use of B-Plane targeting is a mission to Mars. Sending a spacecraft to Mars can be achieved by performing a Trajectory Correction Maneuver (TCM) that targets Mars B-Plane. Once the spacecraft gets close to Mars, then an orbit insertion maneuver can be performed to capture into Mars orbit.



**Figure 83. Geometry of the B-Plane as seen from a viewpoint perpendicular to the B-Plane**



**Figure 84. The B-vector as seen from a viewpoint perpendicular to orbit plane**

In this tutorial, we will use GMAT to model a mission to Mars with the emphasis of how to use GMAT functions. Starting from an out-going hyperbolic trajectory around Earth, we will perform a TCM to target Mars B-Plane. Once we are close to Mars, we will adjust the size of the maneuver to perform a Mars Orbit Insertion (MOI) to achieve a final elliptical orbit with an inclination of 90 degrees. Meeting these mission objectives requires us to create two separate targeting sequences. In order to focus on the configuration of the two targeters, we will make extensive use of the default configurations for spacecraft, propagators, and maneuvers.

The first target sequence employs maneuvers in the Earth-based Velocity (V), Normal (N) and Bi-normal (B) directions and includes four propagation sequences. The purpose

of the maneuvers in VNB directions is to target BdotT and BdotR components of the B-vector. BdotT is targeted to 0 km and BdotR is targeted to a non-zero value to generate a polar orbit that has inclination of 90 degrees. BdotR is targeted to -7000 km to avoid having the orbit intersect Mars, which has a radius of approximately 3396 km. The entire first target sequence will be created inside a GMAT function. In the **Mission** tree, this function will be called through GMAT's **CallGmatFunction** command. Additionally, we'll go ahead and declare pertinent objects (e.g. spacecraft, force models, subscribers, impulsive burns etc.) as global in both the main script and inside the function through GMAT's **Global** command.

The second target sequence employs a single, Mars-based anti-velocity direction (-V) maneuver and includes one propagation sequence. This single anti-velocity direction maneuver will occur at periapsis. The purpose of the maneuver is to achieve MOI by targeting position vector magnitude of 12,000 km at apoapsis. Unlike the first target sequence, the second target sequence will not be created inside a function.

The purpose behind this tutorial is to demonstrate how GMAT functions are created, populated, called-upon and used as part of practical mission design. In this tutorial, we'll deliberately put the entire first target sequence inside a GMAT function. Next in the Mission tree, we'll call and execute the function, then continue with the design of the second target sequence outside of the function. Key objects such as the spacecraft, force models, subscribers etc. will be declared global in order to assure continuous flow of data is plotted and reported to all the subscribers. The basic steps of this tutorial are:

1. Modify the **DefaultSC** to define spacecraft's initial state. The initial state is an out-going hyperbolic trajectory that is with respect to Earth.
2. Create and configure a **Fuel Tank** resource.
3. Create two **ImpulsiveBurn** resources with default settings.
4. Create and configure three **Propagators**: NearEarth, DeepSpace and NearMars
5. Create and configure **DifferentialCorrector** resource.
6. Create and configure three **DefaultOrbitView** resources to visualize Earth, Sun and Mars centered trajectories.
7. Create and configure single **ReportFile** resource that will be used in reporting data.
8. Create and configure three **CoordinateSystems**: Earth, Sun and Mars centered.
9. Create and configure single **GmatFunction** resource that will be called and executed in the **Mission** tree.
10. Create first **Target** sequence inside the GMAT function. This sequence will be used to target BdotT and BdotR components of the B-vector.
11. Create second **Target** sequence to implement MOI by targeting position magnitude at apoapsis.
12. Run the mission and analyze the results.

## Configure Fuel Tank, Spacecraft properties, Maneuvers, Propagators, Differential Corrector, Coordinate Systems and Graphics

For this tutorial, you'll need GMAT open, with the default mission loaded. To load the default mission, click **New Mission** (➕) or start a new GMAT session. **DefaultSC** will be modified to set spacecraft's initial state as an out-going hyperbolic trajectory.

## Create Fuel Tank

We need to create a fuel tank in order to see how much fuel is expended after each impulsive burn. We will modify **DefaultSC** resource later and attach the fuel tank to the spacecraft.

1. In the **Resources** tree, right-click the **Hardware** folder, point to **Add** and click **ChemicalTank**. A new resource called **ChemicalTank1** will be created.
2. Right-click **ChemicalTank1** and click **Rename**.
3. In the **Rename** box, type **MainTank** and click **OK**.
4. Double click on **MainTank** to edit its properties.
5. Set the values shown in the table below.

**Table 15. MainTank settings**

Field	Value
<b>Fuel Mass</b>	<b>1718</b>
<b>Fuel Density</b>	<b>1000</b>
<b>Pressure</b>	<b>5000</b>
<b>Volume</b>	<b>2</b>

6. Click **OK** to save these changes.

## Modify the DefaultSC Resource

We need to make minor modifications to **DefaultSC** in order to define spacecraft's initial state and attach the fuel tank to the spacecraft.

1. In the **Resources** tree, under **Spacecraft** folder, right-click **DefaultSC** and click **Rename**.
2. In the **Rename** box, type **MAVEN** and click **OK**.
3. Double-click on **MAVEN** to edit its properties. Make sure **Orbit** tab is selected.
4. Set the values shown in the table below.

**Table 16. MAVEN settings**

Field	Value
<b>Epoch Format</b>	<b>UTCGregorian</b>
<b>Epoch</b>	<b>18 Nov 2013 20:26:24.315</b>
<b>Coordinate System</b>	<b>EarthMJ2000Eq</b>
<b>State Type</b>	<b>Keplerian</b>
<b>SMA under Elements</b>	<b>-32593.21599272796</b>
<b>ECC under Elements</b>	<b>1.202872548116185</b>
<b>INC under Elements</b>	<b>28.80241266404142</b>
<b>RAAN under Elements</b>	<b>173.9693759331483</b>
<b>AOP under Elements</b>	<b>240.9696529532764</b>
<b>TA under Elements</b>	<b>359.9465533778069</b>

5. Click on **Tanks** tab now.
6. Under **Available Tanks**, you'll see **MainTank**. This is the fuel tank that we created earlier.
7. We attach **MainTank** to the spacecraft **MAVEN** by bringing it under **Selected Tanks** box. Select **MainTank** under **Available Tanks** and bring it over to the right-hand side under the **Selected Tanks**.
8. Click **OK** to save these changes.

## Create the Maneuvers

We'll need two **ImpulsiveBurn** resources for this tutorial. Below, we'll rename the default ImpulsiveBurn and create a new one. We'll also select the fuel tank that was created earlier in order to access fuel for the burns.

1. In the **Resources** tree, under the **Burns** folder, right-click **DefaultIB** and click **Rename**.
2. In the **Rename** box, type **TCM**, an acronym for Trajectory Correction Maneuver and click **OK** to edit its properties.
3. Double-Click **TCM** to edit its properties.
4. Check **Decrement Mass** under **Mass Change**.
5. For **Tank** field under **Mass Change**, select **MainTank** from drop down menu.
6. Click **OK** to save these changes.
7. Right-click the **Burns** folder, point to **Add**, and click **ImpulsiveBurn**. A new resource called **ImpulsiveBurn1** will be created.
8. **Rename** the new **ImpulsiveBurn1** resource to **MOI**, an acronym for Mars Orbit Insertion and click **OK**.
9. Double-click **MOI** to edit its properties.
10. For **Origin** field under **Coordinate System**, select **Mars**.
11. Check **Decrement Mass** under **Mass Change**.

- 
12. For **Tank** field under **Mass Change**, select **MainTank** from the drop down menu.
  13. Click **OK** to save these changes.

## Create the Propagators

We'll need to add three propagators for this tutorial. Below, we'll rename the default **DefaultProp** and create two more propagators.

1. In the **Resources** tree, under the **Propagators** folder, right-click **DefaultProp** and click **Rename**.
2. In the **Rename** box, type **NearEarth** and click **OK**.
3. Double-click on **NearEarth** to edit its properties.
4. Set the values shown in the table below.

**Table 17. NearEarth settings**

Field	Value
<b>Initial Step Size</b> under <b>Integrator</b>	600
<b>Accuracy</b> under <b>Integrator</b>	1e-013
<b>Min Step Size</b> under <b>Integrator</b>	0
<b>Max Step Size</b> under <b>Integrator</b>	600
<b>Model</b> under <b>Gravity</b>	JGM-2
<b>Degree</b> under <b>Gravity</b>	8
<b>Order</b> under <b>Gravity</b>	8
<b>Atmosphere Model</b> under <b>Drag</b>	None
<b>Point Masses</b> under <b>Force Model</b>	Add Luna and Sun
<b>Use Solar Radiation Pressure</b> under <b>Force Model</b>	<input checked="" type="checkbox"/> Check this field

5. Click on **OK** to save these changes.
6. Right-click the **Propagators** folder and click **Add Propagator**. A new resource called **Propagator1** will be created.
7. **Rename** the new **Propagator1** resource to **DeepSpace** and click **OK**.
8. Double-click **DeepSpace** to edit its properties.
9. Set the values shown in the table below.

**Table 18. DeepSpace settings**

Field	Value
Type under Integrator	PrinceDormand78
Initial Step Size under Integrator	600
Accuracy under Integrator	1e-012
Min Step Size under Integrator	0
Max Step Size under Integrator	864000
Central Body under Force Model	Sun
Primary Body under Force Model	None
Point Masses under Force Model	Add Earth, Luna, Sun, Mars, Jupiter, Neptune, Saturn, Uranus, Venus
Use Solar Radiation Pressure under Force Model	<input checked="" type="checkbox"/> Check this field

10. Click **OK** to save these changes.
11. Right-click the **Propagators** folder and click **Add Propagator**. A new resource called **Propagator1** will be created.
12. Rename the new **Propagator1** resource to **NearMars** and click **OK**.
13. Double-click on **NearMars** to edit its properties.
14. Set the values shown in the table below.

**Table 19. NearMars settings**

Field	Value
Type under Integrator	PrinceDormand78
Initial Step Size under Integrator	600
Accuracy under Integrator	1e-012
Min Step Size under Integrator	0
Max Step Size under Integrator	86400
Central Body under Force Model	Mars
Primary Body under Force Model	Mars
Model under Gravity	Mars-50C
Degree under Gravity	8
Order under Gravity	8
Atmosphere Model under Drag	None
Point Masses under Force Model	Add Sun
Use Solar Radiation Pressure under Force Model	<input checked="" type="checkbox"/> Check this field

15. Click **OK** to save the changes.

## Create the Differential Corrector

Two **Target** sequences that we will create later need a **DifferentialCorrector** resource to operate, so let's create one now. We'll leave the settings at their defaults.

1. In the **Resources** tree, expand the **Solvers** folder if it isn't already.
2. Right-click the **Boundary Value Solvers** folder, point to **Add**, and click **DifferentialCorrector**. A new resource called **DC1** will be created.
3. Rename the new **DC1** resource to **DefaultDC** and click **OK**.

## Create the Coordinate Systems

The BdotT and BdotR constraints that we will define later under the first **Target** sequence require us to create a coordinate system. Orbit View resources that we will create later also need coordinate system resources to operate. We will create Sun and Mars centered coordinate systems. So let's create them now.

1. In the **Resources** tree, right-click the **Coordinate Systems** folder and click **Add Coordinate System**. A new Dialog box is created with a title **New Coordinate System**.
2. Type **SunEcliptic** under **Coordinate System Name** box.
3. Under **Origin** field, select **Sun**.
4. For **Type** under **Axes**, select **MJ2000Ec**.
5. Click **OK** to save these changes. You'll see that a new coordinate system **SunEcliptic** is created under **Coordinate Systems** folder.
6. Right-click the **Coordinate Systems** folder and click **Add Coordinate System**. A new Dialog Box is created with a title **New Coordinate System**.
7. Type **MarsInertial** under **Coordinate System Name** box.
8. Under **Origin** field, select **Mars**.
9. For **Type** under **Axes**, select **BodyInertial**.
10. Click **OK** to save these changes. You'll see that a new coordinate system **MarsInertial** is created under **Coordinate Systems** folder.

## Create the Orbit Views

We'll need three **DefaultOrbitView** resources for this tutorial. Below, we'll rename the default **DefaultOrbitView** and create two new ones. We need three graphics windows in order to visualize spacecraft's trajectory centered around Earth, Sun and then Mars

1. In the **Resources** tree, under **Output** folder, right-click **DefaultOrbitView** and click **Rename**.
2. In the **Rename** box, type **EarthView** and click **OK**.
3. In the **Output** folder, delete **DefaultGroundTrackPlot**.
4. Double-click **EarthView** to edit its properties.
5. Set the values shown in the table below.

**Table 20. EarthView settings**

Field	Value
<b>View Scale Factor</b> under View Definition	4
<b>View Point Vector boxes</b> , under View Definition	0, 0, 30000

6. Click **OK** to save these changes.
7. Right-click the **Output** folder, point to **Add**, and click **OrbitView**. A new resource called **OrbitView1** will be created.
8. **Rename** the new **OrbitView1** resource to **SolarSystemView** and click **OK**.
9. Double-click **SolarSystemView** to edit its properties.
10. Set the values shown in the table below.

**Table 21. SolarSystemView settings**

Field	Value
From <b>Celestial Object</b> under <b>View Object</b> , add following objects to <b>Selected Celestial Object</b> box	Mars, Sun (Do not remove Earth)
<b>Coordinate System</b> under View Definition	<b>SunEcliptic</b>
<b>View Point Reference</b> under View Definition	<b>Sun</b>
<b>View Point Vector boxes</b> , under View Definition	0, 0, 5e8
<b>View Direction</b> under View Definition	<b>Sun</b>
<b>Coordinate System</b> under View Up Definition	<b>SunEcliptic</b>

11. Click **OK** to save these changes.
12. Right-click the **Output** folder, point to **Add**, and click **OrbitView**. A new resource called **OrbitView1** will be created.
13. **Rename** the new **OrbitView1** resource to **MarsView** and click **OK**.
14. Double-click **MarsView** to edit its properties.
15. Set the values shown in the table below.

**Table 22. MarsView settings**

Field	Value
From <b>Celestial Object</b> under <b>View Object</b> , add following object to <b>Selected Celestial Object</b> box	Mars (You don't have to remove Earth)
<b>Coordinate System</b> under View Definition	<b>MarsInertial</b>
<b>View Point Reference</b> under View Definition	<b>Mars</b>
<b>View Point Vector boxes</b> , under View Definition	22000, 22000, 0
<b>View Direction</b> under View Definition	<b>Mars</b>
<b>Coordinate System</b> under View Up Definition	<b>MarsInertial</b>

- 
16. Click **OK** to save the changes.

## Create single Report File

We'll need a single **ReportFile** resource for this tutorial that we'll use to report data to.

1. Right-click the **Output** folder, point to **Add**, and click **ReportFile**. A new resource called **ReportFile1** will be created.
2. **Rename** the new **ReportFile1** resource to **rf** and click **OK**.
3. Double-Click **rf** to edit its properties.
4. Empty the **Parameter List** by clicking on the **Edit** button.
5. Click **OK** to save these changes.

## Create a GMAT Function

We'll need a single **GMATFunction** resource for this tutorial. The first target sequence will be implemented inside this function.

1. Right-click the **Functions** folder, point to **Add**, point to **GMAT Function** and click **New**.
2. A new GMAT function panel will open. Type the following name for the function **TargeterInsideFunction** and click **OK** to save these changes.
3. Now open **TargeterInsideFunction** resource and paste the below shown first targeter sequence snippet into this function.
4. After pasting of the below snippet is done, click on **Save As** button and save your function. After saving your function, close **TargeterInsideFunction** resource by clicking on the **Close** button.

```
% Target Desired B-Plane Coordinates in this function:  
  
function TargeterInsideFunction()  
  
BeginMissionSequence  
  
Global 'Make Objects Global' MAVEN DeepSpace_ForceModel DefaultDC ...  
EarthView MainTank MarsView MOI NearEarth_ForceModel ...  
NearMars_ForceModel rf SolarSystemView TCM  
  
Target 'Target B-plane coordinates' DefaultDC {SolveMode = Solve, ...  
ExitMode = SaveAndContinue}  
    Propagate 'Prop 3 days' NearEarth(MAVEN) {MAVEN.ElapsedDays = 3}  
    Propagate 'Prop 12 Days to TCM' DeepSpace(MAVEN) {MAVEN.ElapsedDays = 12}  
    Vary 'Vary TCM.V' DefaultDC(TCM.Element1 = 0.001, ...  
    {Perturbation = 0.00001, MaxStep = 0.002})  
        Vary 'Vary TCM.N' DefaultDC(TCM.Element2 = 0.001, ...  
        {Perturbation = 0.00001, MaxStep = 0.002})  
            Vary 'Vary TCM.B' DefaultDC(TCM.Element3 = 0.001, ...
```

```
{Perturbation = 0.00001, MaxStep = 0.002})  
Maneuver 'Apply TCM' TCM(MAVEN)  
Propagate 'Prop 280 Days' DeepSpace(MAVEN) {MAVEN.ElapsedDays = 280}  
Propagate 'Prop to Mars Periapsis' NearMars(MAVEN) {MAVEN.Mars.Periapsis}  
Achieve 'Achieve BdotT' DefaultDC(MAVEN.MarsInertial.BdotT = 0, ...  
{Tolerance = 0.00001})  
Achieve 'Achieve BdotR' DefaultDC(MAVEN.MarsInertial.BdotR = -7000, ...  
{Tolerance = 0.00001})  
EndTarget;  
  
% Report MAVEN parameters to global 'rf' :  
Report 'Report Parameters' rf MAVEN.UTCGregorian TCM.Element1 ...  
TCM.Element2 TCM.Element3 MAVEN.MarsInertial.BdotT ...  
MAVEN.MarsInertial.BdotR MAVEN.MarsInertial.INC
```

Reminder that the first target sequence will target desired B-Plane coordinates which will get the spacecraft **MAVEN** close to Mars. Note that we have declared all the pertinent objects as global at the beginning of the function. These same objects will also be declared global in the **Mission Sequence** as well. Notice that in this first target sequence, spacecraft **MAVEN** props for 3 days using **NearEarth** propagator. Next using the **DeepSpace** propagator, we propagate for 12 days and execute **TCM** impulsive maneuver. Again using the **DeepSpace** propagator, we propagate for another 280 days and finally propagate to Mars Periapsis. The desired constraints of the B-Plane coordinates are to be met at the Mars periapsis. The three components of the **TCM** impulsive burn are the controls that will help us achieve these two constraints. Note that the tolerances on the two B-Plane constraints are relatively tight.

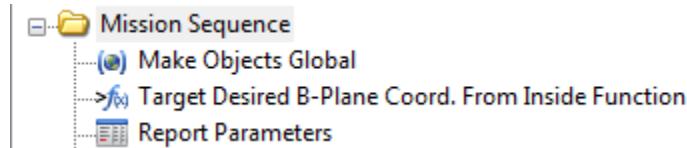
## Configure the Mission Sequence

Now we are ready to configure the **Mission Sequence**. We will first insert a **Global** command and declare the same objects as global that were declared global inside the **TargeterInsideFunction** function. Next we'll insert **CallGmatFunction** command which will call and initiate our **TargeterInsideFunction** function that contains our first target sequence. The first target sequence will solve for the **TCM** maneuver values required to achieve BdotT and BdotR components of the B-vector. BdotT will be targeted to 0 km and BdotR is targeted to a non-zero value in order to generate a polar orbit that will have an inclination of 90 degrees.

The second target sequence employs a single, Mars-based anti-velocity direction (-V) maneuver and includes one propagation sequence. This single anti-velocity direction maneuver will occur at periapsis. The purpose of the maneuver is to achieve MOI by targeting position vector magnitude of 12,000 km at apoapsis. The basic steps of this tutorial are:

### Create Commands to Initiate the First Target Sequence

Now create the commands necessary to perform the first **Target** sequence. Figure 85 illustrates the configuration of the **Mission** tree after you have completed the steps in this section.



**Figure 85. Mission Sequence for the First Target sequence**

Do following steps to set-up for the first **Target** sequence:

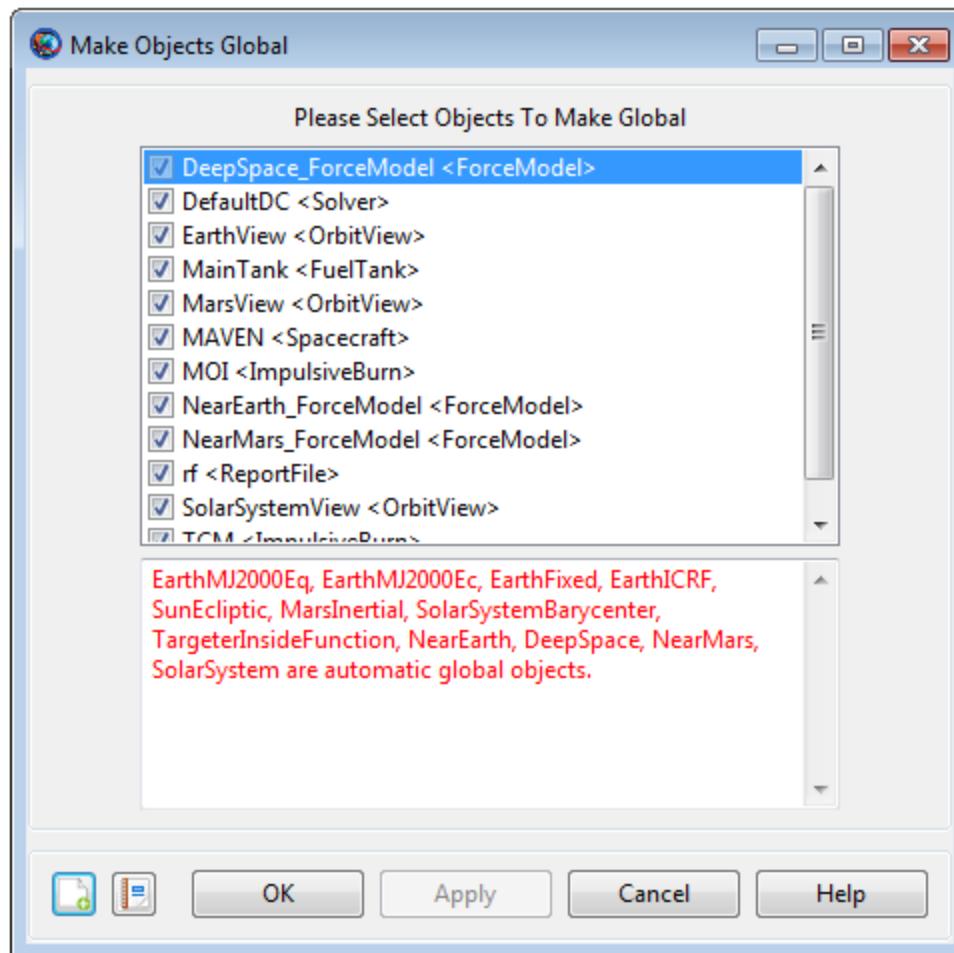
1. Click on the **Mission** tab to show the **Mission** tree.
2. You'll see that there already exists a **Propagate1** command. We need to delete this command
3. Right-click on **Propagate1** command and click **Delete**.
4. Right-click on **Mission Sequence** folder, point to **Append**, and click **Global**. A new command called **Global1** will be created.
5. Right-click **Global1** and click **Rename**. In the **Rename** box, type **Make Objects Global** and click **OK**.
6. Right-click on **Mission Sequence** folder, point to **Append**, and click **CallGmatFunction**. A new command called **CallGmatFunction1** will be created.
7. Right-click **CallGmatFunction1** and click **Rename**. In the **Rename** box, type **Target Desired B-Plane Coord. From Inside Function** and click **OK**.
8. Right-click on **Mission Sequence** folder, point to **Append**, and click **Report**. A new command called **Report1** will be created.
9. Right-click **Report1** and click **Rename**. In the **Rename** box, type **Report Parameters** and click **OK**.

## Configure the Mission Tree to Run the First Target Sequence

Now that the structure is created, we need to configure various parts of the first **Target** sequence to do what we want.

### Configure the Make Objects Global Command

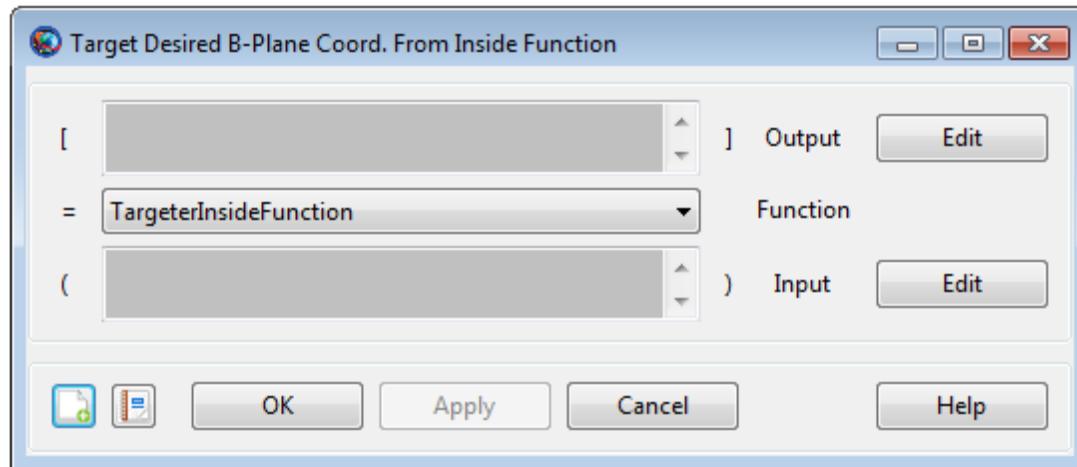
1. Double-click **Make Objects Global** to edit its properties.
2. Under **Please Select Objects to Make Global** check all the available object and make all available objects as global. Recall that same objects were declared as global inside **TargeterInsideFunction** function as well.
3. Click **OK** to save these changes.



**Figure 86. Make Objects Global Command Configuration**

### Configure the Target Desired B-Plane Coord. From Inside Function Command

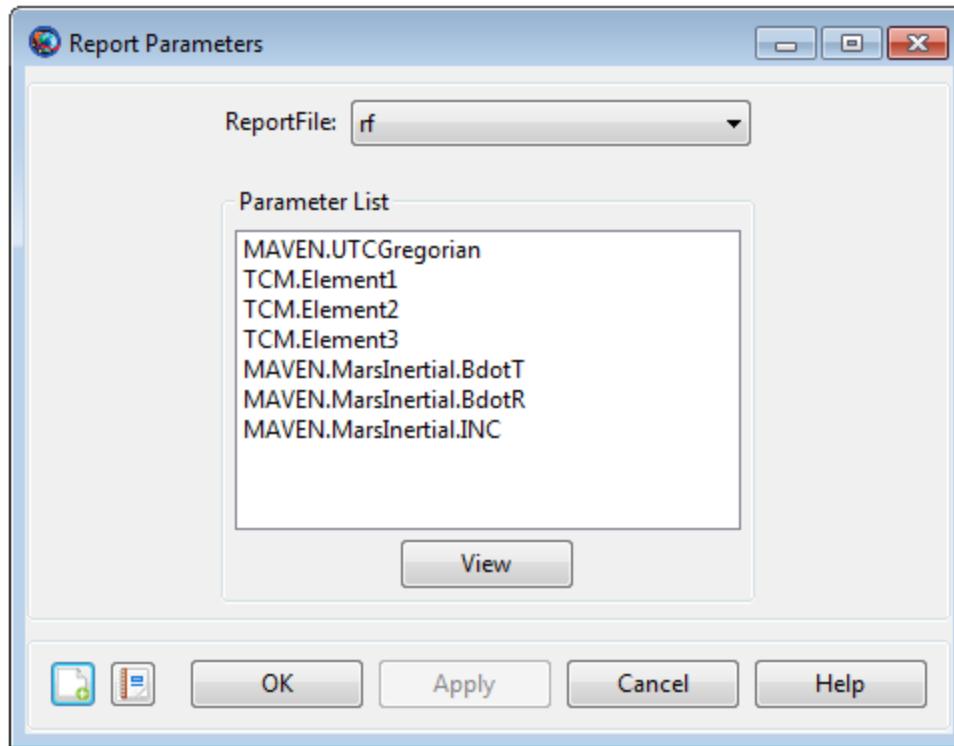
1. Double-click **Target Desired B-Plane Coord. From Inside Function** to edit its properties.
2. Under **Function**, select **TargeterInsideFunction** from drop down menu. In this particular example, since we're not passing any input(s) or receiving any output(s) to and from the function, hence we won't be editing Input/Output menu.
3. Click **OK** to save these changes.



**Figure 87. Target Desired B-Plane Coord.  
From Inside Function Command Configuration**

### Configure the Report Parameters Command

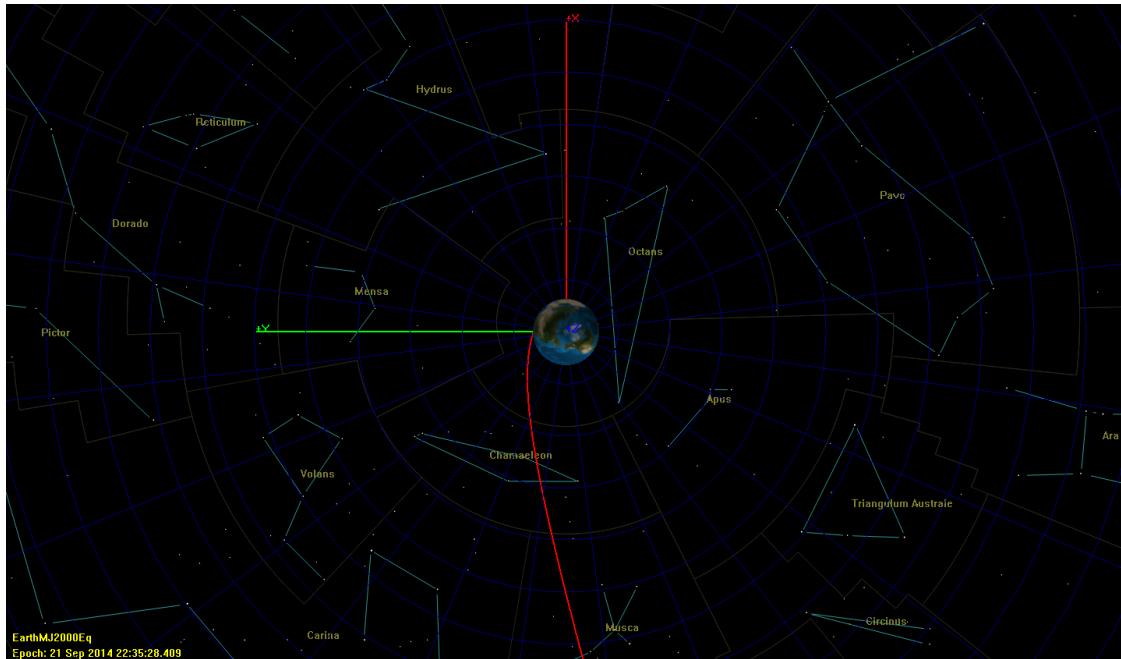
1. Double-click **Report Parameters** to edit its properties.
2. Under **ReportFile**, make sure **rf** is selected from the from drop down menu.
3. Under **Parameter List** click on **View**. This opens up a new **ParameterSelectDialog** panel. Make sure to select the parameters that are shown in the below **Report Parameters** screenshot image.
4. Click **OK** to save these changes.



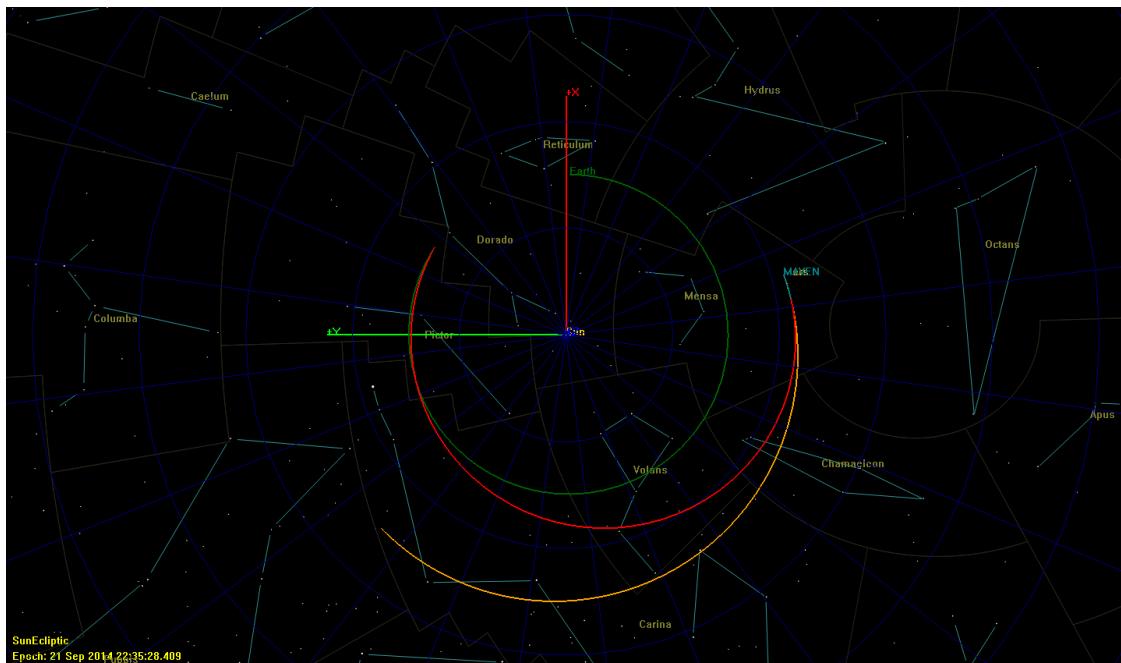
**Figure 88. Report Parameters Command Configuration**

### Run the Mission with first Target Sequence

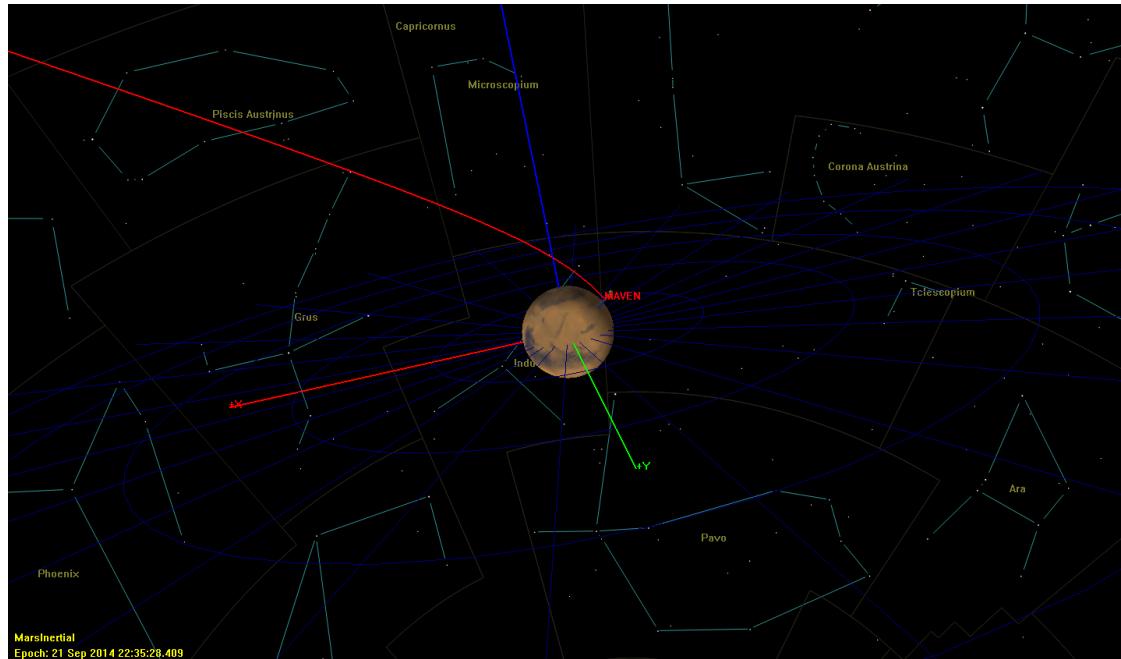
Before running the mission, click **Save** (💾) and save the mission to a file of your choice. Now click **Run** (▶). As the mission runs, you will see GMAT solve the targeting problem. Each iteration and perturbation is shown in **EarthView**, **SolarSystemView** and **MarsView** windows in light blue, and the final solution is shown in red. After the mission completes, the 3D views should appear as in the images shown below. You may want to run the mission several times to see the targeting in progress.



**Figure 89.** 3D View of departure hyperbolic trajectory (EarthView)



**Figure 90.** 3D View of heliocentric transfer trajectory (SolarSystemView)



**Figure 91. 3D View of approach hyperbolic trajectory. MAVEN stopped at periapsis (MarsView)**

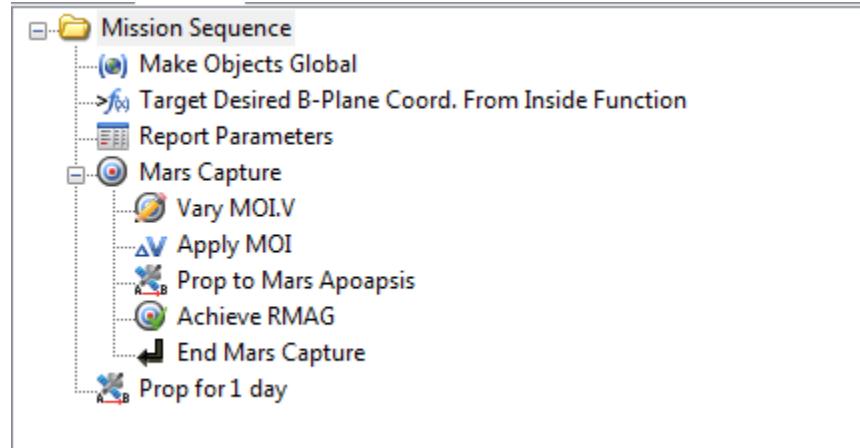
Now go to the **Output** tree and open **rf**. Recall that **rf** was declared as a global object both inside the function and in the main script. Notice that both the controls (i.e. **TCM** burn elements) and constraints (i.e. **BdotT**, **BdotR**) are reported as well as **MAVEN** inclination relative to **MarsInertial** coordinate system. The desired constraints that were set in the first targeter sequence have been successfully achieved.

Now go back to **Mission** tree and right click on **Target Desired B-Plane Coord. From Inside Function** command and click on **Command Summary** option. Under **Coordinate System** drop down menu, select **MarsInertial** and study the command summary. This command summary corresponds to the very last **Propagate** command (i.e. 'Prop to Mars Periapsis') from inside the GMAT function. Under **Hyperbolic Parameters**, notice the values of **BdotT** and **BdotR**. These are the constraints that have been achieved on the very last 'Prop to Mars Periapsis' **Propagate** command from the first targeter which was set up inside the GMAT function.

## Create the Second Target Sequence

Recall that we still need to create second **Target** sequence in order to perform Mars Orbit Insertion maneuver to achieve the desired capture orbit. In the **Mission** tree, we will create the second **Target** sequence right after the first **Target** sequence which was defined inside the GMAT function **TargeterInsideFunction**.

Now let's create the commands necessary to perform the second **Target** sequence. [Figure 92](#) illustrates the configuration of the **Mission** tree after you have completed the steps in this section. Notice that in [Figure 92](#), the second **Target** sequence is created after the first **Target** sequence which was called via the **CallGmatFunction** command. We'll discuss the second **Target** sequence after it has been created.



**Figure 92. Mission Sequence showing first and second Target sequences**

To create the second **Target** sequence:

1. Click on the **Mission** tab to show the **Mission** tree.
2. In the **Mission** tree, right-click on **Mission Sequence** folder, point to **Append**, and click **Target**. This will insert two separate commands: **Target1** and **EndTarget1**.
3. Right-click **Target1** and click **Rename**.
4. Type **Mars Capture** and click **OK**.
5. Right-click **Mars Capture**, point to **Append**, and click **Vary**. A new command called **Vary4** will be created.
6. Right-click **Vary4** and click **Rename**.
7. In the **Rename** box, type **Vary MOI.V** and click **OK**.
8. Complete the **Target** sequence by appending the commands in [Table 23](#).

**Table 23. Additional Second Target Sequence Commands**

Command	Name
Maneuver	Apply MOI
Propagate	Prop to Mars Apoapsis
Achieve	Achieve RMAG



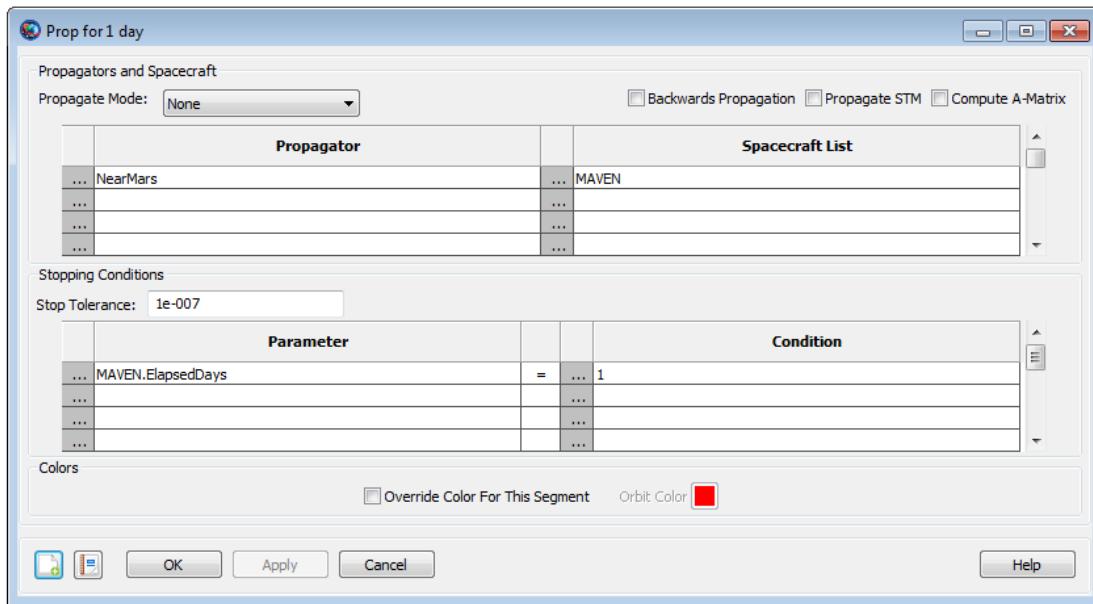
### Note

Let's discuss what the second **Target** sequence does. We know that a maneuver is required for the Mars capture orbit. We also know that the desired radius of capture orbit at apoapsis must be 12,000 km. However, we don't know the size (or #V magnitude) of the **MOI** maneuver that will precisely achieve the desired orbital conditions. You use the second **Target** sequence to solve for that precise maneuver value. You must tell GMAT what controls are available (in this case, a single maneuver) and what conditions must be satisfied (in this case, radius magnitude value). Once again, just like in the first **Target** sequence, here we accomplish this by using the **Vary** and **Achieve** commands. Using the **Vary** command, you tell GMAT what to solve for—in this case, the #V value for **MOI**. You use the **Achieve** command to tell GMAT what conditions the solution must satisfy—in this case, RMAG value of 12,000 km.

## Create the Final Propagate Command

We need a **Propagate** command after the second **Target** sequence so that we can see our final orbit.

1. In the **Mission** tree, right-click **End Mars Capture**, point to **Insert After**, and click **Propagate**. A new **Propagate3** command will appear.
2. Right-click **Propagate6** and click **Rename**.
3. Type **Prop for 1 day** and click **OK**.
4. Double-click **Prop for 1 day** to edit its properties.
5. Under **Propagator**, replace **NearEarth** with **NearMars**.
6. Under **Parameter**, replace **MAVEN.ElapsedSeconds** with **MAVEN.ElapsedDays**.
7. Under **Condition**, replace the value **0.0** with **1**.
8. Click **OK** to save these changes



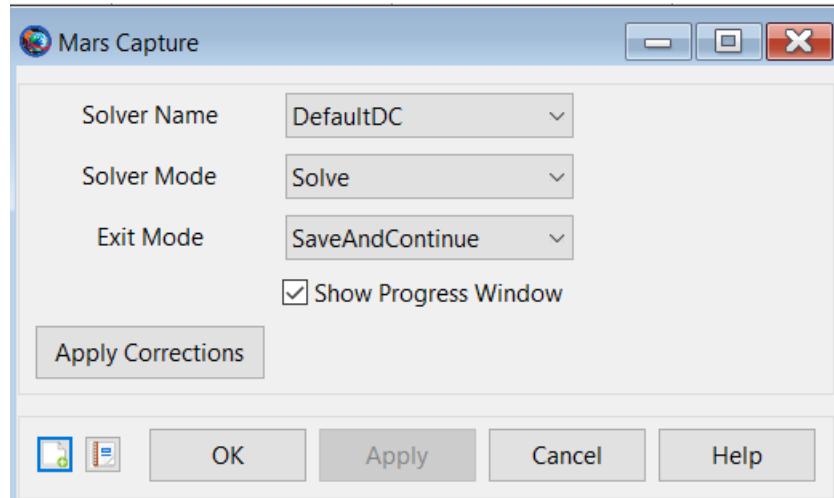
**Figure 93. Prop for 1 day Command Configuration**

### Configure the second Target Sequence

Now that the structure is created, we need to configure various parts of the second **Target** sequence to do what we want.

### Configure the Mars Capture Command

1. Double-click **Mars Capture** to edit its properties.
2. In the **ExitMode** list, click **SaveAndContinue**. This instructs GMAT to save the final solution of the targeting problem after you run it.
3. Click **OK** to save these changes



**Figure 94. Mars Capture Command Configuration**

## Configure the Vary MOI.V Command

1. Double-click **Vary MOI.V** to edit its properties. Notice that the variable in the **Variable** box is **TCM.Element1**. We want **MOI.Element1** which is the velocity component of **MOI** in the local VNB coordinate system. So let's change that.
2. Next to **Variable**, click the **Edit** button.
3. Under **Object List**, click **MOI**.
4. In the **Object Properties** list, double-click **Element1** to move it to the **Selected Value(s)** list. See the image below for results.
5. Click **OK** to close the **ParameterSelectDialog** window.
6. In the **Initial Value** box, type **-1.0**.
7. In the **Perturbation** box, type **0.00001**.
8. In the **Lower** box, type **-10e300**.
9. In the **Upper** box, type **10e300**.
10. In the **Max Step** box, type **0.1**.
11. Click **OK** to save these changes.

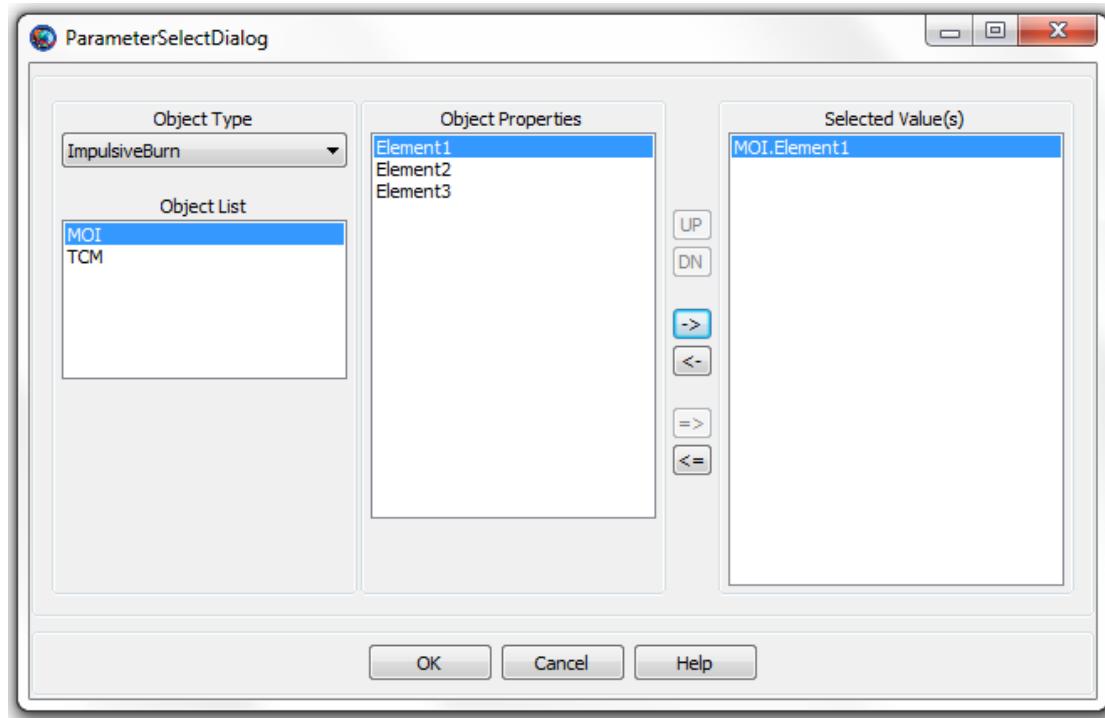


Figure 95. Vary MOI Parameter Selection

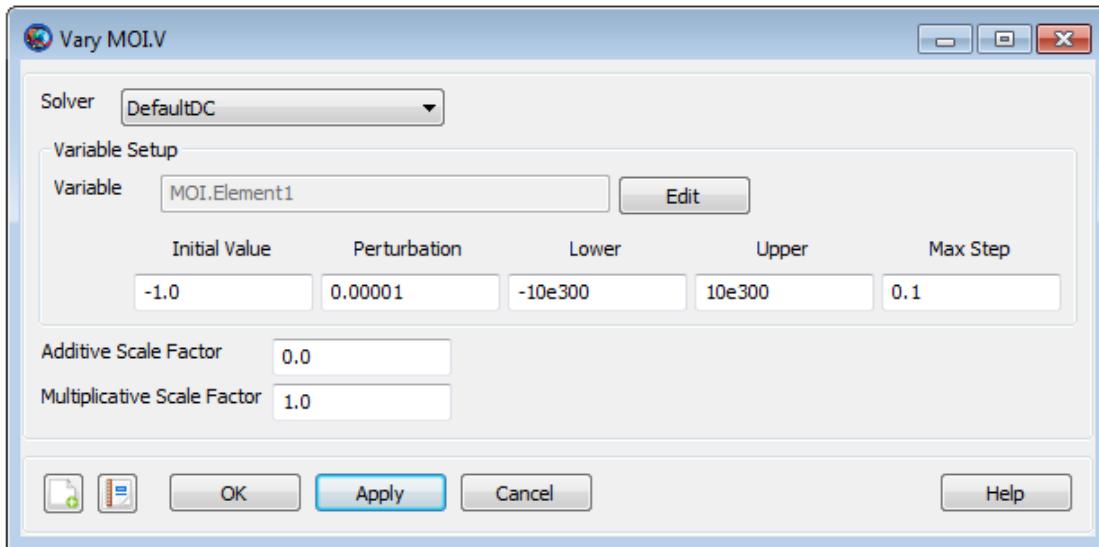


Figure 96. Vary MOI Command Configuration

### Configure the Apply MOI Command

1. Double-click **Apply MOI** to edit its properties.
2. In the **Burn** list, click **MOI**.
3. Click **OK** to save these changes.

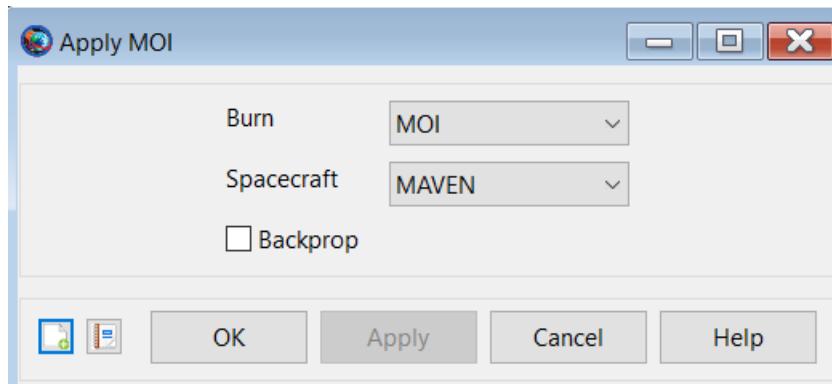
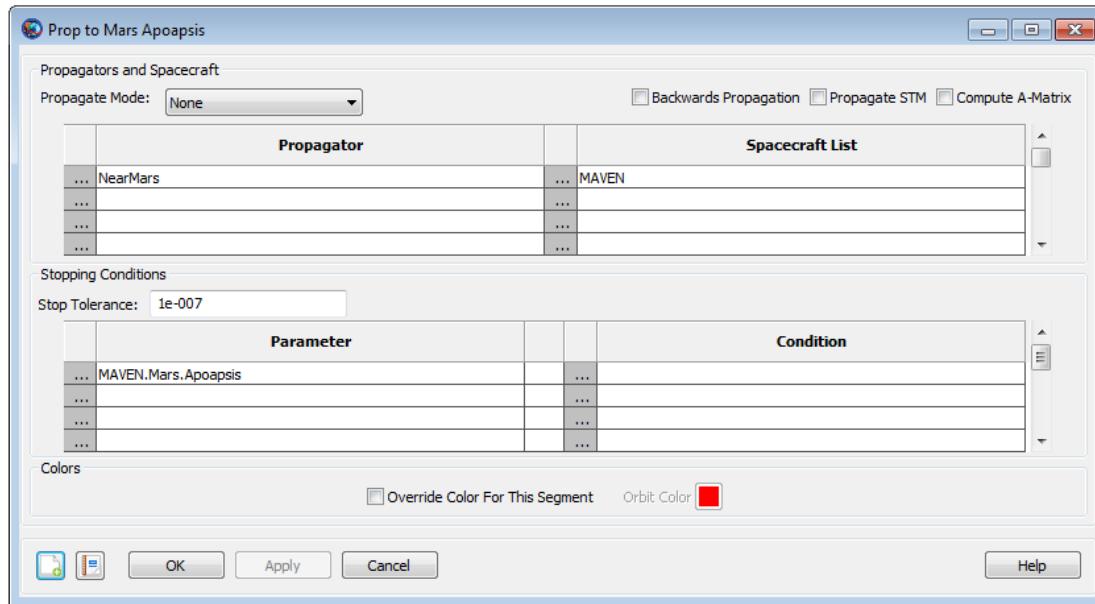


Figure 97. Apply MOI Command Configuration

### Configure the Prop to Mars Apoapsis Command

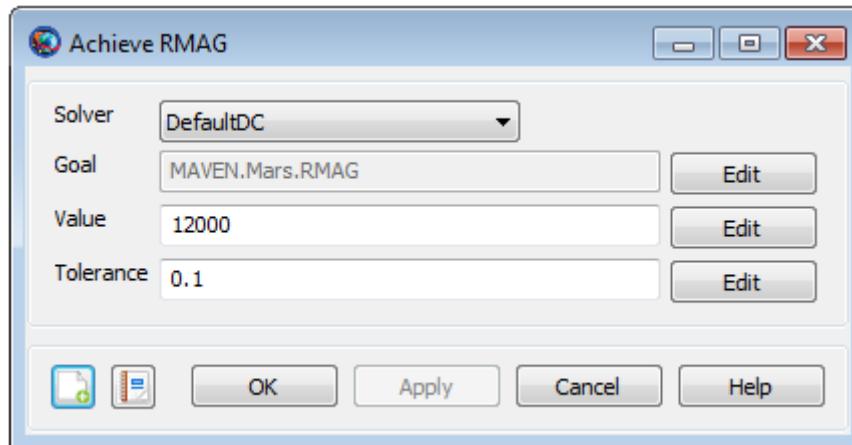
1. Double-click **Prop to Mars Apoapsis** to edit its properties.
2. Under **Propagator**, replace **NearEarth** with **NearMars**.
3. Under **Parameter**, replace **MAVEN.ElapsedSeconds** with **MAVEN.Mars.Apoapsis**.
4. Click **OK** to save these changes.



**Figure 98. Prop to Mars Apoapsis Command Configuration**

### Configure the Achieve RMAG Command

1. Double-click **Achieve RMAG** to edit its properties.
2. Next to **Goal**, click the **Edit** button.
3. In the **Object Properties** list, click **RMAG**.
4. Under **Central Body**, select **Mars** and double-click on **RMAG**.
5. Click **OK** to close the **ParameterSelectDialog** window.
6. In the **Value** box, type **12000**.
7. Click **OK** to save these changes.

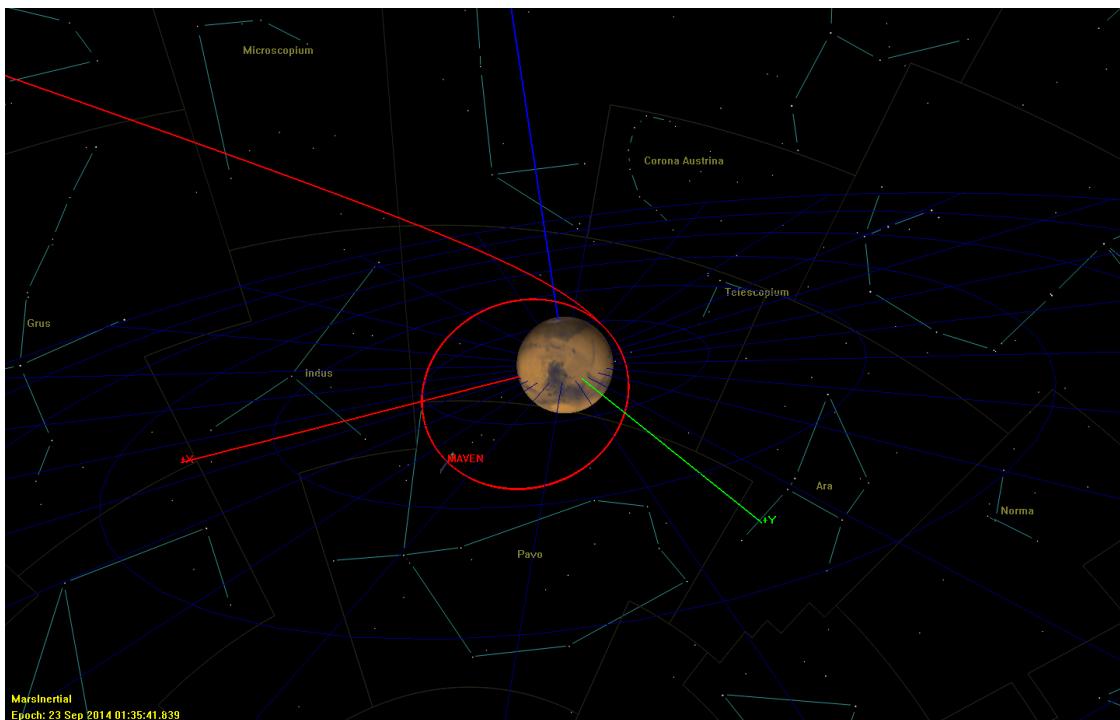


**Figure 99. Achieve RMAG Command Configuration**

## Run the Mission with first and second Target Sequences

Before running the mission, click **Save** (💾). This will save the additional changes that we implemented in the **Mission** tree. Now click **Run** (▶). The first **Target** sequence will converge first after a few iterations.

As the mission runs, you will see GMAT solve the second **Target** sequence's targeting problem. Each iteration and perturbation is shown in **MarsView** windows in light blue, and the final solution is shown in red. After the mission completes, the **MarsView** 3D view should appear as in the image shown below. **EarthView** and **SolarSystemView** 3D views are same as before. You may want to run the mission several times to see the targeting in progress.



**Figure 100. 3D view of Mars Capture orbit after MOI maneuver (MarsView)**

If you want to know MOI maneuver's delta-V vector values and how much fuel was expended during the maneuver, do the following steps:

1. In the **Mission** tree, right-click **Apply MOI**, and click on **Command Summary**.
2. Scroll down and under **Maneuver Summary** heading, values for delta-V vector are:

Delta V Vector:

Element 1: -1.6032580309280 km/s

Element 2: 0.0000000000000 km/s

Element 3: 0.000000000000 km/s

3. Scroll down and under Mass depletion from MainTank heading, Delta V and Mass Change tells you MOI maneuver's magnitude and how much fuel was used for the maneuver:

Delta V: 1.6032580309280 km/s

Mass change: -1075.9520121897 kg

Just to make sure that the goal of second **Target** sequence was met successfully, let us access command summary for **Achieve RMAG** command by doing the following steps:

1. In the **Mission** tree, right-click **Achieve RMAG**, and click on **Command Summary**.
2. Under **Coordinate System**, select **MarsInertial**.
3. Under Keplerian State and Spherical State headings, see the values of TA and RMAG. You can see that the desired radius of the capture orbit at apoapsis was achieved successfully:

TA = 180.0000085377 deg

RMAG = 12000.017390989 km



# Finding Eclipses and Station Contacts

<b>Audience</b>	Beginner
<b>Length</b>	30 minutes
<b>Prerequisites</b>	Complete <i>Simple Orbit Transfer</i>
<b>Script File</b>	Tut_SimpleOrbitTransfer.script

## Objective and Overview

In this tutorial we will modify an existing mission to add eclipse and station contact detection using the **EclipseLocator** and **ContactLocator** resources. We will start with the completed Simple Orbit Transfer mission and modify it to add these event reports.

The basic steps of this tutorial are:

1. Load the Simple Orbit Transfer mission.
2. Configure GMAT for event location.
3. Add and configure an **EclipseLocator** to report eclipses.
4. Run the mission and analyze the eclipse report.
5. Add and configure a **GroundStation** and a **ContactLocator** to report contact times.
6. Run the mission and analyze the contact report.

## Load the Mission

For this tutorial, we will start with a preexisting mission created during the Simple Orbit Transfer tutorial. You can either complete that tutorial prior to this one, or you can load the end result directly, as shown below.

1. Open GMAT.
2. Click **Open** in the toolbar and navigate to the GMAT samples directory.
3. Select `Tut_SimpleOrbitTransfer.script` and click **Open**.
4. Click **Run** (▶) to run the mission.

You should see the following result in the **DefaultOrbitView** window.

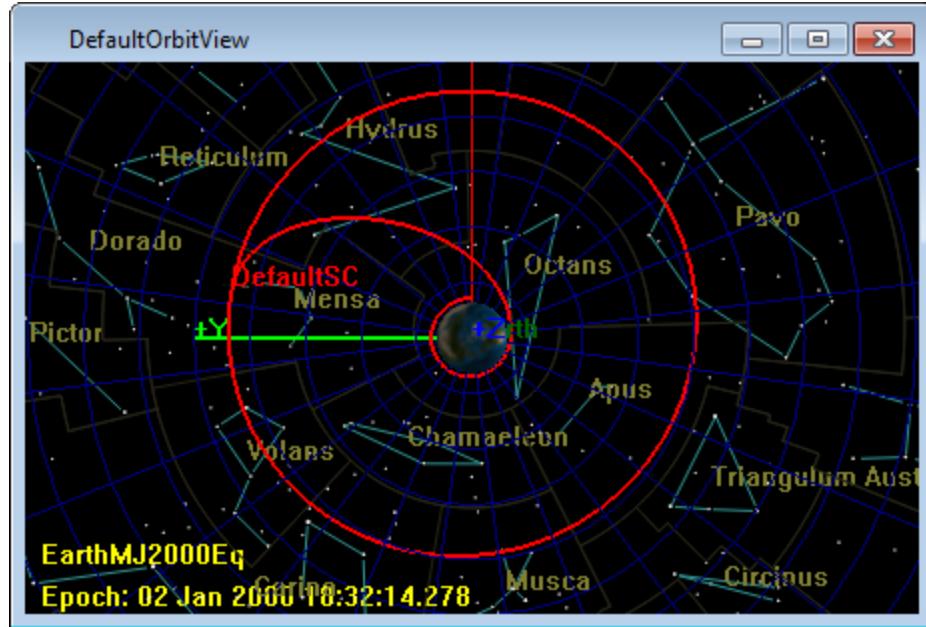


Figure 101. DefaultOrbitView window

## Configure GMAT for Event Location

GMAT's event location subsystem is based on the [NAIF SPICE library](#), which uses its own mechanism for configuration of the solar system. Instead of settings specified in GMAT via CelestialBody resources like Earth and Luna, SPICE uses "kernel" files that define similar parameters independently. This is discussed in detail in the [ContactLocator](#) and [EclipseLocator](#) references.

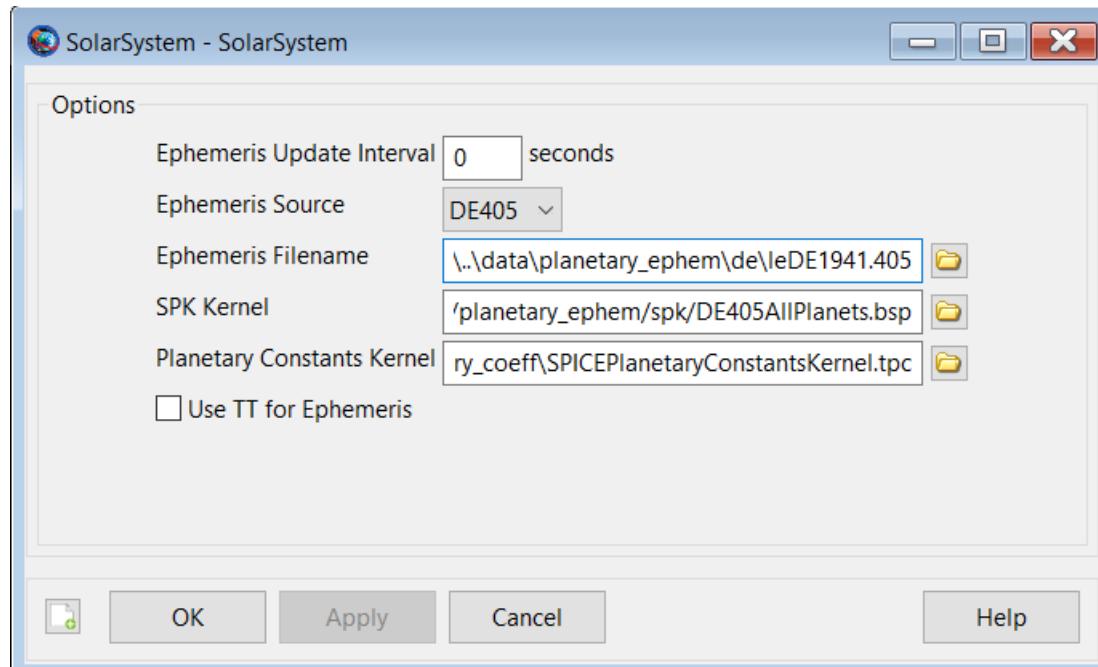
By default, GMAT offers general consistency between both configurations. But, it's useful to verify that the appropriate parameters are correct, and it's necessary for precise applications.

## Verify SolarSystem Configuration

First, let's verify that the SolarSystem resource is configured properly for both configurations.

1. On the **Resources** tab, double-click the **SolarSystem** folder. This will display the **SolarSystem** configuration.
2. Scroll to the end of each input box to see the actual filenames being loaded.

You should see a configuration like this:



**Figure 102. SolarSystem Panel**

Note the following items:

- **Ephemeris Source:** This is set to use the DE405 planetary ephemeris, the default in GMAT. If you switch to another ephemeris version, the fields below will update accordingly.
- **Ephemeris Filename:** This is the DE-format ephemeris file used for propagation and parameter calculations in GMAT itself.
- **SPK Kernel:** This is the SPICE SPK file used for planetary ephemeris for SPK propagation and for event location. Note that this is set consistent with **Ephemeris File-  
name** (both DE405)
- **Leap Second Kernel:** This is the SPICE LSK file used to keep track of leap seconds in the UTC time system for the SPICE subsystem. This is kept consistent with GMAT's internal leap seconds file (tai-utc.dat) specified in the GMAT startup file.
- **Planetary Constants Kernel:** This is the SPICE PCK file used for default configuration for all the default celestial bodies. This file contains planetary shape and orientation information, similar to but independent from the settings in GMAT's **Celestial-  
Body** resources (**Earth**, **Luna**, etc.).

These are already configured correctly, so we don't need to make any changes.

## Configure CelestialBody Resources

Next, let's configure the Earth model for precise usage with the **ContactLocator** resource. By default, the Earth size and shape differ by less than 1 m in equatorial and polar radii between the two subsystems. But we can make them match exactly by modifying GMAT's **Earth** properties.

1. On the **Resources** tab, expand the **SolarSystem** folder.

2. Double-click **Earth** to display the Earth configuration.
3. Note the various configuration options available:
  - **Equatorial Radius** and **Flattening** define the Earth shape for GMAT itself. **PCK Files** lists additional SPICE PCK files to load, in addition to the file shown above in the **SolarSystem Planetary Constants Kernel** box. In this case, these files provide high-fidelity Earth orientation parameters (EOP) data.
  - On the **Orientation** tab, **Spice Frame Id** indicates the Earth-fixed frame to use for the SPICE subsystem, and **FK Files** provides additional FK files that define the frame. In this case, Earth is using the built-in ITRF93 frame, which is different but very close to GMAT's **EarthFixed** coordinate system. See the [CoordinateSystem](#) reference for details on that system.
4. Set **Equatorial Radius** to 6378.1366.
5. Set **Flattening** to 0.00335281310845547.
6. Click **OK**.

These two values were taken from the pck00010.tpc file referenced in the **SolarSystem** configuration. Setting them for **Earth** ensures that the position of the **GroundStation** we create later will be referenced to the exact same Earth definition throughout the mission. Note that the exact position may still differ between the two based on the different body-fixed frame definition and the different EOP data sources, but this residual difference is small.

Your Earth panel should look like this after these steps are complete:

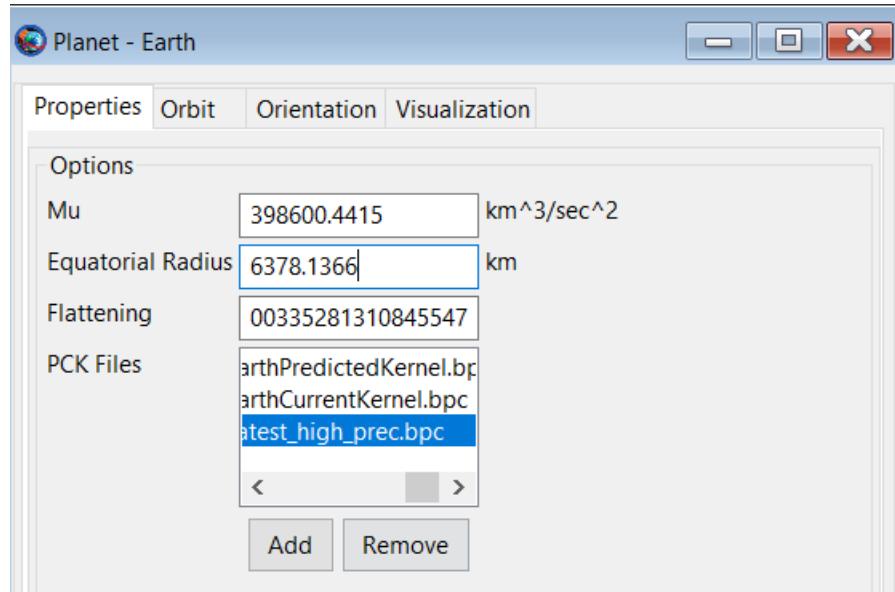


Figure 103. Earth Panel

## Configure and Run the Eclipse Locator

Now we are ready to search for eclipses in our mission. We do this by creating an `EclipseLocator` resource that holds the search configuration. Then we can perform a

search by running the FindEvents command, but GMAT does this automatically at the end of the mission unless you configure it otherwise. In this case, we will use the automatic option.

## Create and Configure the EclipseLocator

First we create the **EclipseLocator**:

- On the **Resources** tab, right-click the **Event Locators** folder, point to **Add**, and click **EclipseLocator**.

This will result in a new resource called **EclipseLocator1**.



Figure 104. Location of EclipseLocator

Next, we need to configure the new resource for our mission:

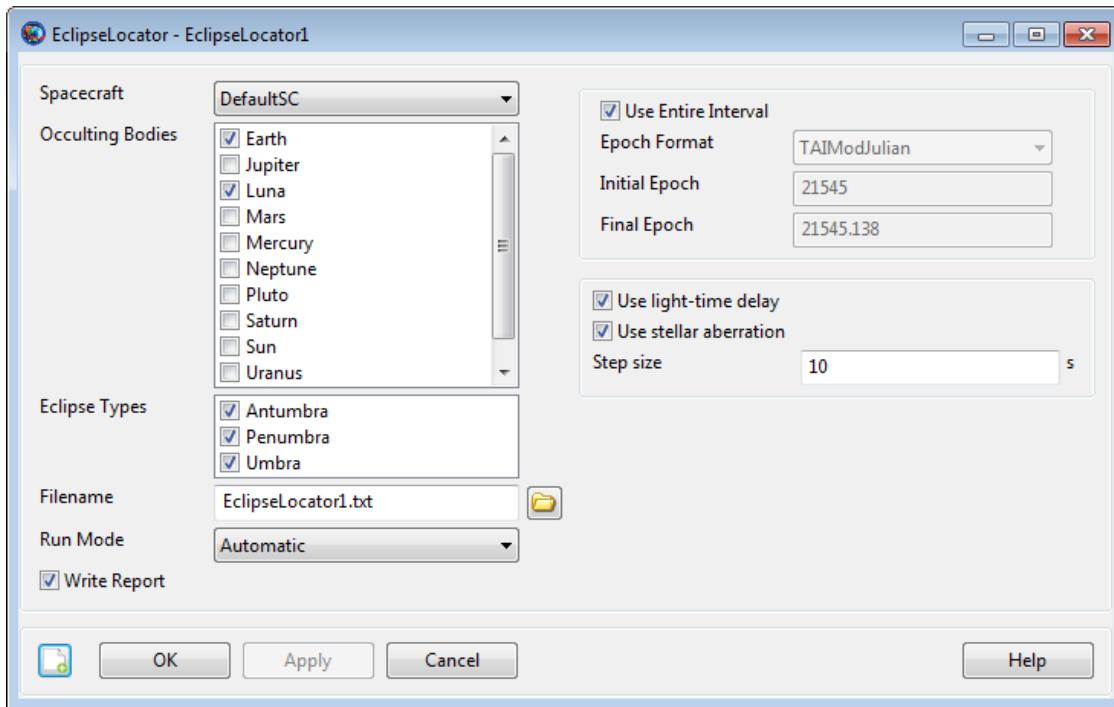
1. Double-click **EclipseLocator1** to edit the configuration.

Note the following default settings:

- **Spacecraft** is set to **DefaultSC**, the name of our spacecraft.
- **OccultingBodies** is set to **Earth** and **Luna**. These are the two bodies that will be searched for eclipses.
- **EclipseTypes** is set to search for all eclipse types (umbra or total, penumbra or partial, and antumbra or annular)
- **Run Mode** is set to **Automatic** mode, which means the eclipse search will be run automatically at the end of the mission.
- **Use Entire Interval** is checked, so the entire mission time span will be searched.
- Light-time delay and stellar aberration are both enabled, so eclipse times will be adjusted appropriately.
- **Step size** is set to 10 s. This is the minimum-duration eclipse (or gap between eclipses) that this locator is guaranteed to find.

2. Click **OK** to accept the default settings. They are fine for our purposes.

The final configuration should match the following screenshot.



**Figure 105. EclipseLocator Configuration**

## Run the Mission

Now it's time to run the mission and look at the results.

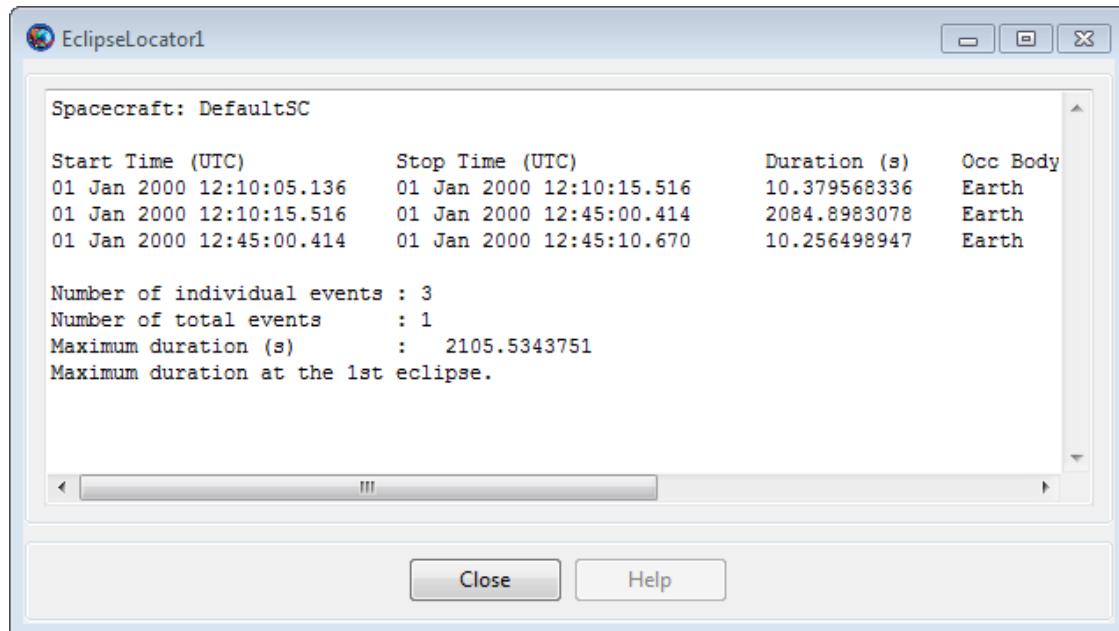
1. Click **Run** (▶) to run the mission.

The eclipse search will take a few seconds. As it progresses, you'll see the following message in the message window at the bottom of the screen:

```
Finding events for EclipseLocator EclipseLocator1 ...
Celestial body properties are provided by SPICE kernels.
```

2. When the run is complete, click the **Output** tab to view the available output.
3. Double-click **EclipseLocator1** to view the eclipse report.

You'll see a report that looks similar to this:



**Figure 106. EclipseLocator Report**

Three eclipses were found, all part of a single "total" eclipse event totalling about 35 minutes. A total event consists of all adjacent and overlapping portions, such as penumbra eclipses occurring adjacent to umbra eclipses as in this case.

- Click **Close** to close the report. The report text is still available as `EclipseLocator1.txt` in the GMAT output folder.

## Configure and Run the Contact Locator

Finding ground station contact times is a very similar process, but we'll use the ContactLocator resource instead. First we need to add a GroundStation, then we can configure the locator to find contact times between it and our spacecraft.

### Create and Configure a Ground Station

Let's create a ground station that will be in view from the final geostationary orbit. By looking at the DefaultGroundTrackPlot window, our spacecraft is positioned over the Indian Ocean. A ground station in India should be in view. We can choose the Hyderabad facility, which has the following properties:

- Latitude: 17.0286 deg
- Longitude: 78.1883 deg
- Altitude: 0.541 km

Let's create this ground station in GMAT:

1. First, close all graphics and solver windows, to allow full manipulation of resources.

2. On the **Resources** tab, right-click the **Ground Station** folder and click **Add Ground Station**. This will create a new resource called **GroundStation1**.
3. Rename **GroundStation1** to **Hyderabad**.
4. Double-click **Hyderabad** to edit its configuration.

The following values are configured appropriately by default, so we won't change them:

- **Min. Elevation:** This is the minimum elevation angle from the ground station for a valid contact. The current value (7 deg) is appropriate for this case.
  - **Central Body:** Earth is the only allowed value at this time.
5. In the **State Type** list, select **Spherical**. This allows input in latitude, longitude, and altitude.
  6. In the **Horizon Reference** list, select **Ellipsoid**.
  7. In the **Latitude** box, type 17.0286.
  8. In the **Longitude** box, type 78.1883.
  9. In the **Altitude** box, type 0.541.
  10. Click **OK** to accept these changes.

The configured **GroundStation** should look like the following screenshot:

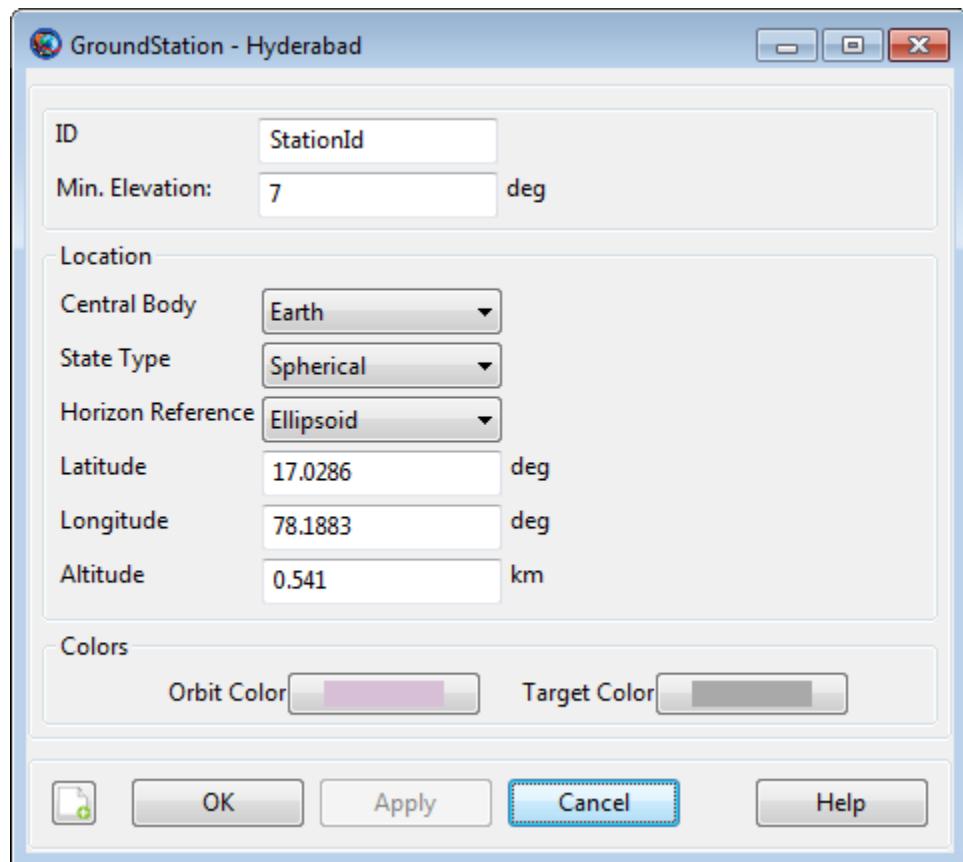
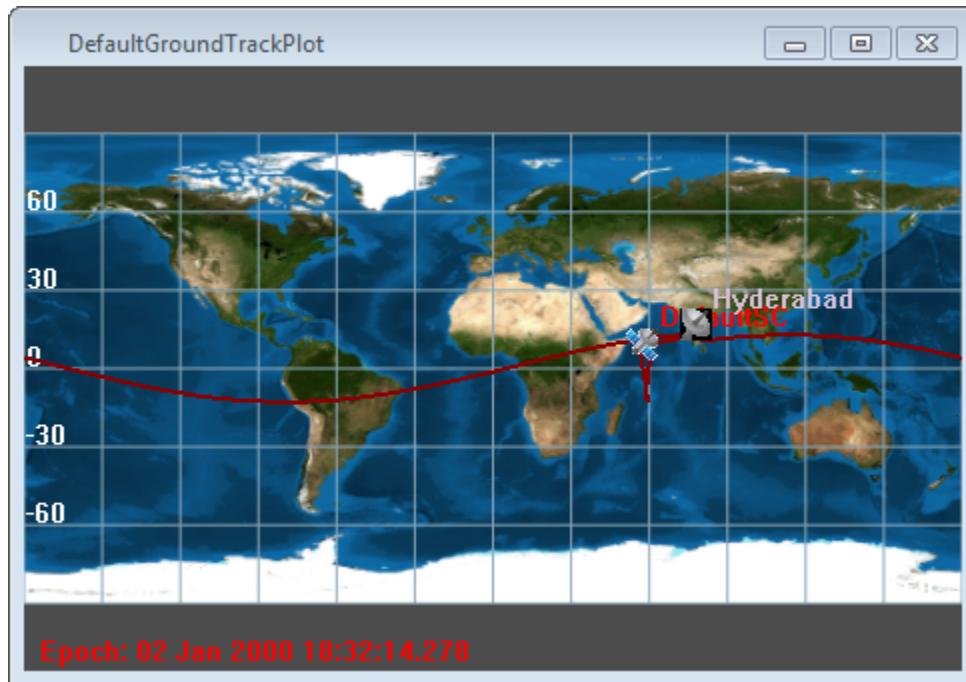


Figure 107. GroundStation Panel

If you add the **GroundStation** to the **DefaultGroundTrackPlot**, you can see the location visually:



**Figure 108. Ground Track Plot Window**

### Create and Configure the ContactLocator

Now we can create a ContactLocator that will search for contact times between our spacecraft and the Hyderabad station.

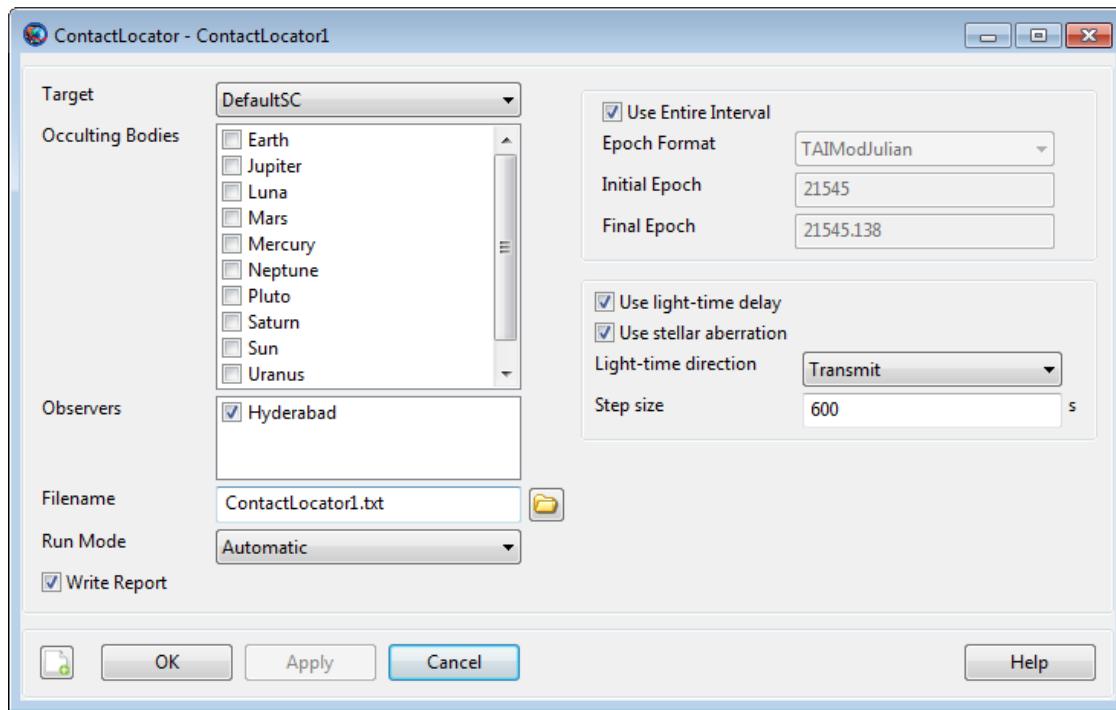
1. On the **Resources** tab, right-click the **Event Locators** folder, point to **Add**, and click **ContactLocator**. This will create **ContactLocator1**.
2. Double-click **ContactLocator1** to edit the configuration.

Many of the default values are identical to the **EclipseLocator**, so we don't need to explain them again. There are a couple new properties that we'll note, but won't change:

- **Occulting Bodies:** These are celestial bodies that GMAT will search for occultations of the line of sight between the spacecraft and the ground station. Since our spacecraft is orbiting the Earth, we don't need to choose any occulting bodies. Note that Earth is considered automatically because it is the central body of the ground station.
  - **Light-time direction:** This is the signal sense of the ground station. You can choose to calculate light-time delay as if the ground station is transmitting, or if it is receiving.
3. In the **Observers** list, enable **Hyderabad**. This will cause GMAT to search for contacts to this station.

4. In the **Step size** box, type 600. Since we're not using third-body occultations, this step size can be increased significantly without missing events. See the [ContactLocator](#) documentation for details.
5. Click **OK** to accept the changes.

When fully configured, the ContactLocator window will look like the following screenshot:



**Figure 109. ContactLocator Configuration Window**

## Run the Mission

Now it's time to run the mission again and look at these new results.

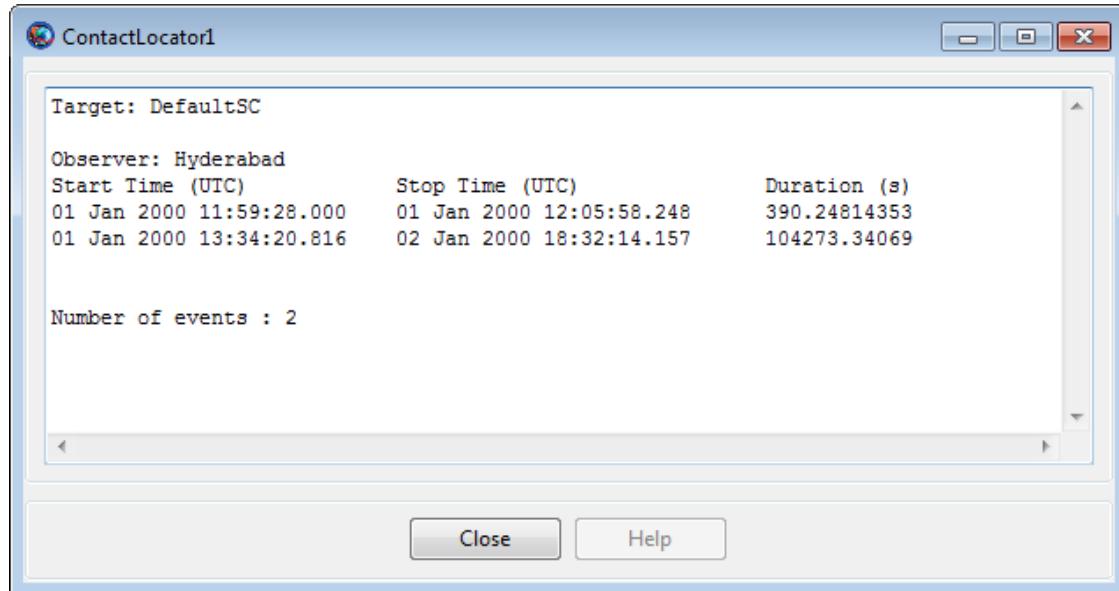
1. Click **Run** (▶) to run the mission.

The contact search will take much less time than the eclipse search, since we're using a larger step size. As it progresses, you'll see the following message in the message window at the bottom of the screen:

```
Finding events for ContactLocator ContactLocator1 ...
Celestial body properties are provided by SPICE kernels.
```

2. When the run is complete, click the **Output** tab to view the available output.
3. Double-click **ContactLocator1** to view the report.

You'll see a report that looks similar to this:



**Figure 110. ContactLocator Report**

Notice that two contact intervals were found: one about 6 minutes long at the very beginning of the mission (it starts at the Spacecraft's initial epoch), and a second one about 29 hours long, starting once it gets into geosynchronous orbit and extending to the end of the simulation.

- Click **Close** to close the report. The report text is still available as `ContactLocator1.txt` in the GMAT output folder.

## Further Exercises

To expand on this tutorial, try the following exercise:

- For a mission like this, you probably will want ground station coverage during both maneuvers. Try the following steps to make sure the coverage is adequate:
  - Change the colors of the **Propagate** commands, so you can see visually where the burns are located.
  - Add **GroundStation** resources near the locations of the burns on the ground track.
  - Confirm the burn epochs in the **Command Summary** for each **Maneuver** command.
  - Confirm in the contact report that these times occur during a contact interval.
  - Check the eclipse report, too: you may not want to perform a maneuver during an eclipse!

This tutorial shows you the basics of adding eclipse and station contact location to your mission. These resources have a lot of power, and there are many different ways to use them. Consult the [ContactLocator](#) and [EclipseLocator](#) documentation for details.



# Electric Propulsion

<b>Audience</b>	Beginner
<b>Length</b>	15 minutes
<b>Prerequisites</b>	Complete <a href="#">Simulating an Orbit</a>
<b>Script File</b>	Tut_ElectricPropulsionModelling.script

## Objective and Overview

In this tutorial, we will use GMAT to perform a finite burn for a spacecraft using an electric propulsion system. Note that targeting and design using electric propulsion is identical to chemical propulsion and we refer you to the tutorial named [Target Finite Burn to Raise Apogee](#) for targeting configuration. This tutorial focuses only on configuration and modeling using electric propulsion systems.

The basic steps of this tutorial are:

1. Create and configure the **Spacecraft** hardware and **FiniteBurn** Resources
2. Configure the Mission Sequence. To do this, we will
  - a. Create **Begin/End FiniteBurn** commands with default settings.
  - b. Create a **Propagate** command to propagate while applying thrust from the electric propulsion system.
3. Run the mission

## Create and Configure Spacecraft Hardware and Finite Burn

For this tutorial, you'll need GMAT open with the default mission loaded. To load the default mission, click **New Mission** (➕) or start a new GMAT session. We will use the default configurations for the spacecraft (**DefaultSC**) and the propagator (**DefaultProp**). **DefaultSC** is configured by default to a near-circular orbit, and **DefaultProp** is configured to use Earth as the central body with a nonspherical gravity model of degree and order 4. You may want to open the dialog boxes for these objects and inspect them more closely as we will leave them at their default settings.

## Create a Thruster, Fuel Tank, and Solar Power System

To model thrust and fuel use associated with a finite burn, we must create an **ElectricThruster**, an **ElectricTank**, a power system, and then attach the newly created **ElectricTank** to the **ElectricThruster**, and attach all hardware to the spacecraft. We'll start by creating the hardware objects.

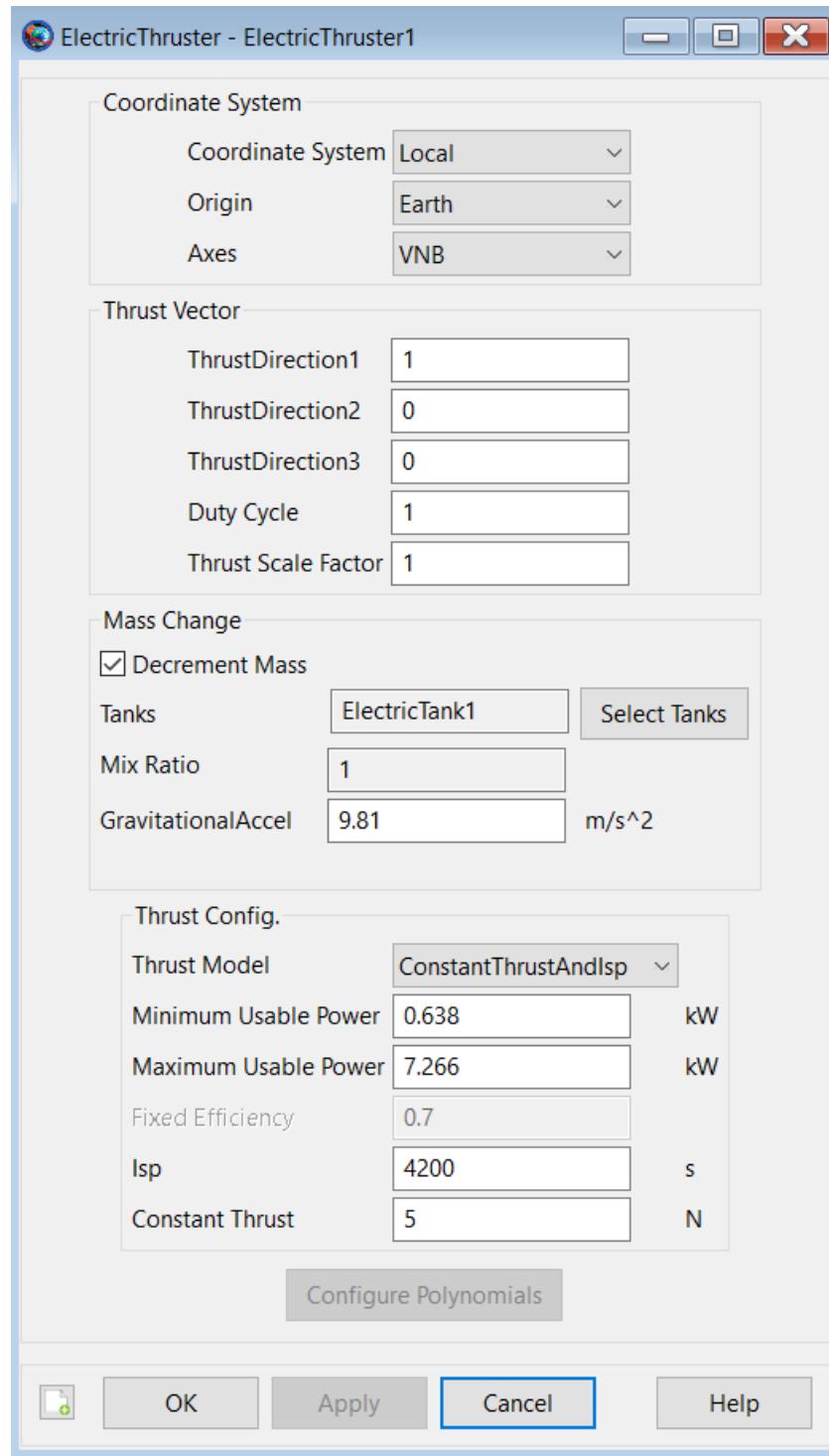
1. In the **Resources** tree, right-click on the **Hardware** folder, point to **Add**, and click **ElectricThruster**. A Resource named **ElectricThruster1** will be created.
2. In the **Resources** tree, right-click on the **Hardware** folder, point to **Add**, and click **ElectricTank**. A Resource named **ElectricTank1** will be created.
3. In the **Resources** tree, right-click on the **Hardware** folder, point to **Add**, and click **SolarPowerSystem**. A Resource named **SolarPowerSystem1** will be created.

## Configure the Hardware

Now we'll configure the hardware models for this exercise.

1. Double-click **ElectricThruster1** to edit its properties.
2. In the **Mass Change** group box, check **Decrement Mass**.
3. In the **Mass Change** group box, select **ElectricTank1** for the **Tank**.
4. In the **Thrust Config** group box, select **ConstantThrustAndIsp** for **ThrustModel** and set **ConstantThrust** to 5.0 N.

Figure 111 below shows the **ElectricThruster1** configuration that we will use.



**Figure 111. ElectricThruster1 Configuration**

We will use the default tank settings. Figure 112 shows the finished **ElectricTank1** configuration.

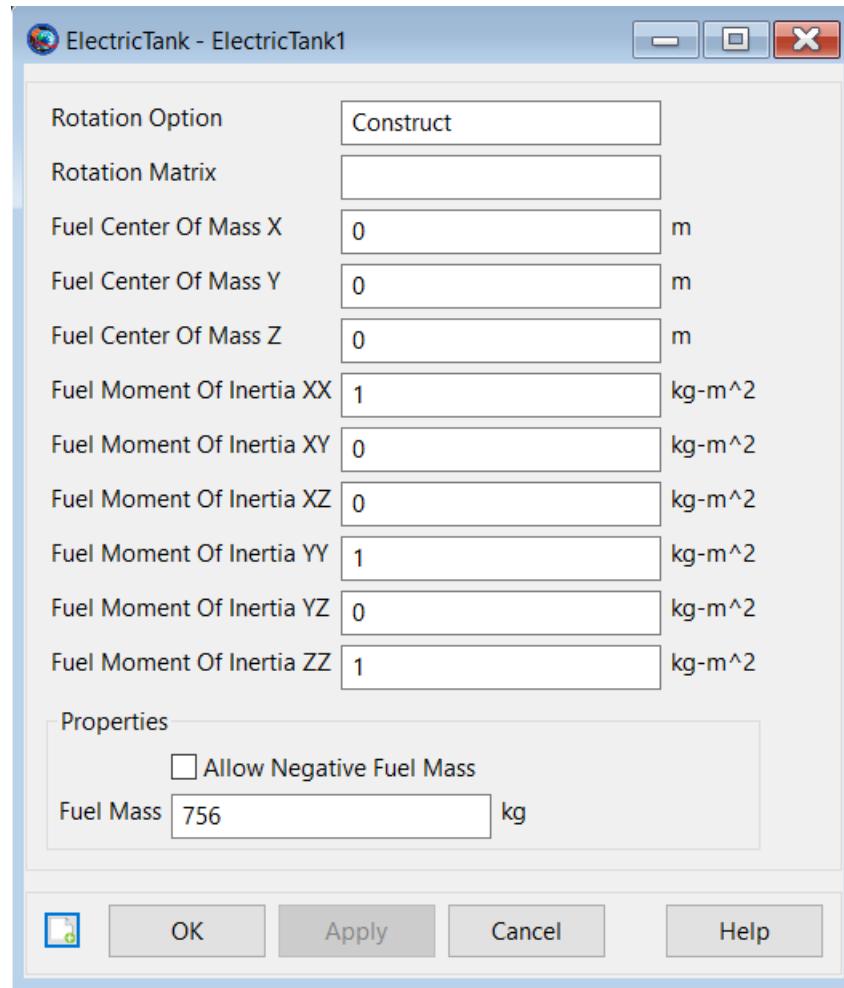
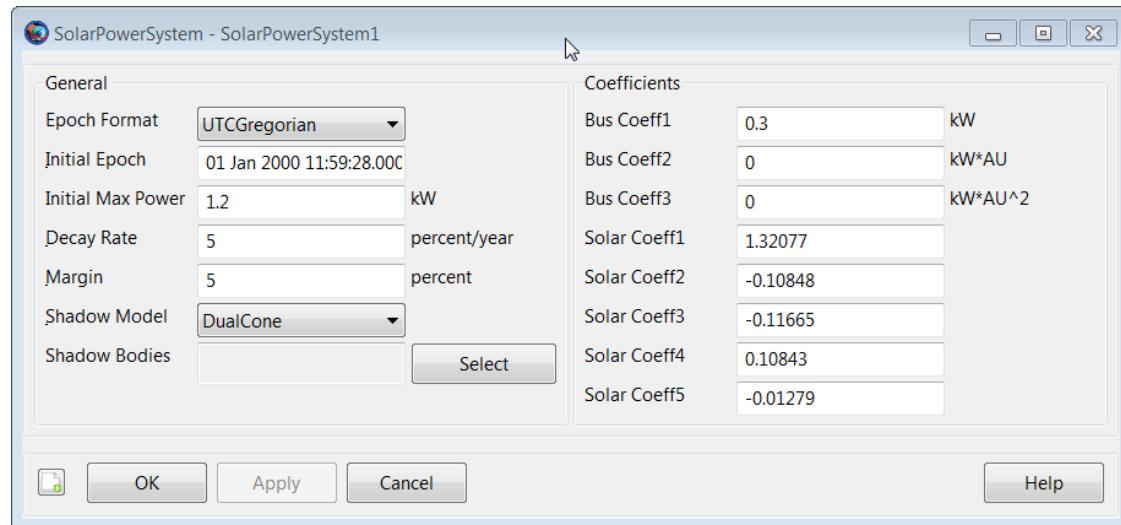


Figure 112. ElectricTank1 Configuration

1. Double-click **SolarPowerSystem1** to edit its properties.
2. In the **General** group box, click the **Select** button next to **ShadowBodies**.
3. Remove **Earth** from the **ShadowBodies** list.

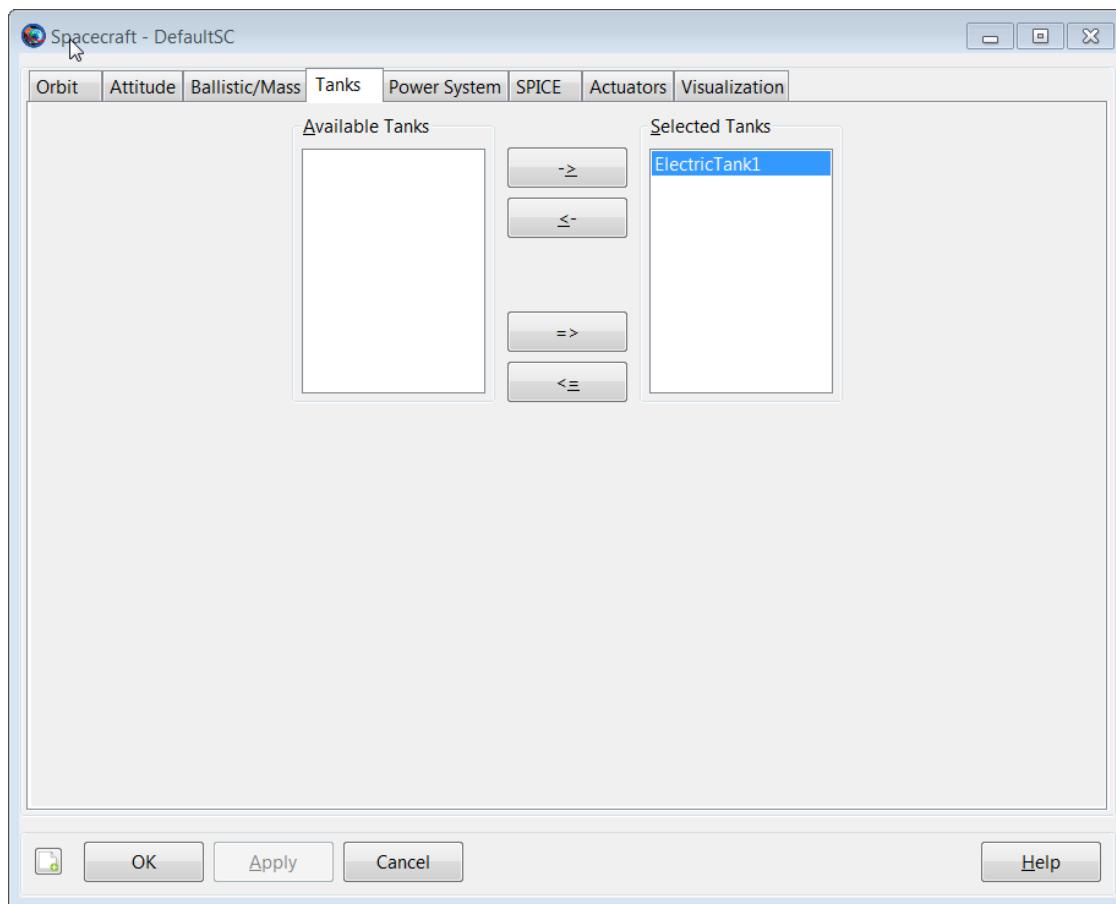
Figure 113 shows the finished **SolarPowerSystem1** configuration.



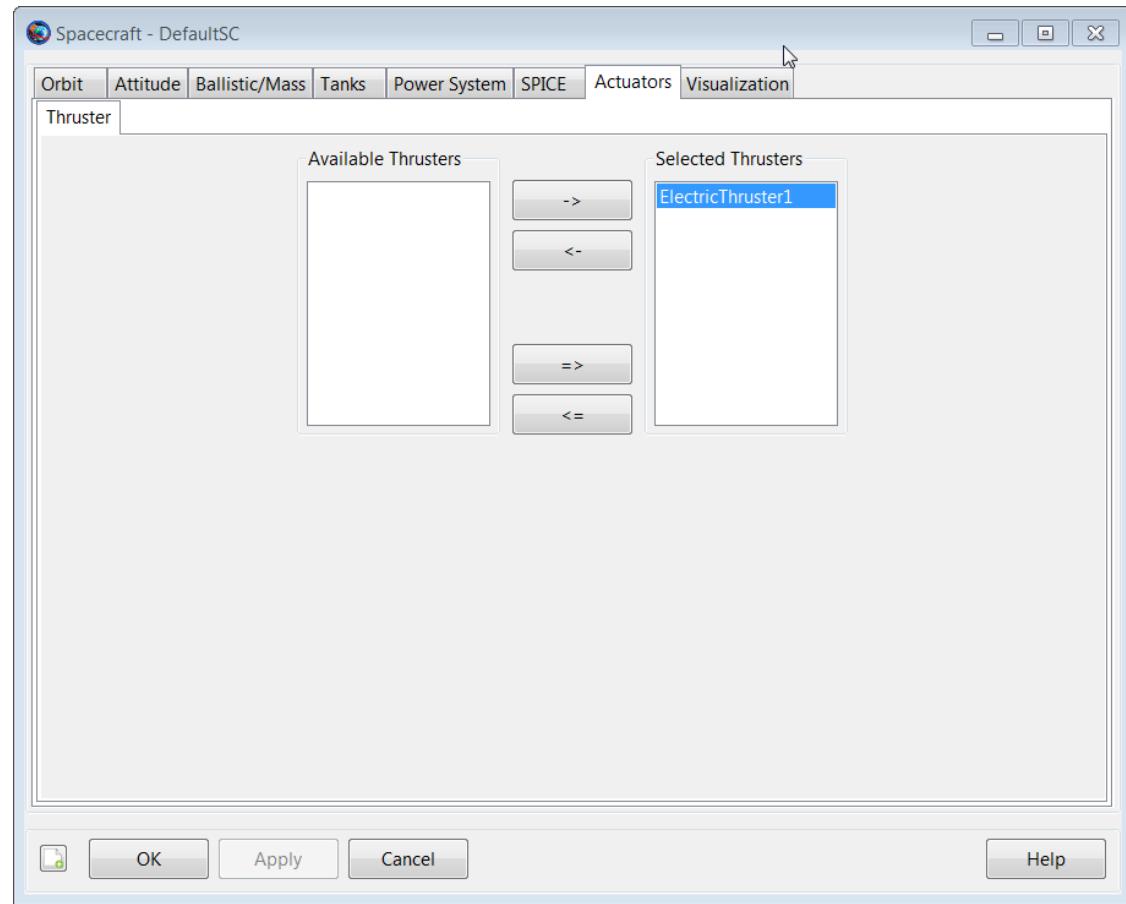
**Figure 113. SolarPowerSystem1 Configuration**

## Attach Hardware to the Spacecraft

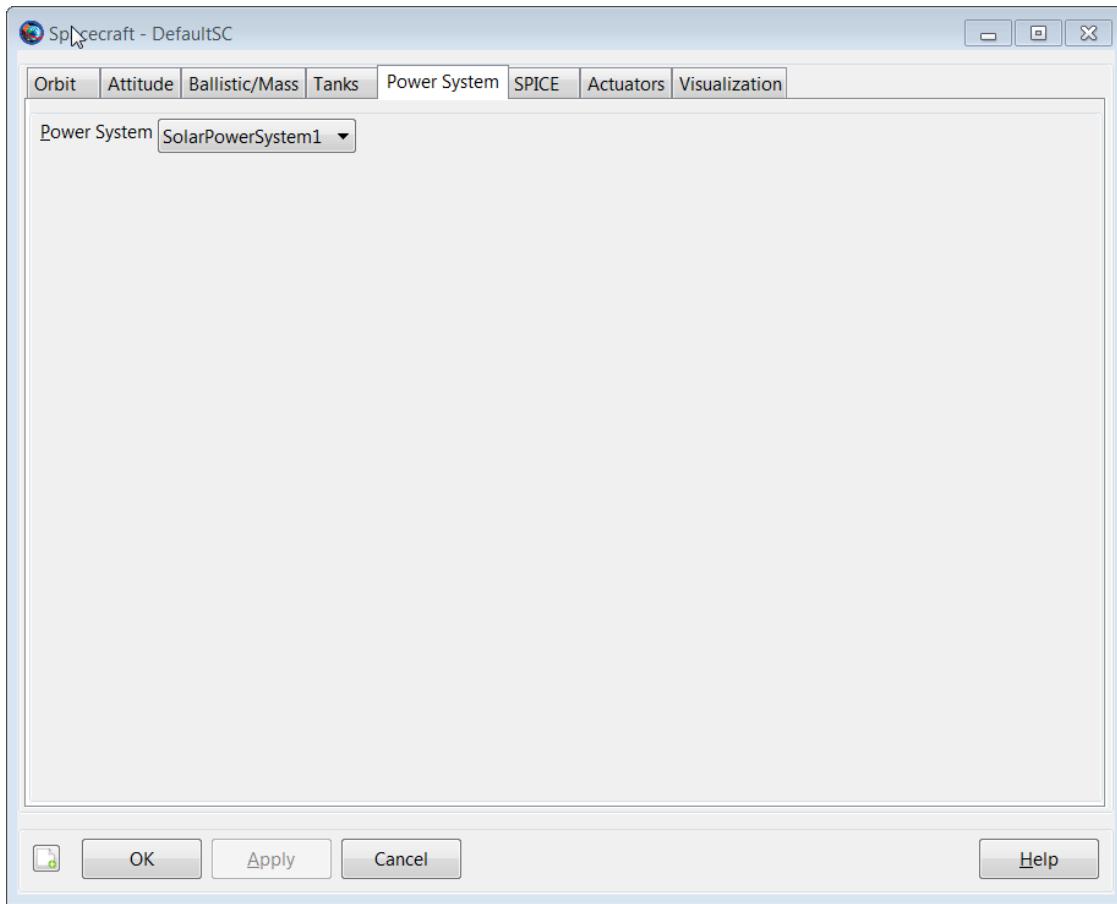
1. In the **Resources** tree, double-click **DefaultSC** to edit its properties.
2. Select the **Tanks** tab. In the **Available Tanks** column, select **ElectricTank1**. Then click the right arrow button to add **ElectricTank1** to the **SelectedTanks** list. Click **Apply**.
3. Select the **Actuators** tab. In the **Available Thrusters** column, select **ElectricThruster1**. Then click the right arrow button to add **ElectricThruster1** to the **SelectedThrusters** list. Click **APPLY**.
4. Select the **PowerSystem** tab. In the **PowerSystem** tab, select **SolarPowerSystem1**. Click **OK**.



**Figure 114. Attach ElectricTank1 to DefaultSC**



**Figure 115. Attach ElectricThruster1 to DefaultSC**

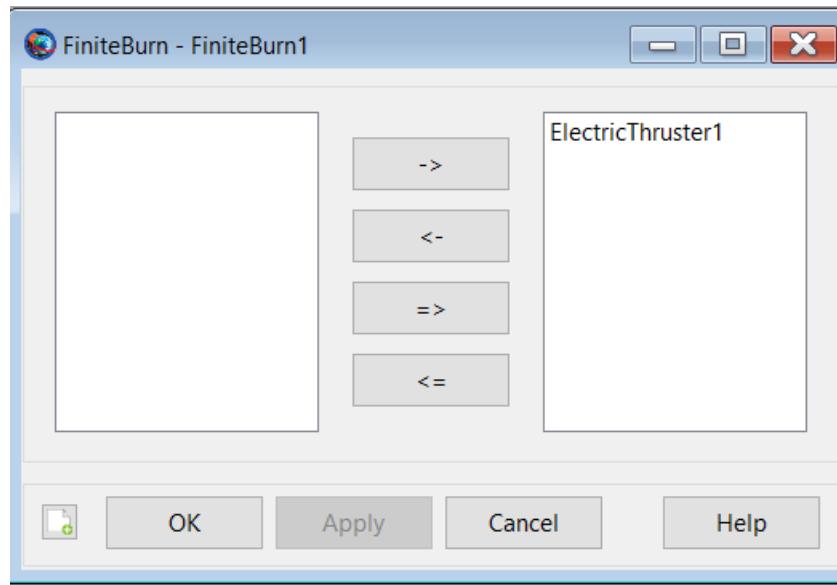


**Figure 116. Attach SolarPowerSystem1 to DefaultSC**

### Create the Finite Burn Maneuver

We'll need a single **FiniteBurn** Resource for this tutorial.

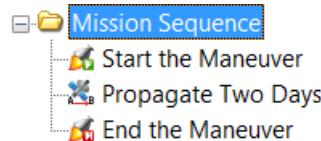
1. In the **Resources** tree, right-click the **Burns** folder and add a **FiniteBurn**. A Resource named **FiniteBurn1** will be created.
2. Double-click **FiniteBurn1** to edit its properties.
3. Select the **ElectricThruster1** from the left side and use the **->** button to move it to the right, setting it as a thruster associated with **FiniteBurn1**. Click **OK**.



**Figure 117. Creation of FiniteBurn Resource FiniteBurn1**

## Configure the Mission Sequence

Now we will configure the mission sequence to apply a finite maneuver using electric propulsion for a two day propagation. When we're done, the mission sequence will appear as shown below.



**Figure 118. Final Mission Sequence**

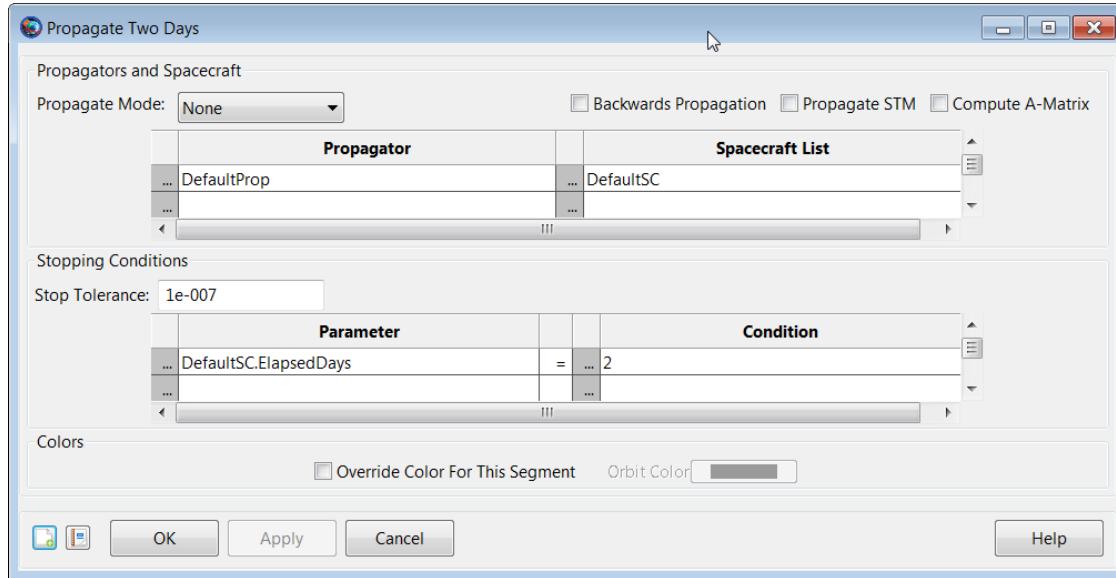
## Create the Commands

1. In the Mission Tree, right click on **Propagate1**, select **Rename**, and enter **Propagate Two Days**.
2. Right click on the command named **Propagate Two Days**, select **Insert Before**, then select **BeginFiniteBurn**.
3. Right click on the command named **Propagate Two Days**, select **Insert After**, then select **EndFiniteBurn**.
4. Rename the command named **BeginFiniteBurn1** to **StartTheManeuver**.
5. Rename the command named **EndFiniteBurn1** to **EndTheManeuver**.

Note that for more complex analysis that has multiple **FiniteBurn** objects, you will need to configure the **BeginFiniteBurn** and **EndFiniteBurn** commands to select the desired **FiniteBurn** Resource. As there is only one **FiniteBurn** Resource in this example, the system automatically selected the correct **FiniteBurn** Resource.

## Configure the Propagate Command

Configure the **Propagate Two Days** command to propagate for DefaultSC.ElapsedDays = 2.0



**Figure 119. Prop To Perigee Command Configuration**

## Run the Mission

Before running the mission, click **Save** to save the mission to a file of your choice. Now click **Run**. As the mission runs, you will see the orbit spiral way from Earth. Note we exaggerated the thrust level so that an appreciable change in the orbit occurs in two days.

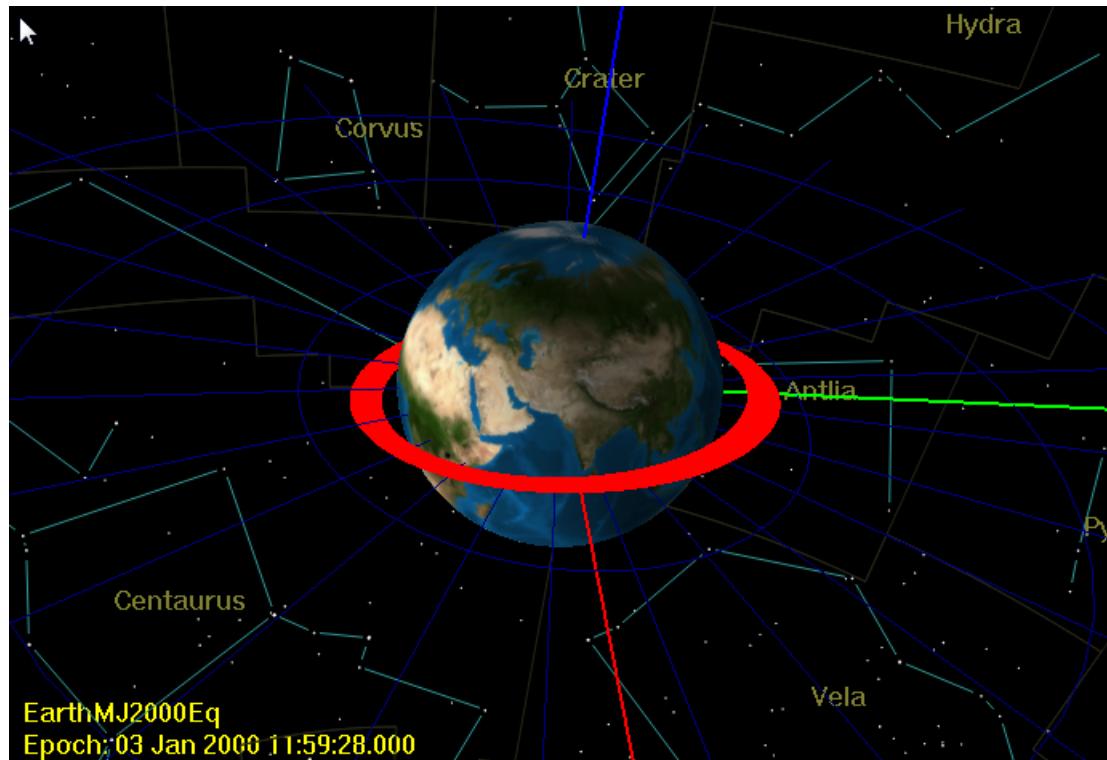


Figure 120. 3D View of Finite Electric Maneuver



# Simulate DSN Range and Doppler Data

<b>Audience</b>	Intermediate level
<b>Length</b>	40 minutes
<b>Prerequisites</b>	Basic Mission Design Tutorials
<b>Script Files</b>	Tut_Simulate_DSN_Range_and_Doppler_Data.script Tut_Simulate_DSN_Range_and_Doppler_Data_3_weeks.script

Tut\_Simulate\_DSN\_Range\_and\_Doppler\_Data\_3\_weeks.script

## Objective and Overview



### Note

GMAT currently implements a number of different data types for orbit determination. Please refer to [Tracking Data Types for Orbit Determination](#) for details on all the measurement types currently supported by GMAT. The measurements being considered here are DSN two way range and DSN two way Doppler.

In this tutorial, we will use GMAT to generate simulated DSN range and Doppler measurement data for a sample spacecraft in orbit about the Sun. The spacecraft in this tutorial is in an Earth “drift away” type orbit about 1 AU away from the Sun and almost 300 million km away from the Earth.

The basic steps of this tutorial are:

1. Create and configure the spacecraft, spacecraft transponder, and related parameters
2. Create and configure the Ground Station and related parameters
3. Define the types of measurements to be simulated
4. Create and configure Force model and propagator
5. Create and configure Simulator object
6. Run the mission and analyze the results
7. Create a realistic GMAT Measurement Data (GMD) file

Note that this tutorial, unlike most of the mission design tutorials, will be entirely script based. This is because most of the resources and commands related to navigation are not implemented in the GUI and are only available via the script interface.

As you go through the tutorial below, it is recommended that you paste the script segments into GMAT as you go along. After each paste into GMAT, you should perform a syntax check by hitting the Save, Sync button (). To avoid syntax errors, where needed, don’t forget to add the following command to the last line of the script segment you are checking.

`BeginMissionSequence`

We note that in addition to the material presented here, you should also look at the individual Help resources for all the objects and commands we create and use here.

For example, **Spacecraft**, **Transponder**, **Transmitter**, **GroundStation**, **ErrorModel**, **TrackingFileSet**, **RunSimulator**, etc all have their own Help pages.

## Create and configure the spacecraft, spacecraft transponder, and related parameters

For this tutorial, you'll need GMAT open, with a new empty script open. To create a new script, click **New Script**, (

### Create a satellite and set its epoch and Cartesian coordinates

Since this is a Sun-orbiting spacecraft, we choose to represent the orbit in a Sun-centered coordinate frame which we define using the scripting below.

```
% Create the Sun-centered J2000 frame.  
Create CoordinateSystem SunMJ2000Eq;  
SunMJ2000Eq.Origin = Sun;  
SunMJ2000Eq.Axes = MJ2000Eq; %Earth mean equator axes
```

Next, we create a new spacecraft, **Sat**, and set its epoch and Cartesian coordinates.

```
Create Spacecraft Sat;  
Sat.DateFormat = UTCGregorian;  
Sat.CoordinateSystem = SunMJ2000Eq;  
Sat.DisplayStateType = Cartesian;  
Sat.Epoch = 19 Aug 2015 00:00:00.000;  
Sat.X = -126544968  
Sat.Y = 61978514  
Sat.Z = 24133221  
Sat.VX = -13.789  
Sat.VY = -24.673  
Sat.VZ = -10.662  
  
Sat.Id = 11111;
```

Note that, in addition to setting **Sat's** coordinates, we also assigned it an ID number. This is the number that will be written to the GMAT Measurement Data (GMD) file that we will discuss later.

### Create a Transponder object and attach it to our spacecraft

To simulate navigation measurements for a given spacecraft, GMAT requires that a **Transponder** object, which receives the ground station uplink signal and re-transmits it, typically, to a ground station, be attached to the spacecraft. Below, we create the **Transponder** object and attach it to our spacecraft.

```
Create Antenna HGA;  
  
Create Transponder SatTransponder;  
SatTransponder.PrimaryAntenna = HGA;
```

```
SatTransponder.HardwareDelay      = 1e-06; %seconds
SatTransponder.TurnAroundRatio    = '880/749';

Sat.AddHardware                  = {SatTransponder, HGA};
```

After we create the **Transponder** object, there are three fields, **PrimaryAntenna**, **HardwareDelay**, and **TurnAroundRatio** that must be set.

The **PrimaryAntenna** is the antenna that the spacecraft transponder, **SatTransponder**, uses to receive and retransmit RF signals. In the example above, we set this field to **HGA** which is an **Antenna** object we have created. Currently the **Antenna** resource has no function but in a future release, it may have a function. **HardwareDelay**, the transponder signal delay in seconds, is set to one micro-second. We set **TurnAroundRatio**, which is the ratio of the retransmitted to the input signal, to '880/749.' See the [FRC-21\\_RunSimulator Help](#) and [Appendix A – Determination of Measurement Noise Values](#) for a discussion on how GMAT uses this input field. As described in the Help, if our DSN data does not use a ramp table, this turn around ratio is used directly to calculate the Doppler measurements.

Note that in the last script command above, we attach our newly created **Transponder** and its related **Antenna** object to our spacecraft, **Sat**.

## Create and configure the Ground Station and related parameters

### Create Ground Station Transmitter, Receiver, and Antenna objects

Before we create the **GroundStation** object itself, as shown below, we first create the **Transmitter**, **Receiver**, and **Antenna** objects that must be associated with any **GroundStation**.

```
% Ground Station electronics.
Create Transmitter DSNTransmitter;
Create Receiver DSNReceiver;
Create Antenna DSNAntenna;

DSNTransmitter.PrimaryAntenna      = DSNAntenna;
DSNReceiver.PrimaryAntenna        = DSNAntenna;
DSNTransmitter.Frequency          = 7200;    %MHz
```

In the script segment above, we first created **Transmitter**, **Receiver**, and **Antenna** objects. The GMAT script line `DSNTransmitter.PrimaryAntenna = DSNAntenna`, sets the main antenna that the **Transmitter** object will be using. Likewise, the `DSNReceiver.PrimaryAntenna = DSNAntenna` script line sets the main antenna that the **Receiver** object will be using. As previously mentioned, the **Antenna** object currently has no function, but we include it here both because GMAT requires it and for completeness since the **Antenna** resource may have a function in a future GMAT release. Finally, we set the transmitter frequency in the last GMAT script line above. See the [RunSimulator Help](#) for a complete description of how this input frequency is used. As described in the Help, since in this example we will not be using a ramp table, this input frequency will be used to calculate the simulated value of the range and Doppler

observations. In addition, this input frequency will also be output to the range data file created by the **RunSimulator** command.

## Create Ground Station

Below, we create and configure a **GroundStation** object.

```
% Create ground station and associated error models
Create GroundStation CAN;
CAN.CentralBody          = Earth;
CAN.StateType             = Cartesian;
CAN.HorizonReference     = Ellipsoid;
CAN.Location1             = -4461.083514;
CAN.Location2             = 2682.281745;
CAN.Location3             = -3674.570392;

CAN.Id                   = 22222;

CAN.MinimumElevationAngle = 7.0;

CAN.IonosphereModel      = 'IRI2007';
CAN.TroposphereModel     = 'HopfieldSaastamoinen';

CAN.AddHardware           = {DSNTransmitter, DSNAntenna, ...
                            DSNReceiver};
```

The script segment above is broken into five sections. In the first section, we create our **GroundStation** object and we set our Earth-Centered Fixed Cartesian coordinates. In the second section, we set the ID of the ground station that will output to the GMD file created by the **RunSimulator** command. In the third section, we set the minimum elevation angle to 7 degrees. Below this ground station to spacecraft elevation angle, no simulated data will be created. In the fourth section, we specify which troposphere and ionosphere model we wish to use to model RF signal atmospheric refraction effects. Finally, in the fifth section, we attached three pieces of previously created required hardware to our ground station, a transmitter, a receiver, and an antenna.

## Create Ground Station Error Models

It is well known that all measurement types have random noise and/or biases associated with them. For GMAT, these affects are modelled using ground station error models. Since we have already created the **GroundStation** object and its related hardware, we now create the ground station error models. Since we wish to simulate both range and Doppler data, we need to create two error models as shown below, one for range measurements and one for Doppler measurements.

```
% Create Ground station error models
Create ErrorModel DSNrange;
DSNrange.Type              = 'DSN_SeqRange';
DSNrange.NoiseSigma         = 10.63;
DSNrange.Bias               = 0.0;
```

```
Create ErrorModel DSNdoppler;
DSNdoppler.Type          = 'DSN_TCP';
DSNdoppler.NoiseSigma    = 0.0282;
DSNdoppler.Bias          = 0.0;

CAN.ErrorModels          = {DSNrangle, DSNdoppler};
```

The script segment above is broken into three sections. The first section defines an **ErrorModel** named **DSNrangle**. The error model Type is DSN\_SeqRange which indicates that it is an error model for DSN sequential range measurements. The 1 sigma standard deviation of the Gaussian white noise is set to 10.63 Range Units (RU) and the measurement bias is set to 0 RU.

The second section above defines an **ErrorModel** named **DSNdoppler**. The error model Type is DSN\_TCP which indicates that it is an error model for DSN total count phase-derived Doppler measurements. The 1 sigma standard deviation of the Gaussian white noise is set to 0.0282 Hz and the measurement bias is set to 0 Hz.

The third section above attaches the two **ErrorModel** resources we have just created to the **CAN GroundStation**. Note that in GMAT, the measurement noise or bias is defined on a per ground station basis. Thus, any range measurement error involving the CAN GroundStation is defined by the **DSNRange ErrorModel** and any Doppler measurement error involving the **CAN GroundStation** is defined by the **DSNdoppler ErrorModel**. Note that since GMAT currently only models two way measurements where the transmitting and receiving ground stations are the same, we do not have to consider the case where the transmitting and receiving ground stations are different. Suppose we were to add an additional **GroundStation** to this simulation. The measurement error for observations involving this new **GroundStation** would be defined by the **ErrorModel** resources attached to it.

See [Appendix A – Determination of Measurement Noise Values](#) for a discussion of how we determined the values for NoiseSigma for the two **ErrorModel** resources we created.

## Define the types of measurements to be simulated

Now we will create and configure a **TrackingFileSet** resource. This resource defines the type of data to be simulated, the ground stations that will be used, and the file name of the output GMD file which will contain the simulated data. In addition, the **TrackingFileSet** resource will define needed simulation parameters for the various data types.

```
Create TrackingFileSet DSNsimData;
DSNsimData.AddTrackingConfig   = {{CAN, Sat, CAN}, 'DSN_SeqRange'};
DSNsimData.AddTrackingConfig   = {{CAN, Sat, CAN}, 'DSN_TCP'};
DSNsimData.FileName            = ...
                                {'Sat_dsn_range_and_doppler_measurements.gmd'};

DSNsimData.UseLightTime        = true;
DSNsimData.UseRelativityCorrection = true;
DSNsimData.UseETminusTAI       = true;
```

```
DSNsimData.SimDopplerCountInterval = 10.0;
DSNsimData.SimRangeModuloConstant = 3.3554432e+07;
```

The script lines above are broken into three sections. In the first section, the resource name, **DSNsimData**, is declared, the data types are defined, and the output file name is specified. **AddTrackingConfig** is the field that is used to define the data types. The first **AddTrackingConfig** line tells GMAT to simulate DSN range two way measurements for the **CAN** to **Sat** to **CAN** measurement strand. The second **AddTrackingConfig** line tells GMAT to simulate DSN Doppler two way measurements for the **CAN** to **Sat** to **CAN** measurement strand.

The second section above sets some simulation parameters that apply to both the range and Doppler measurements. We set **UseLightTime** to True in order to generate realistic measurements where GMAT takes into account the finite speed of light. The last two parameters in this section, **UseRelativityCorrection** and **UseETminusTAI**, are set to True so that general relativistic corrections, as described in Moyer [2000], are applied to the light time equations.

The third section above sets simulation parameters that apply to a specific measurement type. **SimDopplerCountInterval** applies only to Doppler measurements and **SimRangeModuloConstant** applies only to range measurements. We note that the “Sim” in the field names is used to indicate that these fields only are applicable when GMAT is in simulation mode (i.e., when using the **RunSimulator** command) data and not when GMAT is in estimation mode (i.e., when using the **RunEstimator** command). **SimDopplerCountInterval**, the Doppler Count Interval, is set to 10 seconds and **SimRangeModuloConstant**, the maximum possible range value, is set to 33554432. See the **RunSimulator** Help and [Appendix A – Determination of Measurement Noise Values](#) for a description of how these parameters are used to calculate the measurement values.

## Create and configure Force model and propagator

We now create and configure the force model and propagator that will be used for the simulation. For this deep space drift away orbit, we naturally choose the Sun as our central body. Since we are far away from all the planets, we use point mass gravity models and we include the effects of the Sun, Earth, Moon, and most of the other planets. In addition, we model Solar Radiation Pressure (SRP) affects and we include the effect of general relativity on the dynamics. The script segment accomplishing this is shown below.

```
Create ForceModel Fm;
Create Propagator Prop;
Fm.CentralBody          = Sun;
Fm.PointMasses          = {Sun, Earth, Luna, Mars, Saturn, ...
                         Uranus, Mercury, Venus, Jupiter};
Fm.SRP                 = On;
Fm.RelativisticCorrection = On;
Fm.ErrorControl         = None;
Prop.FM                 = Fm;
Prop.MinStep             = 0;
```

## Create and configure Simulator object

As shown below, we create and configure the **Simulator** object used to define our simulation.

```
Create Simulator Sim;
Sim.AddData          = {DSNsimData};
Sim.EpochFormat     = UTCGregorian;
Sim.InitialEpoch    = '19 Aug 2015 00:00:00.000';
Sim.FinalEpoch      = '19 Aug 2015 00:12:00.000';
Sim.MeasurementTimeStep = 600;
Sim.Propagator      = Prop;
Sim.AddNoise         = Off;
```

In the first script line above, we create a **Simulator** object, **Sim**. The next field set is **AddData** which is used to specify which **TrackingFileSet** should be used. Recall that the **TrackingFileSet** specifies the type of data to be simulated and the file name specifying where to store the data. The **TrackingFileSet**, **DSNsimData**, that we created in the [Define the types of measurements to be simulated](#) section, specified that we wanted to simulate two way DSN range and Doppler data that involved the **CAN GroundStation**.

The next three script lines, which set the **EpochFormat**, **InitialEpoch**, and **FinalEpoch** fields, specify the time period of the simulation. Here, we choose a short 12 minute duration.

The next script line sets the **MeasurementTimeStep** field which specifies the requested time between measurements. We choose a value of 10 minutes. This means that our data file will contain a maximum of two range measurements and two Doppler measurements.

The next script line sets the **Propagator** field which specifies which **Propagator** object should be used. We set this field to the **Prop Propagator** object which we created in the [Create and configure Force model and propagator](#) section.

Finally, in the last line of the script segment, we set the **AddNoise** field which specifies whether or not we want to add noise to our simulated measurements. The noise that can be added is defined by the **ErrorModel** objects that we created in the [Create and configure the Ground Station and related parameters](#) section and [Appendix A – Determination of Measurement Noise Values](#), the noise added to the range measurements would be Gaussian with a one sigma value of 10.63 Range Units and the noise added to the Doppler measurements would be Gaussian with a one sigma value of 0.0282 Hz. For this simulation, we choose not to add noise.

## Run the mission and analyze the results

The script segment used to run the mission is shown below.

```
BeginMissionSequence
RunSimulator Sim
```

The first script line, **BeginMissionSequence**, is a required command which indicates that the “Command” section of the GMAT script has begun. The second line of the script issues the **RunSimulator** command with the **Sim** Simulator resource, defined in the [Create and configure Simulator object](#) section, as an argument. This tells GMAT to perform the simulation specified by the **Sim** resource.

We have now completed all of our script segments. See the file, `Tut_Simulate_DSN_Range_and_Doppler_Data.script`, in the GMAT samples folder, for a listing of the entire script. We are now ready to run the script. Hit the Save,Sync,Run button, (). Because we are only simulating a small amount of data, the script should finish execution in about one second.

Let’s take a look at the output created. The file created, `Sat_dsn_range_and_doppler_measurements.gmd`, was specified in the **Tracking-FileSet** resource, **DSNsimData**, that we created in the [Define the types of measurements to be simulated](#) section. The default directory, if none is specified, is the GMAT ‘output’ directory. Let’s analyze the contents of this “GMAT Measurement Data” or GMD file as shown below.

```
% GMAT Internal Measurement Data File
27253.500416666666666666666665  DSN_SeqRange  9004    22222   11111   2.6025689337646484e+07  2    7.20000000000000e+09   3.35544320000000e+07
27253.5004166666666666666665  DSN_TCP     9006    22222   11111   2      10   -8.4593363231570539e+09
27253.507361111111111115728  DSN_SeqRange  9004    22222   11111   2.1736962852050781e+07  2    7.20000000000000e+09   3.35544320000000e+07
27253.507361111111111115728  DSN_TCP     9006    22222   11111   2      10   -8.4593356106484509e+09
```

The first line of the file is a comment line indicating that this is a file containing measurement data stored in GMAT’s internal format. There are 4 lines of data representing range data at two successive times and Doppler data at two successive times. As we expected, we have no more than 4 total measurements. Refer to the [Tracking Data Types for Orbit Determination](#) Help for a description of the range and Doppler GMD file format.

We now analyze the first line of data which represents a DSN two way range measurement at the start of the simulation at ‘19 Aug 2015 00:00:00.000 UTCG’ which corresponds to the output TAI modified Julian Day of 27253.50041666... TAIMJD.

The second and third fields, `DSN_SeqRange` and `9004`, are just internal GMAT codes indicating the use of DSN range (Trk 2-34 type 7) data.

The 4th field, `22222`, is the Downlink station ID. This is the ID we gave the **CAN GroundStation** object that we created in the [Create and configure the Ground Station and related parameters](#) section. The 5th field, `11111`, is the spacecraft ID. This is the ID we gave the **Sat Spacecraft** object that we created in the [Create and configure the spacecraft, spacecraft transponder, and related parameters](#) section.

The 6th field, `2.6025689337646484e+07`, is the actual DSN range observation value in RU.

The 7th field, `2`, is an integer which represents the Uplink Band of the uplink **GroundStation**, **CAN**. The designation, `2`, represents X-band. See the **RunSimulator** Help for a detailed discussion of how GMAT determines what value should be written here. As described in the Help, since we are not using a ramp table, GMAT determines the Uplink Band by looking at the transmit frequency of the **Transmitter** object attached to the

**CAN** ground station. GMAT knows that the 7200 MHz value that we assigned to **CAN's Transmitter** resource, **DSNTransmitter**, corresponds to an X-band frequency.

The 8th field, 7.2e+009, is the transmit frequency of **CAN** at the time of the measurement. Since we are not using a ramp table, this value will be constant for all measurements and it is given by the value of the frequency of the **Transmitter** object, **DSNTransmitter**, that we attached to the **CAN** ground station. Recall the following script segment, **DSNTransmitter.Frequency = 7200; %MHz**, from the [Create and configure the Ground Station and related parameters](#) section.

The 9th field, 3.3554432e+07, represents the integer range modulo number that helps define the DSN range measurement. This is the value that we set when we created and configured the **TrackingFileSet DSNsimData** object in the [Define the types of measurements to be simulated](#) section. Recall the following script command,

```
DSNsimData.SimRangeModuloConstant = 3.3554432e+07;
```

This range modulo number is discussed in [Appendix A – Determination of Measurement Noise Values](#) and is defined as M, the length of the ranging code in RU.

We now analyze the second line of data which represents a DSN two way Doppler measurement at the start of the simulation at '19 Aug 2015 00:00:00.000 UTCG' which corresponds to the output TAI modified Julian Day of 27253.500416666... TAIMJD.

The second and third fields, Doppler and 9006, are just internal GMAT codes indicating the use of DSN Doppler (derived from two successive Trk 2-34 type 17 Total Count Phase measurements) data.

The 4th field, 22222, is the Downlink station ID. This is the ID we gave the **CAN** **GroundStation** object that we created in the [Create and configure the Ground Station and related parameters](#) section. The 5th field, 11111, is the spacecraft ID. This is the ID we gave the **Sat Spacecraft** object that we created in the [Create and configure the spacecraft, spacecraft transponder, and related parameters](#) section.

The 6th field, 2, is an integer which represents the Uplink Band of the uplink **GroundStation**, **CAN**. As we mentioned when discussing the range measurement, the designation, 2, represents X-band.

The 7th field, 10, is the Doppler Count Interval (DCI) used to help define the Doppler measurement. This is the value that we set when we created and configured the **TrackingFileSet DSNsimData** object in the [Define the types of measurements to be simulated](#) section. Recall the following script command,

```
DSNsimData.SimDopplerCountInterval = 10.0;
```

The DCI is also discussed in [Appendix A – Determination of Measurement Noise Values](#).

The 8th field, -8.4593363231570539e+09, is the actual DSN Doppler observation value in Hz.

The third line of data represents the second DSN two way range measurement at '19 Aug 2015 00:10:00.000 UTCG' which corresponds to the output TAI modified Julian

Day time of 27253.507361111... TAIMJD. The fourth line of data represents the second DSN two way Doppler measurement at '19 Aug 2015 00:10:00.000 UTCG.'

## Create a more realistic GMAT Measurement Data (GMD)

We have run a short simple simulation and generated a sample GMD file. Our next goal is to generate a realistic GMD file that a different script can read in and generate an orbit determination solution. To add more realism, we will do the following:

- Generate data from additional ground stations
- Add the use of a ramp table
- Perform a longer simulation
- Add measurement noise

In order to generate measurement data from additional ground stations, we must first create and configure additional **GroundStation** objects. Below, we create and configure two new ground stations, **GDS** and **MAD**.

```
Create GroundStation GDS;
GDS.CentralBody          = Earth;
GDS.StateType            = Cartesian;
GDS.HorizonReference    = Ellipsoid;
GDS.Location1           = -2353.621251;
GDS.Location2           = -4641.341542;
GDS.Location3           = 3677.052370;
GDS.Id                  = '33333';
GDS.AddHardware          = {DSNTransmitter, DSNAntenna, DSNReceiver};
GDS.MinimumElevationAngle = 7.0;
GDS.IonosphereModel     = 'IRI2007';
GDS.TroposphereModel    = 'HopfieldSaastamoinen';

Create GroundStation MAD;
MAD.CentralBody          = Earth;
MAD.StateType            = Cartesian;
MAD.HorizonReference    = Ellipsoid;
MAD.Location1           = 4849.519988;
MAD.Location2           = -0360.641653;
MAD.Location3           = 4114.504590;
MAD.Id                  = '44444';
MAD.AddHardware          = {DSNTransmitter, DSNAntenna, DSNReceiver};
MAD.MinimumElevationAngle = 7.0;
MAD.IonosphereModel     = 'IRI2007';
MAD.TroposphereModel    = 'HopfieldSaastamoinen';
```

Now that we have defined two additional ground stations, we must specify the measurement noise associated with these new ground stations. This can be done using the previously created **ErrorModel** resources as shown below.

```
GDS.ErrorModels      = {DSNrange, DSNdoppler};  
MAD.ErrorModels     = {DSNrange, DSNdoppler};
```

Next, we must add the corresponding two way range and Doppler measurements associated with our new ground stations to our **TrackingFileSet** object, **DSNsimData**, as shown below.

```
DSNsimData.AddTrackingConfig = {{GDS, Sat, GDS}, 'DSN_SeqRange'};  
DSNsimData.AddTrackingConfig = {{GDS, Sat, GDS}, 'DSN_TCP'};  
  
DSNsimData.AddTrackingConfig = {{MAD, Sat, MAD}, 'DSN_SeqRange'};  
DSNsimData.AddTrackingConfig = {{MAD, Sat, MAD}, 'DSN_TCP'};
```

We now create our ramp table that many but not all missions use. A ramp table is a table that allows GMAT to calculate the transmit frequency of all the ground stations involved in our simulation. Recall that GMAT needs to know the transmit frequency, as a function of time, in order to calculate the value of the observations. The term “ramp” is used because the transmit frequency increases linearly with time and a graph of transmit frequency vs. time would typically show a ramp. A mission that does not use a ramp table simply uses a constant transmit frequency for a given ground station.

To modify our script to accommodate the use of a ramp table, we modify our **TrackingFileSet** object, **DSNsimData**, as shown below.

```
DSNsimData.RampTable = ...  
{'..../output/Simulate DSN Range and Doppler Data 3 weeks.rmp'};
```

We must now create a file with the name shown above in the GMAT ‘output’ directory. Refer to the **TrackingFileSet** Help for a description of the ramp table file format. In order for GMAT to determine the transmit frequencies of all the ground stations, the ramp table must have at least one row of data for every ground station providing measurement data. The contents of our ramp table is shown below.

```
27252 22222 11111 2 1 7.2e09 0.2  
27252 33333 11111 2 1 7.3e09 0.3  
27252 44444 11111 2 1 7.4e09 0.4
```

Each row of data above is called a ramp record. Let’s analyze the first ramp record. The first field, 27252, is the TAIMJD date of the ramp record.

The second field, 22222, is the ground station ID of the **GroundStation** object whose frequency is being specified. We note that the ID 22222 corresponds to the **CAN** ground station. The third field, 11111, is the ID of the spacecraft that the **CAN** ground station is transmitting to. We recognize 11111 as the ID of the **Sat** spacecraft.

The 4th field, 2, is an integer representing the uplink band of the transmission. The integer 2 represents X-band. The 5th field, 1, is an integer describing the ramp type. The integer 1 represents the start of a new ramp.

The 6th field, 7.2e9, is the transmission frequency in Hz, from **CAN** to **Sat** at the time given by the first field. The 7th input is the ramp rate in Hz/s.

We now describe how GMAT uses the ramp record to determine the transmit frequency of **CAN** to **Sat** at a given time. We let TAIMJD be the time associated with the ramp record. Then GMAT will calculate the value of the transmit frequency at  $t = 27252.5$  TAIMJD as shown below.

$$f(t) = f(t_o) + \text{RampRate} * 86400 * (t - t_o)$$

where

$f(t_o)$  = Transmit Frequency at the start of the ramp record

$f(t)$  = Transmit Frequency at a later time,  $t > t_o$

Note that, in the typical case where there are numerous ramp records, it is assumed that  $t_o < t$  is chosen as close to time  $t$  as possible. For our case above, the transmit frequency from **CAN** to **Sat** at time  $t$  is

$$f(t) = 7.2e9 + 0.2 * 86400 * (27252.5 - 27252) = 7200008640 \text{ Hz}$$

The second and third rows of the ramp table allow GMAT to calculate the transmit frequency from **GDS** to **Sat** and **MAD** to **Sat**, respectively. We now create a file, Simulate DSN Range and Doppler Data Realistic GMD.rmp, with the contents shown above and place it in GMAT's 'output' folder.

We make one final comment about the use of a ramp table. We note that when a ramp table is used, GMAT uses the various script inputs (e.g., **SatTransponder.TurnAroundRatio** and **DSNTransmitter.Frequency**) differently. See the **RunSimulator** Help for details.

We only have two steps remaining in order to create a script that generates more realistic measurement data. The first step is to increase the simulation time from 10 minutes to the more realistic three weeks worth of data that is typically needed to generate an orbit determination solution for a spacecraft in this type of deep space orbit. The second step is to turn on the measurement noise. These two steps are accomplished by making the following changes to our **TrackingFileSet** object, **DSNsimData**.

```
Sim.FinalEpoch      = '09 Sep 2015 00:00:00.000';
Sim.AddNoise        = On;
Sim.MeasurementTimeStep = 3600;
```

Note that above, in addition to implementing the two needed steps, we also changed the measurement time step from 600 seconds to 3600 seconds. This is not a realistic time step as many missions would use a time step that might even be less than 600 seconds. We used this larger time step for tutorial purposes only so that the script would not take too long to run.

A complete script, containing all the changes we have made in the [Create a more realistic GMAT Measurement Data \(GMD\)](#) section, is contained in the file, **Tut\_Simulate\_DSN\_Range\_and\_Doppler\_Data\_3\_weeks.script**. Note that in this file, in addition to the changes above, we have also changed the GMD output file name to **Simulate DSN Range and Doppler Data 3 weeks.gmd**.

Now run the script which should take approximately 2-3 minutes since we are generating much more data than previously. We will use the GMD file we have created here as

input to an estimation script we will build in the next tutorial, **Orbit Estimation using DSN Range and Doppler Data**.

## References

- |                 |   |
|-----------------|---|
| Mesarch [2007]  | M. Mesarch, M. Robertson, N. Ottenstein, A. Nicholson, M. Nicholson, D. Ward, J. Cosgrove, D. German, S. Hendry, J. Shaw, "Orbit Determination and Navigation of the SOlar TErestrial Relations Observatory (STEREO)", 20th International Symposium on Space Flight Dynamics, Annapolis, MD, September 24-28, 2007. |
| Moyer [2000]    | Moyer, Theodore D., Formulation for Observed and Computed Values of Deep Space Network Data Types for Navigation (JPL Publication 00-7), Jet Propulsion Laboratory, California Institute of Technology, October 2000.   |
| Schanzle [1995] | Schanzle, A., Orbit Determination Error Analysis System (ODEAS) Report on Error Sources and Nominal 3-Sigma Uncertainties for Covariance Analysis Studies Using ODEAS (Update No. 2), Computer Sciences Corporation (CSC) memo delivered as part of NASA contract NAS-5-31500, May 31, 1995.                        |

## Appendix A – Determination of Measurement Noise Values

We now say a few words on how we determined the values for **NoiseSigma** for the two **ErrorModel** resources we created. The computed value of the DSN range measurement is given by (Moyer [2000]):

$$C \int_{t_1}^{t_3} f_T(t) dt, \text{ mod } M \quad (\text{RU})$$

where

$t_1, t_3$  = Transmission and Reception epoch, respectively

$f_T$  = Ground Station transmit frequency

$C$  = transmitter dependent constant (221/1498 for X-band and 1/2 for S-Band)

$M$  = length of the ranging code in RU

We note that  $M$  as defined above is equal to **SimRangeModuloConstant** which was discussed in the *Define the types of measurements to be simulated* section.

By manipulation of the equation above, we can find a relationship between RU and meters, as shown below.

$$C \frac{d(\text{in meters})}{c} \bar{f}_T = d(\text{in RU})$$

where

$$\bar{f}_T = \frac{\int_{t_1}^{t_3} f_T(t) dt}{(t_3 - t_1)} = \text{average transmit frequency (between transmit and receive)},$$

c=speed of light in m/s  
d= round trip distance

If we assume the round trip distance is 1 meter, we have

$$d(\text{in RU}) = C \frac{\bar{f}_T}{c}$$

Recall that in the [Create and configure the Ground Station and related parameters](#) section, we set `DSNTransmitter.Frequency` = 7200; This corresponds to an X-band frequency (so,  $C=221/1498$ ) of  $7200e6$  Hz. For the case where a ramp table is not used, we have a constant frequency,  $\bar{f}_T = f_T$ , and thus

$$d(\text{in RU}) = \frac{221}{1498} \frac{7200e6}{299792458} = 3.543172 \text{ RU}$$

For this example, for DSN range measurements, we want to use a 1 sigma noise bias of 3 meters ([Schanzle \[1995\]](#)). From the calculations above, we determine that this corresponds to  $3*3.543172 \approx 10.63$  RU.

We now turn our attention to the DSN Doppler measurement. The DSN Doppler measurement that GMAT uses is actually a derived observation, O, calculated using two successive Total Count Phase,  $\phi$ , (type 17 Trk 2-34 record) measurements as shown below.

$$O \equiv -\frac{[\phi(t_{3e}) - \phi(t_{3s})]}{t_{3e} - t_{3s}} \text{ (Hz)}$$

where

$t_{1s}, t_{1e}$  = start and end of transmission interval

$t_{3s}, t_{3e}$  = start and end of reception interval

$\phi$  = Total Count Phase (type 17 Trk 2-34 record)

In the absence of measurement noise, one can show ([Moyer \[2000\]](#)), that the Observed value (O) above equals the Computed (C) value below.

$$C = -\frac{M_2}{(t_{3e} - t_{3s})} \int_{t_{1s}}^{t_{1e}} f_T(t_1) dt_1 = -\frac{M_2(t_{1e} - t_{1s})}{DCI} \bar{f}_T \text{ (Hz)}$$

where

$t_{1s}, t_{1e}$  = start and end of transmission interval

$f_T$  = transmit frequency

$M_2$  = Transponder turn around ratio (typically, 240/221 for S-band and 880/749 for X-band)

$DCI = (t_{3e} - t_{3s})$  = Doppler Count Interval

$$\int_{t_{1s}}^{t_{1e}} f_T(t_1) dt_1$$

$$\bar{f}_T \equiv \frac{t_{1e} - t_{1s}}{(t_{1e} - t_{1s})} = \text{average transmit frequency}$$

Neglecting ionospheric media corrections, further calculation ([Mesarch \[2007\]](#)) shows that the values of O and C can be related to an average range rate value,  $\bar{r}$ , as shown below.

$$\bar{\rho}_{Observed} = c \left( 1 + \frac{O}{M_2 \tilde{f}_T} \right), \quad \bar{\rho}_{Computed} = c \left( 1 + \frac{C}{M_2 \tilde{f}_T} \right)$$

where

$$\bar{\rho} \equiv \frac{(\text{Round Trip distance at } t_{3e}) - (\text{Round Trip distance at } t_{3s})}{t_{3e} - t_{3s}}$$

Thus, we determine that

$$\bar{\rho}_{Observed} - \bar{\rho}_{Computed} = \frac{c}{M_2 \tilde{f}_T} (O - C)$$

The quantity,  $(O - C)$ , above represents the measurement noise and thus the equation gives us a way to convert measurement noise in Hz to measurement noise in mm/s.

To convert from mm/s to Hz, simply multiply by  $\frac{M_2 \tilde{f}_T}{c} = \frac{M_2 \tilde{f}_T}{299792458000}$ . In our case, where we use a constant X-band frequency of 7.2e9, the conversion factor is given by  $\frac{880}{749} \frac{7.2e9}{299792458000} \approx 0.0282$ . For this tutorial, we use a 1 sigma noise value of 1 mm/s (Schanzle [1995]) which corresponds to this value of 0.0282 Hz.



# Orbit Estimation using DSN Range and Doppler Data

<b>Audience</b>	Intermediate level
<b>Length</b>	60 minutes
<b>Prerequisites</b>	Simulate DSN Range and Doppler Data Tutorial
<b>Script Files</b>	Tut_Orbit_Estimation_using_DSN_Range_and_Doppler_Data.script

## Objective and Overview



### Note

GMAT currently implements a number of different data types for orbit determination. Please refer to [Tracking Data Types for Orbit Determination](#) for details on all the measurement types currently supported by GMAT. The measurements being considered here are DSN two way range and DSN two way Doppler.

In this tutorial, we will use GMAT to read in simulated DSN range and Doppler measurement data for a sample spacecraft in orbit about the Sun and determine its orbit. The spacecraft is in an Earth “drift away” type orbit about 1 AU away from the Sun and almost 300 million km away from the Earth. This tutorial has many similarities with the Simulate DSN Range and Doppler Data Tutorial in that most of the same GMAT resources need to be created and configured. There are differences, however, in how GMAT uses the resources that we will point out as we go along.

The basic steps of this tutorial are:

1. Create and configure the spacecraft, spacecraft transponder, and related parameters
2. Create and configure the Ground Station and related parameters
3. Define the types of measurements to be processed
4. Create and configure Force model and propagator
5. Create and configure Batch Estimator object
6. Run the mission and analyze the results

Note that this tutorial, unlike most of the mission design tutorials, will be entirely script based. This is because most of the resources and commands related to navigation are not implemented in the GUI and are only available via the script interface.

As you go through the tutorial below, it is recommended that you paste the script segments into GMAT as you go along. After each paste into GMAT, you should perform a syntax check by hitting the Save, Sync button (). To avoid syntax errors, where needed, don’t forget to add the following command, as needed, to the last line of the script segment you are checking.

`BeginMissionSequence`

We note that in addition to the material presented here, you should also look at the individual Help resources for all the objects and commands we create and use here. For example, **Spacecraft**, **Transponder**, **Transmitter**, **GroundStation**, **ErrorModel**, **TrackingFileSet**, **RunEstimator**, etc all have their own Help pages.

## Create and configure the spacecraft, spacecraft transponder, and related parameters

For this tutorial, you'll need GMAT open, with a new empty script open. To create a new script, click **New Script**, (

### Create a satellite and set its epoch and Cartesian coordinates

Since this is a Sun-orbiting spacecraft, we choose to represent the orbit in a Sun-centered coordinate frame which we define using the scripting below.

```
% Create the Sun-centered J2000 frame.  
Create CoordinateSystem SunMJ2000Eq;  
SunMJ2000Eq.Origin = Sun;  
SunMJ2000Eq.Axes = MJ2000Eq; %Earth mean equator axes
```

Next, we create a new spacecraft, **Sat**, and set its epoch and Cartesian coordinates.

```
Create Spacecraft Sat;  
Sat.DateFormat = UTCGregorian;  
Sat.CoordinateSystem = SunMJ2000Eq;  
Sat.DisplayStateType = Cartesian;  
Sat.Epoch = 19 Aug 2015 00:00:00.000;  
Sat.X = -126544963 %-126544968  
Sat.Y = 61978518 %61978514  
Sat.Z = 24133225 %24133221  
Sat.VX = -13.789  
Sat.VY = -24.673  
Sat.VZ = -10.662  
  
Sat.Id = 11111;
```

Note that, in addition to setting **Sat**'s coordinates, we also assigned it an ID number. When GMAT finds this number in the GMD file that it reads in, it will know that the associated data corresponds to the **Sat Spacecraft**.

For the simulation tutorial, the Cartesian state above represented the “true” state. Here, the Cartesian state represents the spacecraft operator’s best “estimate” of the state, the so-called *a priori* estimate. Because, one never has exact knowledge of the true state, we have perturbed the Cartesian state above by a few km in each component as compared to the simulated true state shown in the comment field.

### Create a Transponder object and attach it to our spacecraft

To estimate an orbit state for a given spacecraft, GMAT requires that a **Transponder** object, which receives the ground station uplink signal and re-transmits it, typically, to

a ground station, be attached to the spacecraft. Below, we create the **Transponder** object and attach it to our spacecraft. Note that after we create the **Transponder** object, there are three fields, **PrimaryAntenna**, **HardwareDelay**, and **TurnAroundRatio** that must be set.

```
Create Antenna HGA; %High Gain Antenna

Create Transponder SatTransponder;
SatTransponder.PrimaryAntenna = HGA;
SatTransponder.HardwareDelay = 1e-06; %seconds
SatTransponder.TurnAroundRatio = '880/749';

Sat.AddHardware = {SatTransponder, HGA};
Sat.SolveFors = {CartesianState};
```

The **PrimaryAntenna** is the antenna that the spacecraft transponder, **SatTransponder**, uses to receive and retransmit RF signals. In the example above, we set this field to **HGA** which is an **Antenna** object we have created. Currently the **Antenna** resource has no function but in a future release, it may have a function. **HardwareDelay**, the transponder signal delay in seconds, is set to one micro-second.

We set **TurnAroundRatio**, which is the ratio of the retransmitted to the input signal, to '880/749.' See the **RunEstimator** Help for a discussion on how GMAT uses this input field. Recall that, as part of their calculations, estimators need to form a quantity called the observation residual, O-C, where O is the "Observed" value of a measurement and C is the "Computed," based upon the current knowledge of the orbit state, value of a measurement. As described in the Help, since our DSN data, for this tutorial, uses a ramp table, this input turn around ratio is not used to calculate the computed, C, Doppler measurements. Instead, the turn-around ratio used to calculate the computed Doppler measurement will be inferred from the value of the uplink band contained in the ramp table.

Note that in the second to last script command above, we attach our newly created **Transponder** resource, **SatTransponder**, and its related **Antenna** resource, **HGA**, to our spacecraft, **Sat**.

The last script line, which was not present in the simulation script, is needed to tell GMAT what quantities the estimator will be estimating, the so-called "solve-fors." Here, we tell GMAT to solve for the 6 components of our satellite's Cartesian state. Since we input the **Sat** state in SunMJ2000 coordinates, this is the coordinate system GMAT will use to solve for the Cartesian state.

## Create and configure the Ground Station and related parameters

### Create Ground Station Transmitter, Receiver, and Antenna objects

Before we create the **GroundStation** object itself, as shown below, we first create the **Transmitter**, **Receiver**, and **Antenna** objects that must be associated with any **GroundStation**.

```
% Ground Station electronics.
Create Transmitter DSNTransmitter;
Create Receiver DSNSReceiver;
Create Antenna DSNAntenna;

DSNTransmitter.PrimaryAntenna      = DSNAntenna;
DSNSReceiver.PrimaryAntenna       = DSNAntenna;
DSNTransmitter.Frequency          = 7200; %MHz
```

In the script segment above, we first created **Transmitter**, **Receiver**, and **Antenna** objects. The GMAT script line `DSNTransmitter.PrimaryAntenna = DSNAntenna`, sets the main antenna that the **Transmitter** resource, **DSNTransmitter**, will be using. Likewise, the `DSNSReceiver.PrimaryAntenna = DSNAntenna` script line sets the main antenna that the **Receiver** resource, **DSNSReceiver**, will be using. As previously mentioned, the **Antenna** object currently has no function, but we include it here both because GMAT requires it and for completeness since the **Antenna** resource may have a function in a future GMAT release. Finally, we set the transmitter frequency in the last GMAT script line above. See the **RunEstimator** Help for a complete description of how this input frequency is used. As described in the Help, since in this example we will be using a ramp table, this input frequency will not be used to calculate the computed value of the range and Doppler observations. Instead, the frequency value in the ramp table will be used to calculate the computed range and Doppler observations.

There is one clarification to the statement above. As discussed in the **RunEstimator** Help, the **DSNTransmitter.Frequency** value discussed above as well as the previously discussed **SatTransponder TurnAroundRatio** value will be used to calculate the, typically small, media corrections needed to determine the computed, C, value of the range and Doppler measurements.

## Create Ground Station

Below, we create and configure our **CAN GroundStation** object.

```
% Create ground station and associated error models
Create GroundStation CAN;
CAN.CentralBody           = Earth;
CAN.StateType              = Cartesian;
CAN.HorizonReference      = Ellipsoid;
CAN.Location1              = -4461.083514;
CAN.Location2              = 2682.281745;
CAN.Location3              = -3674.570392;
CAN.Id                     = 22222;
CAN.MinimumElevationAngle = 7.0;
CAN.IonosphereModel       = 'IRI2007';
CAN.TroposphereModel      = 'HopfieldSaastamoinen';
CAN.AddHardware            = {DSNTransmitter, DSNAntenna, ...
                           DSNSReceiver};
```

The script segment above is broken into five sections. In the first section, we create our **GroundStation** object and we set our Earth-Centered Fixed Cartesian coordinates. In

the second section, we set the ID of the ground station so that GMAT will be able to identify data from this ground station contained in the GMD file.

In the third section, we set the minimum elevation angle to 7 degrees. Below this ground station to spacecraft elevation angle, no measurement data will be used to form an orbit estimate. In the fourth section, we specify which troposphere and ionosphere model we wish to use to model RF signal atmospheric refraction effects. Finally, in the fifth section, we attach three pieces of previously created required hardware to our ground station, a transmitter, a receiver, and an antenna.

Next, we create and configure the **GDS GroundStation** resource, and associated **Transmitter** resource.

```
% Create GDS transmitter and ground station
Create GroundStation GDS;
GDS.CentralBody          = Earth;
GDS.StateType             = Cartesian;
GDS.HorizonReference     = Ellipsoid;
GDS.Location1             = -2353.621251;
GDS.Location2             = -4641.341542;
GDS.Location3             = 3677.052370;
GDS.Id                   = '33333';
GDS.MinimumElevationAngle = 7.0;
GDS.IonosphereModel      = 'IRI2007';
GDS.TroposphereModel     = 'HopfieldSaastamoinen';
GDS.AddHardware           = {DSNTransmitter, DSNAntenna, ...
                             DSNReceiver};
```

Next, we create and configure the **MAD GroundStation** resource, and associated **Transmitter** resource.

```
% Create MAD transmitter and ground station
Create GroundStation MAD;
MAD.CentralBody          = Earth;
MAD.StateType             = Cartesian;
MAD.HorizonReference     = Ellipsoid;
MAD.Location1             = 4849.519988;
MAD.Location2             = -360.641653;
MAD.Location3             = 4114.504590;
MAD.Id                   = '44444';
MAD.MinimumElevationAngle = 7.0;
MAD.IonosphereModel      = 'IRI2007';
MAD.TroposphereModel     = 'HopfieldSaastamoinen';
MAD.AddHardware           = {DSNTransmitter, DSNAntenna, ...
                             DSNReceiver};
```

## Create Ground Station Error Models

It is well known that all measurement types have random noise and/or biases associated with them. For GMAT, these effects are modelled using ground station error models.

Since we have already created the **GroundStation** object and its related hardware, we now create the ground station error models. Since we wish to form an orbit estimate using both range and Doppler data, we need to create two error models as shown below, one for range measurements and one for Doppler measurements.

```
% Create Ground station error models
Create ErrorModel DSNrage;
DSNrage.Type          = 'DSN_SeqRange';
DSNrage.NoiseSigma    = 10.63;
DSNrage.Bias          = 0.0;

Create ErrorModel DSNdoppler;
DSNdoppler.Type       = 'DSN_TCP';
DSNdoppler.NoiseSigma = 0.0282;
DSNdoppler.Bias       = 0.0;

CAN.ErrorModels        = {DSNrage, DSNdoppler};
GDS.ErrorModels        = {DSNrage, DSNdoppler};
MAD.ErrorModels        = {DSNrage, DSNdoppler};
```

The script segment above is broken into three sections. The first section defines an **ErrorModel** named **DSNrage**. The error model Type is DSN\_SeqRange which indicates that it is an error model for DSN sequential range measurements. The 1 sigma standard deviation of the Gaussian white noise is set to 10.63 Range Units (RU) and the measurement bias is set to 0 RU.

The second section above defines an **ErrorModel** named **DSNdoppler**. The error model **Type** is DSN\_TCP which indicates that it is an error model for DSN total count phase-derived Doppler measurements. The 1 sigma standard deviation of the Gaussian white noise is set to 0.0282 Hz and the measurement bias is set to 0 Hz. The range and Doppler **NoiseSigma** values above will be used to form measurement weighting matrices used by the estimator algorithm.

The third section above attaches the two **ErrorModel** resources we have just created to the **CAN**, **GDS**, and **MAD GroundStation** resources. Note that in GMAT, the measurement noise or bias is defined on a per ground station basis. Thus, any range measurement error involving the **CAN**, **GDS**, and **MAD GroundStation** is defined by the **DSN-Range ErrorModel** and any Doppler measurement error involving the **CAN**, **GDS**, and **MAD GroundStation** is defined by the **DSN-Doppler ErrorModel**. Note that, if desired, we could have created 6 different **ErrorModel** resources, two error models representing the two data types for 3 ground stations.

## Define the types of measurements that will be processed

Now we will create and configure a **TrackingFileSet** resource. This resource defines the type of data to be processed, the ground stations that will be used, and the file name of the input GMD file which will contain the measurement data. Note that in order to just cut and paste from our simulation tutorial, we name our resource **DSNsimData**. But, since, in this script, we are estimating, perhaps a better name would have been **DSNestData**.

```
Create TrackingFileSet DSNsimData;
```

```
DSNsimData.AddTrackingConfig      = {{CAN, Sat, CAN}, 'DSN_SeqRange'};  
DSNsimData.AddTrackingConfig      = {{CAN, Sat, CAN}, 'DSN_TCP'};  
DSNsimData.AddTrackingConfig      = {{GDS, Sat, GDS}, 'DSN_SeqRange'};  
DSNsimData.AddTrackingConfig      = {{GDS, Sat, GDS}, 'DSN_TCP'};  
DSNsimData.AddTrackingConfig      = {{MAD, Sat, MAD}, 'DSN_SeqRange'};  
DSNsimData.AddTrackingConfig      = {{MAD, Sat, MAD}, 'DSN_TCP'};  
DSNsimData.FileName               = ...  
                                {'../output/Simulate DSN Range and Doppler Data 3 weeks.gmd'};  
DSNsimData.RampTable              = ...  
                                {'../output/Simulate DSN Range and Doppler Data 3 weeks.rmp'};  
  
DSNsimData.UseLightTime           = true;  
DSNsimData.UseRelativityCorrection = true;  
DSNsimData.UseETminusTAI          = true;
```

The script lines above are broken into three sections. In the first section, the resource name, **DSNsimData**, is declared, the data types are defined, and the input GMD file and ramp table name are specified. **AddTrackingConfig** is the field that is used to define the data types. The first **AddTrackingConfig** line tells GMAT to process DSN range two way measurements for the **CAN** to **Sat** to **CAN** measurement strand. The second **AddTrackingConfig** line tells GMAT to process DSN Doppler two way measurements for the **CAN** to **Sat** to **CAN** measurement strand. The remaining 4 **AddTrackingConfig** script lines tell GMAT to also process **GDS** and **MAD** range and Doppler measurements. Note that the input GMD and ramp table files that we specified are files that we created as part of the **Simulate DSN Range and Doppler Data Tutorial**. Don't forget to put these files in the GMAT "output" directory.

The second section above sets some processing parameters that apply to both the range and Doppler measurements. We set **UseLightTime** to True in order to generate realistic computed, C, measurements that take into account the finite speed of light. The last two parameters in this section, **UseRelativityCorrection** and **UseETminusTAI**, are set to True so that general relativistic corrections, as described in Moyer [2000], are applied to the light time equations.

Note that, in the simulation tutorial, we set two other **DSNsimData** fields, **SimDopplerCountInterval** and **SimRangeModuloConstant**. Since these fields only apply to simulations, there is no need to set them here as their values would only be ignored.

## Create and configure Force model and propagator

We now create and configure the force model and propagator that will be used for the simulation. For this deep space drift away orbit, we naturally choose the Sun as our central body. Since we are far away from all the planets, we use point mass gravity models and we include the effects of the Sun, Earth, Moon, and most of the other planets. In addition, we model Solar Radiation Pressure (SRP) effects and we include the effect of general relativity on the dynamics. The script segment accomplishing this is shown below.

```
Create ForceModel Fm;  
Create Propagator Prop;  
Fm.CentralBody             = Sun;
```

```

Fm.PointMasses          = {Sun, Earth, Luna, Mars, Saturn, ...
                           Uranus, Mercury, Venus, Jupiter};
Fm.SRP                 = On;
Fm.RelativisticCorrection = On;
Fm.ErrorControl        = None;
Prop.FM                = Fm;
Prop.MinStep            = 0;

```

We set `ErrorControl = None` because for the current release of GMAT, batch estimation requires fixed step numerical integration. The fixed step size is given by `Prop.InitialStepSize` which has a default value of 60 seconds. For our deep space orbit, the dynamics are slowly changing and this step size is not too big. For more dynamic force models, a smaller step size may be needed.

## Create and configure BatchEstimator object

As shown below, we create and configure the **BatchEstimator** object used to define our estimation process.

```

Create BatchEstimator bat
bat.ShowProgress          = true;
bat.ReportStyle            = Normal;
bat.ReportFile             = ...
                           'Orbit Estimation using DSN Range and Doppler Data.report';
bat.Measurements          = {DSNsimData}
bat.AbsoluteTol            = 0.001;
bat.RelativeTol           = 0.0001;
bat.MaximumIterations      = 10
bat.MaxConsecutiveDivergences = 3;
bat.Propagator             = Prop;
bat.ShowAllResiduals       = On;
bat.OLSEInitialRMSSigma    = 10000;
bat.OLSEMultiplicativeConstant = 3;
bat.OLSEAdditiveConstant   = 0;
bat.EstimationEpochFormat = 'FromParticipants';
bat.InversionAlgorithm     = 'Internal';
bat.MatlabFile             = ...
                           'Orbit Estimation using DSN Range and Doppler Data.mat'

```

All of the fields above are described in **BatchEstimator** Help but we describe them briefly here as well. In the first script line above, we create a **BatchEstimator** object, **bat**. In the next line, we set the **ShowProgress** field to true so that detailed output of the batch estimator will be shown in the message window.

In the third line, we set the **ReportStyle** to Normal. For the R2025a GMAT release, this is the only report style that is available by default. If we wanted to see additional data such as measurement partial derivatives, we would use the Verbose style by setting `RUN_MODE = Testing` in the GMAT startup file. In the next line, we set the **ReportFile** field to the name of our desired output file which by default is written to GMAT's 'output' directory.

We set the Measurements field to the name of the **TrackingFileSet** resource we wish to use. Recall that the **TrackingFileSet**, **DSNsimData**, that we created in the [Define the types of measurements that will be processed](#) section defines the type of measurements that we wish to process. In our case, we wish to process DSN range and Doppler data associated with the **CAN**, **GDS**, and **MAD** ground stations.

The next four fields, **AbsoluteTol**, **RelativeTol**, **MaximumIterations**, and **MaxConsecutiveDivergences** define the batch estimator convergence criteria. See the “Behavior of Convergence Criteria” discussion in the **BatchEstimator** Help for complete details.

The next script line sets the Propagator field which specifies which **Propagator** object should be used during estimation. We set this field to the **Prop Propagator** object which we created in the [Define the types of measurements that will be processed](#) section.

In the 11th script line, we set the **ShowAllResiduals** field to true show that the observation residuals plots, associated with the various ground stations, will be displayed

The next three script lines set fields, **OLSEInitialRMSSigma**, **OLSEMultiplicativeConstant**, and **OLSEAdditiveConstant**, that are associated with GMAT’s Outer Loop Sigma Editing (OLSE) capability that is used to edit, i.e., remove, certain measurements so that they are not used to calculate the orbit estimate. See the “Behavior of Outer Loop Sigma Editing (OLSE)” discussion in the **BatchEstimator** Help for complete details.

Next, we set the **EstimationEpochFormat** field to ‘FromParticipants’ which tells GMAT that the epoch associated with the solve-for variables, in this case the Cartesian State of **Sat**, comes from the value of **Sat.Epoch** which we have set to “19 Aug 2015 00:00:00.000 UTCG.”

Next, we set the **InversionAlgorithm** field to ‘Internal’ which specifies which algorithm GMAT should use to invert the normal equations. There are two other inversion algorithms, ‘Cholesky’ or ‘Schur’ that we could optionally use.

Finally, we set the value of **MatlabFile**. This is the name of the MATLAB output file that will be created, which, by default, is written to GMAT’s ‘output’ directory. This file can be read into MATLAB to perform detailed calculations and analysis. The MATLAB file can only be created if you have MATLAB installed and properly configured for use with GMAT.

## Run the mission and analyze the results

The script segment used to run the mission is shown below.

```
BeginMissionSequence  
RunEstimator bat
```

The first script line, **BeginMissionSequence**, is a required command which indicates that the “Command” section of the GMAT script has begun. The second line of the script issues the **RunEstimator** command with the bat **BatchEstimator** resource, defined in the [Create and configure BatchEstimator object](#) section, as an argument. This tells GMAT to perform the estimation using parameters specified by the bat resource.

We have now completed all of our script segments. See the file, `Tut_Orbit_Estimation_using_DSN_Range_and_Doppler_Data.script`, in the samples folder, for a listing of the entire script. We are now ready to run the script. Hit the Save,Sync,Run button, (`Save,Sync,Run`). Given the amount of data we are processing, our mission orbit, and our choice of force model, the script should finish execution in about 1-2 minutes.

We analyze the results of this script in many ways. In the first subsection, we analyze the Message window output. In the second subsection, we look at the plots of the observation residuals, and in the third subsection, we analyze the batch estimation report. Finally, in the fourth subsection, we discuss how the contents of the MATLAB output file can be used to analyze the results of our estimation process.

## Message Window Output

We first analyze the message window output focusing on the messages that may require some explanation. Follow along using [Appendix A – GMAT Message Window Output](#) where we have put a full listing of the output. Soon into the message flow, we get a message telling us how many measurement records were read in.

```
Data file '../output/Simulate DSN Range and Doppler Data 3 weeks.gmd' has 1348
of 1348 records used for estimation.
```

The value of 1348 is the number of lines of measurement data in the GMD file listed above.

Next, the window output contains a description of the tracking configuration. The output below confirms that we are processing range and Doppler data from the **CAN**, **GDS**, and **MAD** ground stations.

```
List of tracking configurations (present in participant ID) for load
records from data file
'../output/Simulate DSN Range and Doppler Data 3 weeks.gmd':
Config 0: {{22222,11111,22222},DSN_SeqRange}
Config 1: {{22222,11111,22222},DSN_TCP}
Config 2: {{33333,11111,33333},DSN_SeqRange}
Config 3: {{33333,11111,33333},DSN_TCP}
Config 4: {{44444,11111,44444},DSN_SeqRange}
Config 5: {{44444,11111,44444},DSN_TCP}
```

Later on in the output, GMAT echoes out the a priori estimate that we input into the script.

```
a priori state:
Estimation Epoch:
27253.5004170646025158930570 A.1 modified Julian
27253.5004166666661733004647 TAI modified Julian
19 Aug 2015 00:00:00.000 UTCG
Sat.SunMJ2000Eq.X = -126544963
Sat.SunMJ2000Eq.Y = 61978518
Sat.SunMJ2000Eq.Z = 24133225
Sat.SunMJ2000Eq.VX = -13.789
```

```
Sat.SunMJ2000Eq.VY = -24.673
Sat.SunMJ2000Eq.VZ = -10.662
```

Next, GMAT outputs some data associated with the initial iteration of the Outer Loop Sigma Editing (OLSE) process as shown below.

```
Number of Records Removed Due To:
  . No Computed Value Configuration Available : 0
  . Out of Ramp Table Range      : 0
  . Signal Blocked              : 0
  . Initial RMS Sigma Filter   : 0
  . Outer-Loop Sigma Editor    : 0
Number of records used for estimation: 1348
```

As previously mentioned, the OLSE process can edit (i.e., remove) certain data from use as part of the estimation algorithm. There are five conditions which could cause a data point to be edited. For each condition, the output above specifies how many data points were edited. We now discuss the meaning of the five conditions.

The first condition, “No Computed Value Configuration Available” means that GMAT has read in some measurement data but no corresponding tracking configuration has been defined in the GMAT script. Thus, GMAT has no way to form the computed, C, value of the measurement. For example, this might happen if our script did not define a **GroundStation** object corresponding to some data in the GMD file. Since we have defined everything we need to, no data points are edited for this condition.

The second condition, “Out of Ramp Table Range,” means that while solving the light time equations, GMAT needs to know the transmit frequency, for some ground station, at a time that is not covered by the ramp table specified in our **TrackingFileSet** resource, **DSNsimData**. Looking at our input GMD file, we see that our measurement times range from 27253.5004166... to 27274.500416666... TAIMJD. Since our ramp table has a ramp record for all three ground stations at 27252 TAIMJD which is about 1 ½ days before the first measurement and since our *a priori* Cartesian state estimate is fairly good, it makes sense that no measurements were edited for this condition.

The third condition, “Signal Blocked,” indicates that while taking into account its current estimate of the state, GMAT calculates that a measurement for a certain measurement strand is not possible because the signal is “blocked.” Actually, the signal does not have to be blocked, it just has to violate the minimum elevation angle constraint associated with a given ground station. Consider a **GDS** to **Sat** to **GDS** range two way range measurement at given time. If the **GDS** to **Sat** elevation angle was 6 degrees, the measurement would be edited out since the minimum elevation angle, as specified by the **GDS.MinimumElevationAngle** field, is set at 7 degrees. Since, in our simulation, we specified that only data meeting this 7 degree constraint should be written out, it is plausible that no data were edited because of this condition.

The fourth condition, “Initial RMS Sigma Filter,” corresponds to GMAT’s OLSE processing for the initial iteration. As mentioned before, you can find a complete description of the OLSE in the “Behavior of Outer Loop Sigma Editing (OLSE)” discussion in the **BatchEstimator** Help. As described in the Help, for the initial iteration, data is edited if

$|Weighted\ Measurement\ Residual| > \text{OLSEInitialRMSSigma}$

where the Weighted Measurement Residual for a given measurement is given by

$(O-C)/\text{NoiseSigma}$

and where **NoiseSigma** are inputs that we set when we created the various **ErrorModel** resources.

We note that for a good orbit solution, the Weighted Measurement Residual has a value of approximately one. Since our *a priori* state estimate is not that far off from the truth and since we have set **OLSEInitialRMSSigma** to a very large value of 10,000, we do not expect any data to be edited for this condition.

The fifth condition, “Outer-Loop Sigma Editor,” corresponds to GMAT’s OLSE processing for the second or later iteration. Since the output we are analyzing is for the initial iteration of the batch estimator, the number of data points edited because of this condition is 0. We will discuss the OLSE processing for the second or later iterations when we analyze the output for a later iteration.

```
WeightedRMS residuals for this iteration : 1459.96324774
BestRMS residuals : 1459.96324774
PredictedRMS residuals for next iteration: 0.977684716761
```

The first output line above gives the weighted RMS calculated when the estimate of the state is the input *a priori* state (i.e., the 0th iteration state). The weighted RMS value of approximately 1460 is significantly far away from the value of 1 associated with a good orbit solution. The second output line gives the best (smallest) weighted RMS value for all of the iterations. Since this is our initial iteration, the value of the BestRMS is the same as the WeightedRMS. The third output line is the predicted weighted RMS value for the next iteration. Because of the random noise involved in generating the simulated input data, the numbers you see will differ from that above.

Next, GMAT outputs the state associated with the first iteration of the batch estimator. Let’s define what we mean by iteration. The state at iteration ‘n’ is the state after GMAT has solved the so-called normal equations (e.g., Eq. 4.3.22 or 4.3.25 in Tapley [2004]) ‘n’ successive times. By convention, the state at iteration 0 is the input *a priori* state.

-----  
Iteration 1

Current estimated state:

```
Estimation Epoch:
27253.5004170646025158930570 A.1 modified Julian
27253.5004166666661733004647 TAI modified Julian
19 Aug 2015 00:00:00.000 UTCG
Sat.SunMJ2000Eq.X = -126544964.083
Sat.SunMJ2000Eq.Y = 61978520.0714
Sat.SunMJ2000Eq.Z = 24133223.2424
Sat.SunMJ2000Eq.VX = -13.789001388
Sat.SunMJ2000Eq.VY = -24.6729990628
```

```
Sat.SunMJ2000Eq.VZ = -10.662000523
```

Next, GMAT outputs statistics on how many data points were edited for this iteration.

Number of Records Removed Due To:

- . No Computed Value Configuration Available : 0
- . Out of Ramp Table Range : 0
- . Signal Blocked : 0
- . Initial RMS Sigma Filter : 0
- . Outer-Loop Sigma Editor : 1

Number of records used for estimation: 1347

For the same reasons we discussed for the initial 0th iteration, as expected, no data points were edited because “No Computed Value Configuration Available” or because a requested frequency was “Out of Ramp Table Range.” Also, for the same reasons discussed for the 0th iteration, it is plausible that no data points were edited for this iteration because of signal blockage. Note that there are no data points edited because of the “Initial RMS Sigma Filter” condition. This is as expected because this condition only edits data on the initial 0th iteration. Finally, we note that, in this example, 1 data point out of 1348 data points are edited because of the OLSE condition. Due to the randomness of the noise added in the simulation step, you may see more or fewer points edited.

As discussed in the “Behavior of Outer Loop Sigma Editing (OLSE)” section in the **BatchEstimator Help**, data is edited if

$$|\text{Weighted Measurement Residual}| > \text{OLSEMultiplicativeConstant} * \text{WRMSP} + \text{OLSEAdditiveConstant}$$

where

WRMSP is the predicted weighted RMS calculated at the end of the previous iteration.

In the [Create and configure BatchEstimator object](#) section, we chose **OLSEMultiplicativeConstant** = 3 and **OLSEAdditiveConstant** = 0 and thus the equation above becomes

$$|\text{Weighted Measurement Residual}| > 3 * \text{WRMSP}$$

It is a good sign that only a few points are edited out. If too much data is edited out, even if you have a good weighted RMS value, it indicates that you may have a problem with your state estimate. Next, GMAT outputs some root mean square, (RMS), statistical data associated with iteration 1.

```
WeightedRMS residuals for this iteration : 0.974259069508
BestRMS residuals : 0.974259069508
PredictedRMS residuals for next iteration: 0.974224174165
```

The first output line above gives the weighted RMS calculated when the estimate of the state is the iteration 1 state. The weighted RMS value shown here of 0.974 is close to the value of 1 associated with a good orbit solution. The second output line gives

the best (smallest) weighted RMS value for all of the iterations. Since this iteration 1 WeightedRMS value is the best so far, BestRMS is set to the current WeightedRMS value. The third output line is the predicted weighted RMS value for the next iteration. Note that the RMS values calculated above only use data points that are used to form the state estimate. Thus, the edited points are not used to calculate the RMS.

Because the predicted WeightedRMS value is very close to the BestRMS value, GMAT, as shown in the output below, concludes that the estimation process has converged. As previously mentioned, see the “Behavior of Convergence Criteria” discussion in the **BatchEstimator** Help for complete details.

This iteration is converged due to relative convergence criteria.

```
*****
*** Estimating Completed in 2 iterations
*****
```

Estimation converged!

$|1 - \text{RMSP/RMSB}| = |1 - 0.974224 / 0.974259| = 3.58173e-05$  is less than RelativeTol, 0.0001

GMAT then outputs the final, iteration 2, state. Note that GMAT does not actually calculate the weighted RMS associated with this state but we assume that it is close to the predicted value of 1.00804237273 that was previously output.

Final Estimated State:

```
Estimation Epoch:
27253.5004170646025158930570 A.1 modified Julian
27253.5004166666661733004647 TAI modified Julian
19 Aug 2015 00:00:00.000 UTCG
Sat.SunMJ2000Eq.X = -126544963.637
Sat.SunMJ2000Eq.Y = 61978520.6939
Sat.SunMJ2000Eq.Z = 24133223.6628
Sat.SunMJ2000Eq.VX = -13.7890015517
Sat.SunMJ2000Eq.VY = -24.6729992038
Sat.SunMJ2000Eq.VZ = -10.6620000077
```

Finally, GMAT outputs the final Cartesian state error covariance matrix and correlation matrix, as well as the time required to complete this script.

Final Covariance Matrix:

6.568631977218e+00	1.044777728608e+01	3.117063688646e+00	-2.346661054173e-06	4.986079628477e-07	1.614625814366e-06
1.044777710993e+01	2.043036379635e+01	-4.249227712186e+00	-3.704711284679e-06	1.982306082751e-07	3.981551919217e-06
3.117064114026e+00	-4.249226952008e+00	2.371354504010e+01	-1.180689659682e-06	1.672460285882e-06	-2.645600028262e-06
-2.346661055323e-06	-3.704711349403e-06	-1.180689508343e-06	8.389295488954e-13	-1.640460214611e-13	-6.093850987987e-13
4.986079968962e-07	1.982306774906e-07	1.672460265672e-06	-1.6046035201e-13	1.032410080241e-12	-2.192341045550e-12
1.614625733805e-06	3.981551830454e-06	-2.645600161576e-06	-6.093050697768e-13	-2.192341060048e-12	5.785215030292e-12

Final Correlation Matrix:

1.000000000000	0.901879241925	0.249752571898	-0.999655028427	0.191467746900	0.261923625542
0.901879226720	1.000000000000	-0.193051736939	-0.894856861497	0.043162495440	0.366230559395
0.249752605981	-0.193051702403	1.000000000000	-0.264712696708	0.338011482643	-0.225873973518
-0.999655028917	-0.894856877130	-0.264712662778	1.000000000000	-0.176269377245	-0.276574613248
0.191467759975	0.043162510510	0.338011478559	-0.176269377245	1.000000000000	-0.897061553257
0.261923612473	0.366230551230	-0.225873984900	-0.276574600074	-0.897061559189	1.000000000000

```
*****
Mission run completed.  
==> Total Run Time: 220.532 seconds  
=====
```

## Plots of Observation Residuals

GMAT creates plots on a per iteration, per ground station, and per measurement type basis. We elaborate on what this means. When the script first runs, the first plots that show up are the 0th iteration residuals. This means that when calculating the 'O-C' observation residual, GMAT calculates the Computed, C, value of the residual using the a priori state. As shown in [Appendix B – Zeroth Iteration Plots of Observation Residuals](#), there are 6 of these 0th iteration residual plots. For each of the 3 stations, there is one plot of the range residuals and one plot of the Doppler residuals. After iteration 1 processing is complete, GMAT outputs the iteration 1 residuals as shown in [Appendix C – First Iteration Plots of Observation Residuals](#). As previously mentioned, although for this script, GMAT takes two iterations to converge, the actual iteration 2 residuals are neither calculated nor plotted. [DSN\\_Estimation\\_Create\\_and\\_configure\\_the\\_Ground\\_Station\\_and\\_related\\_parameters](#)

We now analyze the CAN range and Doppler residuals. For the 0th iteration, the range residuals vary from approximately 11,000 to 31,000 RU. These residuals are this large because our a priori estimate of the state was deliberately perturbed from the truth. There are multiple indicators on this graph that indicate that GMAT has not yet converged. First, the residuals have an approximate linear structure. If you have modeled the dynamics and measurements correctly, the plots should have a random appearance with no structure. Additionally, the residuals are biased, i.e., they do not have zero mean. For a well modeled system, the mean value of the residuals should be near zero. Finally, the magnitude of the range residuals is significantly too large. Recall that in the [Create and configure the Ground Station and related parameters](#) section, we set the 1 sigma measurement noise for the CAN range measurements to 10.63 RU. Thus, for a large sample of measurements, we expect, roughly, that the vast majority of measurements will lie between the values of approximately -32 and +32 RU. Taking a look at the 1st iteration CAN range residuals, this is, approximately, what we get.

The 0th iteration **CAN** Doppler residuals range from approximately 0.0050 to 0.01535 Hz. As was the case for the range 0th iteration residuals, the fact that the Doppler residuals are biased indicates that GMAT has not yet converged. Recall that in the [Create and configure the Ground Station and related parameters](#) section, we set the 1 sigma measurement noise for the **CAN** Doppler measurements to 0.0282 Hz. Thus, for a large sample of measurements, we expect, roughly, that the vast majority of measurements will lie between the values of approximately -0.0846 and +0.0846 RU. Taking a look at the 1st iteration **CAN** Doppler residuals, this is, approximately, what we get.

There is one important detail on these graphs that you should be aware of. GMAT only plots the residuals for data points that are actually used to calculate the solution. Recall that for iteration 0, all 1348 of 1348 total measurements were used to calculate the orbit state, i.e., no data points were edited. Thus, if you counted up all the data points

on the 6 iteration 0 plots, you would find 1348 points. The situation is different for the 1st iteration. Recall that for iteration 1, 1347 of 1348 total measurements were used to calculate the orbit state, i.e., 1 data point was edited. Thus, if you counted up all the data points on the 6 iteration 1 plots, you would find 1347 points. If you wish to generate plots that contain both non-edited and edited measurements, you will need to generate them yourself using the MATLAB output file as discussed in the [Matlab Output File](#) section.

We note that the graphs have some interactive features. Hover your mouse over the graph of interest and then right click. You will see that you have four options. You can toggle both the grid lines and the Legend on and off. You can also export the graph data to a text file, and finally, you can export the graph image to a bmp file.

## Batch Estimator Output Report

When we created our BatchEstimator resource, bat, in the [Create and configure Batch-Estimator object](#) section, we specified that the output file name would be 'Orbit Estimation using DSN Range and Doppler Data.report'. Go to GMAT's 'output' directory and open this file, preferably using an editor such as Notepad++ where you can easily scroll across the rows of data.

The first approximately 150 lines of the report are mainly an echo of the parameters we input into the script such as initial spacecraft state, force model, propagator settings, measurement types to be processed, etc.

After this echo of the input data, the output report contains measurement residuals associated with the initial 0th iteration. Search the file for the words, 'ITERATION 0: MEASUREMENT RESIDUALS' to find the location of where the relevant output begins. This output sections contains information on all of the measurements, both non-edited and edited, that can possibly be used in the estimation process. Each row of data corresponds to one measurement. For each measurement, the output tells you the following

- Iteration Number
- Record Number
- Epoch in UTC Gregorian format
- Observation type. 'DSN\_SeqRange' corresponds to DSN sequential range and 'DSN\_TCP' corresponds to DSN total count phase-derived Doppler.
- Participants. For example, '22222,11111,22222' tells you that your measurement comes from a **CAN to Sat to CAN link**.
- Edit Criteria.
- Observed Value (O)
- Computed Value (C)
- Observation Residual (O-C)
- Elevation Angle

We have previously discussed the edit criteria. In particular, we discussed the various reasons why data might be edited. If no edit code is shown for a residual record, this means that the data was not edited and the data was used, for this iteration, to calculate a state estimate.

Note that if the elevation angle of any of the measurements is below our input criteria of 7 degrees, then the measurement would be edited because the signal would be con-

sidered to be “blocked.” For range data, we would see  $B_n$  where  $n$  is an integer specifying the leg number. For our two way range data type, we have two legs, the uplink leg represented by the integer, 1, and the downlink leg, represented by the integer 2. Thus, if we saw “B1” in this field, this would mean that the signal was blocked for the uplink leg. Correspondingly, for Doppler data, we would also see  $B_n$ , but the integer  $n$  would be 1 or 2 depending upon whether the blockage occurred in the start path ( $n=1$ ) or the end path ( $n=2$ ).

After all of the individual iteration 0 residuals are printed out, four different iteration 0 observation summary reports, as shown below, are printed out.

- Observation Summary by Station and Data Type
- Observation Summary by Data Type and Station
- Observation Summary by Station
- Observation Summary by Data Type

After all of the observation summaries are printed out, the updated state and covariance information, obtained by processing the previous residual information, are printed out. The output also contains statistical information about how much the individual components of the state estimate have changed for this iteration.

At this point, the output content repeats itself for the next iteration. The new state estimate is used to calculate new residuals and the process starts all over again. The process stops when the estimator has either converged or diverged.

We now give an example of how this report can be used. In the [Message Window Output](#) section, we noted that, for iteration 1, some measurements were edited because of the OLSE criteria. Let’s investigate this in more detail. What type of data was edited? From what station? Could there be a problem with this data type at this station? We look at the ‘Observation Summary by Station and Data Type’ for iteration 1. We see that one range measurement from the **CAN** station was edited. The mean residual and 1-sigma standard deviation for **GDS** range measurements was -0.2222339 and 10.082896 RU, respectively. The mean residual and 1-sigma standard deviation for **MAD** range measurements was 0.199925 and 10.205535 RU, respectively.

Now that we know that the issue was with **GDS** and **MAD** range measurements, we look at the detailed residual output, for iteration 1, to determine the time these measurements occurred. We can search for the OLSE keyword to help do this. We determine that a **CAN** range measurement was edited at 02 Sep 2015 04:00:00.000 UTCG and that it had an observation residual of -33.161377 RU. This is just a bit beyond the 3-sigma value and we conclude that there is no real problem with the **CAN** range measurements. This is just normal statistical variation.

We remind you, that when you do your run, you may have a different number of data points edited. This is because, when you do your simulation, GMAT uses a random number generator and you will be using a different data set.

## Matlab Output File

In the [Create and configure BatchEstimator object](#) section, when we created our **BatchEstimator** resource, bat, we chose our MATLAB output file name, 'Orbit Estimation

using DSN Range and Doppler Data.mat.' By default, this file is created in GMAT's 'output' directory. This file will only be created if you have MATLAB installed and properly configured for use with GMAT.

Start up a MATLAB session. Change the directory to your GMAT 'output' directory and then type the following at the MATLAB command prompt.

```
>> load 'Orbit Estimation using DSN Range and Doppler Data.mat'
```

After the file has loaded, type the following command to obtain a list of available variable names inside this file.

```
>> whos
```

You should see something similar to the following:

Name	Size	Bytes	Class	Attributes
EstimationConfig	1x1	2894	struct	
Iteration	2x1	1479640	struct	
Observed	1x1	1232484	struct	

Each of the variables is a structure with multiple fields containing arrays of data such as measurements, residuals, edit flags, state information, and other information useful for analysis. Full details on the contents of the BatchEstimator MATLAB file can be found in the section called "["Batch Estimator MATLAB Data File"](#)" in the BatchEstimator resource documentation.

You can use the data in the MATLAB file to perform custom plots and statistical analysis using MATLAB. For example, to produce a plot of all range residuals from the second iteration, you can do the following:

```
>> I = find(strcmp(Observed.MeasurementType, 'DSN_SeqRange'));
>> t = Observed.EpochUTC(1,I);
>> y = cell2mat(Iteration(2).Residual(I));
>> plot(t, y, 'go');
>> datetick
```

## References

- GTDS [1989] Goddard Trajectory Mathematical Theory, Revision 1, Edited by A. Long, J. Cappellari, et al., Computer Sciences Corporation, FDD, FDD-552-89-0001, July 1989.
- GTDS [2007] Goddard Trajectory Determination System User's Guide, National Aeronautics and Space Administration, GSFC, Greenbelt, MD, MOMS-FD-UG-0346, July 2007
- Moyer [2000] Moyer, Theodore D., Formulation for Observed and Computed Values of Deep Space Network Data Types for Navigation (JPL Publication 00-7), Jet Propulsion Laboratory, California Institute of Technology, October 2000.

Tapley [2004] Tapley, Schutz, Born, Statistical Orbit Determination, Elsevier, 2004

## Appendix A – GMAT Message Window Output

```

Running mission...
Number of thrown records due to:
    .Invalid measurement value : 0
    .Record duplication or time order : 0
Data file '..\output\Simulate DSN Range and Doppler Data 3 weeks.gmd' has 1348 of 1348 records used for estimation.
Total number of load records : 1348

List of tracking configurations (present in participant ID) for load records from data file '..\output\Simulate DSN Range and Doppler Data 3 weeks.gmd':
Config 0: {{22222,11111,22222},DSN_SeqRange}
Config 1: {{22222,11111,22222},DSN_TCP}
Config 2: {{33333,11111,33333},DSN_SeqRange}
Config 3: {{33333,11111,33333},DSN_TCP}
Config 4: {{44444,11111,44444},DSN_SeqRange}
Config 5: {{44444,11111,44444},DSN_TCP}

***** No tracking configuration was generated because the tracking configuration is defined in the script.

Initializing new mat data writer
MATLAB file will be written to C:\Users\sslojkow\Documents\gmat\builds\LatestCompleteVersion\bin..\output\Orbit Estimation using DSN Range and Doppler Data.mat
MATLAB Writer .mat version w5 invalid; defaulting to w6
*****
*** Performing Estimation (using "bat")
***
****

a priori state:
Estimation Epoch:
27253.5004170646025158930570 A.1 modified Julian
27253.5004166666661733004647 TAI modified Julian
19 Aug 2015 00:00:00.000 UTCG
Sat.SunMJ2000Eq.X = -126544963
Sat.SunMJ2000Eq.Y = 61978518
Sat.SunMJ2000Eq.Z = 24133225
Sat.SunMJ2000Eq.VX = -13.789
Sat.SunMJ2000Eq.VY = -24.673
Sat.SunMJ2000Eq.VZ = -10.662

Number of Records Removed Due To:
. No Computed Value Configuration Available : 0
. Out of Ramp Table Range : 0
. Signal Blocked : 0
. Initial RMS Sigma Filter : 0
. Outer-Loop Sigma Editor : 0
Number of records used for estimation: 1348

WeightedRMS residuals for this iteration : 1459.96324774
BestRMS residuals : 1459.96324774
PredictedRMS residuals for next iteration: 0.977684716761

-----
Iteration 1

Current estimated state:
Estimation Epoch:
27253.5004170646025158930570 A.1 modified Julian
27253.5004166666661733004647 TAI modified Julian
19 Aug 2015 00:00:00.000 UTCG
Sat.SunMJ2000Eq.X = -126544964.083
Sat.SunMJ2000Eq.Y = 61978520.0714
Sat.SunMJ2000Eq.Z = 24133223.2424
Sat.SunMJ2000Eq.VX = -13.789001388
Sat.SunMJ2000Eq.VY = -24.6729990628
Sat.SunMJ2000Eq.VZ = -10.662000523

Number of Records Removed Due To:
. No Computed Value Configuration Available : 0
. Out of Ramp Table Range : 0
. Signal Blocked : 0
. Initial RMS Sigma Filter : 0
. Outer-Loop Sigma Editor : 1
Number of records used for estimation: 1347

WeightedRMS residuals for this iteration : 0.974259069508
BestRMS residuals : 0.974259069508
PredictedRMS residuals for next iteration: 0.974224174165
This iteration is converged due to relative convergence criteria.

*****
*** Estimation Completed in 2 iterations
****

Estimation converged!
|1 - RMSP/RMSB| = |1 - 0.974224 / 0.974259| = 3.58173e-05 is less than RelativeTol, 0.0001

Final Estimated State:

Estimation Epoch:
27253.5004170646025158930570 A.1 modified Julian
27253.5004166666661733004647 TAI modified Julian

```

```
19 Aug 2015 00:00:00.000 UTCG
Sat.SunMJ2000Eq.X = -126544963.637
Sat.SunMJ2000Eq.Y = 61978520.6939
Sat.SunMJ2000Eq.Z = 24133223.6628
Sat.SunMJ2000Eq.VX = -13.7890015517
Sat.SunMJ2000Eq.VY = -24.6729992038
Sat.SunMJ2000Eq.VZ = -10.6620000077
```

## Final Covariance Matrix:

6.568631977218e+00	1.044777728608e+01	3.117063688646e+00	-2.346661054173e-06	4.986079628477e-07	1.614625814366e-06
1.044777710993e+01	2.043036379635e+01	-4.249227712186e+00	-3.704711284679e-06	1.982306082751e-07	3.981551919217e-06
3.117064114026e+00	-4.249226952008e+00	2.371354504010e+01	-1.180689659682e-06	1.672460285882e-06	-2.645600028262e-06
-2.346661055323e-06	-3.704711349403e-06	-1.180689508343e-06	8.389295488954e-13	-1.640460214611e-13	-6.093050987987e-13
4.98607968962e-07	1.982306774906e-07	1.672460265672e-06	-1.640460335201e-13	1.032410880241e-12	-2.192341045550e-12
1.614625733805e-06	3.981551830454e-06	-2.645600161576e-06	-6.093050697768e-13	-2.192341060048e-12	5.785215030292e-12

## Final Correlation Matrix:

1.000000000000	0.901879241925	0.249752571898	-0.999655028427	0.191467746900	0.261923625542
0.901879226720	1.000000000000	-0.193051736939	-0.894856861497	0.043162495440	0.366230559395
0.249752605981	-0.193051702403	1.000000000000	-0.264712696708	0.338011482643	-0.225873973518
-0.999655028917	-0.894856877130	-0.264712662778	1.000000000000	-0.176269364287	-0.276574613248
0.191467759975	0.043162510510	0.338011478559	-0.176269377245	1.000000000000	-0.897061553257
0.261923612473	0.366230551230	-0.225873984900	-0.276574600074	-0.897061559189	1.000000000000

\*\*\*\*\*

Writing Estimator MATLAB File...

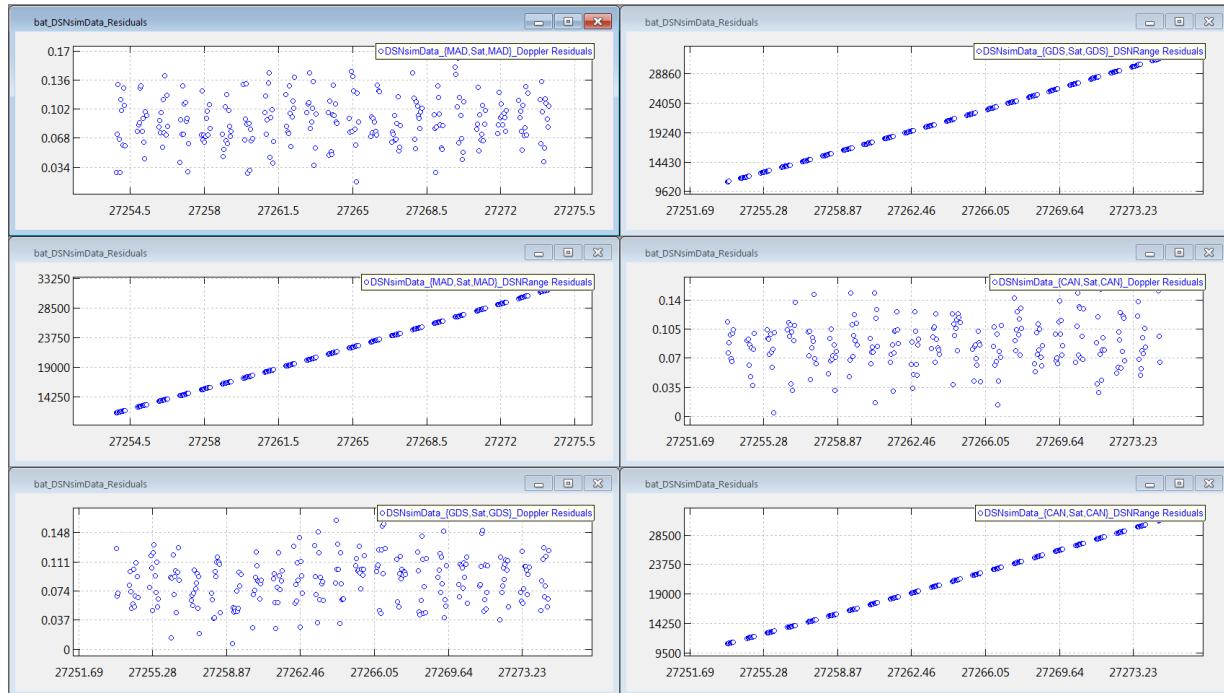
Finished Writing Estimator MATLAB File.

Mission run completed.

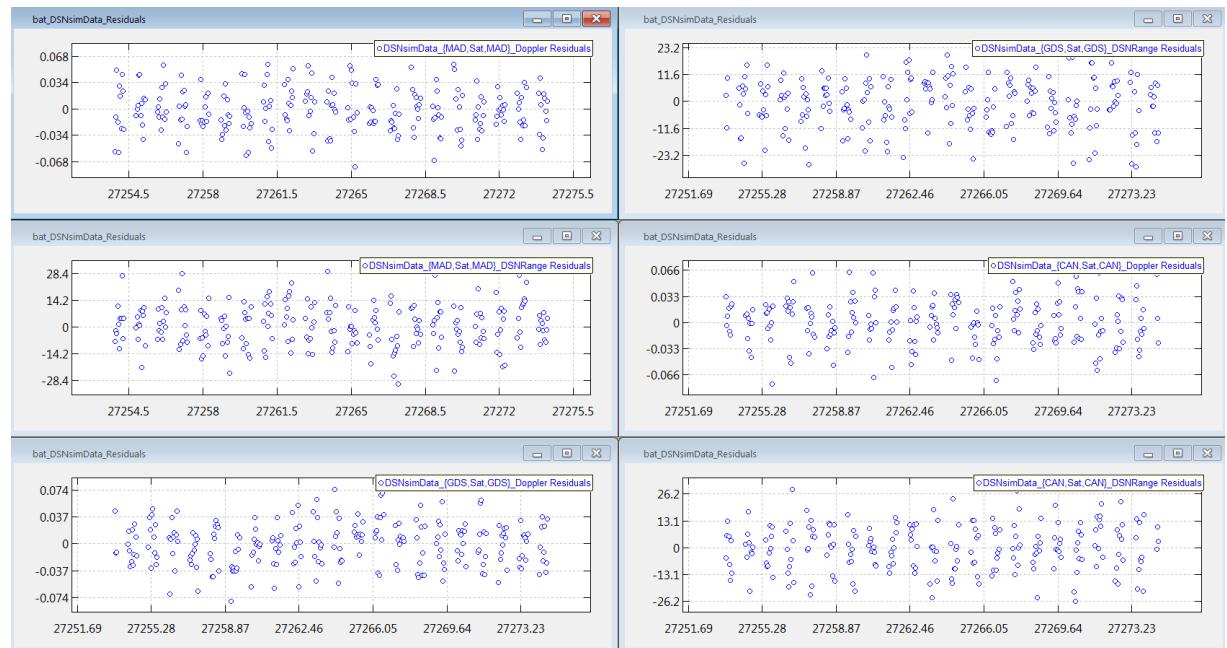
==> Total Run Time: 220.532 seconds

=====

## Appendix B – Zeroth Iteration Plots of Observation Residuals



## Appendix C – First Iteration Plots of Observation Residuals



## Appendix D – Change Scripts to use Ground Network (GN) Data

In this tutorial, we performed estimation using DSN data. In this appendix, we take a look at how our simulation script described in the previous tutorial, `Tut_Simulate_DSN_Range_and_Doppler_Data_3_weeks.script`, and our estimation script described in this tutorial, `Tut_Orbit_Estimation_using_DSN_Range_and_Doppler_Data.script`, need to be changed in order to process GN instead of DSN data. Recall that both of these scripts can be found in the GMAT "samples" folder. We note that these tutorials used a deep space spacecraft state which is consistent with using DSN data. For the discussion that follows, we will use this same spacecraft state even though typically the GN data type is used with a spacecraft closer to Earth.

In the discussion that follows, we will comment out the old commands using DSN data and replace it with new commands using GN data. We start first with the simulation script. In what follows, we will use the object names previously created even though the object names may no longer be accurate. For example, in the simulation script, we created an **Antenna** object, **DSNAntenna**. We will continue to use this object name although clearly a better name for this object would be **GNAntenna**. Let's consider the spacecraft and ground station electronics. For the GN, S-band is typically used. We change the value of the spacecraft transponder turn-around ratio and the ground station transmitter frequency to account for this.

```
SatTransponder.TurnAroundRatio = '240/221';           % was '880/749';
DSNTransmitter.Frequency      = 2067.5;    %MHz.   % was 7200
```

We now consider the **ErrorModels** objects, attached to our 3 **GroundStation** objects, used to describe the DSN noise characteristics. Since we will now be using the GN, we

must change the **ErrorModels** to describe GN noise characteristics. As shown below, the Range 1-sigma noise is set to 10 meters and the RangeRate 1-sigma noise is set to 1 cm/s.

```
DSNrange.Type          = 'Range'           % was 'DSN_SeqRange';
DSNrange.NoiseSigma   = 0.010;            % was 10.63;

DSNdoppler.Type       = 'RangeRate';    %was 'DSN_TCP';
DSNdoppler.NoiseSigma = 0.00001;         %was 0.0282;
```

As shown below, we need to tell GMAT to simulate Range and RangeRate data instead of DSN\_SeqRange and DSN\_TCP data.

```
DSNsimData.AddTrackingConfig = {{CAN, Sat, CAN}, 'Range'};      %was 'DSN_SeqRange'
DSNsimData.AddTrackingConfig = {{CAN, Sat, CAN}, 'RangeRate'};    %was 'DSN_TCP'
DSNsimData.AddTrackingConfig = {{GDS, Sat, GDS}, 'Range'};      %was 'DSN_SeqRange'
DSNsimData.AddTrackingConfig = {{GDS, Sat, GDS}, 'RangeRate'};    %was 'DSN_TCP'
DSNsimData.AddTrackingConfig = {{MAD, Sat, MAD}, 'Range'};      %was 'DSN_SeqRange'
DSNsimData.AddTrackingConfig = {{MAD, Sat, MAD}, 'RangeRate'};    %was 'DSN_TCP'
```

Our original simulation script used a ramp table to specify the ground station transmit frequencies. Since ramp tables are not used with the GN, as shown below, we want to comment out the command that reads in a ramp file. For script clarity, we also comment out a command that does not apply for GN data.

```
%DSNsimData.RampTable  = ...
{'./data/navdata/Simulate DSN Range and Doppler Data 3 weeks.rmp'};
```

```
%DSNsimData.SimRangeModuloConstant = 3.3554432e+07;
```

With all the changes above made to script, *Tut\_Simulate\_DSN\_Range\_and\_Doppler\_Data\_3\_weeks*, save the script to a new name, say, *Simulate\_GN\_data*. Then, run this new script. As we know from the simulation tutorial, a file named *Simulate DSN Range and Doppler Data 3 weeks.gmd* will be written to the local GMAT installation "output" folder location.

We now move on the examining the estimation script. Open up the estimation script from the tutorial and save it to a new name, say *Estimation\_GN\_data*. As was done for the simulation script, we change the value of the spacecraft transponder turn-around ratio and the ground station transmitter frequencies to account for the fact that we are using the GN.

```
SatTransponder.TurnAroundRatio = '240/221';      % was '880/749';
DSNTransmitter.Frequency     = 2067.5;           %MHz. % was 7200
```

As was done for the simulation script, we configure the **ErrorModels** objects to describe GN data as opposed to DSN data.

```
DSNrange.Type          = 'Range'           % was 'DSN_SeqRange';
DSNrange.NoiseSigma   = 0.010;            % was 10.63;
```

```
DSNdoppler.Type      = 'RangeRate'; %was 'DSN_TCP';
DSNdoppler.NoiseSigma = 0.00001;    %was 0.0282;
```

Next, we need to tell GMAT to estimate using Range and RangeRate data instead of DSN\_SeqRange and DSN\_TCP data. We note that, if desired, the new lines below can be deleted and the script will still work. GMAT will just read in the GMD file and automatically detect which ground stations and data types are being used.

```
DSNsimData.AddTrackingConfig = {{CAN, Sat, CAN}, 'Range'};      %was 'DSN_SeqRange'
DSNsimData.AddTrackingConfig = {{CAN, Sat, CAN}, 'RangeRate'};    %was 'DSN_TCP'
DSNsimData.AddTrackingConfig = {{GDS, Sat, GDS}, 'Range'};      %was 'DSN_SeqRange'
DSNsimData.AddTrackingConfig = {{GDS, Sat, GDS}, 'RangeRate'};   %was 'DSN_TCP'
DSNsimData.AddTrackingConfig = {{MAD, Sat, MAD}, 'Range'};      %was 'DSN_SeqRange'
DSNsimData.AddTrackingConfig = {{MAD, Sat, MAD}, 'RangeRate'};   %was 'DSN_TCP'
```

Recall that our new GN simulation script is configured to output the GMD file to the GMAT "output" directory. Let's change our estimation script, which will read in this file, accordingly.

```
% DSNsimData.FileName = {'../data/navdata/Simulate DSN Range and Doppler Data 3 weeks.gmd';
DSNsimData.FileName = {'../output/Simulate DSN Range and Doppler Data 3 weeks.gmd'};
```

As was done for our simulation script, we comment out the line that reads in a ramp table.

```
%DSNsimData.RampTable = {'../data/navdata/Simulate DSN Range and Doppler Data 3 weeks.gmd'}
```

The last step is to run our new `Estimation_GN_data` script and then analyze the results in a similar fashion as to what was done in the Estimation tutorial.



# Filter and Smoother Orbit Determination using GPS\_PosVec Data

<b>Audience</b>	Advanced
<b>Length</b>	2 hours
<b>Prerequisites</b>	None
<b>Script File</b>	Ex_R2022a_FilterSmoother_GpsPosVec.script

## Objective and Overview

This exercise will demonstrate the use of GMAT for orbit determination using spacecraft on-board GPS position estimates. We will go through the following steps:

1. Create a script to simulate GPS measurements,
2. Create a script to use an Extended Kalman Filter to estimate the orbit state using the simulated measurements,
3. Review and quality check the filter run,
4. Modify the estimation script to use a Fraser-Potter smoother to improve the estimates by backward filtering and forward smoothing the filter solution,
5. Review the output and execute analysis scripts to evaluate the smoother run,
6. Explore a demonstration of “warm-starting” the filter.

We'll wrap up at the end with a few words about filter tuning.

## Simulate GPS\_PosVec measurements

We'll begin by creating objects and configuring a GMAT script to simulate on-board GPS position measurements. Of course, in real life you won't run the simulator for orbit determination (OD), you will use the actual measurements from satellite telemetry.

Start by opening GMAT.

1. Find your GMAT installation directory, and in the <GMAT Installation>/bin directory, find and double-click on GMAT.exe to start the application.

You can dismiss the welcome window that appears. Next we'll start a blank script file.

2. In the GMAT File menu, choose New > Script

A script window will open in the GMAT GUI. We will be working in this script window for the rest of this tutorial. We'll begin by creating the Spacecraft object that will be used for simulating the measurements.

3. Type or paste the following into the GMAT script window.

```
%  
%   Spacecraft  
%
```

```
Create Spacecraft SimSat;

SimSat.DateFormat      = UTCGregorian;
SimSat.Epoch           = '10 Jun 2014 00:00:00.000';
SimSat.CoordinateSystem = EarthMJ2000Eq;
SimSat.DisplayStateType = Cartesian;
SimSat.X               = 576.869556
SimSat.Y               = -5701.142761
SimSat.Z               = -4170.593691
SimSat.VX              = -1.76450794
SimSat.VY              = 4.18128798
SimSat.VZ              = -5.96578986
SimSat.DryMass         = 10;
SimSat.Cd              = 2.2;
SimSat.Cr              = 1.8;
SimSat.DragArea        = 10;
SimSat.SRPArea         = 10;
SimSat.Id              = 'LEOSat';

%
%   Mission sequence
%

BeginMissionSequence
```

4. At the bottom of the script window, click on the “Save,Sync” button.
5. GMAT will ask if you would like to save the script and make it the active script. Click on “Yes” and choose a directory to save the script. Let’s call it “simulate.script”.
  - a. After saving, the GMAT console window should show the message “Successfully interpreted the script”

Let’s take a minute here to understand the relationship between the script and the GUI. Firstly, while GMAT has a sophisticated GUI, most GMAT OD components do not have GUI interfaces and can only be configured through the script. Some OD resources (like the Spacecraft, GroundStation, and ForceModel) do have GUI interfaces, and can be created and configured either through the GUI or the script. The “Sync” feature is used to “synchronize” the script object configurations with those in the GUI resources tree. When you hit the “Save,Sync” or “Save,Sync,Run” button GMAT will save your script changes, and then update all applicable objects in the GUI Resource tree to reflect any changes you have made to them in the script. You can verify this by double-clicking on any object in the Resource tree after performing a “Sync” operation. You can do this now for the SimSat spacecraft if you like. The GUI interface for the selected object will display the current settings from your script. You should see that the initial state and spacecraft parameters in the GUI match those assigned in the script. The same is true for the Mission tab of the GUI. We haven’t yet configured any steps in the mission sequence, but once we do, they will appear under the Mission tab in the GUI. However, since much of the orbit determination processing is not configurable through the GUI,

~~we will ignore the GUI for the remainder of this tutorial and focus only on using the script editor to accomplish our OD task.~~



### Note

In this tutorial, avoid using Control-S or the tool bar “Save” icon to save your script. These operations go the “other way” from the “Save/Sync” button. Using Control-S or the Save icon will result in GMAT replacing your script file with code automatically generated by dumping the object configurations into script format. While this in no way affects the functionality of your script, it generally results in a more verbose and “uglier” presentation of the code. When doing this, GMAT makes a “.bak” backup version of your original script in the same directory as your script. If you accidentally do this, you can recover your original script from the “.bak” copy.

The GMAT scripting language is “object-oriented”, which means that each component in the system is a self-contained object (in GMAT, these are called “resources”) with a collection of parameters which need to be specified to configure the state of the resource. GMAT has many built-in resources for modeling various aspects of spacecraft mission planning. The names of these resources, their descriptions, and available parameters are found in the “Reference Guide” section of the User’s Guide. In order to use a resource, the user must create an instance of the resource and configure it as desired. The resource name is fixed by GMAT, but the instance name can be chosen by the user, within rules of syntax. In the example above, **Spacecraft** is the name of the built-in spacecraft resource class, and we here create an instance of a spacecraft and choose to name it SimSat. The user then works with the instance of the resource they have created. Hopefully this paradigm is familiar to you already due to its similarity to other common object-oriented programming languages like Java and Python.

Before going on and creating the rest of our simulation script, we should take some time to understand a little more about the structure of a GMAT script file. Overall, there are two parts to a GMAT script – the object configuration section and the mission sequence. In the “object configuration” section of the script, we create and specify initial configurations for all the GMAT resources (objects) which are required for the task we wish to accomplish. The “mission sequence” defines the steps that will execute the desired task using the objects we have configured. It could be to propagate a Spacecraft, target a maneuver, or (in our case) to simulate and estimate an orbit. The object configurations must always come before the mission sequence, and the two sections are separated by the BeginMissionSequence keyword. The code steps in the mission sequence will eventually populate the “Mission” tab in the GUI left sidebar, but we won’t be interacting with the GUI for our OD task. For now, we will proceed first with creating all the objects we will need, and fill in the mission sequence later.

Everything you are instructed to paste in to the script below should be inserted ahead of the BeginMissionSequence line until we get to the section of the exercise where we are working in the mission sequence.

Let's continue with working on building out the script to simulate GPS position measurement data. The next thing we need to do is to create a GPS receiver for our spacecraft. In GMAT, the GPS receiver object handles the modeling of the GPS measurement data.

6. Type or paste the following into the GMAT script window.

```
%  
% Spacecraft hardware  
  
Create Antenna GpsAntenna;  
Create Receiver GpsReceiver;  
  
GpsReceiver.PrimaryAntenna = GpsAntenna;  
GpsReceiver.Id           = 800;  
GpsReceiver.ErrorModels  = {PosVecModel}  
  
Create ErrorModel PosVecModel;  
  
PosVecModel.Type        = 'GPS_PosVec'  
PosVecModel.NoiseSigma = 0.010;
```

7. At the bottom of the script window, click on the "Save,Sync" button.

Here we are creating three new objects – an Antenna, a Receiver, and an ErrorModel. Our GpsReceiver object connects to an Antenna and possesses an Id and an ErrorModel. The Antenna is used to determine the signal path of the GPS measurement, but otherwise has no functionality. The Receiver Id is a unique identifier for the receiver. When you are simulating GPS data, you can choose any value for this and it will be applied to the simulated data, but when using actual GPS spacecraft measurement records, this Id must match the Id on the formatted GMAT input GPS records. The format of GMAT input data records will be described in more detail shortly.

Lastly, we have created an ErrorModel and attached it to the Receiver. A GMAT ErrorModel is a generic object that describes the properties of the measurements used for OD. Since ErrorModels are generic, we first specify which of GMAT's measurement types we are configuring it for, in this case the GPS\_PosVec measurement type. GPS\_PosVec is a built-in name that must be used when specifying GPS measurement data. Other measurement types have similar built-in names. Refer to [Tracking Data Types for Orbit Determination](#) for more details.

Next, we specify the measurement noise associated with the GPS measurement data. The NoiseSigma represents the 1-sigma noise of the measurement data. Since we are setting up a simulation script, this represents the noise that will be added to the simulated measurements. When we get to the estimation steps, this NoiseSigma will instead be interpreted as the measurement noise assumed to exist in the measurements. Each measurement type in GMAT has different units for NoiseSigma. For the GPS\_PosVec measurements, the units are kilometers, so here we are specifying a 1-sigma measurement noise of 10 meters. When working with real spacecraft GPS measurement data, some analysis is usually required to determine an appropriate value of the noise.

Note that we attach our instance of the ErrorModel (PosVecModel) to the GPS receiver, not ErrorModel itself. Again, this fits the common object-oriented programming paradigm. We must now also attach the receiver we have created to our spacecraft.

8. In the script, go back to the spacecraft parameter configuration section and add the following at the bottom of the spacecraft parameters list.

```
SimSat.AddHardware      = {GpsReceiver, GpsAntenna};
```

9. At the bottom of the script window, click on the “Save, Sync” button.

Although it's not strictly necessary, it's convenient to keep all the spacecraft parameters grouped together. Here we attach the receiver and antenna (and implicitly as well the receiver GPS measurement error model) to our spacecraft, for use when we run the simulation.

Our goal here is to simulate some GPS measurement data for later use in an estimation run. GMAT handles measurement data through the TrackingFileSet resource.

10. Type or paste the following into the GMAT script window.

```
%  
%   Tracking file sets  
%  
  
Create TrackingFileSet SimData;  
  
SimData.AddTrackingConfig = {{SimSat.GpsReceiver}, 'GPS_PosVec'};  
SimData.FileName          = {'gps_posvec.gmd'};
```

11. At the bottom of the script window, click on the “Save, Sync” button.

Here we create an instance of a tracking file set that will write out the simulated measurements. For GPS\_PosVec measurement data, we only need to specify two things – the tracking configuration (or measurement path) for the simulated data, and the name of the output file that will contain the simulated measurements. The inner curly braces of the AddTrackingConfig parameter specify the measurement path for the simulated data. GPS\_PosVec data, while in reality derived from measuring the location of the spacecraft relative to multiple GPS satellites, consists only of X, Y, and Z estimates of the spacecraft state, so our simulation case only requires us to specify which GPS receiver is to be used in the simulation. Recall that the ErrorModel attached to this receiver will provide the measurement noise to be applied in the simulation. Outside the inner curly braces, we specify that the measurement data we wish to simulate is the GPS\_PosVec measurement type. Other measurement types typically have more complicated measurement paths and require more parameters of the tracking file set. You can refer to the User's Guide for examples.

The tracking file set FileName specifies the output file for simulated measurements. Here we just specify a file name (without a full path). In this instance, GMAT will by default write the file into the <GMAT Installation>/output directory. If you want to write the file to a different directory, specify the full path for the file.

By the way, if after hitting “Save, Sync” you ever see a message indicating a syntax or script error, stop and check your work. All of the code we are adding as we go should always parse successfully.

Next we need to create a force model that we wish to use for this orbit simulation.

12.Type or paste the following into the GMAT script window.

```
%  
% Force model  
  
Create ForceModel FM;  
  
FM.CentralBody = Earth;  
FM.PrimaryBodies = {Earth};  
FM.GravityField.Earth.Degree = 8;  
FM.GravityField.Earth.Order = 8;  
FM.GravityField.Earth.PotentialFile = 'JGM2.cof';  
FM.SRP = On;  
FM.Drag.AtmosphereModel = 'JacchiaRoberts';  
FM.Drag.CSSISpaceWeatherFile = 'SpaceWeather-All-v1.2.txt';  
FM.Drag.HistoricWeatherSource = 'CSSISpaceWeatherFile';  
FM.ErrorControl = None;
```

13At the bottom of the script window, click on the “Save, Sync” button.

FM is an instance of a ForceModel that includes Earth 8x8 gravity modeling, atmospheric drag using the Jacchia-Roberts atmospheric density model, and solar radiation pressure. We configure the force model to use the CSSI-formatted space weather file for atmospheric density modeling. This file contains daily solar flux and 3-hourly planetary geomagnetic indices. In this case, since we have not specified a full path, we will just use the default copy of the file, located in the <GMAT Installation>/data/atmosphere/earth directory. If you want to use a different version of the file, you can specify the full path. Using a daily updated version of this file is a best practice for orbit determination of low-earth satellites affected by drag.

It's worth mentioning that the setting FM.ErrorControl = None forces GMAT to use fixed-step integration when propagating the orbit. This is currently required for orbit determination using GMAT.

We're almost there, just a few more objects to create. We'll configure the propagator now.

14.Type or paste the following into the GMAT script window.

```
%  
% Propagator  
  
Create Propagator Prop;
```

```

Prop.FM          = FM;
Prop.Type        = 'RungeKutta89';
Prop.InitialStepSize = 60;
Prop.MinStep      = 0;
Prop.MaxStep      = 60;

```

15At the bottom of the script window, click on the “Save,Sync” button.

Our instance FM of the ForceModel is assigned for use by the propagator. Since on the force model we specified fixed-step integration (FM.ErrorControl = None) for the orbit, on the propagator we must specify the step size for integration. Here we use a 60-second step size, which is typical for low-earth orbiting satellites. We are also using a high-order numerical integrator (the RungeKutta89 propagator), which makes it safer to use a 60-second step size. The appropriate step size to use will vary by the mission orbit type, integrator choice, and force modeling. Note that to configure a 60-second fixed integration step size, you must specify 60 seconds on both the InitialStepSize and MaxStep parameters, while setting MinStep to zero.

We’re almost there now! One more object to configure and then we’ll go on to the mission sequence required to run the simulation. Before we do that, we have to lastly create the simulator resource.

16.Type or paste the following into the GMAT script window.

```

%
% Simulator
%

Create Simulator Sim;

Sim.AddData          = {SimData};
Sim.EpochFormat       = 'UTCGregorian';
Sim.InitialEpoch      = '10 Jun 2014 00:00:00.000';
Sim.FinalEpoch        = '11 Jun 2014 00:00:00.000';
Sim.MeasurementTimeStep = 600;
Sim.Propagator        = Prop;
Sim.AddNoise           = On;

```

17At the bottom of the script window, click on the “Save,Sync” button.

The simulator object will execute the measurement simulation using all of the objects we have configured thus far. On the AddData parameter, we assign the tracking file set, which specifies the measurement paths for data simulation. This links the simulator to the spacecraft, GPS receiver, measurement model, and output file for simulated measurements. The simulator also specifies the start (InitialEpoch) and end (FinalEpoch) times of the data simulation span, and the interval (MeasurementTimeStep) at which observation records will be simulated. Since the simulator will be responsible for propagating the spacecraft over the simulation span, we assign our propagator (and its attached force model) to the simulator as well. Finally, we can choose whether to add

noise to the simulated measurements. If AddNoise is set to Off, the noise sigma specified on the spacecraft GPS receiver error model will be ignored and the simulated measurements will be “perfect”.

We now have all the resources that we need for a properly configured simulation and are nearly ready to execute the simulation. It’s now time to build the mission sequence that will perform the simulation using the objects we have created. In this case, only one line of code is needed.

18.Update the mission sequence as shown below, then click on “Save,Sync”

```
%  
% Mission sequence  
%  
  
BeginMissionSequence  
  
RunSimulator Sim;
```

The RunSimulator command has one argument – the name of the simulator instance to execute. This command instructs GMAT to generate the simulated measurements using the measurement strands, propagator, spacecraft, and error models attached to the simulator and its associated objects.

That’s it for building our simulation script – it’s now finally time to run it.

19At the bottom of the script window, click on the “Save,Sync,Run” button. Alternately, you can execute a GMAT script by clicking on the blue “Run” error in the tool bar, or by hitting the F5 key.

The script will run very quickly – it should finish in a few seconds. In the console window (the text output area just below the script editor), the message “Mission run completed” should appear. You will also see a warning stating, “The orbit state transition matrix does not currently contain SRP contributions from shadow partial derivatives when using Spherical SRP”. This message is normal when using SRP modeling and warns the user that GMAT is ignoring a small correction in the SRP calculation that we won’t worry about for this exercise.

The only other output from the run is the simulated measurement file. Recall that on our tracking file set, we set ‘gps\_posvec.gmd’ as the simulated data file name. Since we didn’t specify a full path for the file, GMAT has created this file in its default location, the <GMAT Installation>/output directory. Take a look in your output directory and locate the new file.

Open the gps\_posvec.gmd file in a text editor. You will see content similar to the following. Because we configured the simulator to add random noise to the measurements, the data in your file will differ slightly from these values.

% GMAT Internal Measurement Data File						
26818.5004050925930316268847	GPS_PosVec	9014	800	5.4582066502576909e+03	1.7472147130503795e+03	-4.1695115857105557e+03
26818.5073495370382845110637	GPS_PosVec	9014	800	2.3029538831047935e+03	-1.4045595913124220e+02	-6.7023373462614209e+03
26818.5142939814798994164372	GPS_PosVec	9014	800	-1.8916402292545524e+03	-1.6523319919249177e+03	-6.6283229876018404e+03
26818.5212384259251523006163	GPS_PosVec	9014	800	-5.4440068853410785e+03	-2.1862351512631685e+03	-3.9759522335154807e+03

---

This is an example of a GMAT measurement data (or GMD) file. The file format is very similar for all the measurement types that GMAT processes, and consists of a series of time ordered ASCII records with space-delimited data fields. This format is described in [Tracking Data Types for Orbit Determination](#) for all of the supported measurement types. For convenience, the format for GPS\_PosVec data is reproduced below.

Field	Description
1	TAI Modified Julian Date of time of observation
2	Observation type name – GPS_PosVec
3	Observation type index number (9014 for GPS_PosVec data)
4	GPS receiver ID
5	Earth-fixed position X component (km)
6	Earth-fixed position Y component (km)
7	Earth-fixed position Z component (km)

Notice that the receiver ID in the simulated records matches the Id we assigned our GpsReceiver object in the script. The X, Y, and Z components shown are simply the predicted (propagated) X, Y, and Z position of the spacecraft in the Earth-fixed reference frame, with 10 meters of random noise (as specified on the PosVecModel error model) added. This completes the task of simulating some on-board GPS position estimates.

In the next section, we'll go on to creating a script that uses this data to estimate the orbit of the spacecraft.

## Estimate the orbit

In this section, we'll walk through the process of creating a script to estimate an orbit using an Extended Kalman Filter. Many of the resources required for this task are the same as those we used in the simulation exercise. But there are a few new resources to contend with, and we'll cover those as we encounter them.

First, we'll start a blank script file for our estimation task. You can do this without closing the simulation script – GMAT can load multiple scripts simultaneously, but we'll be ignoring the simulation script from now on.

1. In the GMAT File menu, choose New > Script

As before, a new script window will open in the GMAT GUI.

2. Type or paste the following into the GMAT script window.

```
Create Spacecraft EstSat;
EstSat.DateFormat      = UTCGregorian;
```

```

EstSat.Epoch          = '10 Jun 2014 00:00:00.000';
EstSat.CoordinateSystem = EarthMJ2000Eq;
EstSat.DisplayStateType = Cartesian;
EstSat.X               = 576.8
EstSat.Y               = -5701.1
EstSat.Z               = -4170.5
EstSat.VX              = -1.7645
EstSat.VY              = 4.1813
EstSat.VZ              = -5.9658
EstSat.DryMass         = 10;
EstSat.Cd              = 2.0;
EstSat.CdSigma         = 0.1;
EstSat.Cr              = 1.8;
EstSat.DragArea        = 10;
EstSat.SRPArea         = 10;
EstSat.Id              = 'LEOSat';
EstSat.SolveFors        = {CartesianState};

%
% Mission sequence
%

BeginMissionSequence

```

3. At the bottom of the script window, click on the “Save, Sync, Run” button.
4. GMAT will ask if you would like to save the script and make it the active script. Click on “Yes” and choose a directory to save the script. Save it to the same location as the simulation script and call it “filter.script”.
  - a. After saving, the GMAT console window should show the message “Successfully interpreted the script.”

Just like in the simulation exercise, we are starting with a spacecraft object. In the simulation case, this represented the spacecraft initial condition for the orbit we wished to simulate. In this case, our spacecraft object is configured with the initial conditions for estimation. To avoid “cheating” and giving the estimation process too accurate an initial estimate of the state, we have reduced the precision of the initial state, effectively introducing about 100 meters position error and a couple of cm/sec velocity error, which is typical for a well-tracked LEO satellite.

We have also added a new parameter – SolveFors. This lists one or more spacecraft parameters that we wish to estimate in the filter run. Here we are using one of GMAT’s built-in solve-for keywords to specify that we intend to estimate the spacecraft Cartesian state, which means the spacecraft position and velocity in Cartesian coordinates (X, Y, X, VX, VY, VZ) in the J2000 Earth-centered coordinate system. Later in this tutorial we will add estimation of the coefficient of drag to this list.

You may also notice that we have changed the spacecraft Cd (coefficient of drag) value from 2.2 in the simulator to 2.0 here for the estimation. This is because we are going to try to estimate the coefficient of drag in addition to the spacecraft position and velocity.

Because we are going to estimate Cd, we have also added a new parameter, CdSigma, to set the presumed uncertainty of our initial estimate of the coefficient of drag. Although in this case we know how much error our guess has, of course in practice you don't know this, and some experimentation may be needed.

Next we'll add the spacecraft hardware we need to model the GPS measurements.

5. Type or paste the following into the GMAT script window.

```
%  
%   Spacecraft hardware  
  
Create Antenna GpsAntenna;  
Create Receiver GpsReceiver;  
  
GpsReceiver.PrimaryAntenna = GpsAntenna;  
GpsReceiver.Id           = 800;  
GpsReceiver.ErrorModels  = {PosVecModel}  
  
Create ErrorModel PosVecModel;  
  
PosVecModel.Type        = 'GPS_PosVec'  
PosVecModel.NoiseSigma = 0.010;
```

6. In the script, go back to the spacecraft parameter configuration section and add the following at the bottom of the spacecraft parameters list.

```
EstSat.AddHardware      = {GpsReceiver, GpsAntenna};
```

7. At the bottom of the script window, click on the "Save, Sync" button.

Here we are just reusing the same hardware configuration we used for the simulation. However, in this instance the NoiseSigma assigned on the error model is now the assumed measurement noise in the existing data. We are "cheating" slightly by using the same value we set in the simulation. In practice, you won't know the measurement noise so well and may need experiment or perform analysis on the orbit determination residuals to find an appropriate value to use.

Next, let's quickly create our tracking file set, force model, and propagator.

8. Type or paste the following into the GMAT script window.

```
%  
%   Tracking file sets  
  
Create TrackingFileSet EstData;  
  
EstData.FileName = {'gps_posvec.gmd'};
```

```
%  
%   Force model  
  
Create ForceModel FM;  
  
FM.CentralBody           = Earth;  
FM.PrimaryBodies         = {Earth};  
FM.GravityField.Earth.Degree = 8;  
FM.GravityField.Earth.Order = 8;  
FM.GravityField.Earth.PotentialFile = 'JGM2.cof';  
FM.SRP                  = On;  
FM.Drag.AtmosphereModel = 'JacchiaRoberts';  
FM.Drag.CSSISpaceWeatherFile = 'SpaceWeather-All-v1.2.txt'  
FM.Drag.HistoricWeatherSource = 'CSSISpaceWeatherFile';  
FM.ErrorControl          = None;  
  
%  
%   Propagator  
  
Create Propagator Prop;  
  
Prop.FM                 = FM;  
Prop.Type               = 'RungeKutta89';  
Prop.InitialStepSize    = 60;  
Prop.MinStep             = 0;  
Prop.MaxStep             = 60;
```

9. At the bottom of the script window, click on the “Save,Sync” button.

The force model and propagator are identical to those we used in the simulation script. For the tracking file set, we have changed the instance name to the more appropriate “EstData”. The assigned tracking data file is now an input file to be read in the estimation process, so it points to the file we created in our simulation run. Note that we have dropped the AddTrackingConfig assignment. When you are using a tracking file set for estimation, GMAT will examine the data in the input tracking data file and automatically determine the tracking measurement paths. The user does not have to specify these for the estimation process. Next let’s create the Kalman filter estimator object.

10. Type or paste the following into the GMAT script window.

```
%  
%   Estimator  
  
Create ExtendedKalmanFilter EKF;  
  
EKF.ShowProgress        = True;  
EKF.Measurements        = {EstData};
```

```
EKF.Propagator      = Prop;
EKF.ShowAllResiduals = On;
EKF.OutputWarmStartFile = 'filter.csv';
EKF.ReportFile       = 'filter.txt';
EKF.MatlabFile       = 'filter.mat';
```

11 At the bottom of the script window, click on the “Save, Sync” button.

Just like the simulator, the estimation gets assigned the tracking file set. In this case, the tracking file set contains the input data to the estimator. The receiver ID on each input measurement record links the input data to our configured GPS receiver, spacecraft, and error model resources. We also assign the estimator a propagator (with its attached force model) for use in propagating the spacecraft orbit during the estimation process.

The ShowProgress setting causes GMAT to provide verbose output in the console window while the estimation is running, and ShowAllResiduals will tell GMAT to display a plot of the residuals while the estimation is running. The EKF ReportFile is a detailed report that the filter will generate to help us interpret and quality check (QA) the run. The MatlabFile is a MATLAB-format file that will be generated from the run. It contains useful data that the filter generates as it runs and we will use it later to assist in quality checking the run. Note that the MatlabFile can only be generated if you have MATLAB installed on the machine running GMAT, and GMAT is properly configured to use the MATLAB connection. See [MATLAB Interface](#) for details on configuring the MATLAB interface.

The OutputWarmStartFile is an additional output file that can be used as input to a subsequent run to allow the filter to operate in a “continuous estimation” mode. We’ll come back to this file to see how this works later in the exercise.

Unlike the simulator, the filter has no start or stop time parameters. The filter will instead start at the initial epoch of the spacecraft object and process all measurements that are present in the input tracking data file.

The GMAT orbit determination filter operates by continuously propagating the uncertainty of the state estimate and comparing the state uncertainty and measurement noise at each measurement to the measurement residual, to determine if the new measurement should be rejected or accepted, and if accepted, how strongly that measurement should be used to correct the current state estimate. Propagation of the state uncertainty begins from an initial estimate of the state uncertainty and takes into account a presumed model of the force modeling and propagation errors. As we propagate a state in the absence of measurements, the state uncertainty grows due to force modeling errors. When we incorporate, or accept, a measurement, the state uncertainty decreases because the measurement improves our orbit knowledge. We’ll see these effects in action shortly when we run the filter, but first we need to create and configure the objects needed for modeling the state and force model uncertainty.

12. Type or paste the following into the GMAT script window. If you wish, you can move the EstSat.ProcessNoiseModel assignment up to the other spacecraft initial parameter settings to keep them grouped together.

%

```
% Process noise model
%
Create ProcessNoiseModel SNC;
SNC.Type          = 'StateNoiseCompensation';
SNC.CoordinateSystem = EarthMJ2000Eq;
SNC.AccelNoiseSigma = [1.0e-9 1.0e-9 1.0e-9];
SNC.UpdateTimeStep = 120.
EstSat.ProcessNoiseModel = SNC;
```

13At the bottom of the script window, click on the “Save,Sync” button.

Here we create an instance of a new resource called a Process Noise Model. This resource models the error in spacecraft propagation in the absence of measurements. This is the error in the prediction “process”. It attempts to model things like error due to imprecise gravity, SRP, and drag modeling, as well as errors due to any small forces, known or unknown, that were not modeled explicitly in the force model we configured. You can see that this model assigns a trio of values representing the noise in the computed nominal acceleration in a specified coordinate system (here the Earth J2000 coordinate frame). This model is assigned to the spacecraft, since it is associated with that spacecraft’s orbit and force model. Process noise supplied by this model will be added to the state uncertainty at the interval defined by the process noise model UpdateTimeStep, which we set to be every 120 seconds. Selection of the proper values of process noise in operations normally requires experimentation and analysis.

The process noise method GMAT implements is called State Noise Compensation, and you can read more about it in Reference 1 if you wish. For now it would take us too far afield to go into the details of this model.

Next, we’ll add estimation of the coefficient of drag to the filter run. Estimation of a coefficient of drag or some other representation of a drag correction factor is common practice for spacecraft in low-earth orbit. This is because the drag force is the most poorly modeled of the forces affecting a spacecraft in this regime. Analytic atmospheric density models have inherent errors of up to 30% or more just due to the immensity and complexity of atmospheric chemistry. On top of that, the drag force depends not only on a presumed coefficient of drag ( $C_d$ ), but on the spacecraft area (which is often only coarsely modeled and usually dynamic), and the spacecraft mass (which may be imprecisely known). Estimating a drag correction value has the effect of compensating for all these errors in an aggregate fashion and can significantly improve the accuracy of the orbit estimate and prediction.

14.Type or paste the following into the GMAT script window.

```
% Create the drag solve-for
%
Create EstimatedParameter FogmCd
```

```
FogmCd.Model      = 'FirstOrderGaussMarkov';
FogmCd.SolveFor   = 'Cd';
FogmCd.SteadyStateValue = 2.0;
FogmCd.SteadyStateSigma = 0.05;
FogmCd.HalfLife     = 864000;
```

15At the bottom of the script window, click on the “Save,Sync” button.

Here is another new resource – the EstimatedParameter resource. We mentioned previously that GMAT has a collection of built-in solve-for parameters, including a coefficient of drag solve-for parameter. However, the built-in Cd solve-for is not ideal for use with a filter because it does not include process noise modeling. The EstimatedParameter resource allows the user to configure more sophisticated modeling for some solve-fors, in a fashion that is more appropriate for a filter and which includes process noise modeling. This resource implements Cd estimation as a “First-Order Gauss-Markov” (FOGM) process. You can read more about this model in Reference 2. This type of model includes three essential parameters – a steady-state value, a steady-state uncertainty (sigma), and a half-life for “decay”.

When a filter runs, the uncertainty of all estimated parameters always increases when propagating in the absence of measurements, and the uncertainty of all estimated parameters always decreases when a measurement is processed. The steady-state value of a FOGM variable is the value to which the parameter will automatically return, in the absence of measurements. This should generally always be set to your best guess of what the actual value is (again, here we are pretending that we don’t know the actual value). Similarly, the steady-state uncertainty of a FOGM variable is the value to which the parameter uncertainty will automatically return, in the absence of measurements. Rather than grow continuously without upper bound, the FOGM Cd uncertainty will, after a given amount of time, level off at a maximum of the SteadyStateSigma value. The amount of time for both the steady-state value and sigma to level-off is given (in seconds) by the HalfLife parameter, which specifies how long it will take the current Cd estimate to return halfway back to its limiting value set by SteadyStateValue.

We need to add the estimated parameter to the Spacecraft solve-fors list.

16Find the line setting the EstSat.SolveFors parameter and edit it to add FOGM Cd estimation as shown below.

```
EstSat.SolveFors      = {CartesianState, FogmCd};
```

17At the bottom of the script window, click on the “Save,Sync” button.

In GMAT, it doesn’t matter that a parameter or resource instance (like FogmCd) is assigned before it is created. It’s not necessary to put the code that created the FogmCd estimated parameter before the EstSat.SolveFors assignment in the GMAT script. GMAT will attempt to connect everything together properly at run-time. As long as all the required objects are defined somewhere in the script, everything should work.

The last thing to do is add the code in the mission sequence to execute the filter run.

---

18.Update the mission sequence as shown below, then click on “Save,Sync”.

```
%  
% Mission sequence  
%  
  
BeginMissionSequence  
  
EstSat.OrbitErrorCovariance = diag([1e-2 1e-2 1e-2 4e-10 4e-10 4e-10]);  
  
RunEstimator EKF;
```

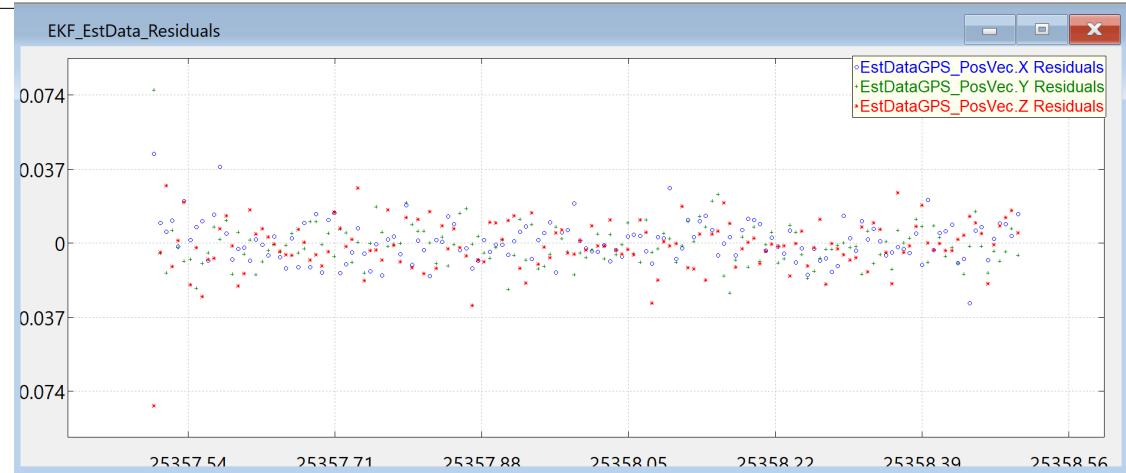
You probably expected to see the RunEstimator command. Just like RunSimulator, the RunEstimator command has one argument – the name of the filter instance to execute. This command instructs GMAT to process the input tracking data measurements and perform the estimation using the propagator, spacecraft, and error and process noise models attached to the filter and its associated objects.

We have one additional command in the mission sequence. Before running the estimator, we are using the **diag()** command to set the spacecraft initial orbit uncertainty. The filter will continuously propagate and adjust the spacecraft uncertainty (“covariance”) as it runs, but it needs some starting value of the uncertainty from which to begin. The spacecraft position and velocity uncertainty is represented by a 6x6 matrix (for three components of position and three components of velocity), but all we care about for initialization are the diagonal components of the matrix. The diag() function is a convenient way of creating a diagonal matrix. Here we specify the initial “covariance” of the three position ( $1\text{e-}2 \text{ km}^2$ ) and velocity ( $4\text{e-}10 \text{ km}^2/\text{sec}^2$ ) components of the initial state of EstSat.

You are probably wondering where these values come from. We have in a way slightly “cheated” here again. Since we know the spacecraft state used in the simulation, we also know the error in the EstSat in this run. Recall from above we said that we reduced the precision of the initial state for the estimation script, and thereby introduced about 100 meters position error and a couple cm/sec velocity error. The values we assign here along the diagonal of EstSat.OrbitErrorCovariance are just the squares of these errors (covariance units are squared uncertainties) in  $\text{km}^2$  and  $\text{km}^2/\text{sec}^2$ . In operational practice, you don’t know the initial uncertainty so well and usually have to make educated “order of magnitude” guesses at the initial orbit uncertainty either through experience, research, or analysis.

19.Run the script by clicking on the “Save,Sync,Run” button, clicking on the blue “Run” error in the tool bar, or by hitting the F5 key.

The script should complete in a few seconds. Unlike the when we ran the simulator, you will this time see a lot of action in the GUI and console window. Firstly, a window similar to that shown below appears in the GUI. This is a plot of all the measurement residuals.



The vertical axis is the measurement residual in kilometers and the horizontal axis is the measurement time in Modified Julian Date (MJD) of atomic time (TAI). Note that the spread of residuals is consistent with the measurement noise (10 meters) that we applied in the simulation.

If you scroll backwards in the console window, you will find a summary of the initial state and estimated parameters, and the final state and estimated parameters (after processing all measurements), as well as the final covariance matrix. This is useful information, but is not enough for a full quality check of the run, so let's now dive into the other output files generated from the run.

## Review and quality check the filter run

Go to your *<GMAT Installation>/output* directory. You should have three new files there – filter.txt, filter.mat, and filter.csv. Let's start with filter.txt.



### Note

Generation of the MATLAB data file requires GMAT to be properly connected to a licensed MATLAB instance. If you do not have MATLAB, the MATLAB data file cannot be generated and you should skip the python plotting exercises below. If you don't have MATLAB it is still possible to generate data files from the run that are suitable for plotting. Many parameters such as SpacecraftOrbitErrorCovariance, Cd, CdSigma, and others can be written dynamically to an external report file. See [ReportFile](#) for details on how to do this.

1. Open filter.txt for reading in a text editor.

The filter.txt file is the detailed estimator output report and is the first stop for reviewing the status of the filter run. There's a lot of detail in the report, so we'll just hit the important points here. From top to bottom, the file contains the following content:

- Initial spacecraft state and covariance,

- 
- Spacecraft hardware summary,
  - Force modeling options summary,
  - Measurement modeling summary,
  - Summary of relevant space environment constants,
  - Report of all filter measurement residuals,
  - Filter estimation summary report,
  - Filter covariance report.

Everything prior to the FILTER MEASUREMENT RESIDUALS report is just feeding back the input configuration you supplied to the filter. You can use those sections when troubleshooting, or to confirm that GMAT interpreted your inputs as you intended.

Review the FILTER MEASUREMENT RESIDUALS report. This shows the results of the filter processing of each measurement. Each input GPS\_PosVec tracking data measurement record produces three lines in this report – the first for the X-value, the second for the Y-value, and the third for the Z-value. Each line starts (from left to right) with the measurement record number, the measurement time (now in UTC), the measurement type name (GPS\_PosVec), and the name of the spacecraft associated with the measurement. Next is a column in which an edit flag may appear. Since this run used simulated data, it is likely that no edit flags appear in your run, but it is possible that you may see a small number of measurements tagged with the SIG edit criteria. This flag will be described shortly below.

Next across the line appears the measurement Observed value. This is the exact value of the measurement extracted from the input tracking data file. The next column shows the Computed value of the measurement. The computed value is the predicted value of the measurement, and is obtained by propagating the spacecraft current estimated state using the force modeling options we have configured in the script. The computed value should normally be close to the observed value if estimation is going well. The final column shows the difference between the observed and computed values. This is called the measurement “residual” and is the value that was plotted in the graph that appeared when the filter was running. The last column, “Elev”, is for the measurement elevation angle and it not populated for GPS\_PosVec measurements.

The filter uses the residual value to determine if a measurement should be accepted or rejected. If the computed residual is larger than three times the combined state uncertainty and measurement noise, the filter will ignore the measurement. If this happens, the measurement will be identified with the SIG (for “sigma”) edit flag in the report. This is called the “scaled residual check”, and the multiplier value (in this case the default of 3) can be changed on the EKF resource instance, if desired. Since we used simulated data in this run, you might not see any edited points, but you are much more likely to encounter autonomous sigma editing when using real data. When QA’ing any filter run, you should review this report to ensure that most of the data was accepted across the entire run, from start to finish. If at some point in the report you begin to see excessive data editing, that is a sign that something has gone wrong in the filter. Perhaps you have insufficient process noise and the covariance has gotten too small, maybe your presumed measurement noise is too small, or maybe an unmodeled maneuver has occurred.

The next section of the output report, FILTER MEASUREMENT STATISTICS, is a useful summary of the residual report. Here you can see the start and end time of the data span.

You should make sure they are what you expected them to be. You also see a summary of the total number of observations available in the run and the number accepted ("Used For Estimation"). If any points were edited out, they will be noted here in the "Sigma Editing" count. Below that, you can see at a glance how much data was accepted in the run along with overall residual statistics. A well-operating filter should normally accept nearly all of the available good tracking data. Remember, that we are looking here at simulated tracking data, which is much closer to perfect than real tracking data, which often has more outliers and poor measurements. Your expectations for data acceptance for your mission need to be set by analysis and trending of your data.

Next in the output report comes the FILTER STATE INFORMATION. This gives a summary of the estimated spacecraft state, and any other estimated parameters, at the end of the run, which specifically is the time of the last measurement processed. In our case, we see the estimated Cartesian state and Cd value, as well as the final uncertainties of each estimated parameter. For convenience, GMAT also reports the Keplerian elements of the estimated state, along with a collection of other useful orbit parameters that may be derived from the Cartesian set. GMAT also reports here the full covariance matrix (here 7x7, since it includes the 6-element Cartesian state and the Cd), and correlation matrix for both the Cartesian and Keplerian element sets.

Lastly, the output report shows a detailed FILTER COVARIANCE REPORT. The filter covariance report displays records at all of the measurement times, and at the process noise update intervals. Recall that on the process noise model we set the UpdateTimeStep to 120 seconds. In the covariance report, between measurements and at 120-seconds intervals, additional records are written. Each record displays the current orbit position uncertainty in a Velocity-Normal-Binormal frame. You should be able to see that the covariance starts with the input value of 100 meters that we assigned on the EstSat OrbitErrorCovariance, and that the orbit uncertainty always decreases when a measurement is used, and always increases between measurements.

Each measurement record also includes reporting of the computed scaled residual. This is a unitless value that is computed in the residual sigma edit check mentioned above. Since we are using the default sigma edit criteria of 3, any measurement with a scaled residual value greater than 3 will have been edited. If any points in your run were edited, you can check this by finding their scaled residual in this report section. Note that the scaled residual of each GPS\_PosVec component (X, Y, Z) is computed separately, but if any of the triplet exceeds the scaled residual threshold, all three components will be rejected.

The filter output report, and especially the filter measurement statistics section, is very useful in assessing the status and quality of the filter run, but graphs are often a more useful way of quickly reviewing large amounts of data. Next, let's take a look at some tools that produce graphs using the filter.mat MATLAB output file. If you have MATLAB but did not get a filter.mat file, then there is a problem with the GMAT MATLAB interface. See [MATLAB Interface](#) for information on configuration and troubleshooting.

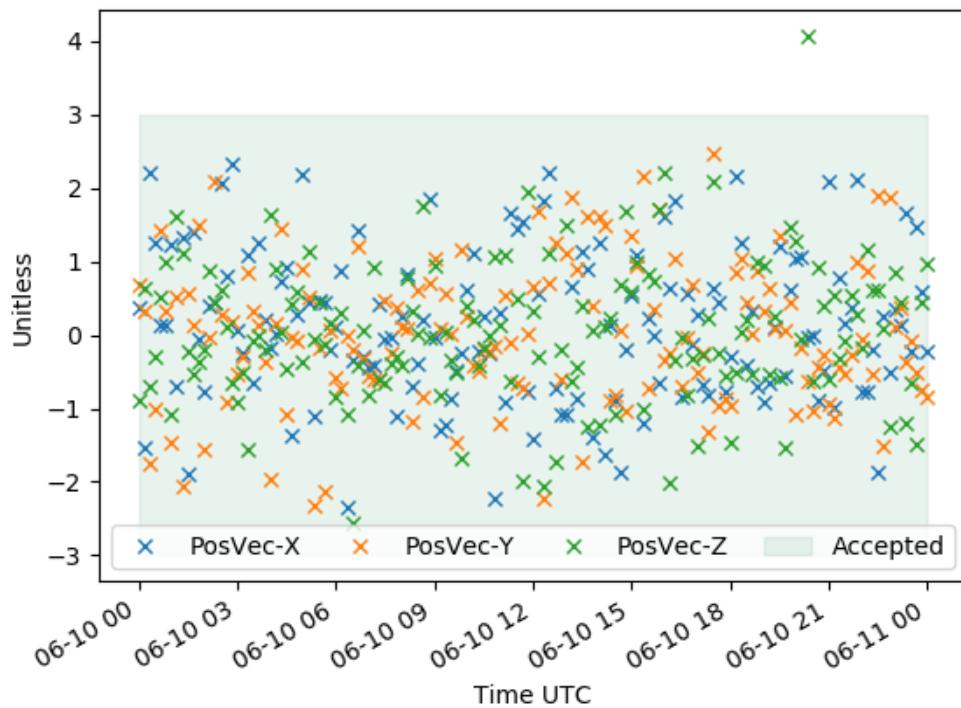
Let's begin by plotting the filter residual ratios. You must have a Python 3 installation that includes scipy, numpy, pandas, and matplotlib to run these examples. If you are using Anaconda Python you should be fine.

2. Open a DOS prompt and navigate to the directory containing the sample Python analysis scripts. You can find them in the <GMAT installation>/utilities/python/navigation directory.
3. In that directory, type the following:

```
python plot_residual_ratios.py <full path to filter.mat>
```

In a few seconds, you should see a plot similar to that below. This shows all the scaled residual values that we previously saw in the filter covariance report section of the report file. In plot form, it is easier to assess the overall trends. The green highlighted region between  $\pm 3$  shows the scaled residual threshold gate we are using. Any point plotted inside this region represents an accepted measurement. If any points appear outside the highlighted region, they were rejected by the scaled residual edit criteria.

Filter Scaled Residuals



Real tracking data won't look this good and can be expected to show more "structure" than just random noise. When reviewing a scaled residual plot, you should make sure that the majority of data was accepted, and especially that the distribution of accepted data looks approximately similar over the entire run (beginning, middle, and end). By the way, each of these Python scripts is also generating a PDF version of the plot and comma-separated value (CSV) file of the plot data, for archive or further analysis.

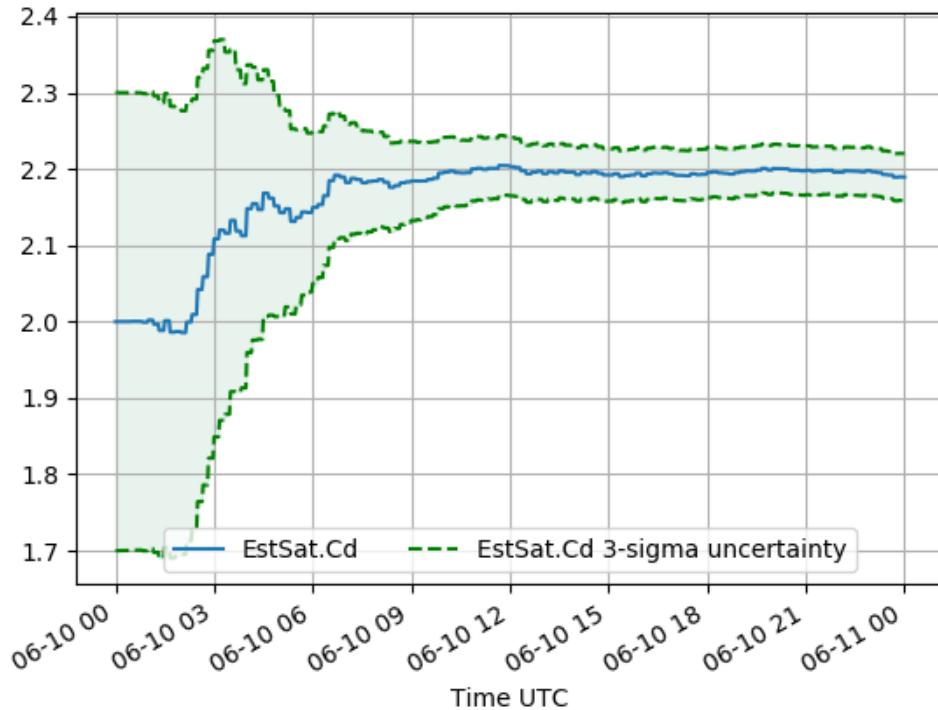
Next, let's look at the estimated coefficient of drag.

4. In the script directory, type the following:

```
python plot_solve_fors.py <full path to filter.mat>
```

After a few seconds, you should see a plot similar to the one below. This displays the filter estimate of the coefficient of drag over the run. Recall that for the simulated data we used a Cd of 2.2, but we started the estimator with an initial Cd of 2.0 and with an initial CdSigma of 0.1. This can be seen at the beginning of the graph, where the initial value of Cd is 2.0 and the 3-sigma uncertainty bounds (the green region in the plot) encompass the range 1.7 to 2.3. As the filter runs and incorporates measurements, it “senses” that the value of Cd it was given is not quite right and begins moving it toward the correct (simulated) value of 2.2. At the same time this is happening, the bounds of uncertainty are decreasing as the filter uses more measurements and becomes more “confident” in its estimate.

Filter EstSat.Cd and 3-Sigma Uncertainty



When running a filter, you should always review plots like this of all the “non-position and velocity” estimated parameters in the run. You should make sure the estimated value is staying within expected bounds based on mission experience and any physical limitations that may be inherent in the parameter (for example Cd should always be positive). You should also ensure that the parameter uncertainty does not become too small. This can happen if our FOGM EstimatedParameter process noise (derived from the SteadyStateSigma and HalfLife) is too small. If the uncertainty is too small, the filter may become overconfident in its estimate of the parameter and unable to react to rapid or sudden changes in drag that might occur, for example in the instance of a solar storm. This could ultimately lead to the filter diverging and starting to reject all incoming new measurements.

We don't typically look at similar plots of the estimated values of position and velocity, because they will oscillate too dramatically to be useful. Ephemeris comparisons (which

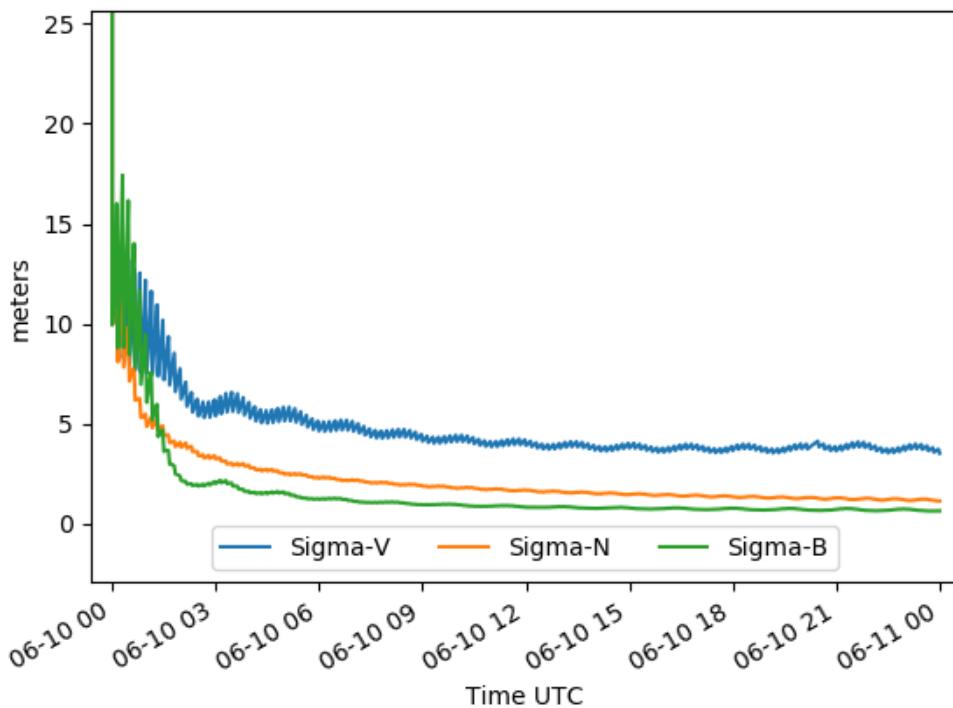
won't be covered in this tutorial) are an essential aid to assessing the estimated position and velocity. However, it's useful to look at plots of the position and velocity uncertainty, so we'll do that next.

5. In the script directory, type the following:

```
python plot_covariance.py <full path to filter.mat>
```

After a few seconds, you should see a plot similar to the one below. The image below is a zoom of the plot that will show up for you. You can zoom in on your plot to see something similar. There will actually be two plots, one for position uncertainty and one for velocity uncertainty, but we just show the position uncertainty plot here. The velocity plot looks and is interpreted similarly to the position uncertainty plot. In the velocity plot, the radial velocity uncertainty will be largest (instead of along-track velocity) due to correlation of along-track position with radial velocity.

Filter 1-Sigma Position Uncertainty



Here we see the filter 1-sigma filter position uncertainty. Notice that the curves all start at the value of 100 meters, which is the value we assigned (in squared form) on the estimated spacecraft initial OrbitErrorCovariance. Secondly, note that the uncertainty rapidly collapses to “steady state” values of about 5 meters in the V (velocity) component, about 2 meters cross-track (N) and about 1 meter or so radial (B). This rapid collapse occurs as the filter begins to incorporate measurements and improves its estimate of the state. The flattening of the covariance curves is a sign of filter “convergence”. When a filter is operating normally, it should remain in a converged state. Because GPS\_PosVec data is very consistent in its measurement density, the covariance should remain pretty constant. Other measurement types that come in more randomly will cause the state

estimation uncertainty to exhibit larger variations due to gaps in the measurement data. If you zoom in closely on your plot you will be able to observe a “sawtooth” pattern, particularly in the V-component, which is characteristic of filter operation. The uncertainty grows in sawtooth-like fashion between each measurement, and then collapses down again each time a measurement is accepted. This reflects how process noise always drives the filter uncertainty larger in the absence of measurements, while using a measurement always decreases the filter uncertainty. Later if you wish, you can experiment with different values of the ProcessNoiseModel AccelNoiseSigma to see how this affects this behavior.

All signs show that this is a good filter run, so let's go on to configure and run the smoother.

## Modify the estimation script to use a smoother to improve the estimates

Now we are going to add a “smoother” to our script. A smoother allows us to improve the definitive (estimated) states by running a filter backwards from the last measurement to the first measurement and then “fusing” the results of the forward filter and backward filter into a new estimate that combines information from both the forward and backward filter. The backward filter is automatically initialized from the last estimated state in the forward filter. A smoother will not improve the accuracy of any predictions made from the last forward filter measurement because the filter and smoother estimates are identical at that time. The primary advantage of a smoother is an improvement in the accuracy of the states during the measurement span, also called the “definitive” span.

In GMAT, the filter instance must be attached to the smoother, so the smoother must be run in the same script and mission sequence as the forward filter. We will make the following edits to the filter script.

1. Open your filter script file.
2. Type or paste the following into the filter script window.
  - a. This must be placed outside the “mission sequence” (before the BeginMissionSequence statement). Put it right under the filter if you wish.

```
%  
% Smoother  
  
Create Smoother FPS;  
  
FPS.Filter = EKF;  
FPS.ShowProgress = True;  
FPS.ShowAllResiduals = On;  
FPS.ReportFile = 'smoother.txt';  
FPS.MatlabFile = 'smoother.mat';
```

3. At the bottom of the script window, click on the “Save, Sync” button.

There are many different types of smoothers. GMAT implements a “Fraser-Potter” smoother. Details of this are given in Reference 2. To configure the smoother, we attach the instance of our forward filter, which will now be run backwards in time starting at the measurement end time. Like the filter, we can set flags on the smoother to produce verbose output in the console window and a residual plot from the backward filter (ShowProgress and ShowAllResiduals). We also assign an output file for the smoother report file and a smoother MATLAB data file similar to that we got from the filter.

4. Update the mission sequence as shown below (to add the RunSmoothen command), then click on “Save,Sync”

```
%  
% Mission sequence  
  
BeginMissionSequence  
  
EstSat.OrbitErrorCovariance = diag([1e-2 1e-2 1e-2 4e-10 4e-10 4e-10]);  
  
RunEstimator EKF;  
RunSmoothen FPS;
```

As you can see, the RunSmoothen command works just the same way as RunSimulator and RunEstimator.

5. Run the script by clicking on the “Save,Sync,Run” button, clicking on the blue “Run” button in the tool bar, or by hitting the F5 key

The script should complete in a few seconds. The filter will first run and generate the same output that we have seen already. After the filter runs, the smoother will run. If you watched the filter residual plot window closely, you should see that it actually replotted the residuals running backward (from right to left) when the smoother was running. In addition, you will see a little more output in the console window, this time from the smoother run. We can summarize what happened as follows:

- i. The filter (in the RunEstimator EKF command) ran forward from the first to last measurement,
- ii. The smoother (in the RunSmoothen FPS) command ran the filter backward from the last measurement to the first measurement,
- iii. The smoother then ran forward (still in the RunSmoothen FPS command) and computed a covariance-weighted average of the forward and backward filter state estimates to obtain the forward smoother estimates.

To understand all of this, let’s jump to the output directory and review the smoother output file.

## Review and quality check the smoother run

Go to your <GMAT Installation>/output directory. You should have the filter files we saw previously, and two new files there – smoother.txt and smoother.mat. Let’s start with smoother.txt.

- 
1. Open smoother.txt for reading in a text editor.

The smoother.txt file is identical in format to the filter output file. At the top, we see the smoother initial conditions. Notice now that the starting state for the backward filter is the ending state for the filter forward run. The force modeling, spacecraft hardware, measurement modeling are the same as those used in the forward filter.

The SMOOTH MEASUREMENT RESIDUALS is also identical in format to the FILTER MEASUREMENT RESIDUALS report. The smoother residuals report shows the measurement residuals versus states computed from the smoother. For this reason they are reported in forward time order. The smoother operates in forward time order when fusing the forward and backward filter runs. Residuals from the backward filter run are not included by default in the smoother output report, but are included in the smoother MATLAB file.

Next in the smoother output report are the smoother measurement summary statistics. Again, the report format is identical to that found in the filter. As in the filter, we should expect to see most of the measurements accepted. Under certain circumstances, the backward filter can diverge and edit out large amounts of measurement data, so the analyst should carefully review the smoother output to be certain this did not occur.

Next comes the smoother state information. This is the smoother state at the end time of the measurement data, and it therefore matches the filter end state exactly. Remember that the backward filter starts at the end time of the forward filter, so the backward filter, the forward filter, and consequently the smoother, all match at the last measurement.

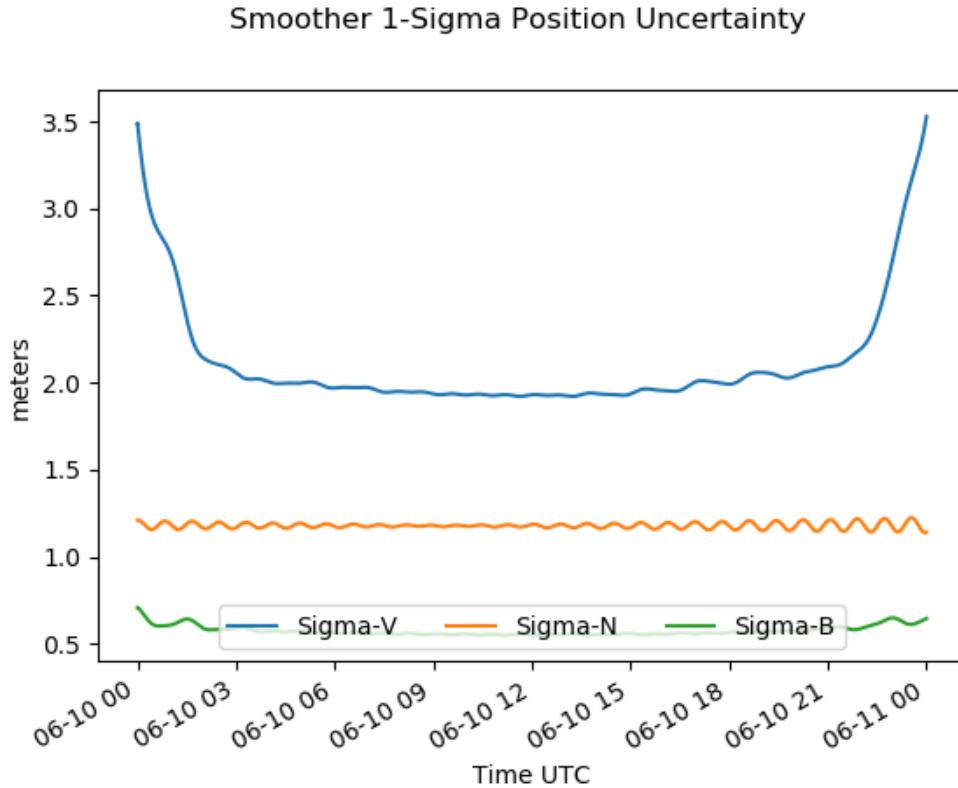
Lastly comes the SMOOTH COVARIANCE REPORT. This is again identical in format to the filter covariance report, but instead reporting the smoother covariance. The function of the smoother is to improve the accuracy of the estimated states and due to the mathematics of the smoother, the smoother covariance is always smaller than the covariance of the forward filter. This may be difficult to see in the smoother output report, but it will be clearer when we examine plots of results from the smoother MATLAB file. Let's do that now.

2. If you are not there already, open a DOS prompt and navigate to the directory containing the sample Python analysis scripts.
3. In that directory, type the following:

```
python plot_covariance.py <full path to smoother.mat>
```

In a few seconds, you should see a plot similar to that below. Compare this to the plot we previously generated for the filter position covariance and note the differences. This plot does not exhibit the “converging” behavior in the previous forward filter plot, and all the components of uncertainty are at least a little smaller than those from the forward filter. This reflects the fact that each point in the smoother contains information obtained from measurements both in the past and in the future of that point. By contrast, each point in the forward filter run contains only information from the past of that point, since the forward filter only processes measurements forward in time. Having more information about the state at a particular point in time (in this case derived from both the past and

future trajectory of that point) improves knowledge of the state and therefore reduces the uncertainty of the state.



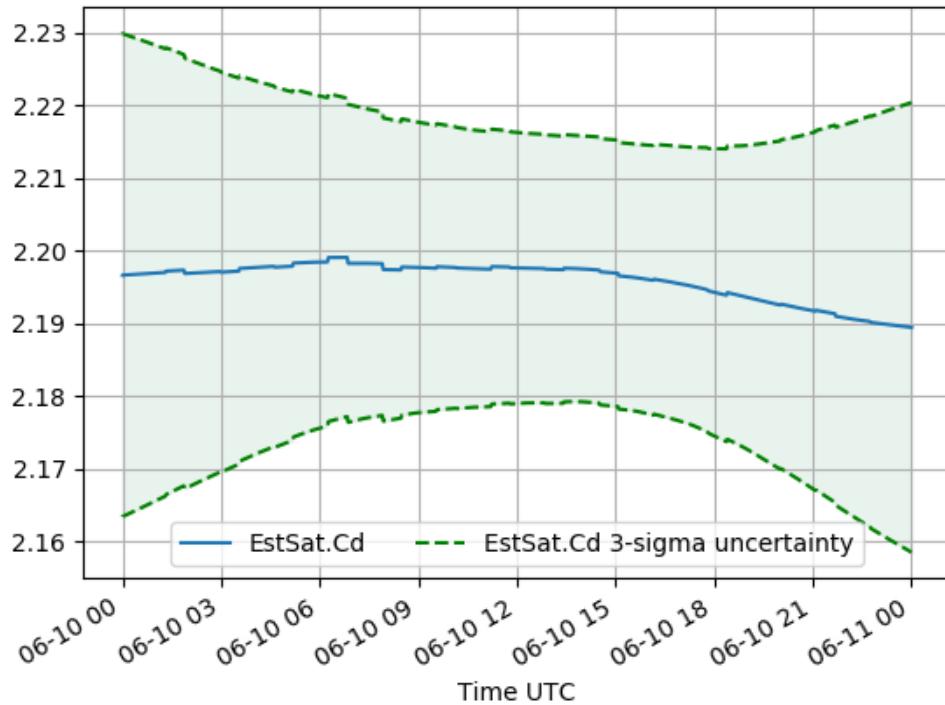
We notice as well as considerable U-shape to the V-component of uncertainty. The other components also show signs of being noisier at the beginning and end of the span. This is again a consequence of how the smoother operates. States near the start of the span have a lot of information from the backward filter, but not much from the forward filter. Similarly, states near the end have a lot of information from the forward filter, but not much from the backward filter. States near the center of the run have the greatest amount of information from both the forward and backward filter and therefore have the smallest uncertainty.

4. In the script directory, type the following:

```
python plot_solve_fors.py <full path to smoother.mat>
```

After a few seconds, you should see a plot similar to the one below. This displays the smoother estimate of the coefficient of drag.

### Smoother EstSat.Cd and 3-Sigma Uncertainty



The envelope of uncertainty around the smoother Cd estimate shows behavior similar to that in the smoother plots for position and velocity. Near the start and end of the run, there is less information about the estimate, and therefore more uncertainty, than near the center.

The last step in QA of the filter and smoother run requires us to generate what are called “filter-smoother consistency plots”. We now have two complete forward estimated time histories of the spacecraft state – the state estimates we got from the forward filter, and the state estimates from the forward smoother (after backward filtering). These plots will allow us to see if the filter state estimate and uncertainty are “consistent” with the smoother state estimate and uncertainty. In other words, if the forward filter places the spacecraft at a certain location with a particular uncertainty, is the smoother state and its uncertainty reasonably within bounds of the filter state and uncertainty?

As an example, consider a case where the filter estimate places the spacecraft at point A with an uncertainty of 10 meters. Now let's say the smoother estimate at the same time places the spacecraft at point B with an uncertainty of 5 meters. If the distance between point A and B is 7 meters, then we can say that the filter estimate is “consistent” with the smoother estimate. The distance between point A and point B is within the uncertainties of the locations of point A and point B.

On the other hand, let's consider the case where point A (with 10 meters uncertainty) and point B (with 5 meters uncertainty), are found to be 100 meters apart. This error in estimated location between the filter (point A) and the smoother (point B) is much

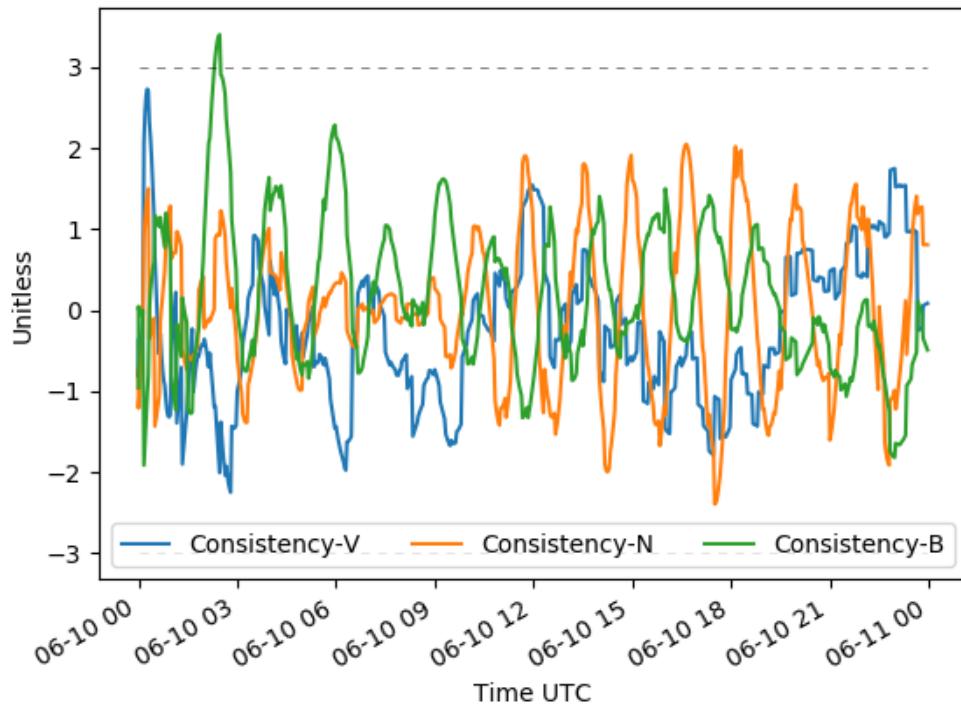
larger than should be expected based on the reported uncertainties of each estimate. In this case, we would say that the filter and smoother estimates are not consistent, and should begin to look for sources of modeling error in either the filter or smoother. The filter-smoother consistency plot will perform this comparison for us at every point over the entire span of the run and generate a plot showing a metric that represents the level of consistency between the filter and smoother runs.

5. In the script directory, type the following:

```
python filter_smoker_consistency.py <full path to filter.mat> <full path to smoother.mat>
```

After a few seconds, you should see a plot similar to the one below. This displays the filter-smoother position consistency.

Filter-Smoother Position Consistency



This plot shows the filter-smoother consistency for the components of the spacecraft position vector in a VNB frame. The plot for velocity consistency is similar. You should also review the filter-smoother consistency of all other estimated parameters. The script should also have generated a consistency plot for the coefficient of drag. Since Cd is just a scalar value, the Cd consistency plot shows only one data series. The consistency metric measures the filter and smoother state differences against their uncertainties, so we expect, in a well-tuned filter, to see the majority of the metric in the  $\pm 3$  range. If this is not the case, you should begin examining the filter configuration. Possible sources of poor filter-smoother consistency are things like poor force modeling, unknown or unmodeled forces like thrusting events, excessive data editing, and inappropriately tuned state noise or FOGM variables.

## Warm-start the filter

We've seen everything that it takes to set up, run, and quality check a GMAT filter/smoothier OD run. There's one more aspect of filter operations that we should take a little time to understand and explore. Recall, or go back and look at, the filter position covariance plot we generated. That plot has a large initial covariance and then takes some amount of time, maybe 6 to 12 hours in our case, to reach a steady or "converged" state. This is because we have performed what is called a filter "initialization" or "cold start". We started the filter from our own coarse initial guesses of the spacecraft state and uncertainty. As the filter runs forward, it improves the state estimate and uncertainty by processing the measurement data. At the end of the filter run, we now have a state estimate and uncertainty that are much better than those we started with.

In mission operations, we will need to run the filter on some regular basis, maybe daily, and the next time we start the filter, it would be best to start it from the filter's own ending state estimate and uncertainty. We might think we could do this manually by updating our script with the filter estimates of the spacecraft state and full (6x6, not just the diagonal elements) spacecraft orbit error covariance matrix. We'd also need to update the spacecraft Cd and Cd uncertainty. This process would be laborious and would not even fully capture the end state of the filter because there's no way to manually provide GMAT the components of covariance that link Cd to the spacecraft position and velocity.

The good news is that there's a much easier way to start the filter from a previously estimated state. When we covered the output files generated by the filter, there was one file we didn't describe – the filter.csv file assigned on the filter OutputWarmStartFile parameter.

1. Go to your <GMAT Installation>/output directory. Find and open filter.csv for reading in a text editor.

The filter.csv file is a comma-separated file containing a record of the full filter state and covariance at every measurement and time update in the processing span. Scroll to the right in the file and look at the header row (if you prefer, you can open the file in Excel for greater convenience). You should see that each record in the file contains the full state of the filter (that is, the spacecraft position and velocity component estimates along with Cd estimates) and the full (7x7) covariance matrix associated with the state and Cd estimates of the record. Any record in this file contains all the information the filter needs to start up and continue processing forward from the record epoch. Starting the filter in this fashion from a previous estimated state and full covariance matrix is called a "warm start", and the filter.csv file is called a warm start file.



### Note

The covariance stored in the warm start file is actually the square root of the full covariance matrix. The headers of the covariance columns indicate this (SqrtCovariance). The full covariance matrix P may be recovered from the square root covariance by the formula  $P = \text{SqrtCovariance} * \text{SqrtCovariance}^T$ .

Let's go through a quick demonstration of how to perform a warm start.

2. Update the filter ExtendedKalmanFilter configuration in the mission sequence as shown below. It may be convenient to just comment-out or remove the current filter instance and paste in this new code.

```
%  
%   Estimator  
  
Create ExtendedKalmanFilter EKF;  
  
EKF.ShowProgress      = True;  
EKF.Measurements     = {EstData};  
EKF.Propagator       = Prop;  
EKF.ShowAllResiduals = On;  
EKF.InputWarmStartFile = 'filter.csv';  
EKF.WarmStartEpochFormat = 'UTCGregorian';  
EKF.WarmStartEpoch    = '10 Jun 2014 18:00:00.000';  
EKF.ReportFile        = 'filter.txt';  
EKF.MatlabFile        = 'filter.mat';
```

3. At the bottom of the script window, click on the “Save,Sync” button.

Here, we've assigned the filter.csv warm start file we have as the InputWarmStartFile, meaning that GMAT will now read from that file instead of writing to it. We have also specified a WarmStartEpoch (and epoch format). This tells GMAT which record to use in the input warm start file as GMAT's starting point. In this case, we're choosing not to write out a new filter OutputWarmStartFile, but we could do that at the same time, as long as we choose a different file name from the input warm start file. Let's run the filter and see how a warm start works.

4. Run the script by clicking on the “Save,Sync,Run” button, clicking on the blue “Run” error in the tool bar, or by hitting the F5 key.
5. When the run completes, go to your <GMAT Installation>/output directory. Find and open filter.txt for reading in a text editor.

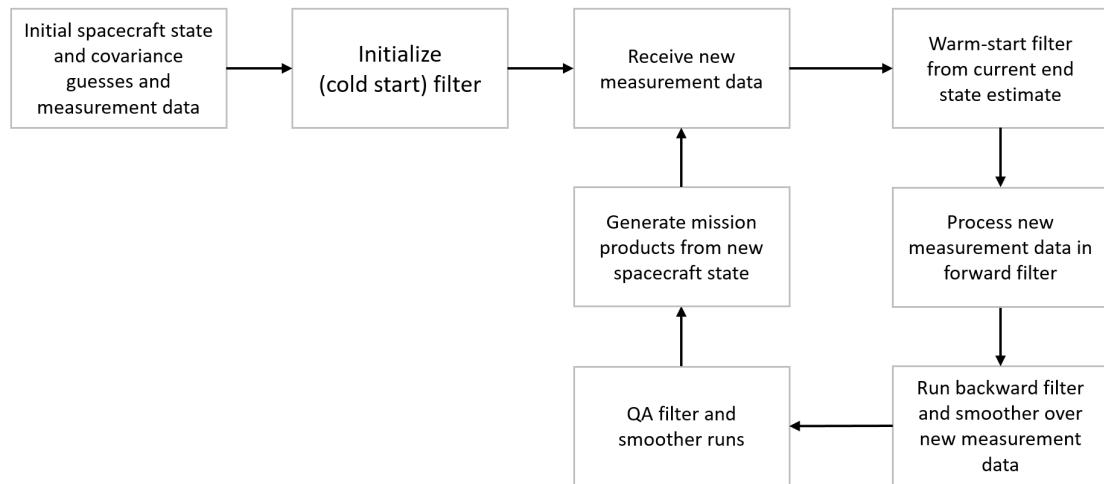
Look at the spacecraft initial conditions at the top of the filter output report file. You should now see that the initial spacecraft epoch state are at the warm start epoch we specified. If you wish, you can manually compare the initial state reported in the filter output report to the 10 Jun 2020 18:00 record in the filter.csv warm start file – they should match. Most importantly, the 7x7 initial covariance reported in the output file will also match the 7x7 covariance from the warm start file record (if you convert the square root covariance in the warm start file to a full covariance).

Next, scroll down in the output to the filter measurement residuals report. Notice that the residual report begins with the 10 Jun 2014 18:10 measurement. When warm-starting the filter, it will automatically ignore any measurements prior to the selected warm start epoch and begin forward processing from the first measurement after the warm start epoch. This is because the warm start record at that epoch already includes the effect of

processing all earlier measurement data. (As an aside, since the forward filter ignored measurements prior to 18:00, the backward filter and the smoother will also ignore the earlier measurement data, since their knowledge of what measurements to process comes solely from the forward filter run.)

If you scroll down further in the output file to the FILTER STATE INFORMATION report, you will see that the end time and final estimated state of the run matches what was obtained in the original full-span run. The purpose of a warm start is to allow the filter to continue running from the warm start epoch as though it had never stopped. Choosing any warm start epoch at all will lead to identically the same estimated state and covariance at the end of the run.

In this instance, we got the same end state because we were just reprocessing the same set of data as our cold-start run, with the only difference of choosing a different starting point. In normal mission operations, the warm start record is used to advance the filter estimated state continuously forward using the new data that is available each time the filter is run. An outline of this process for a routine OD scenario looks like the following:



As the flowchart illustrates, ideally the filter is cold-started, or initialized, only once and then is run continuously in warm start mode, with each new day's run starting from an epoch chosen from the prior run's output warm start file (normally the last or most recent warm start record). In practice, it is occasionally necessary to re-initialize the filter. This may be required if a severe spacecraft thrusting event occurs which cannot be modeled in the filter, or more commonly, due to changes in the filter scenario due to the addition of new tracking stations or significant changes in current tracking stations.

## A few words about filter tuning

Throughout this exercise, we have employed some numbers that affect the filter performance, without really explaining where they came from. These are things like the magnitude of the process noise, the sigma and half-life for estimation of the coefficient of drag, and the initial orbit state uncertainty. In an exercise using simulated data, it is not hard to find values that work well, since we already know the “truth” that was employed in the simulation. When working with real mission data however, the situation is much different. You may have some initial guess of the coefficient of drag, but you

might not know the error in your guess, or how much the coefficient of drag might vary due to possibly dynamic spacecraft area. Even deciding which parameters to estimate and which to apply can be a difficult question to answer. The process of finding appropriate values for all the parameters that affect filter performance is filter “tuning”. The goal of filter tuning is to achieve a filter that runs continuously (using warm starts) with minimal need for reinitialization, and that yields a covariance that hopefully realistically captures the true orbit uncertainty. The process of tuning a filter often requires analysis and experimentation with all the parameters just mentioned. It is furthermore a good idea to examine filter performance under a range of your spacecraft’s environmental conditions. For example, a tuning for a low-Earth spacecraft that works well during solar minimum may be stressed or fail during solar maximum. We can offer a few tips to those new to the filter tuning game.

The Spacecraft initial OrbitErrorCovariance represents the uncertainty in the initial spacecraft state you are providing on the Spacecraft object. In general, an “order of magnitude” guess is sufficient for the initial covariance. The filter will soon “forget” this initial value anyway as it automatically adjusts the covariance in response to the measurements and process noise. While the OrbitErrorCovariance is a full 6x6 matrix, common practice is to specify only the diagonal elements, representing the uncertainties in the initial position and velocity components. To ascertain whether your values are appropriate, examine the filter output at the start of the run. If your initial state is close in time to the first measurement and the filter diverges (begins sigma-editing most or all data) immediately, or very soon, after the first measurement, adjust the OrbitErrorCovariance. An OrbitErrorCovariance that is too small will result in immediate data editing (“divergence”) due to the scaled residual edit check failing to capture the measurements. However, an OrbitErrorCovariance that is too large can also cause divergence. If the initial uncertainty is too large, the filter will accept the first few measurements, but the covariance will collapse too rapidly around a still poorly-estimated state, which will likely lead rapidly to divergence. Use of measurement deweighting can help ameliorate this condition (see the [ExtendedKalmanFilter](#) MeasDeweighting parameters). If possible, it is best to work with an initial state that has an epoch close to the first measurements. If your initial state is not close to the first measurement, propagation of the initial state to the time of the first measurement introduces process noise, which means you will need to try to tune both the initial orbit uncertainty and state noise model at the same time.

Choosing appropriate values for stochastic models like a first-order Gauss-Markov drag model requires some experimentation. For the spacecraft coefficient of drag, you can begin from the basis that most coefficients of drag are between 2.0 and 2.5. A long half-life (one to ten days) is usually a good choice, especially if you don’t know the actual value of drag very well. A short half-life will cause the drag estimate to rapidly decay back to the nominal (steady-state) value, which is not a good option if your chosen steady-state value is not close to the true value. A longer half-life allows the filter more time to sense and adjust to the true value.

Choosing appropriate process noise can be the most opaque and mysterious part of filter tuning. The units of acceleration noise sigma for GMAT’s StateNoiseCompensation algorithm are km per second<sup>(3/2)</sup>, which does not lend itself easily to an intuitive interpretation. Reference 2 recommends the following starting point for along-track process noise for near-circular orbits dominated by along-track error (as is the case for most spacecraft affected by drag):

$$q_{AT} = \frac{\sigma_{AT}^2}{3T^3}$$

Where  $\sigma_{AT}$  is the along-track error per orbit period (perhaps determined empirically), and  $T$  is the orbit period in seconds (Reference 2, eq. 2.88). Note that the square root of  $q_{AT}$  is specified when inputting the components of the AccelNoiseSigma on a process noise model.

Process noise drives the growth of position and velocity uncertainty in the absence of measurements. The effect of this is most easily seen by examining plots of position and velocity uncertainty and looking at how large they get while propagating the orbit between tracking passes. Try to make a judgement whether the growth is consistent with what the actual orbit uncertainty might be. For example, a low-Earth orbiting spacecraft receiving one or two 20-minute passes per orbit might be expected to experience less than 100 meters prediction error per orbit, if the orbit is well-estimated and drag conditions are not rapidly changing. If plots of position covariance show the uncertainty growing to a kilometer between passes, it is likely that the process noise is too large. It can be easy for a filter with too much process noise to look like it is performing well, because it will generally easily accept all of the incoming measurement data. However, the estimated state will not be as accurate as it could be and will likely predict poorly.

Examining the “pre-update” residual of the first measurement of each tracking pass is a useful exercise. The pre-update residual is the filter state measurement residual prior to incorporating (or rejecting) the measurement. This gives you an indication of how well the filter is predicting. Ideally these first-measurement pre-update residuals should not be biased (should not be predominantly positive or negative). Under most conditions, prediction error is larger than measurement noise, so the population of first measurement residuals should roughly reflect the state prediction accuracy. The Filter Measurement Residuals section of GMAT’s filter output report shows pre-update residuals. Examining plots of pre-update residuals is usually more useful than scanning the report visually.

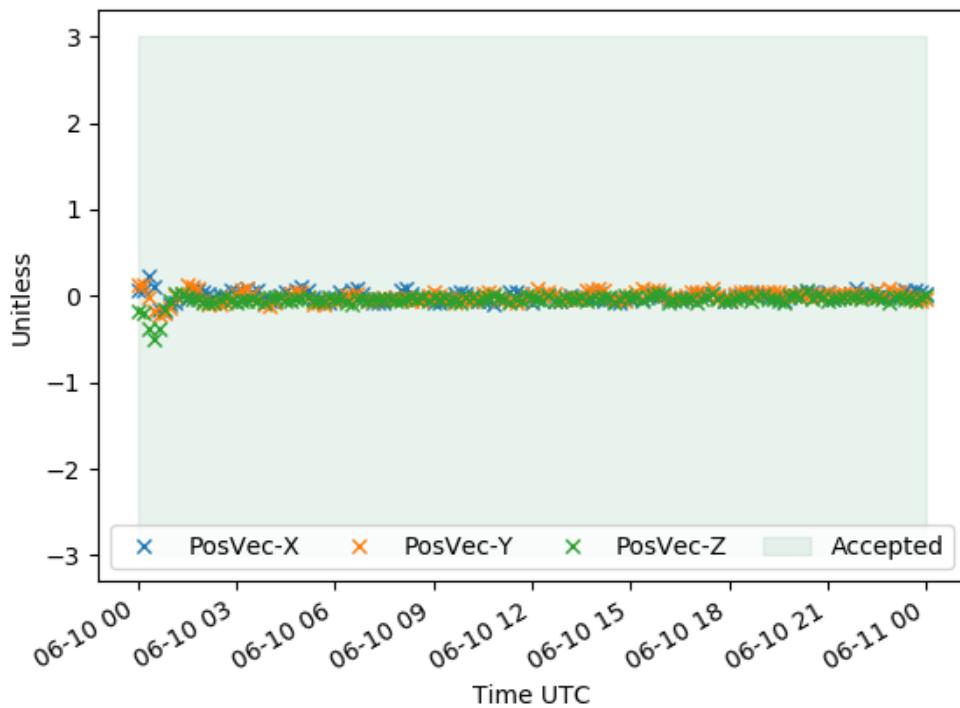
There are three essential tools for assessing filter performance – scaled residual plots, filter-smoother consistency checks, and ephemeris comparisons.

“Scaled residuals” or “residual ratios” are the filter raw measurement (pre-update) residual divided by (roughly) the sum of the state uncertainty and measurement noise. The scaled residual is the metric the filter uses when deciding to accept or reject a new measurement. If the scaled residual exceeds the filter ScaledResidualThreshold, the measurement is rejected by the sigma-edit criteria. Another very useful aspect of the scaled residual is that it is dimensionless, which means it gives you a way to examine the processing of all measurement types in a single plot, rather than looking at separate plots of Doppler, range, and angle residuals. You can see the residual ratios in the Filter Covariance Report section of the GMAT filter output report file, but viewing them in a graph (as we did previously in Section 3 above) is much more useful. A scaled residual plot can quickly show you in a glance how much of your data was accepted (below the scaled residual threshold) and how much is rejected. We expect a well-tuned filter to

accept nearly all incoming measurements (except for those known to be erroneous, biased, or otherwise anomalous).

Scaled residual plots can also tell you other useful things about how the filter is performing. Take a look at the scaled residual plot shown below.

Filter Scaled Residuals



If we just looked quickly at our filter output report, we might be happy with this run, because 100% of the data was accepted. However, the scaled residual plot shows that all of the scaled residuals are squashed on a line close to zero. This tells us that the divisor in the scaled residual computation (the sum of the process noise and measurement noise) is much larger than the raw measurement residual. From this, we can conclude that either the process noise or assumed measurement noise is too large. (If you see a plot like this, it is most often the case that the measurement noise is too large. For reasonable values of process noise, the “spread” of scaled residuals is indicative of how large the modeled measurement noise is relative to the actual measurement noise.) Mathematically speaking, we are not extracting as much value from the residuals as we should be. A well-tuned filter should spread the scaled residuals more evenly through the full range of the scaled residual acceptance region. While strictly speaking it might be considered best to see the scaled residuals cover the entire scaled residual acceptance range (with maybe even a little spillover), in operational practice it usually good to leave a little overhead (perhaps 1-sigma) between the envelope of scaled residuals and the scaled residual threshold. This allows the filter to be more robust to small unpredictable variations that come from solar activity, mis-modeled media corrections, small measurement biases, and the like.

Secondly, when running both the filter and smoother, filter-smoother consistency checks are very useful for assessing your tuning. As was described in above, we should expect that the filter state and associated uncertainty are statistically “consistent” with the smoother state and its uncertainty. For low-Earth spacecraft especially, it is typical for the filter-smoother consistency metric to occasionally stray outside the ideal range, but excesses should not be extreme or of long duration. Poor filter-smoother consistency is a sign that the filter tuning is at least somewhat amiss. Poorly-modeled maneuvers can be one source of poor consistency. In this case, intervention is not typically warranted, as the consistency should return to normal in later post-maneuver runs. Short spans of data editing, sudden solar activity, or other temporary events affecting force modeling can also cause transient issues with filter-smoother consistency. Temporary excesses of the consistency metric are not usually a problem as long as they can be associated with some known or suspected phenomena. Consistently poor filter-smoother consistency should be addressed by reexamining filter tuning in the areas of propagation model fidelity, process noise, and estimated parameter modeling.

Lastly, ephemeris compares should always be performed, and most importantly, trends of predicted accuracy should be maintained and periodically compared against mission requirements and past results. Prior to launch, most missions perform detailed analysis to determine the proper tracking schedule and measurement types needed to meet mission orbit accuracy requirements. Routine navigation operations should assess orbit determination performance against these requirements. Both predicted and definitive ephemeris data should be generated each time the filter is run, and the accuracy of each new prediction should be later assessed against a definitive ephemeris to measure the prediction error. Keep a record of prediction error over consistent spans that are relevant to mission requirements. For example, if your mission has a requirement of a 48-hour prediction accuracy of better than 2 kilometers, make sure that every filter (or smoother) run generates at least 48 hours of predicted ephemeris data. Compare this prediction later to a new definitive filter ephemeris to determine the accuracy of the prediction. Besides ensuring that you are meeting mission requirements, comparison of actual prediction accuracy to predicted orbit uncertainty covariance is a useful way of assessing the realism of the filter predicted orbit covariance.

Here are some additional tips to help develop your “filter intuition”.

- If the state estimation error is very small or the measurement is very noisy, the state change when incorporating a measurement is small and the filter “trusts” the current orbit estimate more than the new measurement. This is the situation if the state is “well-known” or the observation is low-quality.
- If the state is poorly known or the measurement is very good (low noise), the state is strongly corrected by the new measurement. In this case, the filter is “following the data” more than trusting the state estimate.

The estimation error covariance after the measurement update is always less than the estimation error covariance before the measurement update. Using an observation always reduces the orbit error covariance, no matter how bad the observation is. Addition of process noise always increases the state uncertainty. So there is a balance here – incorporating a measurement always decreases the state uncertainty and process noise always increases the state uncertainty. Filter convergence and long-term performance

depends on this balance. If measurement or process noise are too small, the orbit error covariance may become too small and the filter may begin to reject good measurements. The filter will eventually diverge – this is called “smugness”. If process noise is too large, the filter will predict poorly and have little “memory” of state information. The filter state will depend mostly on only the latest measurements and will act like a short-arc batch least-squares estimator. It is helpful for a filter to have a “memory” of prior measurements, since this allows the filter more accurately estimate sometimes hard-to-observe parameters like drag or orbital plane.

## References

1. Tapley, Schutz, and Born, Statistical Orbit Determination, Elsevier Science 2004.
2. Carpenter, Russell and Chris D'Souza. Navigation Filter Best Practices. Technical Report TP-2018-219822, NASA, April 2018.

## Appendix A. Generate an ephemeris while running the filter and smoother

While just knowing the end state of the filter run is useful, flight dynamics operations often requires a complete ephemeris file of the past (“definitive”) and future predicted orbit to assist in generation of various reports and analysis required for spacecraft mission operations. In this section, we will show how to modify the filter/smooth script to generate an ephemeris file during both the filter and smoother run.

1. If you don't already have it open, start GMAT and load the filter.script script file.
2. Paste the following code into your script before the BeginMissionSequence command, then click on “Save,Sync”.

```
%  
% Create ephemeris files  
  
Create EphemerisFile FilterEphem;  
  
FilterEphem.Spacecraft      = EstSat;  
FilterEphem.Filename        = 'filter.e';  
FilterEphem.FileFormat     = 'STK-TimePosVel';  
FilterEphem.IncludeCovariance = 'Position';  
FilterEphem.CoordinateSystem = EarthMJ2000Eq;  
FilterEphem.WriteEphemeris  = False;  
  
Create EphemerisFile SmootherEphem;  
  
SmootherEphem.Spacecraft      = EstSat;  
SmootherEphem.Filename        = 'smoother.e';  
SmootherEphem.FileFormat     = 'STK-TimePosVel';  
SmootherEphem.IncludeCovariance = 'Position';  
SmootherEphem.CoordinateSystem = EarthMJ2000Eq;
```

```
SmoothenEphem.WriteEphemeris = False;
```

Here we create two instances of the EphemerisFile resource – one for the filter and one for the smoother. We attach the EstSat satellite to the ephemeris object, and specify the ephemeris format to be an STK-format ephemeris. Since the filter creates states at each measurement time, and the measurement times are generally not at a uniform time interval across the filter span, the filter can only use ephemeris formats that support a variable time step between states. In this example, we also choose to include the covariance in the STK ephemeris (not all formats support this option), and we specify a coordinate system for the output ephemeris.

The WriteEphemeris parameter tells GMAT whether to output states from the attached spacecraft to the configured ephemeris file. We set it to False here to suppress output to the ephemeris file for now. The reason for this will become clear shortly.

3. Update the mission sequence as shown below, then click on “Save,Sync”.

```
%  
% Mission sequence  
  
BeginMissionSequence  
  
EstSat.OrbitErrorCovariance = diag([1e-2 1e-2 1e-2 4e-10 4e-10 4e-10]);  
  
Toggle FilterEphem On;  
RunEstimator EKF;  
Toggle FilterEphem Off;  
  
Toggle SmootherEphem On;  
RunSmoother FPS;  
Toggle SmootherEphem Off;
```

The Toggle command is used to activate and suppress output to each ephemeris file at the appropriate time. Before running the EKF, we turn on output to the filter ephemeris file. At this point in the script, output to the smoother ephemeris file remains off, due to the setting of the WriteEphemeris parameter on the SmootherEphem resource. We then run the filter with output to the filter ephemeris turned on. While the filter runs, each filter estimated state is written to the filter ephemeris via the EstSat spacecraft that is attached to the filter ephemeris resource. If at this point, the output to the smoother ephemeris were also enabled, output would also be written to the smoother ephemeris, since EstSat is also attached to the SmootherEphem resource. This would cause a problem when the smoother runs next and again writes states to the smoother ephemeris file.

When the filter run completes, output to the filter ephemeris is turned off, and output to the smoother ephemeris is now turned on. The smoother is then run. During the smoother run, output states from EstSat will now go exclusively to the smoother ephemeris file.

4. Run the script by clicking on the “Save,Sync,Run” button, clicking on the blue “Run” error in the tool bar, or by hitting the F5 key.

The filter and smoother will run just the same as we have seen previously. When the run completes the two ephemeris files, filter.e and smoother.e, can be found in the GMAT output directory. In this case, the files will cover only the span of the filter and smoother estimation arcs. GMAT can also generate a prediction past the end time of the tracking data.

5. Add the following line of code to the configuration of the smoother object. Update the mission sequence as shown below, then click on “Save,Sync”.

```
FPS.PredictTimeSpan      = 86400;
```

6. Run the script by clicking on the “Save,Sync,Run” button, clicking on the blue “Run” error in the tool bar, or by hitting the F5 key.

This parameter instructs the smoother to generate an 86400-second (1-day) prediction past the end time (last observation) of the data. Examine the smoother ephemeris file after the run completes to see the extra prediction span in the file. The same parameter is also available for the filter, if you wish to add a prediction to the filter.

## Appendix B. Run the script from the command-line

In this tutorial, we've demonstrated configuring and running a GMAT filter/smooth script from the GMAT application GUI. In mission operations, it is not desirable to have to execute such point-and-click operations regularly, and automated execution is preferred. Here we demonstrate how to run our filter script from the command-line instead of using the GUI.

1. Open a command-line prompt on your platform and navigate to the directory containing the GMAT executable.
2. In that directory, type the following:
  - a. If you are running the Mac or Linux version, type **GmatConsole** instead of **gmat.exe**.

```
gmat.exe --exit --run <full path to filter.script>
```

In a Windows/DOS environment, this will cause GMAT to start the GUI, load and run the script, and then exit the GUI. The GmatConsole command (not currently supported on Windows), runs the script without the GUI at all. On the Windows platform, you can suppress the GUI by adding the --minimize option to the command-line. There are a number of other command-line options. You can type **gmat.exe --help** or look in the User's Guide under [Command-Line Usage](#).

When the script completes, you can examine the GMAT output directory to confirm that all the same files generated when we ran the script inside the GUI were generated from the command-line run.

You can of course run GMAT in this fashion from any directory by specifying the full path to the GMAT executable. Note however, that in all instances it is necessary to specify the full path to the script, even if the script is in the directory from which you are calling GMAT. GMAT treats all relative paths as relative to its own **bin/** directory.

## Appendix C. Check covariance matrix conditioning

Filters can be susceptible to effects of numerical noise arising from finite machine precision. This tends to manifest itself in numerical instability of the covariance matrix. The covariance of the backward filter step of the Fraser-Potter smoother is particularly vulnerable to this condition if large data gaps occur near the start of backward filter processing (the end of the forward filter processing span). Users can examine the condition number of the forward filter, backward filter, and smoother using the `plot_cond_cov.py` tool.

1. In the python script directory, type the following:

```
python plot_cond_cov.py <full path to filter.mat> <full path to smoother.mat>
```

This command will produce a plot of the base-10 logarithm of the covariance condition numbers over the processing span. Users with access to MATLAB or python can use the filter and smoother MATLAB files for additional analysis of the covariance, such as testing that the covariance eigenvalues are positive and real or checking the symmetry of the covariance matrix.



# Simulate and Estimate Inter-Spacecraft Tracking

<b>Audience</b>	Intermediate level
<b>Length</b>	40 minutes
<b>Prerequisites</b>	Basic Mission Design Tutorials
<b>Script Files</b>	Tut_Inter_Spacecraft_Tracking.script

## Objective and overview



### Note

GMAT currently implements a number of different data types for orbit determination. Please refer to [Tracking Data Types for Orbit Determination](#) for details on all the measurement types currently supported by GMAT. The measurements being considered here are two way range and range-rate.

In this tutorial, we will use GMAT to generate simulated range and range-rate measurement data between two spacecraft. One spacecraft, referred to as the tracking Spacecraft, is performing observations on the other, referred to as the observed Spacecraft. The tracking spacecraft is in geosynchronous orbit and the observed spacecraft is in low-earth orbit. These simulated measurements will then be used to perform state estimation on the observed Spacecraft.

The basic steps of this tutorial are:

1. Create and configure the spacecraft, spacecraft hardware, and related parameters
2. Define the types of measurements to be simulated and the associated error models
3. Create and configure the force model and propagator
4. Create and configure the simulator and batch estimator objects
5. Run the mission and review the results

Note that this tutorial, unlike most of the mission design tutorials, will be entirely script based. This is because most of the resources and commands related to navigation are not implemented in the GUI and are only available via the script interface.

As you go through the tutorial below, it is recommended that you paste the script segments into GMAT as you go along. After each paste into GMAT, you should perform a syntax check by hitting the Save, Sync button (). To avoid syntax errors, where needed, don't forget to add the following command to the last line of the script segment you are checking.

`BeginMissionSequence`

We note that in addition to the material presented here, you should also look at the individual help resources for all the objects and commands we create and use here. For example, **Spacecraft**, **Transponder**, **Transmitter**, **Receiver**, **ErrorModel**, **TrackingFileSet**, **RunSimulator**, etc all have their own help pages.

## Create and configure the spacecraft, spacecraft hardware, and related parameters

For this tutorial, you will need GMAT open, with a new empty script open. To create a new script, click **New Script**, (  )

### Create the simulation satellites, set their epoch and Cartesian coordinates

First, we create new spacecraft for simulation, **SimSat** and **SimTrackSat**, and set their epochs and Cartesian coordinates.

```
%  
% Simulated Spacecraft  
  
Create Spacecraft SimSat  
  
SimSat.DateFormat = UTCGregorian  
SimSat.Epoch = '10 Jun 2010 00:00:00.000'  
SimSat.CoordinateSystem = EarthMJ2000Eq  
SimSat.DisplayStateType = Cartesian  
SimSat.X = 576.86955  
SimSat.Y = -5701.14276  
SimSat.Z = -4170.59369  
SimSat.VX = -1.76450794  
SimSat.VY = 4.18128798  
SimSat.VZ = -5.96578986  
SimSat.Id = 'ObservedSat'  
  
Create Spacecraft SimTrackSat  
  
SimTrackSat.DateFormat = UTCGregorian  
SimTrackSat.Epoch = '10 Jun 2010 00:00:00.000'  
SimTrackSat.CoordinateSystem = EarthMJ2000Eq  
SimTrackSat.DisplayStateType = Cartesian  
SimTrackSat.X = -36517.051189  
SimTrackSat.Y = -21083.129334  
SimTrackSat.Z = -0.000000  
SimTrackSat.VX = -0.005964  
SimTrackSat.VY = 0.010330  
SimTrackSat.VZ = 0.267968  
SimTrackSat.Id = 'TrackSat'
```

Note that, in addition to setting each spacecraft's coordinates, we also assigned each an ID. This is the label that will be written to the GMAT Measurement Data (GMD) file that we will discuss later.

## Create the estimation satellites, set their epoch and Cartesian co-ordinates

Next, we create new spacecraft for the estimation, **EstSat** and **EstTrackSat**, and set their epochs and Cartesian coordinates.

```
%  
%   Estimator Spacecraft  
  
Create Spacecraft EstSat  
  
EstSat.DateFormat      = UTCGregorian  
EstSat.Epoch           = '10 Jun 2010 00:00:00.000'  
EstSat.CoordinateSystem = EarthMJ2000Eq  
EstSat.DisplayStateType = Cartesian  
EstSat.X               = 576.87  
EstSat.Y               = -5701.14  
EstSat.Z               = -4170.59  
EstSat.VX              = -1.764508  
EstSat.VY              = 4.181288  
EstSat.VZ              = -5.965790  
EstSat.Id              = 'ObservedSat'  
EstSat.AddHardware     = {Transponder1, SpacecraftAntenna}  
EstSat.SolveFor         = {CartesianState}  
  
Create Spacecraft EstTrackSat  
  
EstTrackSat.DateFormat = UTCGregorian  
EstTrackSat.Epoch      = '10 Jun 2010 00:00:00.000'  
EstTrackSat.CoordinateSystem = EarthMJ2000Eq  
EstTrackSat.DisplayStateType = Cartesian  
EstTrackSat.X           = -36517.051189  
EstTrackSat.Y           = -21083.129334  
EstTrackSat.Z           = -0.000000  
EstTrackSat.VX          = -0.005964  
EstTrackSat.VY          = 0.010330  
EstTrackSat.VZ          = 0.267968  
EstTrackSat.Id          = 'TrackSat'
```

Note that in this example we are assuming that the location of the TrackSat has been determined already, either through estimation from previous tracking or otherwise. As such the coordinates for **SimTrackSat** and **EstTrackSat** are set to the same values. We do however set the initial state of **EstSat** to be different from that of **SimSat**, since we will eventually try to estimate the state of **EstSat** from the simulated tracking and don't want to give it a perfect initial guess.

## Create a Transponder object and attach it to the spacecraft

To simulate navigation measurements for a given spacecraft, GMAT requires that a **Transponder** object, which receives the uplink signal and re-transmits it, be attached to the spacecraft. Below, we create the **Transponder** object and attach it to our spacecraft. After we create the **Transponder** object, there are three fields, **PrimaryAntenna**, **HardwareDelay**, and **TurnAroundRatio** that must be set.

```
%  
% Spacecraft hardware  
  
Create Antenna SpacecraftAntenna  
Create Transponder HGA  
  
HGA.PrimaryAntenna = SpacecraftAntenna  
HGA.HardwareDelay = 1e-06  
HGA.TurnAroundRatio = '880/749'  
  
SimSat.AddHardware = {HGA, SpacecraftAntenna}  
EstSat.AddHardware = {HGA, SpacecraftAntenna}
```

The **PrimaryAntenna** is the antenna that the spacecraft transponder, **SatTransponder**, uses to receive and retransmit RF signals. In the example above, we set this field to **HGA** which is an **Antenna** object we have created. Currently the **Antenna** resource has no function but is required for measurement simulation and estimation. **HardwareDelay**, the transponder signal delay in seconds, is set to one micro-second. We set **TurnAroundRatio**, which is the ratio of the retransmitted to the input signal, to '880/749.' See the **FRC-21\_RunSimulator** help for a discussion on how GMAT uses this input field. In the last script commands above, we attach our newly created **Transponder** and its related **Antenna** object to each of the observed spacecraft.

## Create a Receiver object and attach it to the measurement spacecraft

To perform measurements with a given spacecraft, GMAT requires that a **Transmitter** and a **Receiver** object, which send and receive the forward and return tracking signals, be attached to the tracking spacecraft. Below, we create the objects and attach them to our spacecraft.

```
%  
% Measurement Spacecraft hardware  
  
Create Transmitter MeasurementTransmitter  
Create Receiver MeasurementReceiver  
  
MeasurementTransmitter.PrimaryAntenna = SpacecraftAntenna  
MeasurementTransmitter.Frequency = 7200  
MeasurementReceiver.PrimaryAntenna = SpacecraftAntenna  
  
SimTrackSat.AddHardware = {HGA, SpacecraftAntenna, MeasurementTransmitter, MeasurementReceiver}  
EstTrackSat.AddHardware = {HGA, SpacecraftAntenna, MeasurementTransmitter, MeasurementReceiver}
```

We set **Frequency**, which is the frequency of the forward/uplink tracking signal, to 7200 MHz. In the last script commands above, we attach our newly created **Transmitter** and **Receiver** objects to the spacecraft performing measurements.

## Define the types of measurements to be simulated and their associated error models

### Define the TrackingFileSets for the simulation and the estimator

Now we will create and configure a **TrackingFileSet** resource. This resource defines the type of data to be simulated, the ground stations that will be used, and the file name of the output GMD file which will contain the simulated data. In addition, the **TrackingFileSet** resource will define needed simulation parameters for the various data types. A similar **TrackingFileSet** is created for the estimation, with inputs corresponding to the estimated Spacecraft.

```
%  
%   Tracking file sets  
  
Create TrackingFileSet simData  
  
simData.AddTrackingConfig      = {{SimTrackSat, SimSat, SimTrackSat}, 'Range', 'RangeRate'}  
simData.FileName               = {'InterSpacecraft_Range_and_RangeRate.gmd'}  
simData.UseLightTime           = True  
simData.UseRelativityCorrection = True  
simData.UseETminusTAI          = True  
simData.SimDopplerCountInterval = 10.  
  
Create TrackingFileSet estData  
  
estData.AddTrackingConfig      = {{EstTrackSat, EstSat, EstTrackSat}, 'Range', 'RangeRate'}  
estData.FileName               = {'InterSpacecraft_Range_and_RangeRate.gmd'}  
estData.UseLightTime           = True  
estData.UseRelativityCorrection = True  
estData.UseETminusTAI          = True
```

For each **TrackingFileSet**, the script lines are broken into three sections. In the first section (the first two lines of each **TrackingFileSet**), the resource name, is declared, the data types are defined, and the output file name is specified. **AddTrackingConfig** is the field that is used to define the data types. The **AddTrackingConfig** line tells GMAT to simulate Range and RangeRate two-way measurements for the **TrackSat** to **Sat** to **TrackSat** measurement strand.

The second section (the next three lines) sets some simulation parameters that apply to both the range and Doppler measurements. We set **UseLightTime** to True in order to generate realistic measurements where GMAT takes into account the finite speed of light. The last two parameters in this section, **UseRelativityCorrection** and **UseETminusTAI**, are set to True so that general relativistic corrections, as described in Moyer [2000], are applied to the light time equations.

The third section (the last line of the **simData** configuration) above sets simulation parameters that apply to a specific measurement type. **SimDopplerCountInterval** applies only to RangeRate measurements. We note that the “Sim” in the field names is used to indicate that these fields only are applicable when GMAT is in simulation mode (i.e., when using the **RunSimulator** command) and not when GMAT is in estimation mode (i.e., when using the **RunEstimator** command). **SimDopplerCountInterval**, the

Doppler Count Interval, is set to 10 seconds. This parameter is only applicable to the tracking file set used by the simulator and is not set on the tracking file set used by the estimator. See the **RunSimulator** help for a description of how this parameter is used to calculate the measurement values.

## Create the measurement error models

All measurement types have random noise and/or biases associated with them. For inter-spacecraft measurements, these effects are modelled using error models on the receiver of the tracking Spacecraft. Since we have already created the **Spacecraft** object and its related hardware, we now create the receiver error models. Since we wish to simulate both Range and RangeRate data, we need to create two error models as shown below, one for range measurements and one for range-rate measurements.

```
%  
% Spacecraft error models  
  
Create ErrorModel Range  
  
Range.Type      = 'Range'  
Range.NoiseSigma = 0.010  
Range.Bias      = 0.0  
Range.SolveFors = {}  
  
Create ErrorModel RangeRate  
  
RangeRate.Type      = 'RangeRate'  
RangeRate.NoiseSigma = 0.000001  
RangeRate.Bias      = 0.0  
RangeRate.SolveFors = {}  
  
MeasurementReceiver.ErrorModels = {Range, RangeRate}
```

The script segment above is broken into three sections. The first section defines an **ErrorModel** named **Range**. The error model Type is Range which indicates that it is an error model for two-way range measurements. The one-sigma standard deviation of the Gaussian white noise is set to 10 meters (0.010 km) and the measurement bias is set to 0 km.

The second section above defines an **ErrorModel** named **RangeRate**. The error model Type is RangeRate which indicates that it is an error model for two-way averaged range-rate measurements. The one-sigma standard deviation of the Gaussian white noise is set to 1 mm/sec and the measurement bias is set to 0 km/sec.

The third section above attaches the two **ErrorModel** resources we have just created to the **MeasurementReceiver Receiver**. For inter-spacecraft measurement, the measurement noise or bias is defined on the Receiver hardware. Each measurement performed by a Spacecraft containing that Receiver must have an associated ErrorModel. Thus, any range measurement error involving a **Spacecraft** with the **Measuremen-**

**tReceiver Receiver** is defined by the **Range ErrorModel** and any range-rate measurement error involving a **Spacecraft** with the **MeasurementReceiver**. **Receiver** is defined by the **RangeRate ErrorModel**. Note that since GMAT currently only models two way measurements where the transmitting and receiving Spacecraft are the same, we do not have to consider the case where the transmitting and receiving Spacecraft are different.

## Create and configure force model and propagator

We now create and configure the force model and propagator that will be used for the simulation. For this constellation, we are using simplified force modeling, just accounting for the Earth's gravitational effect, and disabling the modeling of solar radiation pressure and drag. The script segment accomplishing this is shown below.

```
%  
% Propagator and force model  
  
Create ForceModel FM  
  
FM.CentralBody = Earth  
FM.PointMasses = {Earth}  
FM.Drag = None  
FM.SRP = Off  
FM.ErrorControl = None  
  
Create Propagator Prop  
  
Prop.FM = FM  
Prop.Type = 'RungeKutta56'  
Prop.InitialStepSize = 60  
Prop.Accuracy = 1e-13  
Prop.MinStep = 0  
Prop.MaxStep = 60  
Prop.MaxStepAttempts = 50
```

## Create and configure the simulator and batch estimator objects

### Create the simulator object

As shown below, we create and configure the **Simulator** object used to define our simulation.

```
%  
% Simulator  
  
Create Simulator sim  
  
sim.AddData = {simData}
```

```

sim.EpochFormat          = 'UTCGregorian'
sim.InitialEpoch         = '10 Jun 2010 00:00:00.000'
sim.FinalEpoch           = '11 Jun 2010 00:00:00.000'
sim.MeasurementTimeStep = 60
sim.Propagator          = Prop
sim.AddNoise              = On

```

In the first script line above, we create a **Simulator** object, **sim**. The next field set is **AddData** which is used to specify which **TrackingFileSet** should be used. Recall that the **TrackingFileSet** specifies the type of data to be simulated and the file name specifying where to store the data. The **TrackingFileSet**, **simData**, that we created in the [Define the types of measurements to be simulated and their associated error models](#) section, specified that we wanted to simulate two-way range and range-rate data that involved the **SimMeasureSat Spacecraft**.

The next three script lines, which set the **EpochFormat**, **InitialEpoch**, and **FinalEpoch** fields, specify the time period of the simulation. Here, we choose a two-day duration.

The next script line sets the **MeasurementTimeStep** field which specifies the requested time between measurements. We choose a value of 1 minute.

The next script line sets the **Propagator** field which specifies which **Propagator** object should be used. We set this field to the **Prop** object which we created in the [Create and configure force model and propagator](#) section.

Finally, in the last line of the script segment, we set the **AddNoise** field which specifies whether or not we want to add noise to our simulated measurements. The noise added is defined by the **ErrorModel** objects that we created in the [Create the measurement error models](#) section. As discussed in the [Create the measurement error models](#) section, the noise added to the range measurements will be Gaussian with a one-sigma value of 10 meters, and the noise added to the range-rate measurements will be Gaussian with a one sigma value of 1 mm/sec.

## Create the batch estimator object

In order to estimate the true initial state of the observed spacecraft, we define the **Batch-Estimator bat** in the script below.

```

%
% Estimator
%

Create BatchEstimator bat

bat.ShowProgress          = True
bat.Measurements          = {estData}
bat.AbsoluteTol            = 0.000001
bat.RelativeTol           = 0.005
bat.MaximumIterations      = 10
bat.MaxConsecutiveDivergences = 3
bat.Propagator             = Prop
bat.ShowAllResiduals       = On
bat.OLSEInitialRMSSigma   = 3000
bat.OLSEMultiplicativeConstant = 3
bat.OLSEAdditiveConstant  = 0
bat.ReportFile             = 'InterSpacecraft_Range_and_RangeRate.txt'

```

For more information on the parameters involved in defining the BatchEstimator object, see the documentation for the [BatchEstimator](#).

## Run the mission and review the output

### Review the simulated measurements

The script segment used to run the mission is shown below.

```
BeginMissionSequence  
  
RunSimulator sim  
RunEstimator bat
```

The first script line, **BeginMissionSequence**, is a required command which indicates that the “command” section of the GMAT script has begun. The second line of the script issues the **RunSimulator** command with the **Sim** Simulator resource, defined in the [Create the simulator object](#) section, as an argument. This tells GMAT to perform the simulation specified by the **sim** resource. The third line of the script issues the **RunEstimator** command with the **bat** batch estimator resource, defined in the [Create the batch estimator object](#) section, as an argument.

We have now completed all of our script segments. See the file, `Tut_Inter_Spacecraft_Tracking.script`, in the GMAT samples folder, for a listing of the entire script. We are now ready to run the script. Hit the Save,Sync,Run button, ([Save,Sync,Run](#)). The script will take a few moments to run as GMAT simulates the data and then attempts the estimation.

Let’s take a look at the output created. The file created, `InterSpacecraft_Range_and_Rate.gmd`, was specified in the **TrackingFileSet** resource, **DSNSimData**, that we created in the [Define the types of measurements to be simulated and their associated error models](#) section. The default directory, if none is specified, is the GMAT installation ‘output’ directory. Let’s analyze the contents of this “GMAT Measurement Data” or GMD file as shown below.

```
% GMAT Internal Measurement Data File  
  
25357.5003935185185185190    Range    9029    TrackSat    ObservedSat    8.0745608409918510e+04  
25357.5003935185185185190    RangeRate  9030    { TrackSat    ObservedSat    TrackSat }    2    10    1.2080451949525264e+00  
25357.5010879629629629630    Range    9029    TrackSat    ObservedSat    8.0828956472718346e+04  
25357.5010879629629629630    RangeRate  9030    { TrackSat    ObservedSat    TrackSat }    2    10    1.5166696445321948e+00
```

The first line of the file is a comment line indicating that this is a file containing measurement data stored in GMAT’s internal format. There are four lines of data representing range data at two successive times and range-rate data at two successive times. The first line of data which represents a two-way range measurement at the start of the simulation at ‘10 Jun 2010 00:00:00.000 UTCG’ which corresponds to the output TAI modified Julian day of 25357.5003935185... TAIMJD. The second and third fields, Range and 9029, are just internal GMAT codes indicating the use of two-way range data. The fourth field, TrackSat, is the tracking spacecraft ID. This is the ID we gave the **Spacecraft SimTrackSat** object. The fifth field, ObservedSat, is the tracked spacecraft ID, which is the ID we gave the **SimSat Spacecraft** object that we created. The 6th

field, 8.0745614120287588e+04, is the actual inter-spacecraft range observation value in km. Note that your value will be different, since we've added random noise to the data.

The second line of data represents a two-way range-rate measurement at the start of the simulation at '10 Jun 2010 00:00:00.000 UTCG' which corresponds to the output TAI modified Julian Day of 25357.5003935185... TAIMJD. This range-rate measurement is simultaneous with the simulated range measurement. The second and third fields, RangeRate and 9030, are just internal GMAT codes indicating the use of the RangeRate observation type. The fields enclosed in curly braces represent the measurement path - from spacecraft TrackSat, to spacecraft ObservedSat, back to spacecraft TrackSat. The fifth field, 2, is an integer which represents the Uplink Band of the signal from the **Spacecraft, SimTrackSat**. The designation 2 represents X-band. The sixth field, 10, is the Doppler Count Interval (DCI) used to help define the Doppler measurement. This is the value that we set when we created and configured the **TrackingFileSet DSNsim-Data** object in the [Define the types of measurements to be simulated and their associated error models](#) section. Recall the following script command,

```
DSNsimData.SimDopplerCountInterval = 10.0
```

The seventh field, 1.2080451949525264e+00, is the actual range-rate observation value in km/sec. Again, your value will differ from that appearing here.

The third line of data represents the second two-way range measurement at '10 Jun 2010 00:01:00.000 UTCG' which corresponds to the output TAI modified Julian Day time of 25357.5010879629... TAIMJD. The fourth line of data represents the second two-way range-rate measurement at '10 Jun 2010 00:01:00.000 UTCG.' All the following lines show the simulated measurements at each minute during until the end of the simulation, which was defined as '11 Jun 2010 00:00:00.000'. There will be gaps in the simulated data corresponding to when the Earth blocks the signal from the tracking spacecraft in geosynchronous orbit to the target spacecraft in low-earth orbit.

## Review the estimator results

Let's take a look at the output created from the **BatchEstimator**. The file created, **InterSpacecraft\_Range\_and\_RangeRate.txt**, was specified in the **TrackingFileSet** resource, **simData**, that we created in the [Define the types of measurements to be simulated and their associated error models](#) section. The default directory, if none is specified, is the GMAT 'output' directory. The contents of this file are extensive, but can be summarized into three sections.

The first section is the header, which contains information about the initial information that the estimator is provided, as well as details about the objects involved in the estimation. A sample of this is seen in the text below.

```
***** SPACECRAFT INITIAL CONDITIONS *****
Spacecraft State at Beginning of Estimation :
Spacecraft Name           EstTrackSat          EstSat
ID                         TrackSat            ObservedSat
Epoch (UTC)                10 Jun 2010 00:00:00.000 10 Jun 2010 00:00:00.000
Coordinate System           EarthMJ2000Eq        EarthMJ2000Eq
```

X (km)	-36517.05118900	576.87000000
Y (km)	-21083.12933400	-5701.14000000
Z (km)	0.00000000	-4170.59000000
VX (km/s)	-0.005964000000	-1.764508000000
VY (km/s)	0.010330000000	4.181288000000
VZ (km/s)	0.267968000000	-5.965790000000
Cr	1.800000	1.800000
CrSigma	Not Estimated	Not Estimated
Cd	2.200000	2.200000
CdSigma	Not Estimated	Not Estimated
DryMass (kg)	850.000000	850.000000
DragArea (m^2)	15.000000	15.000000
SRPArea (m^2)	1.000000	1.000000

The second section is the iteration section, which contains a computed estimation for each measurement and the resulting residual. At the end of each iteration is information on the progress of the batch estimation, detailing whether or not the solution is converging and how the iteration compares to previous iterations. The final section contains the estimated solution, with the estimated Cartesian coordinates and the covariance matrix for the solution.

## References

- Moyer [2000] Moyer, Theodore D., Formulation for Observed and Computed Values of Deep Space Network Data Types for Navigation (JPL Publication 00-7), Jet Propulsion Laboratory, California Institute of Technology, October 2000.
- Schanzle [1995] Schanzle, A., Orbit Determination Error Analysis System (ODEAS) Report on Error Sources and Nominal 3-Sigma Uncertainties for Covariance Analysis Studies Using ODEAS (Update No. 2), Computer Sciences Corporation (CSC) memo delivered as part of NASA contract NAS-5-31500, May 31, 1995.



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# Reference Guide

The [\*Reference Guide\*](#) contains individual topics that describe each of GMAT's resources and commands. When you need detailed information on syntax or application-specific examples for specific features, go here. It also includes system-level references that describe the script language syntax, parameter listings, external interfaces, and configuration files.

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# API

## User Guide



### Note

The user guide for the API is written in Sphinx and located in the GMAT distribution here: [gmat/docs/GMAT\\_API\\_UsersGuide.pdf](#)



# Dynamics and Modeling

This chapter contains documentation for Resources and Commands related to dynamics and modeling.

## Resources

## Barycenter

The center of mass of selected celestial bodies

### Description

A **Barycenter** is the center of mass of a set of celestial bodies. GMAT contains two barycenter resources: a built-in **SolarSystemBarycenter** resource and the **Barycenter** resource that allows you to build a custom **Barycenter** such as the Earth-Moon barycenter. This resource cannot be modified in the Mission Sequence.

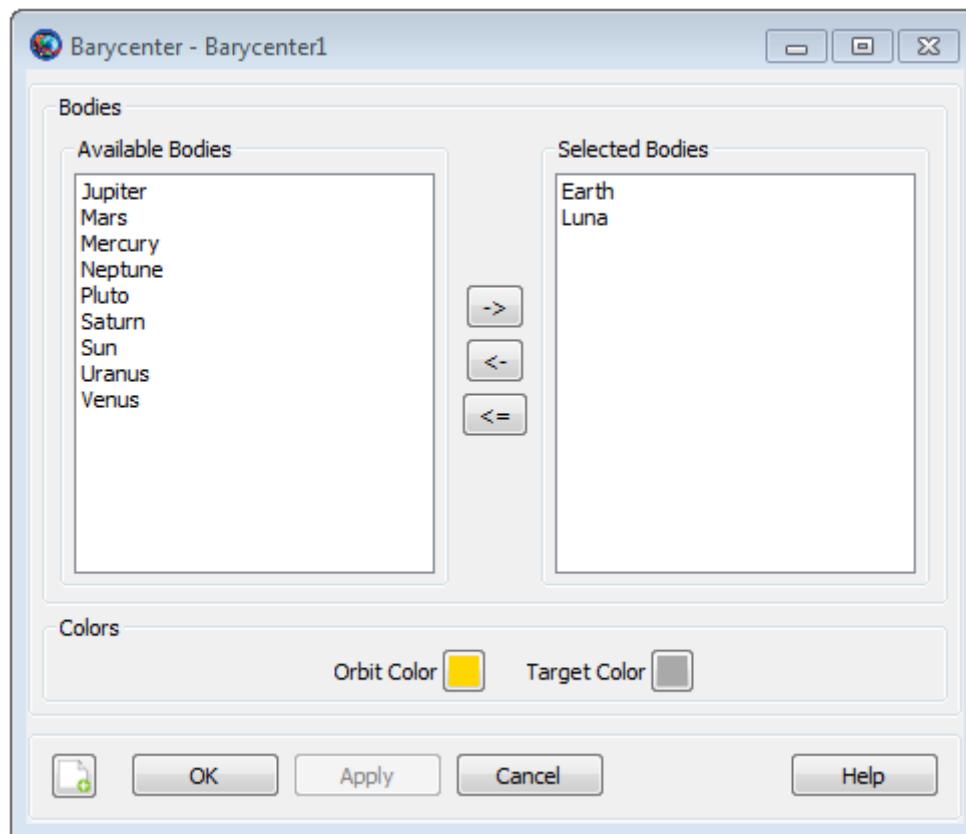
See Also: [LibrationPoint](#), [CoordinateSystem](#), [CelestialBody](#), [SolarSystem](#), [Color](#)

### Fields

Field	Description
<b>BodyNames</b>	<p>The list of <b>CelestialBody</b> resources included in the Barycenter. Providing empty brackets sets the bodies to the default list described below.</p> <p><b>Data Type</b> String array <b>Allowed Values</b> array of celestial bodies. You cannot add bodies to the built-in <b>SolarSystemBarycenter</b> resource. A <b>CelestialBody</b> can only appear once in the <b>BodyNames</b> list. <b>Access</b> set <b>Default Value</b> <b>Earth, Luna</b> <b>Units</b> N/A <b>Interfaces</b> GUI, script</p>
<b>OrbitColor</b>	<p>Allows you to set available colors on user-defined <b>Barycenter</b> object orbits. The barycenter orbits are drawn using the <b>OrbitView</b> graphics resource. Colors on <b>Barycenter</b> object can be set through a string or an integer array. For example: Setting a barycenter's orbit color to red can be done in the following two ways: <code>Barycenter.OrbitColor = Red</code> or <code>Barycenter.OrbitColor = [255 0 0]</code>. This field can be modified in the Mission Sequence as well.</p> <p><b>Data Type</b> Integer Array or String <b>Allowed Values</b> Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255. <b>Access</b> set <b>Default Value</b> Gold <b>Units</b> N/A <b>Interfaces</b> GUI, script</p>

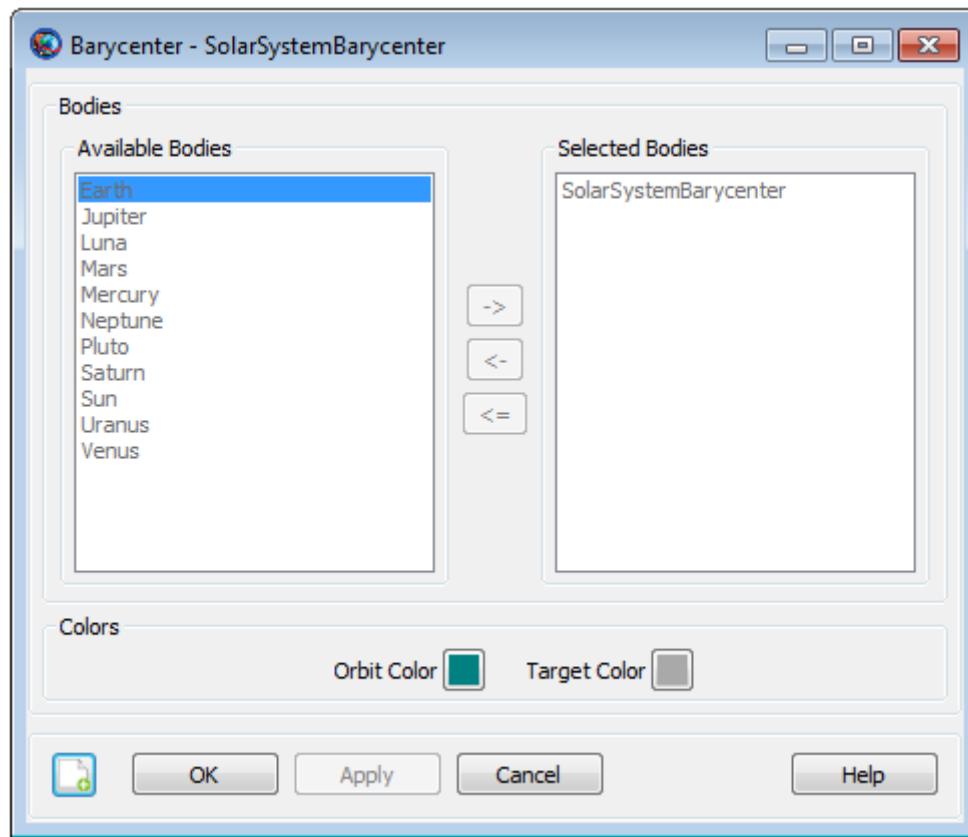
Field	Description
<b>TargetColor</b>	Allows you to select available colors for <b>Barycenter</b> object's perturbing orbital trajectories that are drawn during iterative processes such as Differential Correction or Optimization. The target color can be identified through a string or an integer array. For example: Setting a barycenter's perturbing trajectory color to yellow can be done in following two ways: <code>Barycenter.TargetColor = Yellow</code> or <code>Barycenter.TargetColor = [255 255 0]</code> . This field can be modified in the Mission Sequence as well.
<b>Data Type</b>	Integer Array or String
<b>Allowed Values</b>	Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255.
<b>Access</b>	set
<b>Default Value</b>	DarkGray
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

## GUI



The **Barycenter** dialog box allows you to define the celestial bodies included in a custom **Barycenter**. All celestial bodies, including user-defined bodies, are available for use in a

**Barycenter** and appear in either the **Available Bodies** list or the **Selected Bodies** list. The example above illustrates the default configuration which contains **Earth** and **Luna**.



The **SolarSystemBarycenter** dialog box shown above is a built-in object and you cannot modify its configuration. See the Remarks section for details regarding the model for the **SolarSystemBarycenter**.

## Remarks

### *Built-in SolarSystemBarycenter Object*

The built-in **SolarSystemBarycenter** is modelled using the ephemerides selected in the **SolarSystem.EphemerisSource** field. For example, if you select **DE421** for **SolarSystem.EphemerisSource**, then the barycenter location is computed by calling the DE421 ephemeris routines. For DE and SPICE ephemerides, the model for the solar system barycenter includes the planets and several hundred minor planets and asteroids. Note that you cannot add bodies to the **SolarSystemBarycenter**.

### *Custom Barycenter Objects*

You can create a custom barycenter using the **Barycenter** resource. The position and velocity of a **Barycenter** is a mass-weighted average of the position and velocity of the included celestial bodies. In the equations below  $m_i$ ,  $r_i$ , and  $v_i$  are respectively the mass, position, and velocity of the  $i^{\text{th}}$  body in the barycenter, and  $r_b$  and  $v_b$  are respectively the position and velocity of the barycenter.

$$\mathbf{r}_b = \frac{\sum_{i=1}^n m_i \mathbf{r}_i}{\sum_{i=1}^n m_i}$$

$$\mathbf{v}_b = \frac{\sum_{i=1}^n m_i \mathbf{v}_i}{\sum_{i=1}^n m_i}$$

## Setting Colors On Barycenter Orbits

GMAT allows you to assign colors to barycenter orbits that are drawn using the **OrbitView** graphics resource. GMAT also allows you to assign colors to perturbing barycenter orbital trajectories which are drawn during iterative processes such as differential correction or optimization. The **Barycenter** object's **OrbitColor** and **TargetColor** fields are used to assign colors to both orbital and perturbing trajectories. See the [Fields](#) section to learn more about these two fields. Also see [Color](#) documentation for discussion and examples on how to set colors on a barycenter orbit.

## Examples

Define the state of a spacecraft in **SolarSystemBarycenter** coordinates.

```
Create CoordinateSystem SSB
SSB.Origin = SolarSystemBarycenter
SSB.Axes   = MJ2000Eq

Create ReportFile aReport

Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = SSB
aSpacecraft.X   = -27560491.88656896
aSpacecraft.Y   = 132361266.8009069
aSpacecraft.Z   = 57419875.95483227
aSpacecraft.VX  = -29.78491261798486
aSpacecraft.VY  = 2.320067257851091
aSpacecraft.VZ  = -1.180722388963864

BeginMissionSequence

Report aReport aSpacecraft.EarthMJ2000Eq.X aSpacecraft.EarthMJ2000Eq.Y ...
```

**aSpacecraft.EarthMJ2000Eq.Z**

Report the state of a spacecraft in **SolarSystemBarycenter** coordinates.

```
Create CoordinateSystem SSB
SSB.Origin = SolarSystemBarycenter
SSB.Axes   = MJ2000Eq

Create Spacecraft aSpacecraft
Create ReportFile aReport

BeginMissionSequence

Report aReport aSpacecraft.SSB.X aSpacecraft.SSB.Y aSpacecraft.SSB.Z ...
      aSpacecraft.SSB.VX aSpacecraft.SSB.VY aSpacecraft.SSB.VZ
```

Create an Earth-Moon **Barycenter** and use it in a Sun-Earth-Moon **LibrationPoint**.

```
Create Barycenter EarthMoonBary
EarthMoonBary.BodyNames = {Earth,Luna}

Create LibrationPoint SunEarthMoonL2
SunEarthMoonL2.Primary   = Sun
SunEarthMoonL2.Secondary = EarthMoonBary
SunEarthMoonL2.Point     = L2

Create CoordinateSystem SEML2Coordinates
SEML2Coordinates.Origin = SunEarthMoonL2
SEML2Coordinates.Axes   = MJ2000Eq

Create Spacecraft aSpacecraft
GMAT aSpacecraft.DateFormat = UTCGregorian
GMAT aSpacecraft.Epoch = '09 Dec 2005 13:00:00.000'
GMAT aSpacecraft.CoordinateSystem = SEML2Coordinates
GMAT aSpacecraft.X = -32197.88223741966
GMAT aSpacecraft.Y = 211529.1500044117
GMAT aSpacecraft.Z = 44708.57017366499
GMAT aSpacecraft.VX = 0.03209516489451751
GMAT aSpacecraft.VY = 0.06086386504053736
GMAT aSpacecraft.VZ = 0.0550442738917212

Create ReportFile aReport

BeginMissionSequence

Report aReport aSpacecraft.EarthMJ2000Eq.X aSpacecraft.EarthMJ2000Eq.Y ...
      aSpacecraft.EarthMJ2000Eq.Z
```

## CelestialBody

Modeling of Moon, Planet, Asteroid, and Comet objects

### Description



#### Note

There is no CelestialBody resource. The user must instead create instances of **Moon**, **Planet**, **Asteroid**, or **Comet** as shown in the examples below. The user interface parameters for all of these objects are identical and are described in the table below.

The **Moon**, **Planet**, **Asteroid**, and **Comet** resources model a celestial body containing settings for the physical properties, as well as the models for the orbital motion and orientation. GMAT contains built-in models for the Sun, the eight planets, Earth's moon, and Pluto. You can create a custom resource to model a planet, asteroid, comet, or moon. This resource cannot be modified in the Mission Sequence.

See Also: [SolarSystem](#), [Barycenter](#), [LibrationPoint](#), [CoordinateSystem](#), [Color](#)



#### Warning

When creating a new **Moon**, **Planet**, **Asteroid**, or **Comet** the default values for **Mu**, **EquitorialRadius**, **Flattening**, **SpinAxisRAConstant**, **SpinAxisRARate**, **SpinAxisDECConstant**, **SpinAxisDECRate**, **RotationConstant**, **RotationRate** are all set to 0. These parameters are relevant to gravity modeling and placement of ground stations for user-defined bodies, so appropriate values should be assigned by the user when needed. The body attitude and shape parameters may be left unset if non-spherical gravity and shape modeling are not needed.

### Fields

Field	Description
<b>3DModelFile</b>	Allows you to load 3D models for your celestial body. Models must be in .3ds model formats.  <b>Data Type</b> String <b>Allowed Values</b> . 3ds model formats only <b>Access</b> set <b>Default Value</b> empty <b>Units</b> N/A <b>Interfaces</b> GUI, script

<b>Field</b>	<b>Description</b>												
<b>3DModelOffsetX</b>	<p>This field lets you translate a celestial body in +X or -X axis of central body's coordinate system.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-3.5 &lt;= Real &lt;= 3.5</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0.000000</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-3.5 <= Real <= 3.5	<b>Access</b>	set	<b>Default Value</b>	0.000000	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-3.5 <= Real <= 3.5												
<b>Access</b>	set												
<b>Default Value</b>	0.000000												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>3DModelOffsetY</b>	<p>This field lets you translate a celestial body in +Y or -Y axis of central body's coordinate system.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-3.5 &lt;= Real &lt;= 3.5</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0.000000</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-3.5 <= Real <= 3.5	<b>Access</b>	set	<b>Default Value</b>	0.000000	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-3.5 <= Real <= 3.5												
<b>Access</b>	set												
<b>Default Value</b>	0.000000												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>3DModelOffsetZ</b>	<p>This field lets you translate a celestial body in +Z or -Z axis of central body's coordinate system.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-3.5 &lt;= Real &lt;= 3.5</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0.000000</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-3.5 <= Real <= 3.5	<b>Access</b>	set	<b>Default Value</b>	0.000000	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-3.5 <= Real <= 3.5												
<b>Access</b>	set												
<b>Default Value</b>	0.000000												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>3DModelRotationX</b>	<p>Allows you to perform a fixed rotation of a celestial body's attitude w.r.t X-axis of central body's coordinate system.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-180 &lt;= Real &lt;= 180</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0.000000</td></tr> <tr> <td><b>Units</b></td><td>Deg.</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-180 <= Real <= 180	<b>Access</b>	set	<b>Default Value</b>	0.000000	<b>Units</b>	Deg.	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-180 <= Real <= 180												
<b>Access</b>	set												
<b>Default Value</b>	0.000000												
<b>Units</b>	Deg.												
<b>Interfaces</b>	GUI, script												
<b>3DModelRotationY</b>	<p>Allows you to perform a fixed rotation of a celestial body's attitude w.r.t Y-axis of central body's coordinate system.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-180 &lt;= Real &lt;= 180</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0.000000</td></tr> <tr> <td><b>Units</b></td><td>Deg.</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-180 <= Real <= 180	<b>Access</b>	set	<b>Default Value</b>	0.000000	<b>Units</b>	Deg.	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
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<b>Access</b>	set												
<b>Default Value</b>	0.000000												
<b>Units</b>	Deg.												
<b>Interfaces</b>	GUI, script												

Field	Description
<b>3DModelRotationZ</b>	<p>Allows you to perform a fixed rotation of a celestial body's attitude w.r.t Z-axis of central body's coordinate system.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> -180 &lt;= Real &lt;= 180  <b>Access</b> set  <b>Default Value</b> 0.000000  <b>Units</b> Deg.  <b>Interfaces</b> GUI, script</p>
<b>3DModelScale</b>	<p>Allows you to apply a scale factor to the celestial body's model size.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> 0.001 &lt;= Real &lt;= 1000  <b>Access</b> set  <b>Default Value</b> 10  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>CentralBody</b>	<p>The central body of the custom body's orbit. This field is used primarily by the GUI.</p> <p><b>Data Type</b> String  <b>Allowed Values</b> An instance of <b>Comet</b>, <b>Planet</b>, <b>Asteroid</b>, or <b>Moon</b>  <b>Access</b> set  <b>Default Value</b> For instances of <b>Comet</b>, <b>Planet</b>, or <b>Asteroid</b>, the default is <b>Sun</b>. For instances of <b>Moon</b>, the default is <b>Earth</b>.  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>DSNMediaFileDirectories</b>	<p>List of directories containing DSN TRK-2-23 media correction files. Directories must be given with full paths or paths relative to the GMAT executable. Files in the directories must be in format of .csp or .csp.ql. This parameter is used when a ground station has set 'TRK-2-23' for the tropospheric or ionospheric model. This field is only valid for <b>Earth</b>. See <a href="#">GroundStation</a> for more details on TRK-2-23 media models.</p> <p><b>Data Type</b> String array  <b>Allowed Values</b> Valid directory path  <b>Access</b> set  <b>Default Value</b> {}  <b>Units</b> N/A  <b>Interfaces</b> script</p>

Field	Description
<b>EquatorialRadius</b>	The body's equatorial radius.
	<b>Data Type</b> Real <b>Allowed Values</b> Real > 0 <b>Access</b> set <b>Default Value</b> 0.0 <b>Units</b> km <b>Interfaces</b> GUI, script
<b>EopFileName</b>	Optional Earth EOP file to use instead of the EOP file defined in the startup file. Note that an empty string is the default, and when set to an empty string, the EOP file defined in the GMAT startup file is used. This field is only valid for <b>Earth</b> .
	<b>Data Type</b> Filename <b>Allowed Values</b> Valid file name <b>Access</b> set <b>Default Value</b> " <b>Units</b> N/A <b>Interfaces</b> script
<b>FileName</b>	Path and/or name of texture map file used in <b>OrbitView</b> graphics.
	<b>Data Type</b> String <b>Allowed Values</b> A file of the following format:  .jpeg,.bmp,.png,.gif,.tif,.pcx,.pnm,.tga, or .xpm <b>Access</b> set <b>Default Value</b> '../ data/graphics/tex- ture/GenericCelestialBody.jpg' <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>Flattening</b>	The body's polar flattening. The flattening is defined as $f = 1 - \text{polar\_radius} / \text{equatorial\_radius}$ .
	<b>Data Type</b> Real <b>Allowed Values</b> Real $\geq 0$ <b>Access</b> set <b>Default Value</b> 0.0 <b>Units</b> N/A <b>Interfaces</b> GUI, script

Field	Description
<b>FrameSpiceKernel-Name</b>	<p>List of SPICE FK files to load for this body. Used to define celestial body properties for use with <b>ContactLocator</b> and <b>EclipseLocator</b>, and to define the body-fixed axes for Luna or user-defined bodies when the <b>RotationDataSource</b> is set to SPICE. See <a href="#">Remarks</a>.</p>
	<p><b>Data Type</b> String array  <b>Allowed Values</b> Paths to valid SPICE FK files  <b>Access</b> set  <b>Default Value</b> Varies for built-in bodies. Empty for user-defined bodies.  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>Mu</b>	The body's gravitational parameter.
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real &gt; 0  <b>Access</b> set  <b>Default Value</b> 0.0  <b>Units</b> km^3/s^2  <b>Interfaces</b> GUI, script</p>
<b>NAIFId</b>	NAIF Integer ID for body.
	<p><b>Data Type</b> Integer  <b>Allowed Values</b> Integer  <b>Access</b> set  <b>Default Value</b> -123456789  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>NutationUpdateInterval</b>	The time interval between updates for Earth nutation matrix. If NutationUpdateInterval = 3600, then GMAT only updates nutation on an hourly basis.
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real &gt;= 0  <b>Access</b> set  <b>Default Value</b> 60  <b>Units</b> sec.  <b>Interfaces</b> GUI, script</p>

Field	Description												
<b>OrbitColor</b>	<p>Allows you to set available colors on built-in or user-defined celestial body objects that are drawn on the 3D <b>OrbitView</b> graphics displays. Colors on an object can be set through a string or an integer array. For example: Setting a celestial body's orbit color to red can be done in the following two ways: <code>CelestialBody.OrbitColor = Red</code> or <code>Celestialbody.OrbitColor = [255 0 0]</code>. This field can be modified in the Mission Sequence as well.</p> <table> <tr> <td><b>Data Type</b></td><td>Integer Array or String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255.</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>Orchid for user-defined <b>Planet</b>, Pink for user-defined <b>Comet</b>, Salmon for user-defined <b>Asteroid</b> and Tan for user-defined <b>Moon</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Integer Array or String	<b>Allowed Values</b>	Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255.	<b>Access</b>	set	<b>Default Value</b>	Orchid for user-defined <b>Planet</b> , Pink for user-defined <b>Comet</b> , Salmon for user-defined <b>Asteroid</b> and Tan for user-defined <b>Moon</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Integer Array or String												
<b>Allowed Values</b>	Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255.												
<b>Access</b>	set												
<b>Default Value</b>	Orchid for user-defined <b>Planet</b> , Pink for user-defined <b>Comet</b> , Salmon for user-defined <b>Asteroid</b> and Tan for user-defined <b>Moon</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>OrbitSpiceKernelName</b>	<p>List of SPK kernels. Providing empty brackets unloads previously loaded kernels.</p> <table> <tr> <td><b>Data Type</b></td><td>Reference array</td></tr> <tr> <td><b>Allowed Values</b></td><td>valid list of SPK kernels</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>N/A</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Reference array	<b>Allowed Values</b>	valid list of SPK kernels	<b>Access</b>	set	<b>Default Value</b>	N/A	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Reference array												
<b>Allowed Values</b>	valid list of SPK kernels												
<b>Access</b>	set												
<b>Default Value</b>	N/A												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>OrientationEpoch</b>	<p>The reference epoch for orientation data.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td><math>6116.0 \leq \text{Epoch} \leq 58127.5</math></td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>21545.0</td></tr> <tr> <td><b>Units</b></td><td>A1 Modified Julian Epoch</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	$6116.0 \leq \text{Epoch} \leq 58127.5$	<b>Access</b>	set	<b>Default Value</b>	21545.0	<b>Units</b>	A1 Modified Julian Epoch	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	$6116.0 \leq \text{Epoch} \leq 58127.5$												
<b>Access</b>	set												
<b>Default Value</b>	21545.0												
<b>Units</b>	A1 Modified Julian Epoch												
<b>Interfaces</b>	GUI, script												

Field	Description
<b>PlanetarySpiceKernelName</b>	<p>List of SPICE PCK files to load for this body. Used to define celestial body properties for use with <b>ContactLocator</b> and <b>EclipseLocator</b>, and to define the body-fixed axes for Luna or user-defined bodies when the <b>RotationDataSource</b> is set to SPICE. See <a href="#">Remarks</a>.</p>
	<p><b>Data Type</b> String array  <b>Allowed Values</b> Paths to valid SPICE PCK files  <b>Access</b> set  <b>Default Value</b> Varies for built-in bodies. Empty for user-defined bodies.  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>PosVelSource</b>	<p>The model for user-defined body orbit ephemerides. GMAT currently only supports a single ephemeris model for custom bodies (SPICE) and this is set using <b>PosVelSource</b> field. The default for <b>PosVelSource</b> is SPICE and it is not necessary to configure this field in the current version of GMAT. This field has no effect for built-in bodies.</p>
	<p><b>Data Type</b> String  <b>Allowed Values</b> SPICE  <b>Access</b> set  <b>Default Value</b> DE405 for built-in bodies. SPICE for user-defined bodies.  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>RotationConstant</b>	<p>The body's spin angle at the orientation epoch.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0.0  <b>Units</b> deg  <b>Interfaces</b> GUI, script</p>

Field	Description												
<b>RotationDataSource</b>	<p>Specify a source for the body's body-fixed frame (the <b>CoordinateSystem BodyFixed</b> axes for the body). This parameter can only be modified for Luna and any user-defined CelestialBody. The <b>RotationDataSource</b> cannot currently be changed for built-in bodies other than Luna.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>IAUSimplified</b>, <b>SPICE</b> (Luna and user-defined bodies only).</td></tr> <tr> <td><b>Access</b></td><td>none</td></tr> <tr> <td><b>Default Value</b></td><td><b>IAUSimplified</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, Script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	<b>IAUSimplified</b> , <b>SPICE</b> (Luna and user-defined bodies only).	<b>Access</b>	none	<b>Default Value</b>	<b>IAUSimplified</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, Script
<b>Data Type</b>	String												
<b>Allowed Values</b>	<b>IAUSimplified</b> , <b>SPICE</b> (Luna and user-defined bodies only).												
<b>Access</b>	none												
<b>Default Value</b>	<b>IAUSimplified</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, Script												
<b>RotationRate</b>	<p>The body's spin rate.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0.0</td></tr> <tr> <td><b>Units</b></td><td>deg/day</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real	<b>Access</b>	set	<b>Default Value</b>	0.0	<b>Units</b>	deg/day	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real												
<b>Access</b>	set												
<b>Default Value</b>	0.0												
<b>Units</b>	deg/day												
<b>Interfaces</b>	GUI, script												
<b>SpiceFrameId</b>	<p>SPICE ID of body-fixed frame. Used to define celestial body properties for use with <b>ContactLocator</b> and <b>EclipseLocator</b>, and to define the body-fixed axes for Luna or user-defined bodies when the <b>RotationDataSource</b> is set to SPICE. See <a href="#">Remarks</a>.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Valid SPICE frame ID (text or numeric)</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>Varies for built-in bodies. Empty for user-defined bodies.</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Valid SPICE frame ID (text or numeric)	<b>Access</b>	set	<b>Default Value</b>	Varies for built-in bodies. Empty for user-defined bodies.	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Valid SPICE frame ID (text or numeric)												
<b>Access</b>	set												
<b>Default Value</b>	Varies for built-in bodies. Empty for user-defined bodies.												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>SpinAxisDECCConstant</b>	<p>The declination of the body's spin axis at the orientation epoch.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>90</td></tr> <tr> <td><b>Units</b></td><td>deg</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real	<b>Access</b>	set	<b>Default Value</b>	90	<b>Units</b>	deg	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real												
<b>Access</b>	set												
<b>Default Value</b>	90												
<b>Units</b>	deg												
<b>Interfaces</b>	GUI, script												

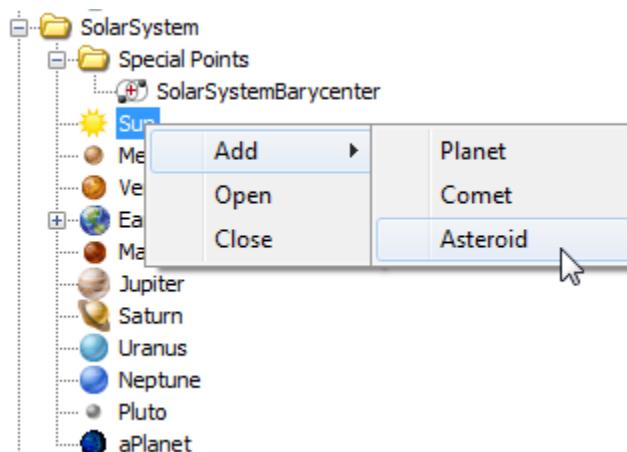
Field	Description
<b>SpinAxisDECRate</b>	The rate of change of the body's spin axis declination.
	<b>Data Type</b> Real <b>Allowed Values</b> Real <b>Access</b> set <b>Default Value</b> 0.0 <b>Units</b> deg/century <b>Interfaces</b> GUI, script
<b>SpinAxisRAConstant</b>	The right ascension of the body's spin axis at the orientation epoch.
	<b>Data Type</b> Real <b>Allowed Values</b> Real <b>Access</b> set <b>Default Value</b> 0.0 <b>Units</b> deg <b>Interfaces</b> GUI, script
<b>SpinAxisRARate</b>	The rate of change of the body's right ascension.
	<b>Data Type</b> Real <b>Allowed Values</b> Real <b>Access</b> set <b>Default Value</b> 0.0 <b>Units</b> deg/century <b>Interfaces</b> GUI, script
<b>TargetColor</b>	Allows you to set available colors on the object's perturbing orbital trajectories that are drawn during iterative processes such as Differential Correction or Optimization. The target color can be identified through a string or an integer array. For example: Setting a body's perturbing trajectory color to yellow can be done in following two ways: Celestialbody.TargetColor = Yellow or Celestialbody.TargetColor = [255 255 0]. This field can be modified in the Mission Sequence as well.
	<b>Data Type</b> Integer Array or String <b>Allowed Values</b> Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255. <b>Access</b> set <b>Default Value</b> Dark Gray for built-in or user-defined <b>Planet</b> , <b>Comet</b> , <b>Asteroid</b> and <b>Moon</b> <b>Units</b> N/A <b>Interfaces</b> GUI, script

Field	Description	
<b>TextureMapFileName</b>	Allows you to load a texture map file for your celestial body.	
	<b>Data Type</b>	String
	<b>Allowed Values</b>	texture map files in jpeg format
	<b>Access</b>	set
	<b>Default Value</b>	'GenericCelestialBody.jpg'
	<b>Units</b>	N/A
	<b>Interfaces</b>	GUI, script

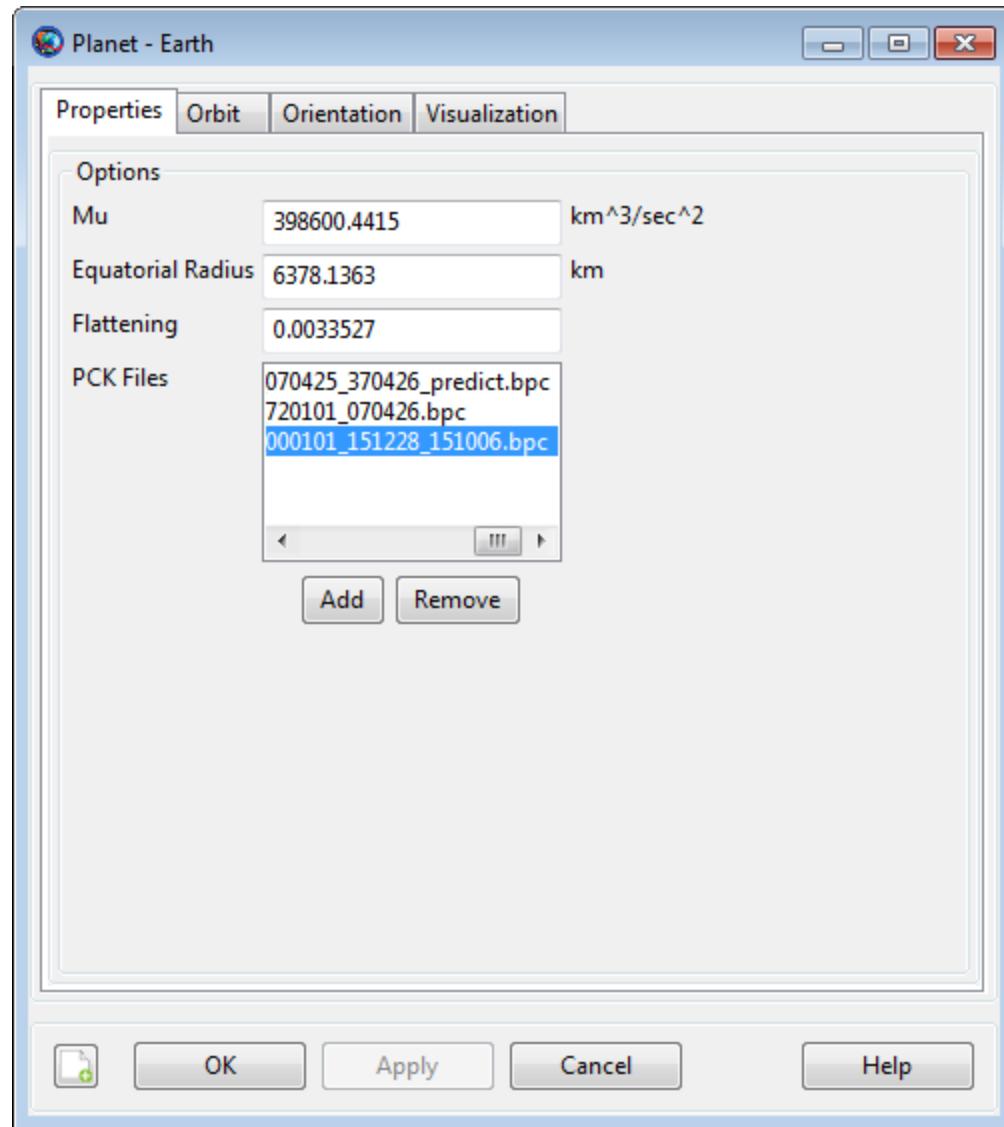
## GUI

The GUI has three tabs that allow you to set the physical properties, orbital properties, and the orientation model. Celestial body resources can be used in **ForceModels**, **CoordinateSystems**, **LibrationPoints**, and **Barycenters**, among others. For a built-in celestial body, the **Orbit** and **Orientation** tabs are largely inactive and the behavior is discussed below. To create a custom **Asteroid** - as an example of how to create a custom body - perform the following steps.

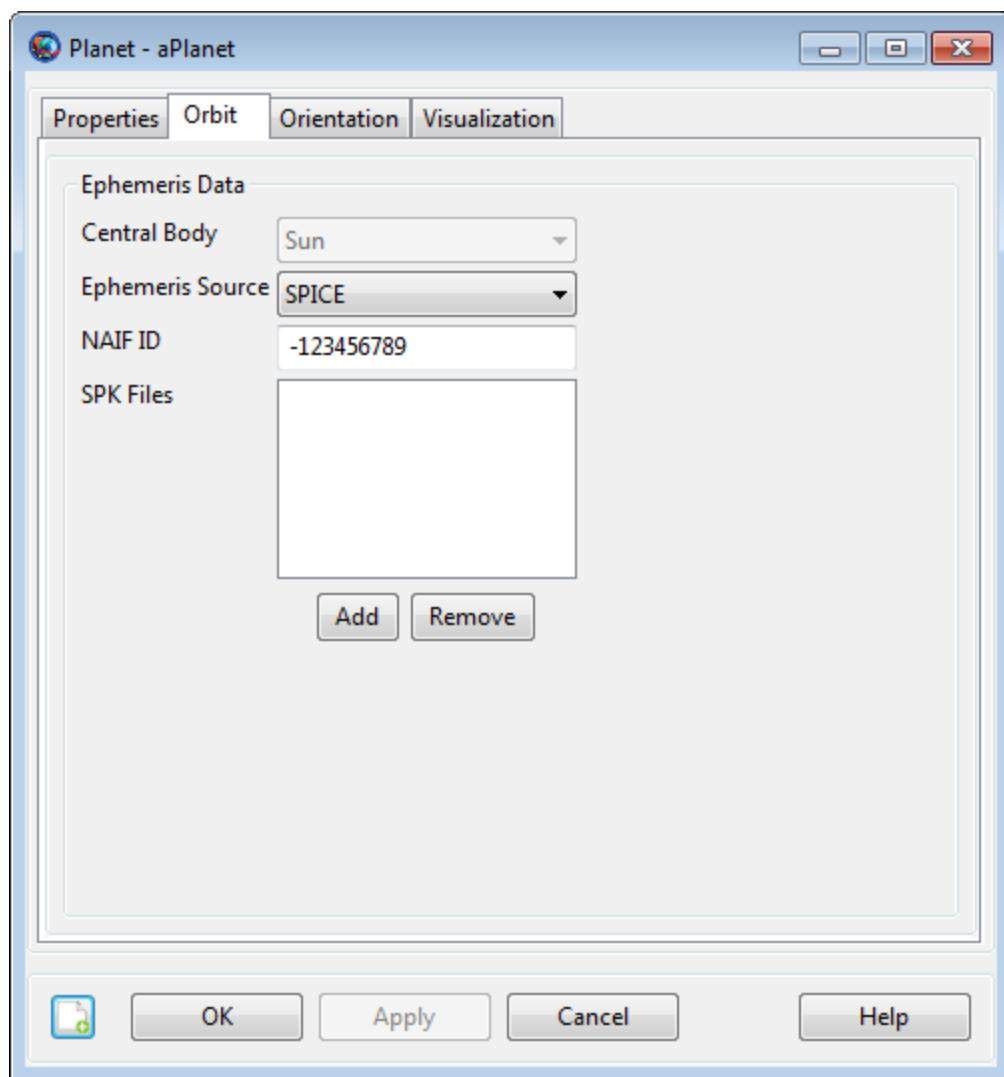
1. In the **Resource Tree**, expand the **SolarSystem** folder.
2. Right-click **Sun** and select **Add -> Asteroid**.
3. In the **New Asteroid** dialog box, type the desired name.



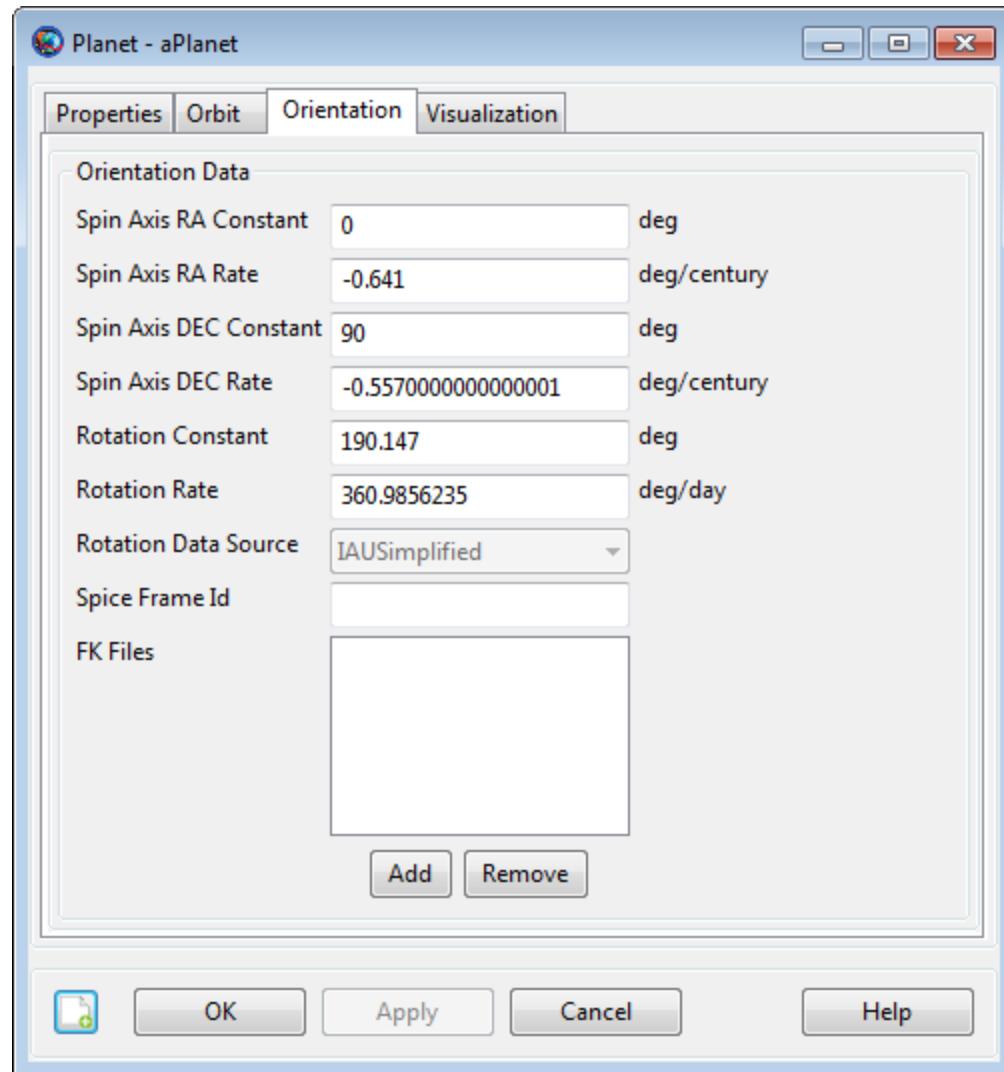
The body Properties tab is shown below. GMAT models all bodies as spherical ellipsoids and you can set the **Equatorial Radius**, **Flattening**, and **Mu** (gravitational parameter) on this dialog box, as well as the texture map used in **OrbitView** graphics displays.



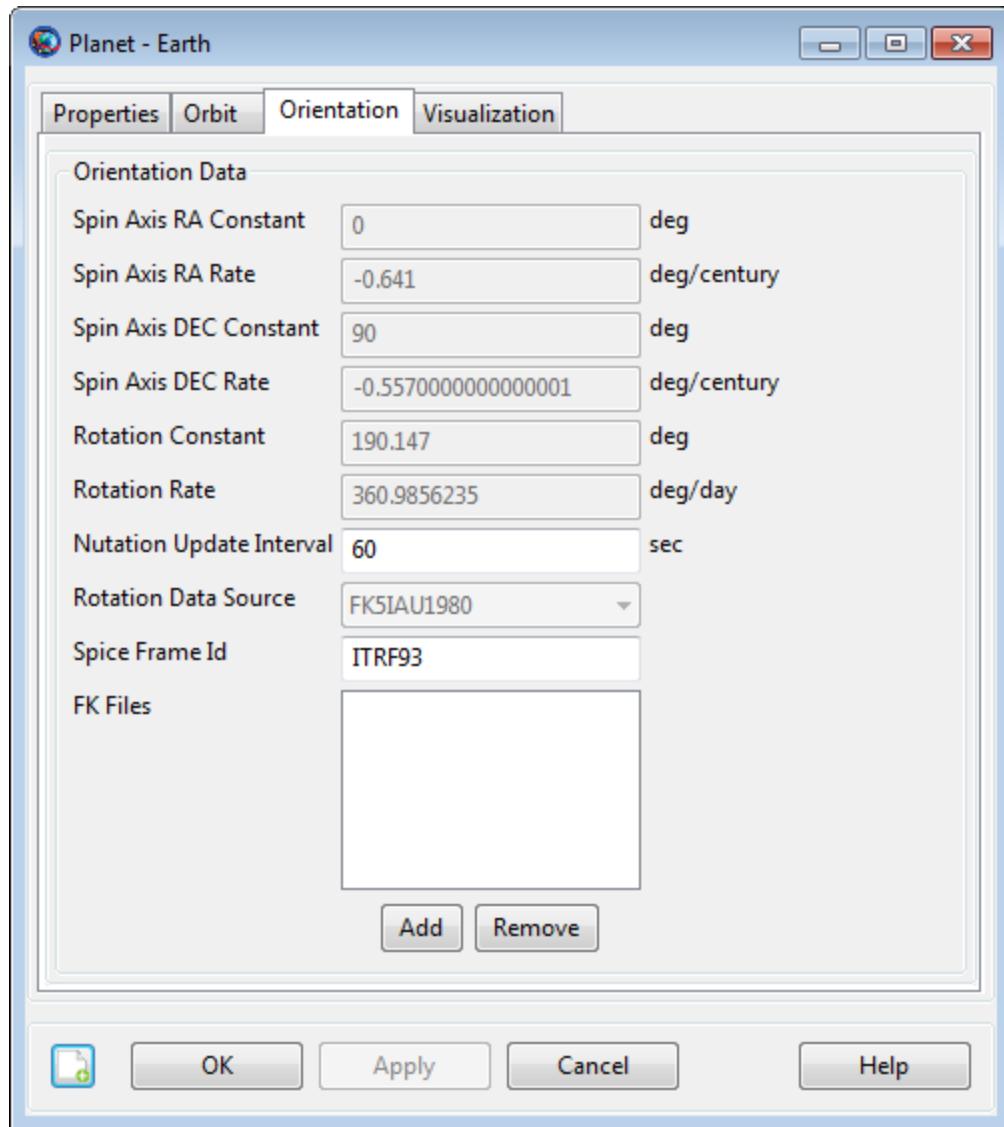
The body **Orbit** tab is shown below for creating a custom body. Settings on this panel are inactive for built-in celestial bodies and the ephemeris for built-in bodies is configured on the **SolarSystem** dialog. The **CentralBody** field is populated automatically when the object is created and is always inactive. To configure **SPICE** ephemerides for a custom body, provide a list of SPK files and the **NAIF ID**. See the discussion below for more information on configuring **SPICE** files.



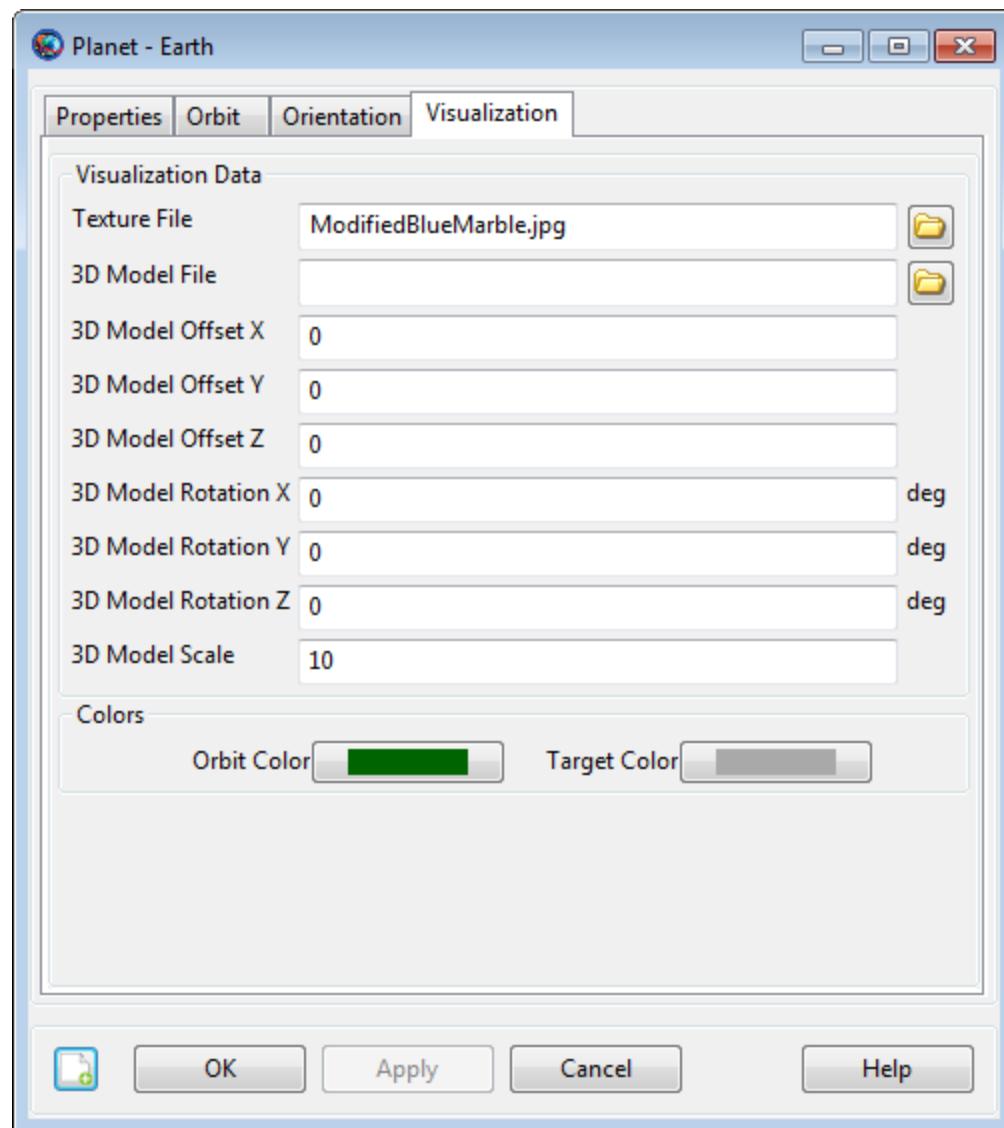
The body **Orientation** tab is shown below. Most settings on this panel are inactive for built-in celestial bodies and exceptions for the Earth and Earth's moon are described further below. To define the orientation for a celestial body you provide a reference epoch, the initial orientation at the reference epoch, and angular rates. See the discussion below for a more detailed description of the orientation model.



The Earth and Earth's moon have unique fields to configure their orientation models. The Earth has an extra field called **NutationUpdateInterval** that can be used when lower fidelity, higher performance simulations are required.



The body **Visualization** tab is shown below. On the visualization tab, you can set data such as 3d model of a celestial body, texture file, translation and rotation of a celestial body on all three axes, scale of the 3D model as well as assign orbit and target colors to the orbit of the body.



## Remarks

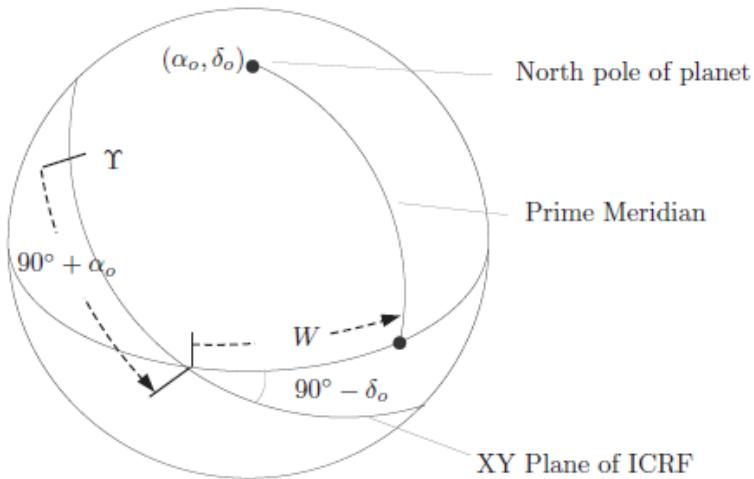
### Celestial body orientation model

The orientation of built-in celestial bodies is modeled using high fidelity theories on a per-body basis. The orientation of Earth is modeled using IAU-1976/FK5. The orientation of Neptune is modeled using IAU-2002. The remaining built-in celestial body orientations are modeled using data published by the IAU/IAG in "Report of the IAU/IAG Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites: 2000".

By default, the orientation of Earth's Moon is modeled using lunar librations from the DE file. The user may assign the orientation of the Earth's moon (**Luna**) according to the following rules.

- If **SolarSystem EphemerisSource** is set to one of the DE file options (**DE405**, **DE421**, **DE424**) and **Luna RotationDataSource** is unset, the lunar orientation is derived from the orientation provided in the selected DE file.
- Regardless of the setting of SolarSystem EphemerisSource, if **Luna RotationDataSource** is set to **SPICE**, the lunar orientation for event location and **CoordinateSystem BodyFixed** axes is given by the frame set on the **SpiceFrameId** parameter assigned to **Luna**, and proper SPICE kernels providing the frame must also be specified for **Luna** on the **PlanetarySpiceKernelName** and **FrameSpiceKernelName** parameters.
- Gravity modeling for Luna will always utilize a high-accuracy DE file fixed frame, regardless of the choice of the rotation data source.

By default, the orientation of a custom body is modeled by providing three angles and their rates based on IAU/IAG conventions. The figure below illustrates the angles. The angles  $\#o$ ,  $\#o$ , and  $W$ , are respectively the **SpinAxisRAConstant**, **SpinAxisDECConstant**, and **RotationConstant**. The angular rates are respectively **SpinAxisRARate**, **SpinAxisDECRate**, and **RotationRate**. All angles are referenced to the X-Y plane of the ICRF axis system. The constant values **SpinAxisRAConstant**, **SpinAxisDECConstant**, and **RotationConstant** are defined to be the values at the epoch defined in **OrientationEpoch**.



Custom bodies may also make use of SPICE-defined fixed frames by choosing the SPICE option for the body's **RotationDataSource** and assigning the proper **SpiceFrameId**, **PlanetarySpiceKernelName**, and **FrameSpiceKernelName**. Gravity modeling for custom bodies will be performed using the assigned rotation data source.



### Note

The spacecraft **Latitude**, **Longitude**, and **Altitude** calculation parameters will use the assigned SPICE frame to convert the spacecraft state from inertial to body-fixed, but the latitude, longitude, and altitude will be computed using the values of **EquatorialRadius** and **Flattening** assigned to the celestial body in the GMAT script, and not the values present in any SPICE kernel files.

Below is an example illustrating how to configure an **Asteroid** according to the IAU 2006 recommended values for Vesta. Note the orientation epoch typically used by the IAU is 01 Jan 2000 12:00:00.00.000 TDB and this must be converted to A1ModJulian which can easily be performed using the **Spacecraft Orbit** dialog box.

```
Create Asteroid Vesta
Vesta.CentralBody      = Sun
% Note that currently the only available
% format for OrientationEpoch is A1ModJulian
Vesta.OrientationEpoch = 21544.99962789878
Vesta.SpinAxisRAConstant = 301.9
Vesta.SpinAxisRARate    = 0.9
Vesta.SpinAxisDECConstant = 90.9
Vesta.SpinAxisDECRate   = 0.0
Vesta.RotationConstant  = 292.9
Vesta.RotationRate       = 1617.332776
```

The orientation models available for Earth and Luna have additional fields for configuration. Earth has an additional field called **NutationUpdateInterval** that controls the update frequency for the Nutation matrix. For high fidelity applications, **NutationUpdateInterval** should be set to zero.

### Setting colors on orbits of celestial bodies

GMAT allows you to assign colors to orbits of celestial bodies that are drawn in the **OrbitView** graphics display windows. GMAT also allows you to assign colors to perturbing celestial body orbital trajectories drawn during iterative processes such as differential correction or optimization. The object's **OrbitColor** and **TargetColor** fields are used to assign colors to both orbital and perturbing trajectories. See the [Fields](#) section for description of these two fields. Also see [Color](#) documentation for discussion and examples on how to set colors on a celestial body.

### Configuring orbit ephemerides

The ephemeris for built-in celestial bodies is specified by the **SolarSystem.EphemerisSource** field and the same source is used for all built-in bodies. Ephemerides for a custom body are provided by SPICE files. Archives of available SPICE files can be found at the [JPL NAIF site](#) and the [Solar System Dynamics site](#). JPL provides utilities to create custom SPICE files in the event existing kernels don't satisfy requirements for your application. To create custom SPICE kernels, see the [documentation provided by JPL](#). The list of NAIF Ids for celestial bodies is located [here](#).

Note that the DE files model the barycenter of planetary systems. So for Jupiter, when using **DE405** for example, you are modeling Jupiter's location as the barycenter of the Jovian system. **SPICE** kernels differentiate the barycenter of a planetary system from the location of the individual bodies. So when using **SPICE** to model Jupiter, you are modeling the location of Jupiter using Jupiter's center of mass.

To specify the SPICE kernels for a custom body, use the **NAIFId**, **CentralBody**, and **OrbitSpiceKernelName** fields. GMAT is distributed with an SPK file for CERES which has **NAIF ID** 2000001. Here is how to configure an **Asteroid** to use the CERES SPICE ephemeris data.

```
Create Asteroid Ceres
Ceres.CentralBody      = Sun
Ceres.OrbitSpiceKernelName = ...
{ '../data/planetary_ephem/spk/ceres_1900_2100.bsp' }
```

Note: GMAT currently only supports a single ephemeris model for custom bodies (SPICE) and this is set using **PosVelSource** field. The default for **PosVelSource** is SPICE and it is not necessary to configure this field in the current version of GMAT.



### Warning

NAIF distributes SPICE kernels for many celestial bodies and each kernel is consistent with a particular primary ephemeris release such as DE421. For high precision analysis, it is important to ensure that the ephemerides used for a custom celestial body are consistent with the ephemeris source selection in the **SolarSystem.EphemerisSource** field. SPICE kernels are typically distributed with a ".cmt" file and in that file the line that contains the ephemeris model looks like this:

Planetary Ephemeris Number: DE-0421/LE-0421

## Configuring physical properties

GMAT models all celestial bodies as spherical ellipsoids. To define the physical properties use the **Flattening**, **EquatorialRadius**, and **Mu** fields.

## Configuring for event location

GMAT's event location subsystem (consisting of **ContactLocator** and **EclipseLocator**) uses celestial body definitions from the SPICE toolkit. Properties such as radius, flattening, ephemeris, and orientation must be configured separately for use with the event locators.

Body shape and orientation are configured via SPICE PCK files, loaded from two sources in the following order:

1. **SolarSystem.PCKFilename**
2. **Sun.PlanetarySpiceKernelName** (in list order), followed by **Mercury**, **Venus**, **Earth**, **Mars**, **Jupiter**, **Saturn**, **Uranus**, **Neptune**, **Pluto**, **Luna**
3. User-defined bodies

Data loaded last takes precedence over data loaded first, if there is a conflict. Note that because the SPICE kernel pool is shared for the entire run, a PCK file loaded for **Pluto** may override data loaded by **Sun**, if the file contains conflicting data. Note that this order isn't absolute—coordinate systems that with an SPK-defined origin load differently, for example. To determine the exact load order, see the `GmatLog.txt` file.



### Note

GMAT's SPICE kernel load order is based on many factors, and can be unpredictable. Therefore, it is important that the kernels referenced by a mission be consistent. For example, NAIF's `de421.bsp` and `mar085.bsp` are consistent, because they are both based on the DE421 model. Inconsistent kernels can cause unpredictable behavior based on the order in which they are loaded.

The body-fixed frame for a celestial body is defined on the **Orientation** tab by the **SpiceFrameId** and **SpiceFrameKernelFile** fields. The **SpiceFrameId** contains the SPICE ID for the body-fixed frame, which may be built-in or defined via external FK files. External FK files can be loaded by adding them to the **SpiceFrameKernelFile** list for each body. These files are loaded just after **PlanetarySpiceKernelName** for each body. The list of built-in frames is available as an appendix in the [SPICE documentation](#). GMAT's default frames are:

- Earth: ITRF93
- Luna: MOON\_PA
- Other default bodies: `IAU_CelestialBody`

The Earth ITRF93 frame is defined by three high-fidelity orientation PCK files, shown below. More information on these files can be found in the NAIF [aareadme.txt](#) file.

- `earth_start_end_predict.bpc`: long-term low-fidelity EOP predictions
- `earth_start_end.bpc`: long-term low-fidelity historical EOP
- `earth_start_end_filedate.bpc`: near-term high-fidelity EOP history and predictions

The Luna MOON\_PA frame is defined by an orientation PCK file and a frame-defining FK file, shown below. More information can be found in the NAIF PCK [aareadme.txt](#) file and the FK [aareadme.txt](#) file. Other versions of the MOON\_PA frame are available from NAIF.

- `moon_pa_de421_1900-2050.bpc`: Moon orientation consistent with DE421 PA frame
- `moon_080317.tf`: MOON\_PA frame definition

## Examples

Configure a **Moon** to model Saturn's moon Titan. Note you must obtain the SPICE kernel named "sat288.bsp" from [here](#) and place it in the directory identified in the script snippet below

```
Create Moon Titan
Titan.NAIFId          = 606
Titan.OrbitSpiceKernelName = { ...
    '../data/planetary_ephem/spk/sat288.bsp' ...
}
Titan.SpiceFrameId     = 'IAU_TITAN'
Titan.EquatorialRadius = 2575
Titan.Flattening       = 0
Titan.Mu               = 8978.5215
Titan.PosVelSource     = 'SPICE'
Titan.CentralBody       = 'Saturn'
Titan.RotationDataSource = 'IAUSimplified'
Titan.OrientationEpoch = 21545
Titan.SpinAxisRAConstant = 36.41
Titan.SpinAxisRARate   = -0.036
Titan.SpinAxisDECConstant = 83.94
Titan.SpinAxisDECRate  = -0.004
Titan.RotationConstant = 189.64
Titan.RotationRate      = 22.5769768
```

Configure the body-fixed frame of Earth's moon (Luna) to be the MOON\_ME frame.

```
Luna.PlanetarySpiceKernelName = '../data/planetary_coeff/SPICE_Luna_CurrentKernel.bpc'
Luna.FrameSpiceKernelName   = '../data/planetary_coeff/SPICE_Luna_FrameKernel.tf'
Luna.RotationDataSource     = 'SPICE'
Luna.SpiceFrameId          = 'MOON_ME'

%
% Create a body-fixed coordinate system tied to the MOON_ME axes
%

Create CoordinateSystem MoonME

MoonME.Origin = Luna
MoonME.Axes   = BodyFixed
```

## ChemicalTank

Model of a chemical fuel tank

### Description

A **ChemicalTank** is a thermodynamic model of a tank and is required for finite burn modeling or for impulsive burns that use mass depletion. The thermodynamic properties of the tank are modeled using Boyle's law and assume that there is no temperature change in the tank as fuel is depleted. To use a **ChemicalTank**, you must first create the tank, and then attach it to the desired **Spacecraft** and associate it with a **ChemicalThruster** as shown in the example below.

See Also [ImpulsiveBurn](#), [ChemicalThruster](#)

### Fields

Field	Description
<b>AllowNegativeFuelMass</b>	This field allows the <b>ChemicalTank</b> to have negative fuel mass which can be useful in optimization and targeting sequences before convergence has occurred. This field cannot be modified in the Mission Sequence.  <b>Data Type</b> Boolean <b>Allowed Values</b> true, false <b>Access</b> set <b>Default Value</b> false <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>DirectionX</b>	X-component of the primary direction of the <b>ChemicalTank</b> 's orientation in the body frame. Used in conjunction with the secondary direction elements to calculate the orientation.  <b>Data Type</b> Real <b>Allowed Values</b> Real number <b>Access</b> set <b>Default Value</b> 0 <b>Units</b> N/A <b>Interfaces</b> script

Field	Description
<b>DirectionY</b>	<p>Y-component of the primary direction of the <b>ChemicalTank's</b> orientation in the body frame. Used in conjunction with the secondary direction elements to calculate the orientation.</p>
	<b>Data Type</b> Real
	<b>Allowed Values</b> Real number
	<b>Access</b> set
	<b>Default Value</b> 0
	<b>Units</b> N/A
	<b>Interfaces</b> script
<b>DirectionZ</b>	<p>Z-component of the primary direction of the <b>ChemicalTank's</b> orientation in the body frame. Used in conjunction with the secondary direction elements to calculate the orientation.</p>
	<b>Data Type</b> Real
	<b>Allowed Values</b> Real number
	<b>Access</b> set
	<b>Default Value</b> 1
	<b>Units</b> N/A
	<b>Interfaces</b> script
<b>FuelCenterOfMassX</b>	<p>The X component of the fuel center of mass in the hardware coordinate system.</p>
	<b>Data Type</b> Real
	<b>Allowed Values</b> Any Real number
	<b>Access</b> set, get
	<b>Default Value</b> 0.0
	<b>Units</b> meters
	<b>Interfaces</b> GUI, script
<b>FuelCenterOfMassY</b>	<p>The Y component of the fuel center of mass in the hardware coordinate system.</p>
	<b>Data Type</b> Real
	<b>Allowed Values</b> Any Real number
	<b>Access</b> set, get
	<b>Default Value</b> 0.0
	<b>Units</b> meters
	<b>Interfaces</b> GUI, script

<b>Field</b>	<b>Description</b>
<b>FuelCenterOfMassZ</b>	<p>The Z component of the fuel center of mass in the body coordinate system.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Any Real number  <b>Access</b> set, get  <b>Default Value</b> 0.0  <b>Units</b> meters  <b>Interfaces</b> GUI, script</p>
<b>FuelDensity</b>	<p>The density of the fuel.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real &gt; 0  <b>Access</b> set, get  <b>Default Value</b> 1260  <b>Units</b> kg/m<sup>3</sup>  <b>Interfaces</b> GUI, script</p>
<b>FuelMass</b>	<p>The mass of fuel in the tank.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real &gt; 0  <b>Access</b> set, get  <b>Default Value</b> 756  <b>Units</b> kg  <b>Interfaces</b> GUI, script</p>
<b>FuelMomentOfInertiaXX</b>	<p>The XX component of the fuel moment of inertia.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real &gt;= 0  <b>Access</b> set, get  <b>Default Value</b> 99  <b>Units</b> Kg-m<sup>2</sup>  <b>Interfaces</b> GUI, script</p>
<b>FuelMomentOfInertiaXY</b>	<p>The XY component of the fuel moment of inertia.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real &gt;= 0  <b>Access</b> set, get  <b>Default Value</b> 0  <b>Units</b> Kg-m<sup>2</sup>  <b>Interfaces</b> GUI, script</p>

Field	Description
<b>FuelMomentOfInertiaXZ</b>	The XZ component of the fuel moment of inertia.  <b>Data Type</b> Real <b>Allowed Values</b> Real $\geq 0$ <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> Kg-m <sup>2</sup> <b>Interfaces</b> GUI, script
<b>FuelMomentOfInertiaYY</b>	The YY component of the fuel moment of inertia.  <b>Data Type</b> Real <b>Allowed Values</b> Real $\geq 0$ <b>Access</b> set, get <b>Default Value</b> 99 <b>Units</b> Kg-m <sup>2</sup> <b>Interfaces</b> GUI, script
<b>FuelMomentOfInertiaYZ</b>	The YZ component of the fuel moment of inertia.  <b>Data Type</b> Real <b>Allowed Values</b> Real $\geq 0$ <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> Kg-m <sup>2</sup> <b>Interfaces</b> GUI, script
<b>FuelMomentOfInertiaZZ</b>	The ZZ component of the fuel moment of inertia.  <b>Data Type</b> Real <b>Allowed Values</b> Real $\geq 0$ <b>Access</b> set, get <b>Default Value</b> 99 <b>Units</b> Kg-m <sup>2</sup> <b>Interfaces</b> GUI, script
<b>HWOrginInBCSX</b>	X-component of the origin of the hardware's coordinate system expressed in the spacecraft's body coordinate system.  <b>Data Type</b> Real <b>Allowed Values</b> Real <b>Access</b> set <b>Default Value</b> 0 <b>Units</b> N/A <b>Interfaces</b> script

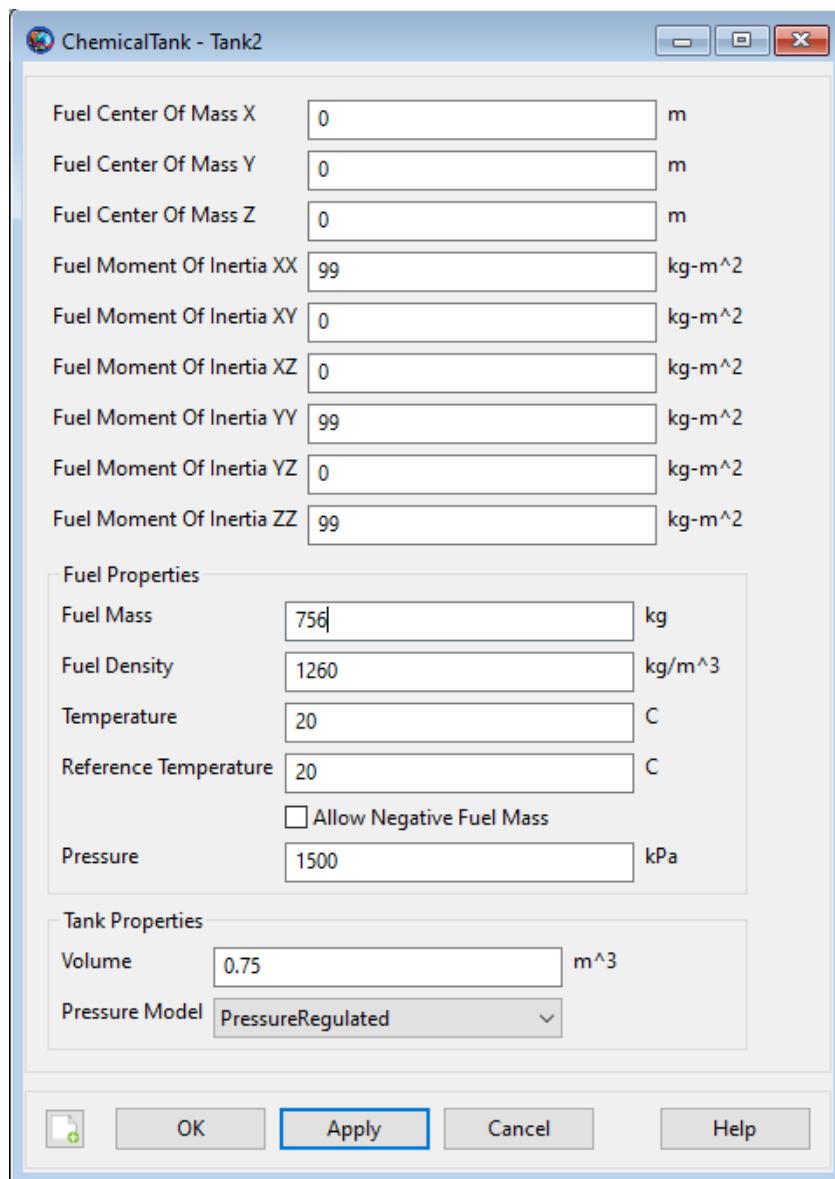
Field	Description
<b>HWOrginInBCSY</b>	<p>Y-component of the origin of the hardware's coordinate system expressed in the spacecraft's body coordinate system.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>HWOrginInBCSZ</b>	<p>Z-component of the origin of the hardware's coordinate system expressed in the spacecraft's body coordinate system.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>Pressure</b>	<p>The pressure in the tank.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real &gt; 0  <b>Access</b> set, get  <b>Default Value</b> 1500  <b>Units</b> kPa  <b>Interfaces</b> GUI, script</p>
<b>PressureModel</b>	<p>The pressure model describes how pressure in the <b>ChemicalTank</b> changes as fuel is depleted. This field cannot be modified in the Mission Sequence.</p> <p><b>Data Type</b> Enumeration  <b>Allowed Values</b> <b>PressureRegulated</b>, <b>BlowDown</b>  <b>Access</b> set  <b>Default Value</b> <b>PressureRegulated</b>  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>RefTemperature</b>	<p>The temperature of the tank when fuel was loaded.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real &gt; -273.15 and  Real  &gt; 0.01  <b>Access</b> set, get  <b>Default Value</b> 20  <b>Units</b> C  <b>Interfaces</b> GUI, script</p>

<b>Field</b>	<b>Description</b>
<b>SecondDirectionX</b>	<p>X-component of the vector, expressed in the body frame, used to resolve the hardware's orientation about the direction vector.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>SecondDirectionY</b>	<p>Y-component of the vector, expressed in the body frame, used to resolve the hardware's orientation about the direction vector.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> -1  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>SecondDirectionZ</b>	<p>Z-component of the vector, expressed in the body frame, used to resolve the hardware's orientation about the direction vector.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>Temperature</b>	<p>The temperature of the fuel and ullage in the tank. GMAT currently assumes ullage and fuel are always at the same temperature.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real &gt; -273.15  <b>Access</b> set, get  <b>Default Value</b> 20  <b>Units</b> C  <b>Interfaces</b> GUI, script</p>

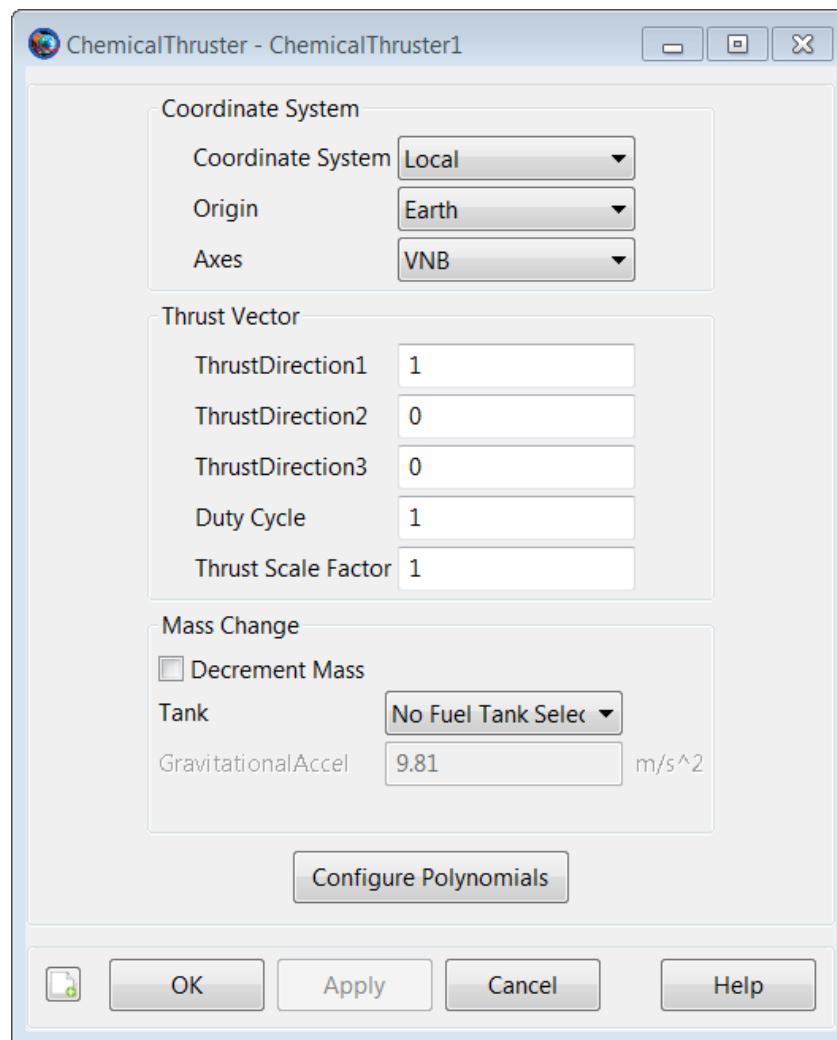
Field	Description
<b>Volume</b>	The volume of the tank. GMAT checks to ensure that the input volume of the tank is larger than the calculated volume of fuel loaded in the tank and throws an exception in the case that the calculated fuel volume is larger than the input tank volume.
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real $> 0$ such that calculated fuel volume is $<$ input tank Volume.
<b>Access</b>	set, get
<b>Default Value</b>	0.75
<b>Units</b>	m <sup>3</sup>
<b>Interfaces</b>	GUI, script

## GUI

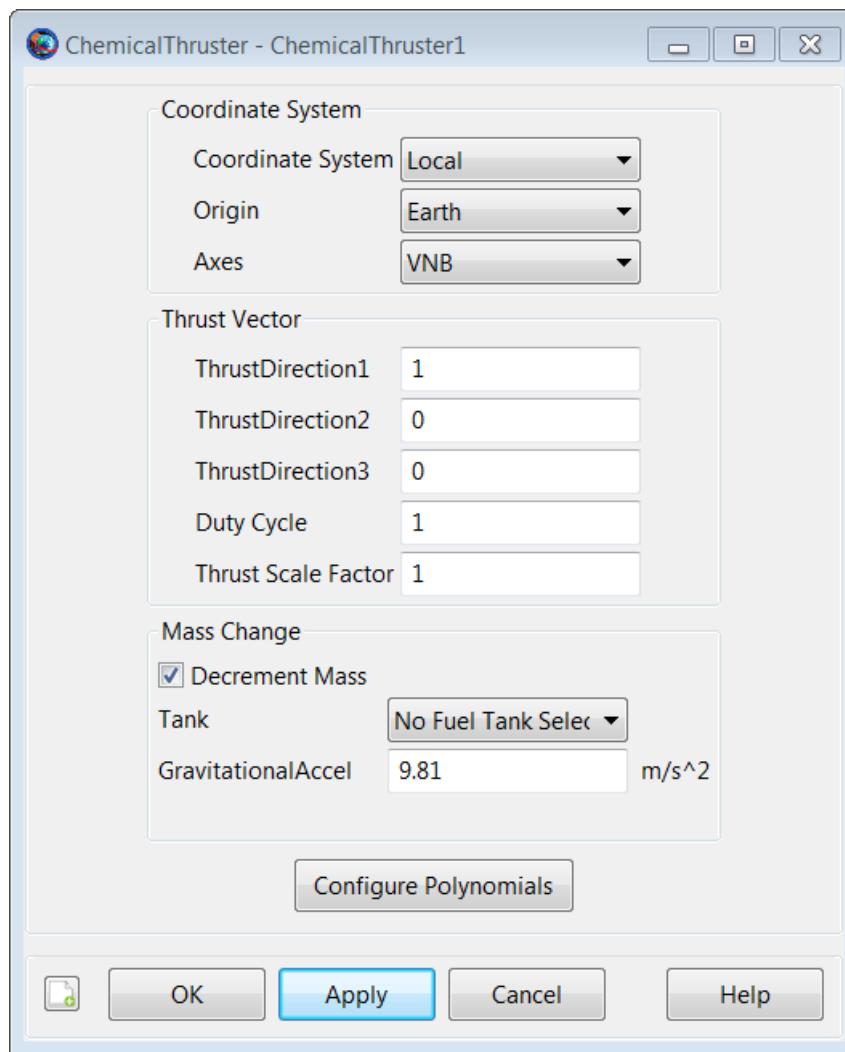
The **ChemicalTank** dialog box allows you to specify properties of a fuel tank including center of mass, moment of inertia, fuel mass, density, and temperature as well as tank pressure and volume. The layout of the **ChemicalTank** dialog box is shown below.



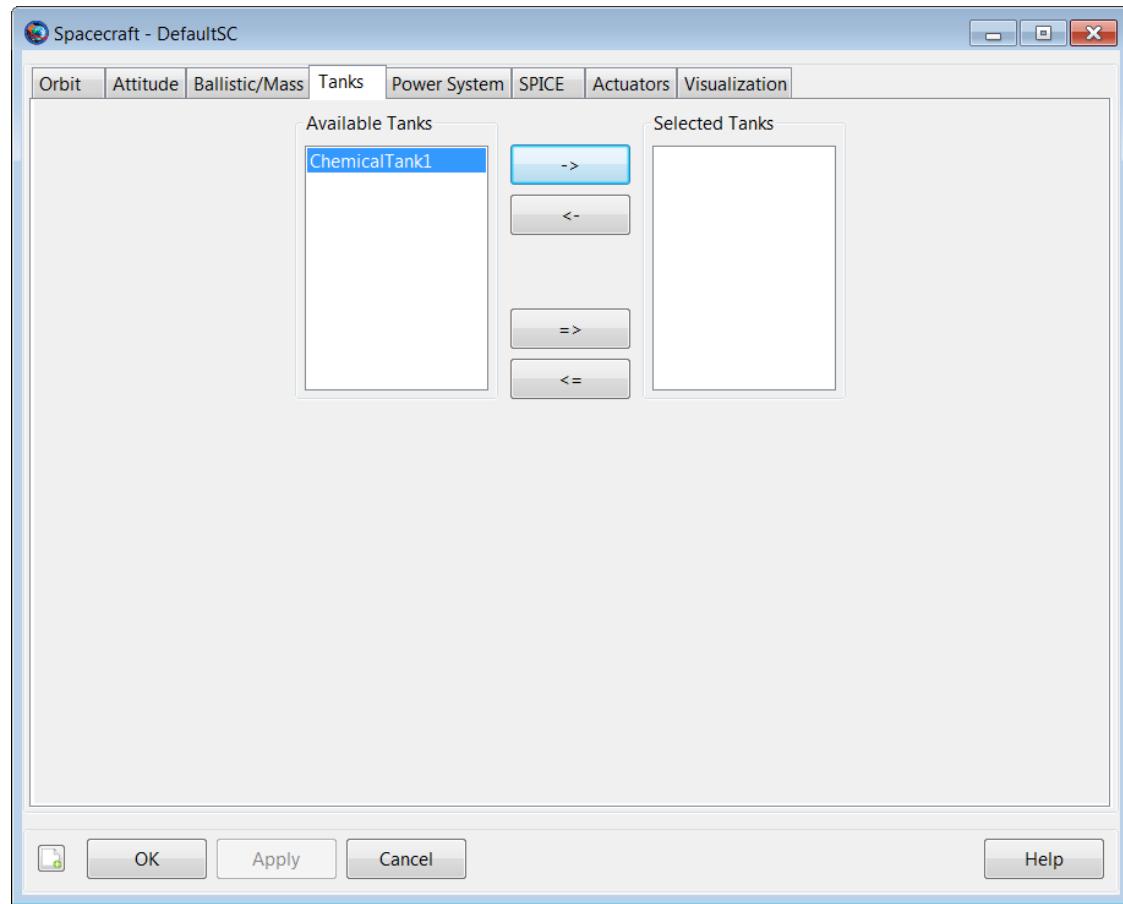
The **ChemicalThruster** resource is closely related to the **ChemicalTank** resource and thus, we also discuss it here. The **ChemicalThruster** dialog box allows you to specify properties of a thruster including the coordinate system of the Thrust acceleration direction vector, the thrust magnitude and Isp. The layout of the **ChemicalThruster** dialog box is shown below.



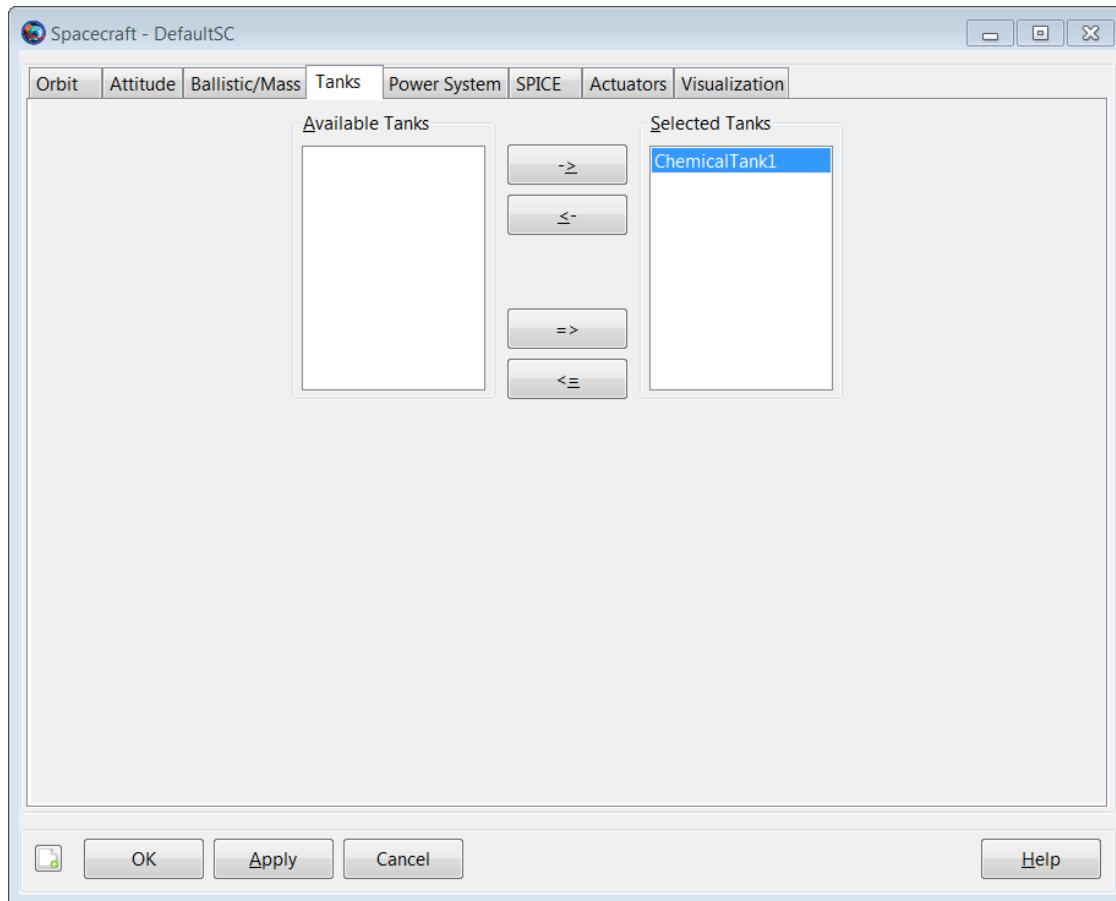
When performing a finite burn, you will typically want to model fuel depletion. To do this, select the **Decrement Mass** button and then select the previously created **Chemical-Tank** as shown below.



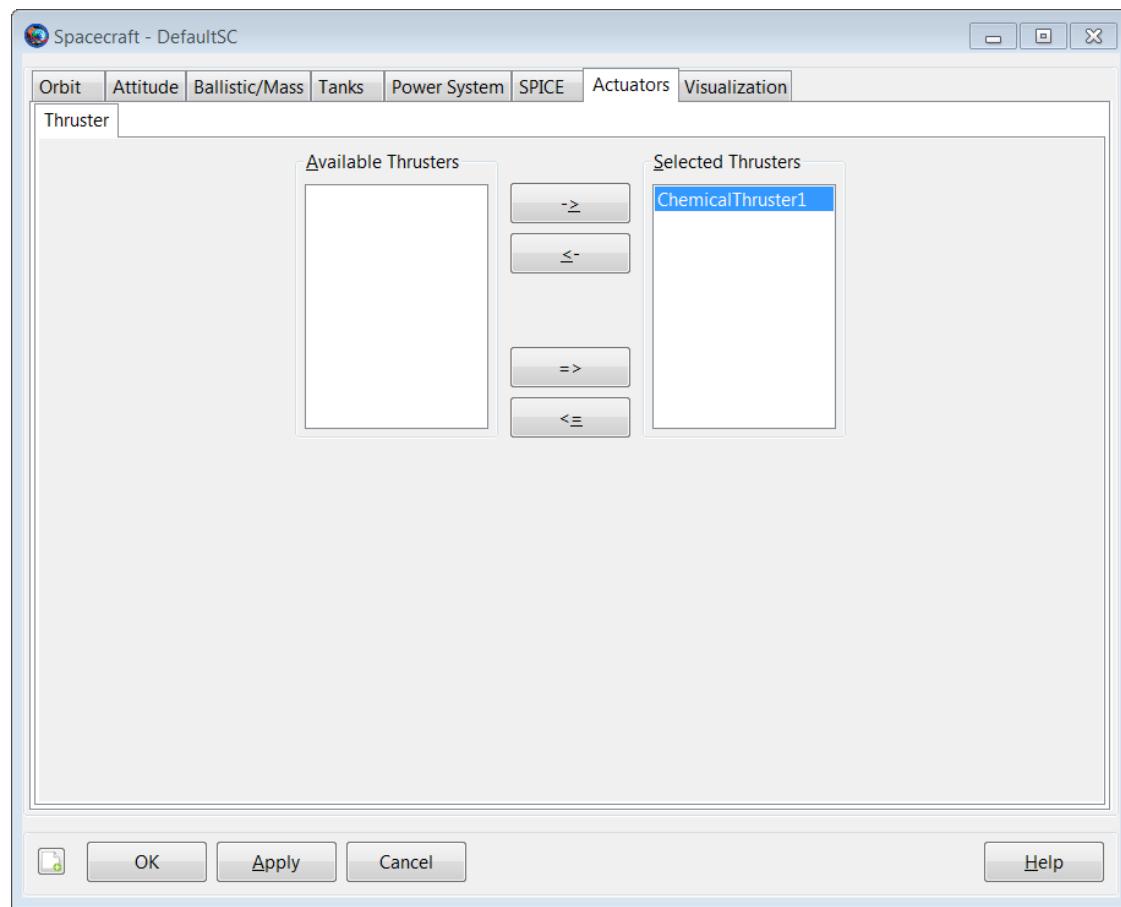
Thus far, we have created both a **ChemicalTank** and a **ChemicalThruster**, and we have associated a **ChemicalTank** with our **ChemicalThruster**. We are not done yet. We must tell GMAT that we want to attach both the **ChemicalTank** and the **ChemicalThruster** to a particular spacecraft. To do this, double click on the desired spacecraft under the **Spacecraft** resource to bring up the associated GUI panel. Then click on the **Tanks** tab to bring up the following GUI display.



Next, select the desired **ChemicalTank** and use the right arrow button to attach the **ChemicalTank** to the spacecraft. Then, click the **Apply** button as shown below.



Similarly, to attach a **ChemicalThruster** to a spacecraft, double click on the desired spacecraft under the **Spacecraft** resource and then select the **Actuators** tab. Then select the desired thruster and use the right arrow to attach the thruster to the spacecraft. Finally, click the **Apply** button as shown below.



## Remarks

### Use of ChemicalTank Resource in Conjunction with Maneuvers

A **ChemicalTank** is used in conjunction with both impulsive and finite maneuvers. To implement an impulsive maneuver, one must first create an **ImpulsiveBurn** resource and (optionally) associate a **ChemicalTank** with it. The actual impulsive maneuver is implemented using the **Maneuver** command. See the **Maneuver** command documentation for worked examples on how the **ChemicalTank** resource is used in conjunction with impulsive maneuvers.

To implement a finite maneuver, you must first create both a **ChemicalThruster** and a **FiniteBurn** resource. You must also associate a **ChemicalTank** with the **ChemicalThruster** resource and you must associate a **Thruster** with the **FiniteBurn** resource. The actual finite maneuver is implemented using the **BeginFiniteBurn/EndFiniteBurn** commands. See the **BeginFiniteBurn/EndFiniteBurn** command documentation for worked examples on how the **ChemicalTank** resource is used in conjunction with finite maneuvers.

### Orientation of the ChemicalTank Resource

The **ChemicalTank** supports orientation and location settings. The location is the position of the origin of the hardware frame, expressed in the spacecraft body coordinate

frame. The orientation is represented as a direction cosine matrix that is initially computed from two non-colinear vectors, provided by the user as **Direction** and **SecondDirection** components. The three axes for the hardware coordinate frame expressed in Body coordinates are computed as follows:

1. Normalize **z** & **v**, where **z** is represented by **Direction** and **v** is the **SecondDirection** vector.
2. Compute the normal **N** = **z** x **v** and its magnitude **m**.
3. Verify magnitude of **N** isn't 0.0, send message if it is too close. This will happen if one of the input vectors is a zero vector or if the two vectors are co-linear, including the case where they point in opposite directions.
4. **x** = **N** / **m**
5. **y** = **z** x **x**
6. The rotation matrix **Rsb** is constructed with **x** on the first row, **y** on the second, and **z** on the third. This matrix rotates vectors from the body frame to the hardware frame.

### Behavior When Configuring Tank and Attached Tank Properties

Create a default **ChemicalTank** and attach it to a **Spacecraft** and **ChemicalThruster**.

```
% Create the ChemicalTank Resource
Create ChemicalTank aTank
aTank.AllowNegativeFuelMass = false
aTank.FuelMass = 756
aTank.Pressure = 1500
aTank.Temperature = 20
aTank.RefTemperature = 20
aTank.Volume = 0.75
aTank.FuelDensity = 1260
aTank.PressureModel = PressureRegulated
% Create a ChemicalThruster and assign it a ChemicalTank
Create ChemicalThruster aThruster
aThruster.Tank = {aTank}

% Add the ChemicalTank and ChemicalThruster to a Spacecraft
Create Spacecraft aSpacecraft
aSpacecraft.Tanks = {aTank}
aSpacecraft.Thrusters = {aThruster}
```

As exhibited below, there are some subtleties associated with setting and getting parent vs. cloned resources. In the example above, **aTank** is the parent **ChemicalTank** resource and the field **aSpacecraft.Tanks** is populated with a cloned copy of **aTank**.

Create a second spacecraft and attach a fuel tank using the same procedure used in the previous example. Set the **FuelMass** in the parent resource, **aTank**, to 900 kg.

```
% Add the ChemicalTank and ChemicalThruster to a second Spacecraft
Create Spacecraft bSpacecraft
bSpacecraft.Tanks = {aTank}
bSpacecraft.Thrusters = {aThruster}
```

```
aTank.FuelMass = 900 %Can be performed in both resource and  
%command modes
```

Note that, in the example above, setting the value of the parent resource, aTank, changes the fuel mass value in both cloned fuel tank resources. More specifically, the value of both aSpacecraft.aTank.FuelMass and bSpacecraft.aTank.FuelMass are both now equal to the new value of 900 kg. We note that the assignment command for the parent resource, aTank.FuelMass, can be performed in both resource and command modes.

To change the value of the fuel mass in only the first created spacecraft, **aSpacecraft**, we do the following.

```
% Create the Fuel Tank Resource  
aTank.FuelMass = 756 %Fuel tank mass in both s/c set back to default  
aSpacecraft.aTank.FuelMass = 1000 %Can only be performed in command mode.
```

As a result of the commands in the previous example, the value of aSpacecraft.aTank.FuelMass is 1000 kg and the value of bSpacecraft.aTank.FuelMass is 756 kg. We note that the assignment command for the cloned resource, aSpacecraft.aTank.FuelMass, can only be performed in command mode.

### Caution: Value of AllowNegativeFuelMass Flag Can Affect Iterative Processes

By default, GMAT will not allow the fuel mass to be negative. However, occasionally in iterative processes such as targeting, a solver will try values of a maneuver parameter that result in total fuel depletion. Using the default tank settings, this will throw an exception stopping the run unless you set the AllowNegativeFuelMass flag to true. GMAT will not allow the the total spacecraft mass to be negative. If DryMass + FuelMass is negative GMAT will throw an exception and stop.

### Examples

Create a default **ChemicalTank** and attach it to a **Spacecraft** and **ChemicalThruster**.

```
% Create the Fuel Tank Resource  
Create ChemicalTank aTank  
aTank.AllowNegativeFuelMass = false  
aTank.FuelMass = 756  
aTank.Pressure = 1500  
aTank.Temperature = 20  
aTank.RefTemperature = 20  
aTank.Volume = 0.75  
aTank.FuelDensity = 1260  
aTank.PressureModel = PressureRegulated  
  
% Create a ChemicalThruster and assign it a ChemicalTank  
Create ChemicalThruster aThruster  
aThruster.Tank = {aTank}
```

```
% Add the ChemicalTank and ChemicalThruster to a Spacecraft
Create Spacecraft aSpacecraft
aSpacecraft.Tanks = {aTank}
aSpacecraft.Thrusters = {aThruster}

BeginMissionSequence
```

## ChemicalThruster

A chemical thruster model

### Description

The **ChemicalThruster** resource is a model of a chemical thruster which uses polynomials to model the thrust and specific impulse as a function of tank pressure and temperature. The **ChemicalThruster** model also allows you to specify properties such as a duty cycle and scale factor and to connect a **ChemicalThruster** with a **ChemicalTank**. You can flexibly define the direction of the thrust by specifying the thrust components in coordinate systems such as (locally defined) **SpacecraftBody** or **LVLH**, or by choosing any configured **CoordinateSystem** resource.

See Also: [BeginFiniteBurn](#), [ChemicalTank](#), [FiniteBurn](#)

### Fields

The constants **C<sub>i</sub>** below are used in the following equation to calculate thrust (in Newtons),  $F_T$ , as a function of pressure P (kPa) and temperature T (Celsius).

$$F_T(T, P) = C_1 + C_2 P + (C_3 + C_4 P + C_5 P^2 + C_6 P^{C_7} + C_8 P^{C_9} + C_{10} P^{C_{11}} + C_{12}(C_{13})^{C_{14}P}) \left( \frac{T}{T_{ref}} \right)^{1+C_{15}+C_{16}P}$$

The constants **K<sub>i</sub>** below are used in the following equation to calculate ISP (in seconds),  $I_{sp}$ , as a function of pressure P (kPa) and temperature T (Celsius).

$$I_{sp}(T, P) = K_1 + K_2 P + (K_3 + K_4 P + K_5 P^2 + K_6 P^{K_7} + K_8 P^{K_9} + K_{10} P^{K_{11}} + K_{12}(K_{13})^{K_{14}P}) \left( \frac{T}{T_{ref}} \right)^{1+K_{15}+K_{16}P}$$

Field	Description	
<b>Axes</b>	Allows the user to define a spacecraft centered set of axes for the <b>ChemicalThruster</b> . This field cannot be modified in the Mission Sequence	
	<b>Data Type</b>	Reference Array
	<b>Allowed Values</b>	<b>VNB</b> , <b>LVLH</b> , <b>MJ2000Eq</b> , <b>SpacecraftBody</b>
	<b>Access</b>	set
	<b>Default Value</b>	<b>VNB</b>
	<b>Units</b>	N/A
	<b>Interfaces</b>	GUI, script

Field	Description
<b>CoordinateSystem</b>	Determines what coordinate system the orientation parameters, <b>ThrustDirection1</b> , <b>ThrustDirection2</b> , and <b>ThrustDirection3</b> refer to. This field cannot be modified in the Mission Sequence.
	<p><b>Data Type</b> Reference Array</p> <p><b>Allowed Values</b> <b>Local</b>, <b>EarthMJ2000Eq</b>, <b>EarthMJ2000Ec</b>, <b>EarthFixed</b>, or any user defined system</p> <p><b>Access</b> set</p> <p><b>Default Value</b> <b>Local</b></p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>C1</b>	Thrust coefficient.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Real Number</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 10</p> <p><b>Units</b> N</p> <p><b>Interfaces</b> GUI, script</p>
<b>C2</b>	Thrust coefficient.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Real Number</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 0</p> <p><b>Units</b> N/kPa</p> <p><b>Interfaces</b> GUI, script</p>
<b>C3</b>	Thrust coefficient.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Real Number</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 0</p> <p><b>Units</b> N</p> <p><b>Interfaces</b> GUI, script</p>
<b>C4</b>	Thrust coefficient.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Real Number</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 0</p> <p><b>Units</b> N/kPa</p> <p><b>Interfaces</b> GUI, script</p>

<b>Field</b>	<b>Description</b>	
<b>C5</b>	Thrust coefficient.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real Number
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	N/kPa <sup>2</sup>
	<b>Interfaces</b>	GUI, script
<b>C6</b>	Thrust coefficient.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real Number
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	N/kPa <sup>C7</sup>
	<b>Interfaces</b>	GUI, script
<b>C7</b>	Thrust coefficient.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real Number
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	None
	<b>Interfaces</b>	GUI, script
<b>C8</b>	Thrust coefficient.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real Number
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	N/kPa <sup>C9</sup>
	<b>Interfaces</b>	GUI, script
<b>C9</b>	Thrust coefficient.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real Number
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	None
	<b>Interfaces</b>	GUI, script

<b>Field</b>	<b>Description</b>	
<b>C10</b>	Thrust coefficient.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real Number
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	N/kPa <sup>C11</sup>
	<b>Interfaces</b>	GUI, script
<b>C11</b>	Thrust coefficient.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real Number
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	None
	<b>Interfaces</b>	GUI, script
<b>C12</b>	Thrust coefficient.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real Number
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	N
	<b>Interfaces</b>	GUI, script
<b>C13</b>	Thrust coefficient.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real Number
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	None
	<b>Interfaces</b>	GUI, script
<b>C14</b>	Thrust coefficient.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real Number
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	1/kPa
	<b>Interfaces</b>	GUI, script

Field	Description
<b>C15</b>	Thrust coefficient.
	<b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> None <b>Interfaces</b> GUI, script
<b>C16</b>	Thrust coefficient.
	<b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> 1/kPa <b>Interfaces</b> GUI, script
<b>DecrementMass</b>	Flag which determines if the <b>FuelMass</b> is to be decremented as it used. This field cannot be modified in the Mission Sequence.
	<b>Data Type</b> Boolean <b>Allowed Values</b> true, false <b>Access</b> set <b>Default Value</b> false <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>DutyCycle</b>	Fraction of time that the thrusters are on during a maneuver. The thrust applied to the spacecraft is scaled by this amount. Note that this scale factor also affects mass flow rate.
	<b>Data Type</b> Real Number <b>Allowed Values</b> $0 \leq \text{Real} \leq 1$ <b>Access</b> set, get <b>Default Value</b> 1 <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>GravitationalAccel</b>	The gravitational acceleration.
	<b>Data Type</b> Real Number <b>Allowed Values</b> $\text{Real} > 0$ <b>Access</b> set, get <b>Default Value</b> 9.81 <b>Units</b> $\text{m/s}^2$ <b>Interfaces</b> GUI, script

<b>Field</b>	<b>Description</b>
<b>HWOriginInBCSX</b>	X-component of the origin of the hardware's coordinate system expressed in the spacecraft's body coordinate system.
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> meters  <b>Interfaces</b> script</p>
<b>HWOriginInBCSY</b>	Y-component of the origin of the hardware's coordinate system expressed in the spacecraft's body coordinate system.
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> meters  <b>Interfaces</b> script</p>
<b>HWOriginInBCSZ</b>	Z-component of the origin of the hardware's coordinate system expressed in the spacecraft's body coordinate system.
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> meters  <b>Interfaces</b> script</p>
<b>K1</b>	ISP coefficient.
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real Number  <b>Access</b> set, get  <b>Default Value</b> 300  <b>Units</b> s  <b>Interfaces</b> GUI, script</p>
<b>K2</b>	ISP coefficient.
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real Number  <b>Access</b> set, get  <b>Default Value</b> 0  <b>Units</b> s/kPa  <b>Interfaces</b> GUI, script</p>

<b>Field</b>	<b>Description</b>	
<b>K3</b>	ISP coefficient.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real Number
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	s
	<b>Interfaces</b>	GUI, script
<b>K4</b>	ISP coefficient.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real Number
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	s/kPa
	<b>Interfaces</b>	GUI, script
<b>K5</b>	ISP coefficient.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real Number
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	s/kPa <sup>2</sup>
	<b>Interfaces</b>	GUI, script
<b>K6</b>	ISP coefficient.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real Number
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	s/kPa <sup>C7</sup>
	<b>Interfaces</b>	GUI, script
<b>K7</b>	ISP coefficient.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real Number
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	None
	<b>Interfaces</b>	GUI, script

Field	Description
K8	ISP coefficient.
	<b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> s/kPa <sup>C9</sup> <b>Interfaces</b> GUI, script
K9	ISP coefficient.
	<b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> None <b>Interfaces</b> GUI, script
K10	ISP coefficient.
	<b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> s/kPa <sup>C11</sup> <b>Interfaces</b> GUI, script
K11	ISP coefficient.
	<b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> None <b>Interfaces</b> GUI, script
K12	ISP coefficient.
	<b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> s <b>Interfaces</b> GUI, script

Field	Description
<b>K13</b>	ISP coefficient.
	<b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> None <b>Interfaces</b> GUI, script
<b>K14</b>	ISP coefficient.
	<b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> 1/kPa <b>Interfaces</b> GUI, script
<b>K15</b>	ISP coefficient.
	<b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> None <b>Interfaces</b> GUI, script
<b>K16</b>	ISP coefficient.
	<b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> 1/kPa <b>Interfaces</b> GUI, script
<b>MixRatio</b>	<p>The mixture ratio employed to draw fuel from multiple tanks. For example, if there are two tanks and <b>MixRatio</b> is set to [2 1], then twice as much fuel will be drawn from tank one as from tank 2 in the <b>Tank</b> list. Note, if a MixRatio is not supplied, fuel is drawn from tanks in equal amounts, (the <b>MixRatio</b> is set to a vector of ones the same length as the <b>Tank</b> list).</p>
	<b>Data Type</b> Array <b>Allowed Values</b> Array of real numbers with same length as number of tanks in the <b>Tank</b> array <b>Access</b> set <b>Default Value</b> [1] <b>Units</b> N/A <b>Interfaces</b> GUI, script

Field	Description												
<b>Origin</b>	<p>This field, used in conjunction with the <b>Axes</b> field, allows the user to define a spacecraft centered set of axes for the <b>ChemicalThruster</b>. <b>Origin</b> has no affect when a <b>Local</b> coordinate system is used and the <b>Axes</b> are set to <b>MJ2000Eq</b> or <b>Spacecraft-Body</b>. This field cannot be modified in the Mission Sequence.</p> <table> <tr> <td><b>Data Type</b></td><td>Reference Array</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>Sun, Mercury, Venus, Earth, Luna, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto</b></td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>Earth</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Reference Array	<b>Allowed Values</b>	<b>Sun, Mercury, Venus, Earth, Luna, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto</b>	<b>Access</b>	set	<b>Default Value</b>	<b>Earth</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Reference Array												
<b>Allowed Values</b>	<b>Sun, Mercury, Venus, Earth, Luna, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto</b>												
<b>Access</b>	set												
<b>Default Value</b>	<b>Earth</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>Tank</b>	<p>A list of <b>ChemicalTank(s)</b> from which the thruster draws propellant from. A thruster requires the assignment of at least one tank. This field cannot be modified in the Mission Sequence.</p> <table> <tr> <td><b>Data Type</b></td><td>Reference Array</td></tr> <tr> <td><b>Allowed Values</b></td><td>User defined list of tank(s).</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>N/A</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Reference Array	<b>Allowed Values</b>	User defined list of tank(s).	<b>Access</b>	set	<b>Default Value</b>	N/A	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Reference Array												
<b>Allowed Values</b>	User defined list of tank(s).												
<b>Access</b>	set												
<b>Default Value</b>	N/A												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>ThrustDirection1</b>	<p>X component of the spacecraft thrust vector direction.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real Number</td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>1</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real Number	<b>Access</b>	set, get	<b>Default Value</b>	1	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real Number												
<b>Access</b>	set, get												
<b>Default Value</b>	1												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>ThrustDirection2</b>	<p>Y component of the spacecraft thrust vector direction.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real Number</td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real Number	<b>Access</b>	set, get	<b>Default Value</b>	0	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real Number												
<b>Access</b>	set, get												
<b>Default Value</b>	0												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

Field	Description												
<b>ThrustDirection3</b>	Z component of the spacecraft thrust vector direction.												
	<table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real Number</td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real Number	<b>Access</b>	set, get	<b>Default Value</b>	0	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real Number												
<b>Access</b>	set, get												
<b>Default Value</b>	0												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

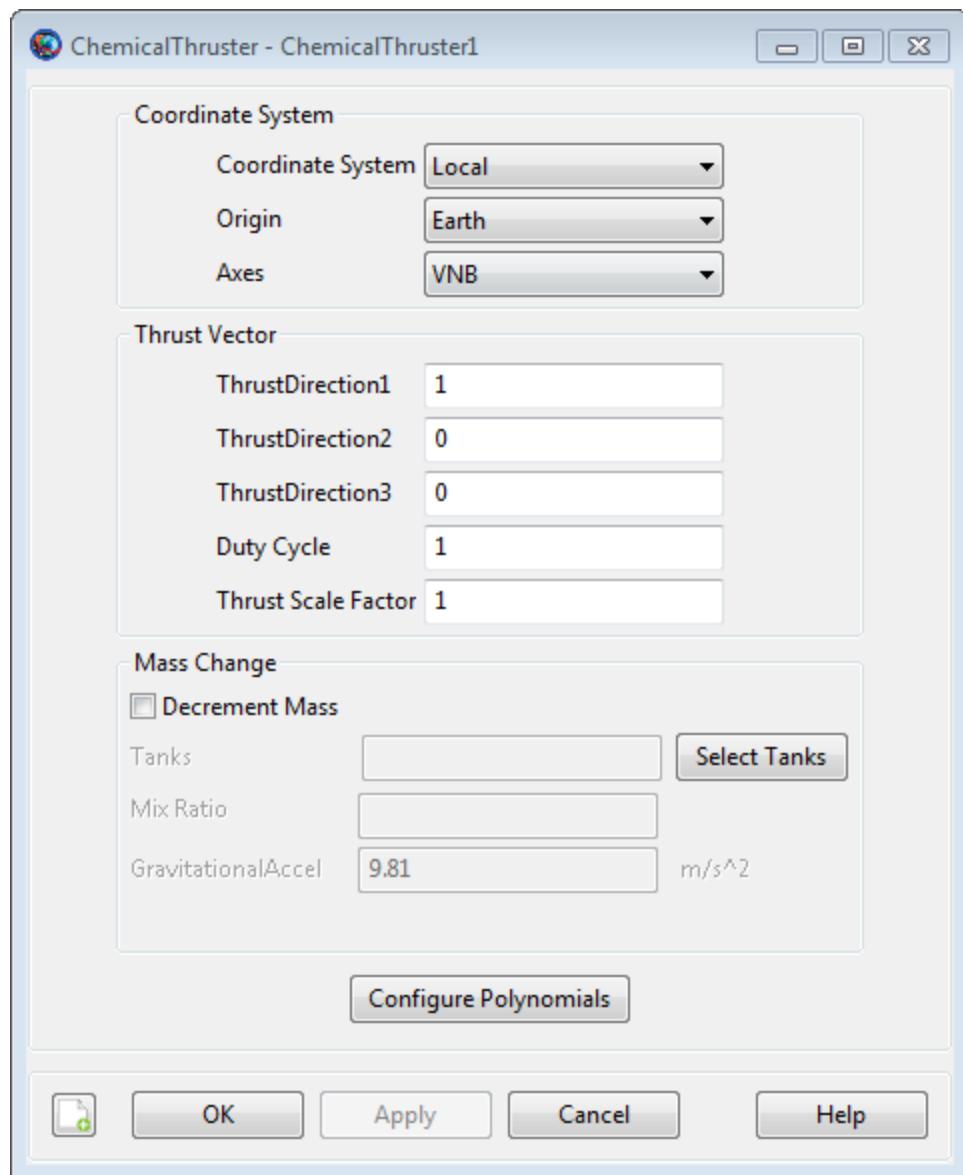
Field	Description												
<b>ThrustScaleFactor</b>	<b>ThrustScaleFactor</b> is a scale factor that is multiplied by the thrust vector, for a given thruster, before the thrust vector is added into the total acceleration. Note that the value of this scale factor does not affect the mass flow rate.												
	<table> <tr> <td><b>Data Type</b></td><td>Real Number</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real <math>\geq 0</math></td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>1</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real Number	<b>Allowed Values</b>	Real $\geq 0$	<b>Access</b>	set, get	<b>Default Value</b>	1	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real Number												
<b>Allowed Values</b>	Real $\geq 0$												
<b>Access</b>	set, get												
<b>Default Value</b>	1												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

## Interactions

Command or Re- source	Description
<b>BeginFinite- Burn/EndFinite- Burn command</b>	Use these commands, which require a <b>Spacecraft</b> and a <b>FiniteBurn</b> name as input, to implement a finite burn.
<b>ChemicalTank re- source</b>	This resource contains the fuel used to power the <b>ChemicalThruster</b> specified by the <b>FiniteBurn</b> resource.
<b>FiniteBurn re- source</b>	When using the <b>BeginFiniteBurn/EndFiniteBurn</b> commands, you must specify which <b>FiniteBurn</b> resource to implement. The <b>FiniteBurn</b> resource specifies which <b>ChemicalThruster(s)</b> to use for the finite burn.
<b>Spacecraft re- source</b>	When using the <b>BeginFiniteBurn/EndFiniteBurn</b> commands, you must specify which <b>Spacecraft</b> to apply the finite burn to.
<b>Propagate com- mand</b>	In order to implement a non-zero finite burn, a <b>Propagate</b> statement must occur within the <b>BeginFiniteBurn</b> and <b>EndFiniteBurn</b> statements.

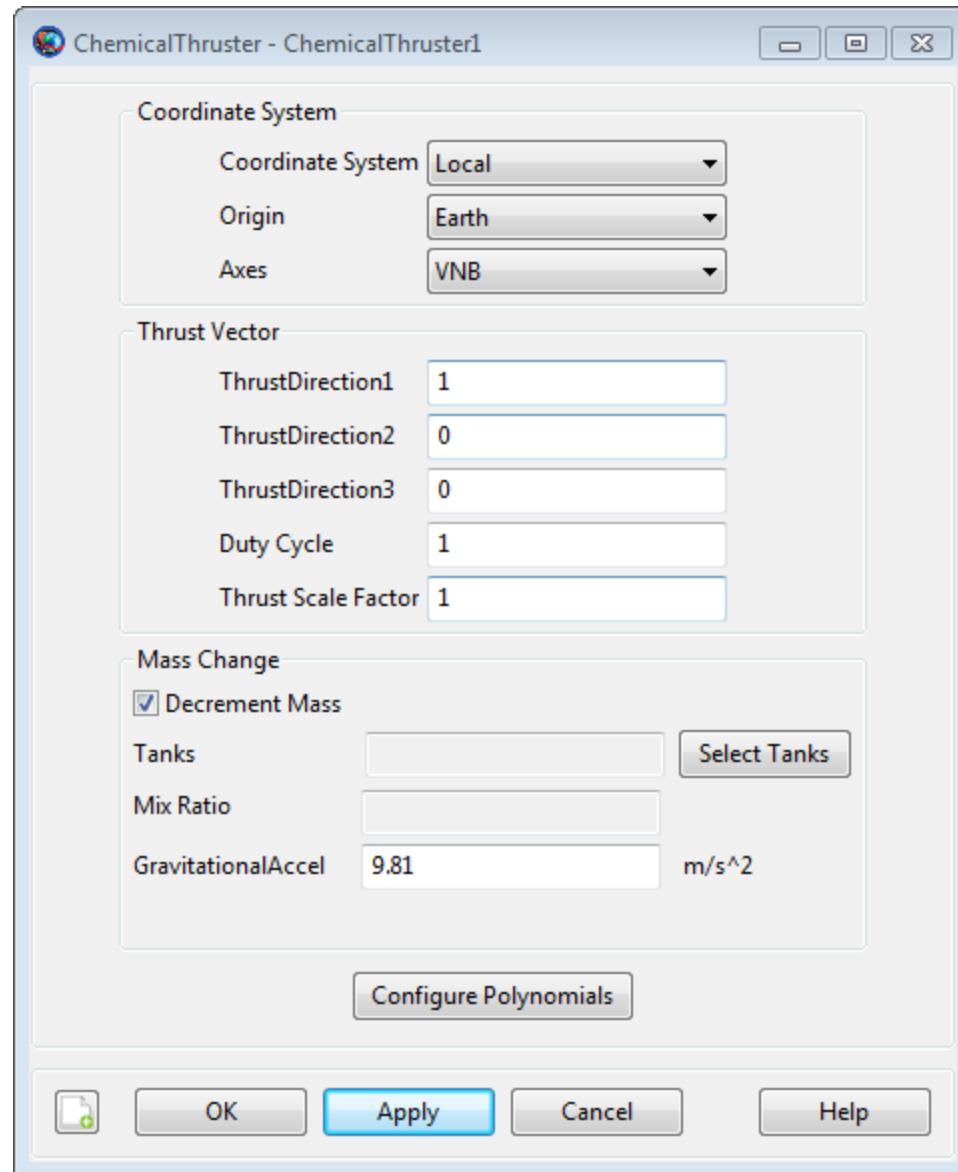
## GUI

The **ChemicalThruster** dialog box allows you to specify properties of a **ChemicalThruster** including the **Coordinate System** of the thrust acceleration direction vector, the thrust magnitude and Isp coefficients, and choice of **ChemicalTank**. The layout of the **ChemicalThruster** dialog box is shown below.

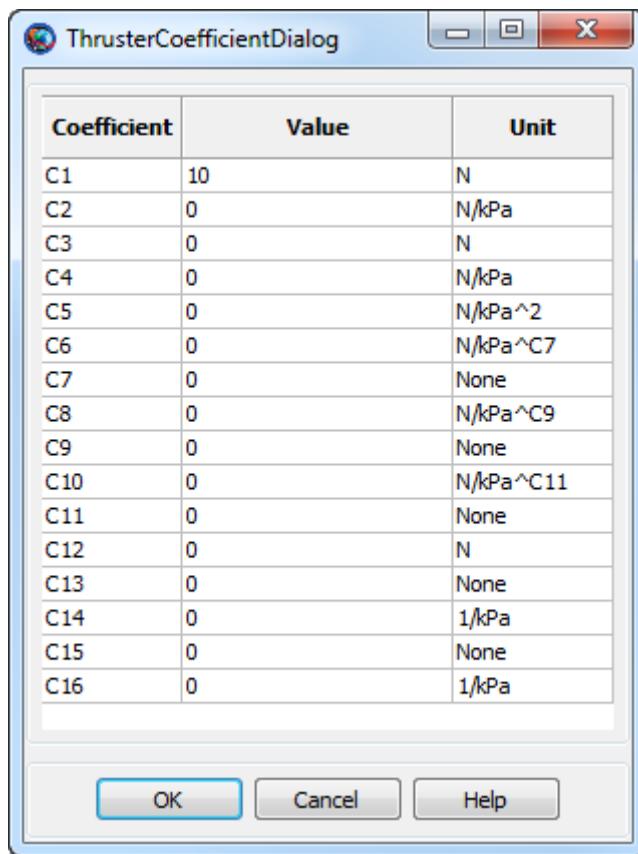


When configuring the **Coordinate System** field, you can choose between existing coordinate systems or use locally defined coordinate systems. The **Axes** field is only active if **Coordinate System** is set to **Local**. The **Origin** field is only active if **Coordinate System** is set to **Local** and **Axes** is set to either **VNB** or **LVLH**.

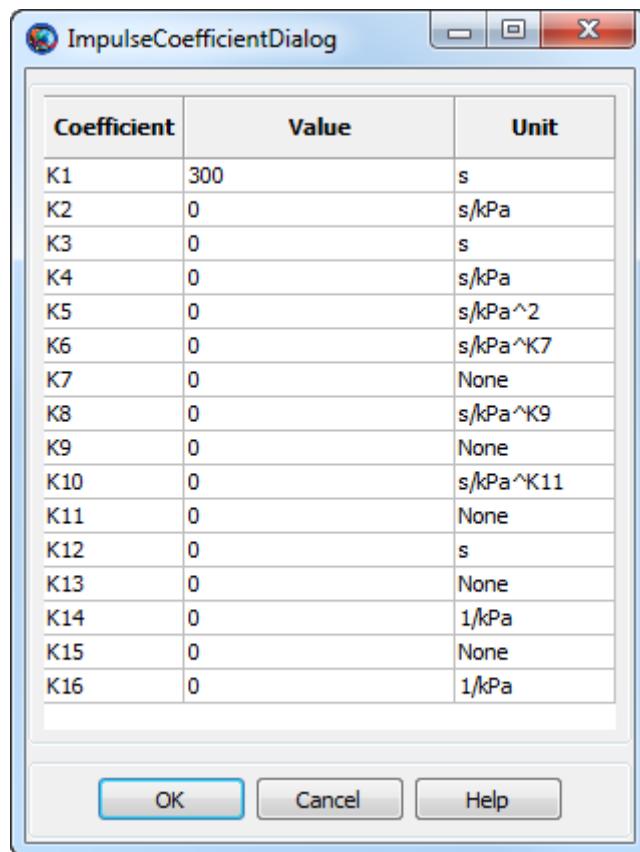
As shown below, if **Decrement Mass** is checked, then you can input the gravitational acceleration value used to calculate fuel use. The value of the gravitational acceleration input here only affects fuel use and does not affect the force model.



Selecting the **Edit Thruster Coef.** button brings up the following dialog box where you may input the coefficients for the **ChemicalThruster** polynomial.



Similarly, clicking the **Edit Impulse Coef.** button brings up the following dialog box where you may input the coefficients for the specific impulse (ISP) polynomial.



## Remarks

### Use of ChemicalThruster Resource in Conjunction With Maneuvers

A **ChemicalThruster** resource is used only in association with finite maneuvers. To implement a finite maneuver, you must first create both a **ChemicalTank** and a **FiniteBurn** resource. You must also associate a **ChemicalTank** with the **ChemicalThruster** resource and you must associate a **ChemicalThruster** with the **FiniteBurn** resource. The finite maneuver is implemented using the **BeginFiniteBurn/EndFiniteBurn** commands. See the **BeginFiniteBurn/EndFiniteBurn** command documentation for worked examples on how the **ChemicalThruster** resource is used in conjunction with finite maneuvers.

### Thrust and ISP Calculation

Unscaled thrust,  $F_T$ , and  $I_{sp}$ , as a function of Pressure, in kPa, and Temperature, in degrees Celsius, are calculated using the following polynomials.

$$F_T(T, P) = C_1 + C_2 P + (C_3 + C_4 P + C_5 P^2 + C_6 P^{C_7} + C_8 P^{C_9} + C_{10} P^{C_{11}} + C_{12}(C_{13})^{C_{14}P}) \left( \frac{T}{T_{ref}} \right)^{1+C_{15}+C_{16}P}$$

$$I_{sp}(T, P) = K_1 + K_2 P + (K_3 + K_4 P + K_5 P^2 + K_6 P^{K_7} \\ + K_8 P^{K_9} + K_{10} P^{K_{11}} + K_{12} (K_{13})^{K_{14} P}) \left( \frac{T}{T_{ref}} \right)^{1+K_{15}+K_{16}P}$$

The thrust, T, output in Newtons, is scaled by the **Duty Cycle** and **Thrust Scale Factor**. The thrust acceleration direction vector (the direction of the actual acceleration not the thruster nozzle) is given by **ThrustDirection1-3** and is applied in the input **Coordinate System**. The Isp is output in seconds.

The mass flow rate and the thrust equations are shown below where  $F_T$  and  $I_{sp}$  are defined above,  $f_d$  is the duty cycle,  $f_s$  is the thrust scale factor,  $R_{iT}$  is the rotation matrix from the thrust coordinate system to the inertial system, and  $T_d$  is the unitized thrust direction.

$$\dot{m} = f_d \frac{F_T(T, P)}{I_{sp}(T, P)g}$$

$$\mathbf{T} = f_s f_d F_T(T, P) \mathbf{R}_{iT} \hat{\mathbf{T}}_d$$

## Local Coordinate Systems

Here, a Local coordinate system is defined as one that we configure "locally" using the **ChemicalThruster** resource interface as opposed to defining a coordinate system using the **Coordinate Systems** folder in the **Resources** Tree.

To configure a local coordinate system, you must specify the coordinate system of the input thrust acceleration direction vector, **ThrustDirection1-3**. If you choose a local coordinate system, the four choices available, as given by the **Axes** sub-field, are **VNB**, **LVLH**, **MJ2000Eq**, and **SpacecraftBody**. **VNB** or Velocity-Normal-Binormal is a non-inertial coordinate system based upon the motion of the spacecraft with respect to the **Origin** sub-field. For example, if the **Origin** is chosen as Earth, then the X-axis of this coordinate system is along the velocity of the spacecraft with respect to the Earth, the Y-axis is along the instantaneous orbit normal (with respect to the Earth) of the spacecraft, and the Z-axis completes the right-handed set.

Similarly, Local Vertical Local Horizontal or **LVLH** is also a non-inertial coordinate system based upon the motion of the spacecraft with respect to the **Origin** sub-field. Again, if we choose Earth as the origin, then the X-axis of this coordinate system is the position of the spacecraft with respect to the Earth, the Z-axis is the instantaneous orbit normal (with respect to the Earth) of the spacecraft, and the Y-axis completes the right-handed set.

**MJ2000Eq** is the J2000-based Earth-centered Earth mean equator inertial coordinate system. Note that the **Origin** sub-field is not needed to define this coordinate system.

**SpacecraftBody** is the attitude system of the spacecraft. Since the thrust is applied in this system, GMAT uses the attitude of the spacecraft, a spacecraft attribute, to deter-

mine the inertial thrust direction. Note that the **Origin** sub-field is not needed to define this coordinate system.

### Caution When Setting the ChemicalTank Temperature and Reference Temperature

Note that both the thrust and ISP polynomials have terms that involve the ratio, (Temperature / Reference Temperature). For GMAT, this temperature ratio is calculated in Celsius units, and thus, there is a discontinuity when the Reference Temperature is equal to zero. For this reason, GMAT requires that the absolute value of the input Reference Temperature is greater than 0.01.

Note also that the form of the Thrust and ISP polynomial has some behavior, when the Reference Temperature is near 0 degrees Centigrade, that you need to be aware of. Because of the previously mentioned discontinuity, the polynomials do not vary smoothly when the Reference Temperature is near zero. For example, consider the two Reference Temperatures, -0.011 and + 0.011 degrees Centigrade. These two temperatures are close to each other in value and one might expect that they have roughly similar thrust and ISP values. This may not be the case, depending upon your choice of thrust/ISP coefficients, since the temperature ratios associated with the two Reference Temperatures have the same magnitude but different signs. You may choose to set the input Reference Temperature equal to the input Temperature, thus eliminating any dependence of thrust and ISP with temperature when using the currently implemented **ChemicalTank** model based upon Boyle's Law where the fuel Temperature does not change as fuel is depleted.

### Examples

Create a default **ChemicalTank** and a **ChemicalThruster** that allows for fuel depletion, assign the **ChemicalThruster** the default **ChemicalTank**, and attach both the **ChemicalThruster** and **ChemicalTank** to a **Spacecraft**.

```
% Create the ChemicalTank Resource
Create ChemicalTank FuelTank1
FuelTank1.AllowNegativeFuelMass = false
FuelTank1.FuelMass = 756
FuelTank1.Pressure = 1500
FuelTank1.Temperature = 20
FuelTank1.RefTemperature = 20
FuelTank1.Volume = 0.75
FuelTank1.FuelDensity = 1260
FuelTank1.PressureModel = PressureRegulated

% Create a ChemicalThruster, that allows fuel depletion, and assign it a Chemical
Create ChemicalThruster Thruster1
Thruster1.CoordinateSystem = Local
Thruster1.Origin = Earth
Thruster1.Axes = VNB
Thruster1.ThrustDirection1 = 1
Thruster1.ThrustDirection2 = 0
```

```
Thruster1.ThrustDirection3 = 0
Thruster1.DutyCycle = 1
Thruster1.ThrustScaleFactor = 1
Thruster1.DecrementMass = true
Thruster1.Tank = {FuelTank1}
Thruster1.GravitationalAccel = 9.81000000000001
Thruster1.C1 = 10
Thruster1.C2 = 0
Thruster1.C3 = 0
Thruster1.C4 = 0
Thruster1.C5 = 0
Thruster1.C6 = 0
Thruster1.C7 = 0
Thruster1.C8 = 0
Thruster1.C9 = 0
Thruster1.C10 = 0
Thruster1.C11 = 0
Thruster1.C12 = 0
Thruster1.C13 = 0
Thruster1.C14 = 0
Thruster1.C15 = 0
Thruster1.C16 = 0
Thruster1.K1 = 300
Thruster1.K2 = 0
Thruster1.K3 = 0
Thruster1.K4 = 0
Thruster1.K5 = 0
Thruster1.K6 = 0
Thruster1.K7 = 0
Thruster1.K8 = 0
Thruster1.K9 = 0
Thruster1.K10 = 0
Thruster1.K11 = 0
Thruster1.K12 = 0
Thruster1.K13 = 0
Thruster1.K14 = 0
Thruster1.K15 = 0
Thruster1.K16 = 0

% Add the ChemicalThruster and the ChemicalTank to a Spacecraft
Create Spacecraft DefaultSC
DefaultSC.Tanks = {FuelTank1}
DefaultSC.Thrusters = {Thruster1}

BeginMissionSequence
```

Create two **ChemicalTanks** (called **aTank1** and **aTank2**) and a **ChemicalThruster**, attach both the **ChemicalThruster** and **ChemicalTanks** to a **Spacecraft**, and configure the thruster to draw four times as much fuel from **aTank1** than **aTank2**.

```
% Create the ChemicalTank Resource
Create Spacecraft aSat
aSat.Tanks = {aTank1,aTank2}
aSat.Thrusters = {aThruster}

% Create two tanks
Create ChemicalTank aTank1 aTank2

% Configure thruster to draw four times as much fuel
% from aTank1 than aTank2
Create ChemicalThruster aThruster
aThruster.Tank = {aTank1,aTank2}
aThruster.MixRatio = [4 1]

BeginMissionSequence
```

## ContactLocator

A line-of-sight event locator between a target **Spacecraft** and a **GroundStation** or **PlanetographicRegion**.

### Description



#### Note

**ContactLocator** is a SPICE-based subsystem that uses a parallel configuration for the solar system and celestial bodies from other GMAT components. For precision applications, care must be taken to ensure that both configurations are consistent. See [Remarks](#) for details.

A **ContactLocator** is an event locator used to find line-of-sight contact events between a **Spacecraft** and a **GroundStation** or **PlanetographicRegion**. By default, a **ContactLocator** generates a text event report listing the beginning and ending times of each line-of-sight event, along with the duration. Contact location can be performed over the entire propagation interval or over a subinterval, and can optionally adjust for light-time delay and stellar aberration. Contact location can be configured to search for times of occultation of other **CelestialBody** resources that may block line of sight, and can limit contact events to a specified minimum elevation angle configured on the **GroundStation**.

Contact location can be performed between one **Spacecraft (Target)** and any number of **GroundStation** resources (**Observers**). Each target-observer pair is searched individually, and results in a separate segment of the resulting report. All pairs must use the same interval and search options; to customize the options per pair, use multiple **ContactLocator** resources.

Third-body occultation searches can be included by listing one or more **CelestialBody** resources in the **OccultingBodies** list. Any configured **CelestialBody** can be used as an occulting body, including user-defined ones. By default, no occultation searches are performed; the central body of the **GroundStation** is included automatically in the basic line-of-sight algorithm.

By default, the **ContactLocator** searches the entire interval of propagation of the **Target**, after applying certain endpoint light-time adjustments; see [Remarks](#) for details. To search a custom interval, set **UseEntireInterval** to False and set **InitialEpoch** and **FinalEpoch** accordingly. Note that these epochs are assumed to be at the observer, and so must be valid when translated to the target via light-time delay and stellar aberration, if configured. If they fall outside the propagation interval of the **Target**, GMAT will display an error.

The contact locator can optionally adjust for both light-time delay and stellar aberration, using either a transmit sense (**Observer**→**Target**) or receive sense (**Observer**#**Target**) depending on the value of **LightTimeDirection**. The light-time direction affects the valid

search interval by limiting searches near the start of the interval (for transmit sense) or the end of the interval (for receive sense). See [Remarks](#) for details. Stellar aberration is only applied for the line-of-sight portion of the search; it has no effect during occultation searches.

The event search is performed at a fixed step through the interval. You can control the step size (in seconds) by setting the **StepSize** field. An appropriate choice for step size is no greater than half the period of the line-of-sight function—that is, half the orbit period for an elliptical orbit. If third-body occultations are used, the maximum step size is no greater than the minimum-duration occultation event you wish to find. See [Remarks](#) for details.

GMAT uses the SPICE library for the fundamental event location algorithm. As such, all celestial body data is loaded from SPICE kernels for this subsystem, rather than GMAT's own **CelestialBody** shape and orientation configuration. See [Remarks](#) for details.

Unless otherwise mentioned, **ContactLocator** fields cannot be set in the mission sequence.

See Also: [CelestialBody](#), [GroundStation](#), [Spacecraft](#), [EclipseLocator](#), [FindEvents](#)

## Fields

Field	Description	
<b>Filename</b>	Name and path of the contact report file. This field can be set in the mission sequence.	<b>Data Type</b> String <b>Allowed Values</b> Valid file path <b>Access</b> set <b>Default Value</b> 'ContactLocator.txt' <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>FinalEpoch</b>	Last epoch to search for contacts, in the format specified by <b>InputEpochFormat</b> . The epoch is relative to the <b>Observer</b> , and must map to a valid epoch in the <b>Target</b> ephemeris interval, including any light time. This field can be set in the mission sequence.	<b>Data Type</b> String <b>Allowed Values</b> Valid epoch in available spacecraft ephemeris <b>Access</b> set <b>Default Value</b> '21545.138' <b>Units</b> ModifiedJulian epoch formats: days  <b>Interfaces</b> Gregorian epoch formats: N/A GUI, script

Field	Description												
<b>InitialEpoch</b>	<p>First epoch to search for contacts, in the format specified by <b>InputEpochFormat</b>. The epoch is relative to the <b>Observer</b>, and must map to a valid epoch in the <b>Target</b> ephemeris interval, including any light time. This field can be set in the mission sequence.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Valid epoch in available spacecraft ephemeris</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>'21545'</td></tr> <tr> <td><b>Units</b></td><td>Modified Julian epoch formats: days</td></tr> <tr> <td><b>Interfaces</b></td><td>Gregorian epoch formats: N/A GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Valid epoch in available spacecraft ephemeris	<b>Access</b>	set	<b>Default Value</b>	'21545'	<b>Units</b>	Modified Julian epoch formats: days	<b>Interfaces</b>	Gregorian epoch formats: N/A GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Valid epoch in available spacecraft ephemeris												
<b>Access</b>	set												
<b>Default Value</b>	'21545'												
<b>Units</b>	Modified Julian epoch formats: days												
<b>Interfaces</b>	Gregorian epoch formats: N/A GUI, script												
<b>InputEpochFormat</b>	The field allows you to set the type of the epoch that you choose to enter for <b>InitialEpoch</b> and <b>FinalEpoch</b> fields. This field cannot be modified in the Mission Sequence.												
	<table> <tr> <td><b>Data Type</b></td><td>Enumeration</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any of the following epoch formats: <b>UTC-Gregorian</b>, <b>UTCModJulian</b>, <b>TAIGregorian</b>, <b>TAIModJulian</b>, <b>TTGregorian</b>, <b>TTModJulian</b>, <b>A1Gregorian</b>, <b>A1ModJulian</b></td></tr> <tr> <td><b>Access</b></td><td>Set</td></tr> <tr> <td><b>Default Value</b></td><td><b>TAIModJulian</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Enumeration	<b>Allowed Values</b>	Any of the following epoch formats: <b>UTC-Gregorian</b> , <b>UTCModJulian</b> , <b>TAIGregorian</b> , <b>TAIModJulian</b> , <b>TTGregorian</b> , <b>TTModJulian</b> , <b>A1Gregorian</b> , <b>A1ModJulian</b>	<b>Access</b>	Set	<b>Default Value</b>	<b>TAIModJulian</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Enumeration												
<b>Allowed Values</b>	Any of the following epoch formats: <b>UTC-Gregorian</b> , <b>UTCModJulian</b> , <b>TAIGregorian</b> , <b>TAIModJulian</b> , <b>TTGregorian</b> , <b>TTModJulian</b> , <b>A1Gregorian</b> , <b>A1ModJulian</b>												
<b>Access</b>	Set												
<b>Default Value</b>	<b>TAIModJulian</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>IntervalStepSize</b>	Determines the resolution of time intervals for the intermediate step reporting. If set to 0, then only the beginning and end of contact periods are recorded.												
	<table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Positive Real values</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0.0</td></tr> <tr> <td><b>Units</b></td><td>Seconds</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Positive Real values	<b>Access</b>	set	<b>Default Value</b>	0.0	<b>Units</b>	Seconds	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Positive Real values												
<b>Access</b>	set												
<b>Default Value</b>	0.0												
<b>Units</b>	Seconds												
<b>Interfaces</b>	script												
<b>LeftJustified</b>	Modifies the contact report to have columns be left or right justified.												
	<table> <tr> <td><b>Data Type</b></td><td>Boolean</td></tr> <tr> <td><b>Allowed Values</b></td><td>true, false</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>false</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Boolean	<b>Allowed Values</b>	true, false	<b>Access</b>	set	<b>Default Value</b>	false	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Boolean												
<b>Allowed Values</b>	true, false												
<b>Access</b>	set												
<b>Default Value</b>	false												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												

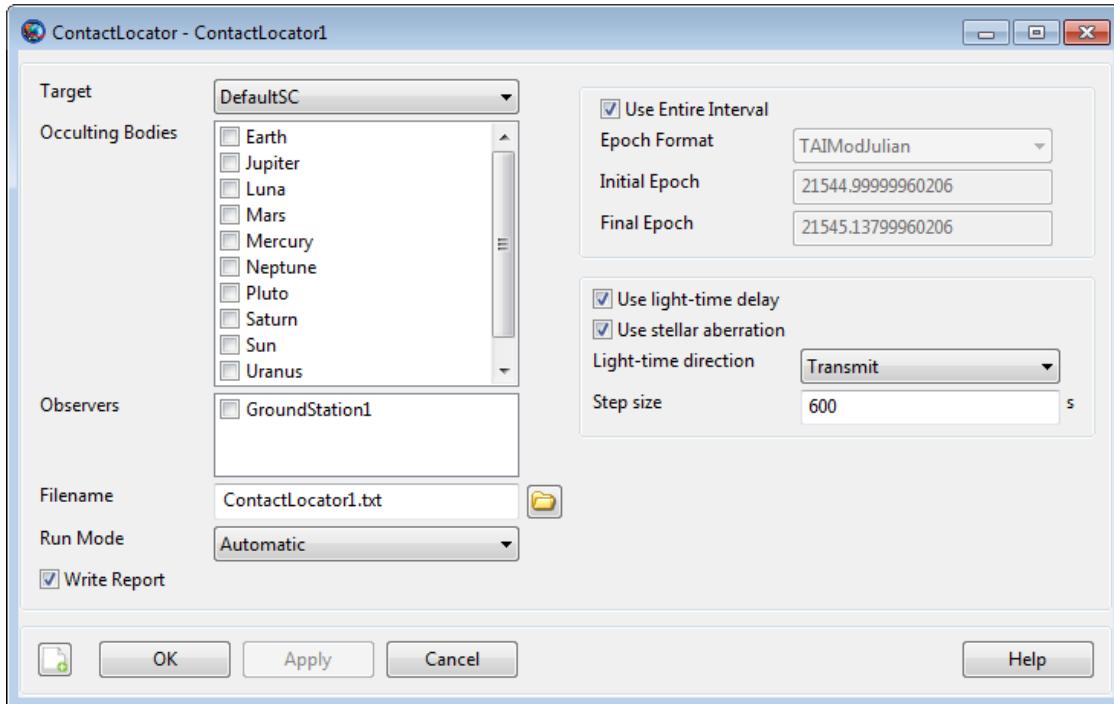
Field	Description
<b>LightTimeDirection</b>	Sense of light-time calculation: transmit from observer or receive at observer.
	<p><b>Data Type</b> Enumeration</p> <p><b>Allowed Values</b> Transmit, Receive</p> <p><b>Access</b> set</p> <p><b>Default Value</b> Transmit</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>Observers</b>	<p>List of the contact observer objects. Can be any number of GMAT <b>GroundStation</b> resources. Observations will be calculated using the minimum elevation angle of the ground station as well as any FOV attached to its antenna if available. These ground stations must have a <b>Planet</b> or <b>Moon</b> for their central body. For contact location to a <b>PlanetographicRegion</b>, the observer is the space-craft passing over the defined region.</p> <p><b>Data Type</b> List of <b>GroundStation</b> resources, or a single <b>Spacecraft</b> resource (<b>PlanetographicRegion</b> overflight finding only)</p> <p><b>Allowed Values</b> Any existing <b>GroundStation</b> or <b>Spacecraft</b> resources</p> <p><b>Access</b> set</p> <p><b>Default Value</b> Empty list</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>OccultingBodies</b>	<p>List of occulting bodies to search for contacts. Can be any number of GMAT <b>CelestialBody</b>-type resources, such as <b>Planet</b>, <b>Moon</b>, <b>Asteroid</b>, etc. Note that an occulting body must have a mass (e.g. not <b>LibrationPoint</b> or <b>Barycenter</b>).</p> <p><b>Data Type</b> List of <b>CelestialBody</b> resources (e.g. <b>Planet</b>, <b>Asteroid</b>, <b>Moon</b>, etc.)</p> <p><b>Allowed Values</b> Any existing <b>CelestialBody</b>-class resources</p> <p><b>Access</b> set</p> <p><b>Default Value</b> Empty list</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>

Field	Description
<b>ReportPrecision</b>	Modifies the contact report precision on fields other than times.
	<p><b>Data Type</b> Integer</p> <p><b>Allowed Values</b> Positive integers</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 6</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> script</p>
<b>ReportFormat</b>	Defines the report style to return from the ContactLocator.
	<p><b>Data Type</b> Enumeration</p> <p><b>Allowed Values</b> SiteViewMaxElevationReport, ContactRangeReport, AzimuthElevationRangeReport, AzimuthElevationRangeRateReport, SiteViewMaxElevationRateReport</p> <p><b>Access</b> set</p> <p><b>Default Value</b> Legacy</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> script</p>
<b>ReportTimeFormat</b>	Determines the time format to be written in the ContactLocator report file. Does not affect reports of the 'Legacy' format
	<p><b>Data Type</b> Enumeration</p> <p><b>Allowed Values</b> UTCGregorian, UTCTMJD, ISOYD</p> <p><b>Access</b> set</p> <p><b>Default Value</b> UTCGregorian</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> script</p>
<b>RunMode</b>	Mode of event location execution. 'Automatic' triggers event location to occur automatically at the end of the run. 'Manual' limits execution only to the <b>FindEvents</b> command. 'Disabled' turns off event location entirely.
	<p><b>Data Type</b> Enumeration</p> <p><b>Allowed Values</b> Automatic, Manual, Disabled</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 'Automatic'</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>StepSize</b>	Step size of event locator. See <a href="#">Remarks</a> for discussion of appropriate values.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> <b>StepSize</b> &gt; 0</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 10</p> <p><b>Units</b> s</p> <p><b>Interfaces</b> GUI, script</p>

Field	Description
<b>Target</b>	<p>The target <b>Spacecraft</b> or <b>PlanetographicRegion</b> resource to search for contacts.</p> <p><b>Data Type</b> <b>Spacecraft</b> or <b>PlanetographicRegion</b> resource</p> <p><b>Allowed Values</b> Any existing <b>Spacecraft</b> or <b>PlanetographicRegion</b> resource</p> <p><b>Access</b> set</p> <p><b>Default Value</b> First configured <b>Spacecraft</b> resource</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>UseEntireInterval</b>	<p>Search the entire available <b>Target</b> ephemeris interval, after adjusting the end-points for light-time delay as appropriate. See <a href="#">Remarks</a> for details. This field can be set in the mission sequence.</p> <p><b>Data Type</b> Boolean</p> <p><b>Allowed Values</b> true, false</p> <p><b>Access</b> set</p> <p><b>Default Value</b> true</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>UseLightTimeDelay</b>	<p>Use light-time delay in the event-finding algorithm. The clock is always hosted on the <b>Observer</b>. For more information on how this is being calculated, see the link to the SPICE aberration correction documentation in the references.</p> <p><b>Data Type</b> Boolean</p> <p><b>Allowed Values</b> true, false</p> <p><b>Access</b> set</p> <p><b>Default Value</b> true</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>UseStellarAberration</b>	<p>Use stellar aberration in addition to light-time delay in the event-finding algorithm. Light-time delay must be enabled. Stellar aberration only affects line-of-sight searches, not occultation searches.</p> <p><b>Data Type</b> Boolean</p> <p><b>Allowed Values</b> true, false</p> <p><b>Access</b> set</p> <p><b>Default Value</b> true</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>

Field	Description	
<b>WriteReport</b>	Write an event report when event location is executed. This field can be set in the mission sequence.	
	<b>Data Type</b>	Boolean
	<b>Allowed Values</b>	true, false
	<b>Access</b>	set
	<b>Default Value</b>	true
	<b>Units</b>	N/A
	<b>Interfaces</b>	GUI, script

## GUI



The default **ContactLocator** GUI for a new resource is shown above. You can choose one **Spacecraft** from **Target**, which is populated by all the **Spacecraft** resources currently configured in the mission. In the **Observers** list, you can check the box next to all **GroundStations** you want to use in the contact search.

To search for third-body occultations, check the boxes next to any applicable **CelestialBody** resources in the **Occulting Bodies** list. This list shows all celestial bodies currently configured in the mission. Note that each occultation search will increase the execution time of the overall search.

You can configure the output via **Filename**, **Run Mode**, and **Write Report** near the bottom. If **Write Report** is enabled, a text report will be written to the file specified in **Filename**. The search will execute during **FindEvents** commands (for **Manual** or **Automatic** modes) and automatically at the end of the mission (for **Automatic** mode), depending on the **Run Mode**.

You can configure the search interval via the options in the upper right. Uncheck **Use Entire Interval** to set the search interval manually. See the [Remarks](#) section for considerations when setting the search interval.

You can control the search algorithm via the options in the bottom right. Configure light-time and stellar aberration via the check boxes next to each, and select the signal direction via the **Light-time direction** selection.

To control the fidelity and execution time of the search, set the **Step size** appropriately. See the [Remarks](#) section for details.

Note that configuration of the **ContactLocator** for **PlanetographicRegion** overflight searches is not currently available through the GUI panel and can be done only in script.

## Scripting

Beyond the basic ContactLocator options offered through the GUI, GMAT offers a number of additional report customization options that can be accessed through the script interface. To create a report that gives information at set intervals within the contact period, the user may set **IntervalSize** to a positive value in seconds. Finally, using **ReportPrecision** and **LeftJustified** allows for configuring the advanced output with additional specificity.

## Remarks

### Data configuration

The **ContactLocator** implementation is based on the [NAIF SPICE toolkit](#), which uses a different mechanism for environmental data such as celestial body shape and orientation, planetary ephemerides, body-specific frame definitions, and leap seconds. Therefore, it is necessary to maintain two parallel configurations to ensure that the event location results are consistent with GMAT's own propagation and other parameters. The specific data to be maintained is:

- Planetary shape and orientation:
  - GMAT core: **CelestialBody.EquatorialRadius**, **Flattening**, **SpinAxisRAConstant**, **SpinAxisRARate**, etc.
  - ContactLocator: **SolarSystem.PCKFilename**,  
**CelestialBody.PlanetarySpiceKernelName**
- Planetary ephemeris:
  - GMAT core: **SolarSystem.DEFfilename**, or (**SolarSystem.SPKFilename**,  
**CelestialBody.OrbitSpiceKernelName**, **CelestialBody.NAIFId**)
  - ContactLocator: **SolarSystem.SPKFilename**,  
**CelestialBody.OrbitSpiceKernelName**, **CelestialBody.NAIFId**
- Body-fixed frame:
  - GMAT core: built-in
  - ContactLocator: **CelestialBody.SpiceFrameId**,  
**CelestialBody.FrameSpiceKernelName**
- Leap seconds:

- GMAT core: startup file LEAP\_SECS\_FILE setting
- ContactLocator: **SolarSystem.LSKFilename**



### Note

For precise applications, the **CelestialBody** shape must be consistent in both subsystems to ensure consistent placement of a **GroundStation**. The following script lines make the two definitions consistent for Earth.

```
SolarSystem.PCKfilename = '..\data\planetary_coeff\pck00010.tpc'  
Earth.EquatorialRadius = 6378.1366  
Earth.Flattening = 0.00335281310845547
```

See [SolarSystem](#) and [CelestialBody](#) for more details.

### Search interval

The **ContactLocator** search interval can be specified either as the entire ephemeris interval of the **Target**, or as a user-defined interval. Each mode offers specific behavior related to handling of light-time delay and discontinuous intervals.

If **UseEntireInterval** is true, the search is performed over the entire ephemeris interval of the **Target**, including any gaps or discontinuities. If light-time delay is enabled, the search interval is truncated by the approximate light time to allow SPICE to determine the exact light-time delay between the participants during the search. If **LightTimeDirection** is **Transmit**, the beginning of the interval is truncated. If **LightTimeDirection** is **Receive**, the end of the interval is truncated. In either case, the other end of the interval is trimmed slightly via bisection to avoid stepping beyond the end of the ephemeris due to numeric precision issues. This trimming is typically less than 1 s. The endpoints of gaps or discontinuities are not modified, so these are not fully supported if light-time delay is enabled. If light-time delay is disabled, the entire interval is used directly, with no endpoint manipulation.

If **UseEntireInterval** is false, the provided **InitialEpoch** and **FinalEpoch** are used to form the search interval directly. This interval is consistent with the **Observer** clock, and does not support the inclusion of gaps or discontinuities from the **Target** ephemeris. The user must ensure that the provided interval results in valid **Target** ephemeris epochs after light-time delay and stellar aberration have been applied.

These rules are summarized in the following table, where  $t_0$  and  $t_f$  are the beginning and end of the **Target** ephemeris, respectively, and  $l$  is the light time between the **Target** and the **Observer**.

	<b>UseEntireInterval</b> true	<b>UseEntireInterval</b> false
--	-------------------------------	--------------------------------

<b>UseLightTimeDelay</b> true	<p><b>Effective interval</b></p> <p><b>LightTimeDirection = 'Transmit':</b> <math>[t_0+lt, t_f]</math></p> <p><b>LightTimeDirection = 'Receive':</b> <math>[t_0, t_f-lt]</math></p> <p><b>Discontinuous intervals</b> Unsupported. Behavior is undefined.</p>	<p><b>Effective interval</b> [InitialEpoch, FinalEpoch]</p> <p><b>Discontinuous intervals</b> Unsupported. Behavior is undefined.</p>
<b>UseLightTimeDelay</b> false	<p><b>Effective interval</b> <math>[t_0, t_f]</math></p> <p><b>Discontinuous intervals</b> Fully supported</p>	<p><b>Effective interval</b> [InitialEpoch, FinalEpoch]</p> <p><b>Discontinuous intervals</b> Fully supported</p>

## Run modes

The **ContactLocator** works in conjunction with the **FindEvents** command: the **ContactLocator** resource defines the configuration of the event search, and the **FindEvents** command executes the search at a specific point in the mission sequence. The mode of interaction is defined by **ContactLocator.RunMode**, which has three options:

- **Automatic:** All **FindEvents** commands are executed as-is, plus an additional **FindEvents** is executed automatically at the end of the mission sequence.
- **Manual:** All **FindEvents** commands are executed as-is.
- **Disabled:** **FindEvents** commands are ignored.

## Observer Field of View

The contact locator has two approaches to determining the field of view of the observer. The most basic way is to initialize a **GroundStation** with a **MinimumElevationAngle** defined. This approach will use a constant elevation off the horizon as the threshold for visibility. If a **HorizonMaskFileName** is defined for the ground station, the masking profile defined in the mask file will be used to determine visibility. For more complex observers, users may attach an imager with either a CircularFOV, RectangularFOV, or CustomFOV to the ground station. For each observer in the ContactLocator, GMAT will conduct an individual search for each **Imager** with a **FOV**, listing the contacts separately in the report.

## Search algorithm

The **ContactLocator** uses the NAIF SPICE GF (geometry finder) subsystem to perform event location. Specifically, to find the initial contact windows, GMAT uses the intersection of the windows found by the following two functions:

- **gfposc\_c:** For line-of-sight search above the **GroundStation.MinimumElevationAngle**
- **gftfov\_c:** For line-of-sight search within the **FOV** on any attached **Imager** (ignored if no FOV are available)

The following call is made to perform occultation calculations:

- `gfoclt_c`: For third-body occultation searches

All functions implement a fixed-step search method through the interval, with an embedded root-location step if an event is found. Proper selection of **StepSize** differs between the two types.

For the basic line-of-sight search, without third-body occultations, **StepSize** can be set as high as one-half the period of the event function. For an elliptic orbit, this is up to one-half the orbit period. Note however, when computing view periods to a **GroundStation** utilizing a horizon mask (either via the **GroundStation HorizonMaskFileName** or sensor **FieldOfView**), **StepSize** should be sized to the resolution of the horizon mask. If the step size is too large, GMAT may completely overstep some portions of the mask and view periods may be incorrect or missing some events.

For third-body occultations, **StepSize** should be set equal to the length of the minimum-duration event to be found, or equal to the length of the minimum-duration gap between events, whichever is smaller. To guarantee location of 10-second occultations, set **StepSize** = 10.

If no third-body occultations are to be found, you can increase performance of the search by increasing **StepSize** per the notes above.

For further details, see the reference documentation for the two functions linked above.

### Report format

When **WriteReport** is enabled, **ContactLocator** outputs an event report at the end of each search execution. There are six report types. The "Legacy" report contains the following data:

- Target name
- For each Observer:
  - Observer name
  - For each event:
    - Event start time (UTC)
    - Event stop time (UTC)
    - Duration (s)
  - Total number of events

A sample report of the Legacy format is shown below.

Target: DefaultSC		
Observer: GroundStation1		
Start Time (UTC)	Stop Time (UTC)	Duration (s)
01 Jan 2000 13:18:45.268	01 Jan 2000 13:29:54.824	669.55576907
01 Jan 2000 15:06:44.752	01 Jan 2000 15:18:22.762	698.01023654

Number of events : 2		
Observer: GroundStation2		
Start Time (UTC)	Stop Time (UTC)	Duration (s)
01 Jan 2000 13:36:13.792	01 Jan 2000 13:47:51.717	697.92488540
Number of events : 1		

The "SiteViewMaxElevationReport" report contains the following data:

- Target name
- For each Observation:
  - Observer name
  - For each event:
    - Event start time (ReportTimeFormat)
    - Event stop time (ReportTimeFormat)
    - Duration (s)
    - Maximum Elevation (degrees)
    - Maximum Elevation Time (ReportTimeFormat)

The "SiteViewMaxElevationRangeReport" report contains the following data:

- Target name
- For each Observation:
  - Observer name
  - For each event:
    - Event start time (ReportTimeFormat)
    - Event stop time (ReportTimeFormat)
    - Duration (s)
    - Maximum Elevation (degrees)
    - Maximum Elevation Time (ReportTimeFormat)
    - Range at start time
    - Range at stop time

The "AzimuthElevationRangeReport" report uses the IntervalStepSize parameter to produce the following data:

- Target name
- For each Observation:
  - The Pass number
  - Observer name
  - For Each Time Stamp
    - The Azimuth (degrees)
    - The elevation (degrees)
    - The Range (km)

The "AzimuthElevationRangeRateReport" report uses the IntervalStepSize parameter to produce the following data:

- Target name
- For each Observation:
  - The Pass number
  - Observer name
- For Each Time Stamp
  - The Azimuth (degrees)
  - The elevation (degrees)
  - The Range (km)
  - The Range Rate (km/s)

The ContactRangeReport report contains the following data:

- Target name
- For each Observer:
  - Observer name
  - For each event:
    - Duration (s)
    - Event start time
    - Event stop time
    - Range at start time
    - Range at stop time

### Event location with SPK propagator

When using the SPK propagator, you load one or more SPK ephemeris files using the **Spacecraft.OrbitSpiceKernelName** field. For the purposes of event location, this field causes the appropriate ephemeris files to be loaded automatically on run, and so use of the **Propagate** command is not necessary. This is an easy way of performing event location on an existing SPK ephemeris file. See the example below.

### Examples

Perform a basic contact search in LEO:

```
SolarSystem.EphemerisSource = 'DE421'

Earth.EquatorialRadius = 6378.1366
Earth.Flattening      = 0.00335281310845547

Create Spacecraft sat

sat.DateFormat      = UTCGregorian
sat.Epoch          = '15 Sep 2010 16:00:00.000'
sat.CoordinateSystem = EarthMJ2000Eq
sat.DisplayStateType = Keplerian
sat.SMA            = 6678.14
sat.ECC            = 0.001
sat.INC            = 0
sat.RAAN           = 0
sat.AOP            = 0
```

```

sat.TA          = 180

Create ForceModel fm

fm.CentralBody = Earth
fm.PointMasses = {Earth}

Create Propagator prop

prop.FM    = fm
prop.Type = RungeKutta89

Create GroundStation GS

GS.CentralBody      = Earth
GS.StateType        = Spherical
GS.HorizonReference = Ellipsoid
GS.Location1        = 0
GS.Location2        = 0
GS.Location3        = 0

Create ContactLocator cl

cl.Target    = sat
cl.Observers = {GS}
cl.Filename  = 'Simple.report'

BeginMissionSequence

Propagate prop(sat) {sat.ElapsedSecs = 10800}

```

Perform a contact event search from an Earth ground station to a Mars orbiter, with Phobos occultations. The required mar063.bsp file can be found at [https://naif.jpl.nasa.gov/pub/naif/generic\\_kernels/spk/satellites/a\\_old\\_versions/mar063.cmt](https://naif.jpl.nasa.gov/pub/naif/generic_kernels/spk/satellites/a_old_versions/mar063.cmt).

```

% Mars orbiter, 2 days, Mars and Phobos eclipses

SolarSystem.EphemerisSource = 'SPICE'
SolarSystem.SPKFilename     = 'de421.bsp'

Mars.OrbitSpiceKernelName = '../data/planetary_ephem/spk/mar063.bsp'

Earth.EquatorialRadius = 6378.1366
Earth.Flattening       = 0.00335281310845547

Create CoordinateSystem MarsMJ2000Eq

MarsMJ2000Eq.Origin = Mars
MarsMJ2000Eq.Axes   = MJ2000Eq

```

```
Create Spacecraft sat
```

```
sat.DateFormat      = UTCGregorian
sat.Epoch          = '11 Mar 2004 12:00:00.000'
sat.CoordinateSystem = MarsMJ2000Eq
sat.DisplayStateType = Cartesian
sat.X              = -1.436997966893255e+003
sat.Y              = 2.336077717512823e+003
sat.Z              = 2.477821416108639e+003
sat.VX             = -2.978497667195258e+000
sat.VY             = -1.638005864673213e+000
sat.VZ             = -1.836385137438366e-001
```

```
Create ForceModel fm
```

```
fm.CentralBody = Mars
fm.PointMasses = {Mars}
```

```
Create Propagator prop
```

```
prop.FM    = fm
prop.Type = RungeKutta89
```

```
Create Moon Phobos
```

```
Phobos.CentralBody      = 'Mars'
Phobos.PosVelSource     = 'SPICE'
Phobos.NAIFId           = 401
Phobos.OrbitSpiceKernelName = {'mar063.bsp'}
Phobos.SpiceFrameId     = 'IAU_PHOBOS'
Phobos.EquatorialRadius = 13.5
Phobos.Flattening        = 0.3185185185185186
Phobos.Mu                = 7.093399e-004
```

```
Create Moon Deimos
```

```
Deimos.CentralBody      = 'Mars'
Deimos.PosVelSource     = 'SPICE'
Deimos.NAIFId           = 402
Deimos.OrbitSpiceKernelName = {'mar063.bsp'}
Deimos.SpiceFrameId     = 'IAU_DEIMOS'
Deimos.EquatorialRadius = 7.5
Deimos.Flattening        = 0.30666666666666664
Deimos.Mu                = 1.588174e-004
```

```
Create GroundStation GS
```

```
GS.CentralBody      = Earth
```

```
GS.StateType      = Spherical
GS.HorizonReference = Ellipsoid
GS.Location1     = 36.3269
GS.Location2     = 127.433
GS.Location3     = 0.081

Create ContactLocator cl

cl.Target        = sat
cl.Observers    = {GS}
cl.OccultingBodies = {Sun, Mercury, Venus, Luna, Mars, Phobos, Deimos}
cl.Filename      = 'Martian.report'
cl.StepSize       = 5

BeginMissionSequence

Propagate prop(sat) {sat.ElapsedDays = 2}
```

Perform contact location on an existing SPK ephemeris file:

```
SolarSystem.EphemerisSource = 'DE421'

Earth.EquatorialRadius = 6378.1366
Earth.Flattening      = 0.00335281310845547

Create Spacecraft sat

sat.OrbitSpiceKernelName = {'../data/vehicle/ephem/spk/MoonTransfer.bsp'}
sat.NAIFId                = -123456789

Create GroundStation GS

GS.CentralBody      = Earth
GS.StateType        = Spherical
GS.HorizonReference = Ellipsoid
GS.Location1        = 0
GS.Location2        = 0
GS.Location3        = 0

Create ContactLocator cl

cl.Target        = sat
cl.Observers    = {GS}
cl.Filename      = 'SPKPropagation.report'

BeginMissionSequence
```

Perform a contact search with a station mask in LEO:

```
Create Spacecraft sat
```

```
sat.DateFormat      = UTCGregorian
sat.Epoch          = '15 Sep 2010 16:00:00.000'
sat.CoordinateSystem = EarthMJ2000Eq
sat.DisplayStateType = Keplerian
sat.SMA            = 6678.14
sat.ECC            = 0.001
sat.INC            = 0
sat.RAAN           = 0
sat.AOP            = 0
sat.TA             = 180

Create ForceModel fm

fm.CentralBody = Earth
fm.PointMasses = {Earth}

Create Propagator prop

prop.FM    = fm
prop.Type = RungeKutta89

Create CustomFOV ArrowFOV

ArrowFOV.Elevation = [ 75 75 82 75 75 82 75 ]
ArrowFOV.Azimuth   = [ 0 90 90.09999999999999 150 210 270 270.1 ]

Create Antenna CustomAntenna

CustomAntenna.FieldOfView = ArrowFOV
CustomAntenna.DirectionX = 0
CustomAntenna.DirectionY = 0
CustomAntenna.DirectionZ = 1

Create GroundStation GS

GS.CentralBody      = Earth
GS.StateType        = Spherical
GS.HorizonReference = Ellipsoid
GS.Location1        = 0
GS.Location2        = 0
GS.Location3        = 0
GS.AddHardware      = {CustomAntenna}

Create ContactLocator cl

cl.Target    = sat
cl.Observers = {GS}
cl.Filename  = 'Simple.report'
```

```
BeginMissionSequence  
Propagate prop(sat) {sat.ElapsedSecs = 10800}
```

Perform a contact search with advanced reporting in LEO:

```
Create Spacecraft sat  
  
sat.DateFormat      = UTCGregorian  
sat.Epoch           = '15 Sep 2010 16:00:00.000'  
sat.CoordinateSystem = EarthMJ2000Eq  
sat.DisplayStateType = Keplerian  
sat.SMA             = 6678.14  
sat.ECC              = 0.001  
sat.INC              = 0  
sat.RAAN             = 0  
sat.AOP              = 0  
sat.TA               = 180  
  
Create ForceModel fm  
  
fm.CentralBody = Earth  
fm.PointMasses = {Earth}  
  
Create Propagator prop  
  
prop.FM    = fm  
prop.Type = RungeKutta89  
  
Create GroundStation GS  
  
GS.CentralBody      = Earth  
GS.StateType        = Spherical  
GS.HorizonReference = Ellipsoid  
GS.Location1        = 0  
GS.Location2        = 0  
GS.Location3        = 0  
  
Create ContactLocator cl  
  
cl.Target          = sat  
cl.Filename         = 'Advanced.report'  
cl.Observers        = {GS}  
cl.LeftJustified    = false  
cl.ReportPrecision  = 6  
cl.IntervalStepSize = 60  
cl.ReportTimeFormat = 'UTCGregorian'  
cl.ReportFormat     = 'AzimuthElevationRangeReport'
```

```
BeginMissionSequence  
  
Propagate prop(sat) {sat.ElapsedSecs = 10800}
```

Perform a contact search with interval reporting in LEO:

```
Create Spacecraft sat  
  
sat.DateFormat      = UTCGregorian  
sat.Epoch           = '15 Sep 2010 16:00:00.000'  
sat.CoordinateSystem = EarthMJ2000Eq  
sat.DisplayStateType = Keplerian  
sat.SMA             = 6678.14  
sat.ECC              = 0.001  
sat.INC              = 0  
sat.RAAN             = 0  
sat.AOP              = 0  
sat.TA               = 180  
  
Create ForceModel fm  
  
fm.CentralBody = Earth  
fm.PointMasses = {Earth}  
  
Create Propagator prop  
  
prop.FM    = fm  
prop.Type = RungeKutta89  
  
Create GroundStation GS  
  
GS.CentralBody      = Earth  
GS.StateType        = Spherical  
GS.HorizonReference = Ellipsoid  
GS.Location1        = 0  
GS.Location2        = 0  
GS.Location3        = 0  
  
Create ContactLocator cl  
  
cl.Target          = sat  
cl.Filename        = 'Interval.report'  
cl.Observers       = {GS}  
cl.LightTimeDirection = Transmit  
cl.LeftJustified   = true  
cl.ReportPrecision = 6  
cl.IntervalStepSize = 60  
cl.ReportTimeFormat = 'UTCGregorian'
```

```
c1.ReportFormat      = 'AzimuthElevationRangeReport'  
  
BeginMissionSequence  
  
Propagate prop(sat) {sat.ElapsedSecs = 10800}
```

## References

1. SPICE Toolkit Documentation, [Aberration Corrections Required Reading](#)

## CoordinateSystem

An axis and origin pair

### Description

A **CoordinateSystem** in GMAT is defined as an origin and an axis system. You can select the origin of a **CoordinateSystem** from various points such as a **CelestialBody**, **Spacecraft**, **GroundStation**, or **LibrationPoint** to name a few. GMAT supports numerous axis systems such as J2000 equator, J2000 ecliptic, **ICRF**, **ITRF**, **Topocentric**, and **ObjectReferenced** among others. **CoordinateSystems** are tightly integrated into GMAT to enable you to define, report, and visualize data in coordinate systems relevant to your application. This resource cannot be modified in the Mission Sequence.

See Also: [Spacecraft](#), [Calculation Parameters](#), [OrbitView](#)

### Fields

Field	Description
<b>AlignmentVectorX</b>	The x component of the <b>AlignmentVector</b> expressed in the local frame (for example, expressed in the <b>LocalAlignedConstrained</b> frame). Used for the following axis systems: <b>LocalAlignedConstrained</b> .
<b>Data Type</b>	Real
<b>Allowed Values</b>	-# < Real < # (norm of <b>AlignmentVector</b> ) $\geq 1e-9$
<b>Access</b>	set
<b>Default Value</b>	1
<b>Units</b>	N/A
<b>Interfaces</b>	gui,script
<b>AlignmentVectorY</b>	The y component of the <b>AlignmentVector</b> expressed in the local frame (for example, expressed in the <b>LocalAlignedConstrained</b> frame). Used for the following axis systems: <b>LocalAlignedConstrained</b> .
<b>Data Type</b>	Real
<b>Allowed Values</b>	-# < Real < # (norm of <b>AlignmentVector</b> ) $\geq 1e-9$
<b>Access</b>	set
<b>Default Value</b>	0
<b>Units</b>	N/A
<b>Interfaces</b>	gui, script
<b>AlignmentVectorZ</b>	The z component of the <b>AlignmentVector</b> expressed in the local frame (for example, expressed in the <b>LocalAlignedConstrained</b> frame). Used for the following axis systems: <b>LocalAlignedConstrained</b> .
<b>Data Type</b>	Real
<b>Allowed Values</b>	-# < Real < # (norm of <b>AlignmentVector</b> ) $\geq 1e-9$
<b>Access</b>	set
<b>Default Value</b>	0
<b>Units</b>	N/A
<b>Interfaces</b>	gui,script

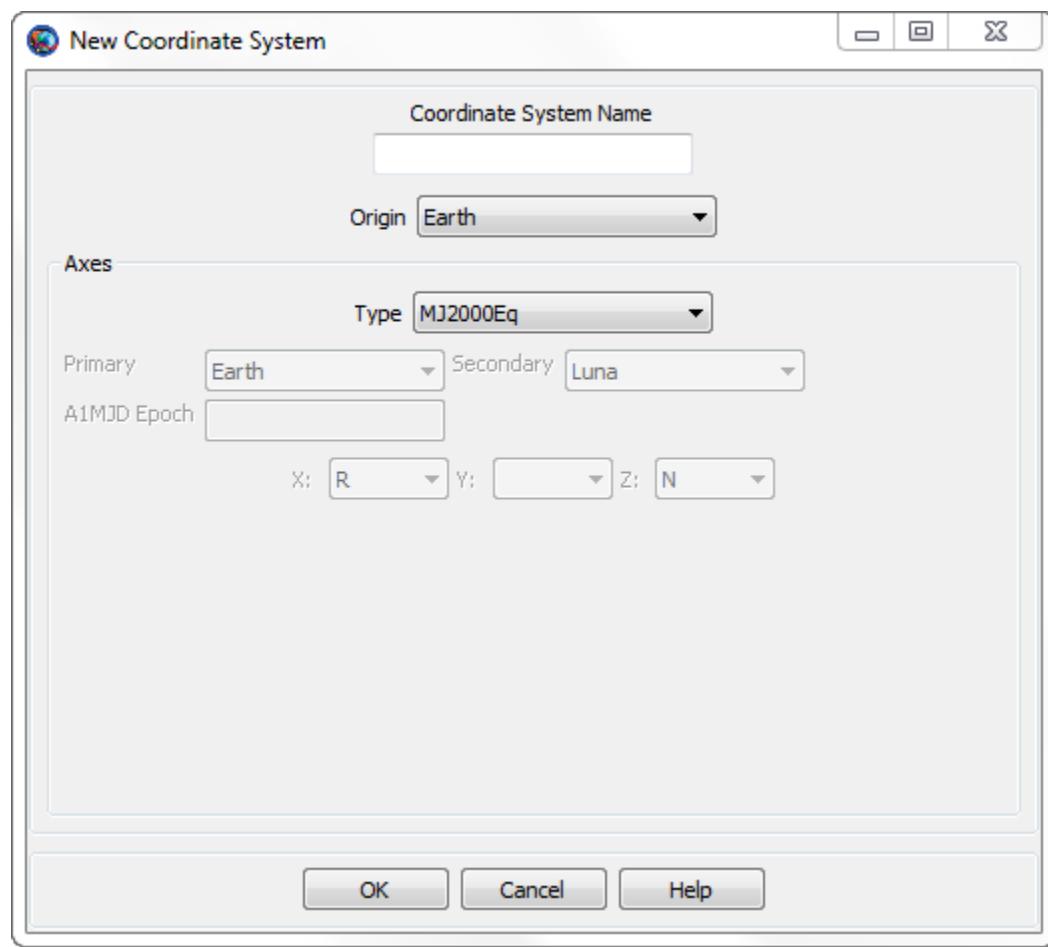
Field	Description
Axes	The axes of the <b>CoordinateSystem</b> .
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> MJ2000Eq, MJ2000Ec, ICRF, MODEq, MOD-Ec, TODEq, TODEc, MOEEq, MOEEc, TOEEq, TOEEc, TEME, ObjectReferenced, Equator, BodyFixed, BodyInertial, GSE, GSM, Topocentric, BodySpinSun</p> <p><b>Access</b> set</p> <p><b>Default Value</b> MJ2000Eq</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
Con- straintVec- torX	The x component of the <b>ConstraintVector</b> expressed in the local frame (for example, expressed in the <b>LocalAlignedConstrained</b> frame). Used for the following axis systems: <b>LocalAlignedConstrained</b> .
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> -# &lt; Real &lt; # (norm of <b>ConstraintVector</b>)=<math>1e-9</math></p> <p><b>Access</b> set</p> <p><b>Default Value</b> 0</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> gui,script</p>
Con- straintVec- torY	The y component of the <b>ConstraintVector</b> expressed in the local frame (for example, expressed in the <b>LocalAlignedConstrained</b> frame). Used for the following axis systems: <b>LocalAlignedConstrained</b> .
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> -# &lt; Real &lt; # (norm of <b>ConstraintVector</b>)=<math>1e-9</math></p> <p><b>Access</b> set</p> <p><b>Default Value</b> 0</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> gui,script</p>
Con- straintVec- torZ	The z component of the <b>ConstraintVector</b> expressed in the local frame (for example, expressed in the <b>LocalAlignedConstrained</b> frame). Used for the following axis systems: <b>LocalAlignedConstrained</b> .
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> -# &lt; Real &lt; # (norm of <b>ConstraintVector</b>)=<math>1e-9</math></p> <p><b>Access</b> set</p> <p><b>Default Value</b> 1</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> gui,script</p>

Field	Description		
<b>Con-</b> <b>straintRe-</b> <b>fer-</b> <b>enceVec-</b> <b>torX</b>	The x component of the <b>ConstraintReferenceVector</b> expressed in the <b>ConstraintCoordinateSystem</b> . Used for the following axis systems: <b>Lo-</b> <b>calAlignedConstrained</b> .		
	<b>Data Type</b>	Real	
	<b>Allowed Values</b>	-# < Real < # (norm of <b>ConstraintReferenceVec-</b> tor>= 1e-9)	
	<b>Access</b>	set	
	<b>Default Value</b>	0	
	<b>Units</b>	N/A	
	<b>Interfaces</b>	gui,script	
<b>Con-</b> <b>straintRe-</b> <b>fer-</b> <b>enceVec-</b> <b>torY</b>	The y component of the <b>ConstraintReferenceVector</b> expressed in the <b>ConstraintCoordinateSystem</b> . Used for the following axis systems: <b>Lo-</b> <b>calAlignedConstrained</b> .		
	<b>Data Type</b>	Real	
	<b>Allowed Values</b>	-# < Real < # (norm of <b>ConstraintReferenceVec-</b> tor>= 1e-9)	
	<b>Access</b>	set	
	<b>Default Value</b>	0	
	<b>Units</b>	N/A	
	<b>Interfaces</b>	gui,script	
<b>Con-</b> <b>straintRe-</b> <b>fer-</b> <b>enceVec-</b> <b>torZ</b>	The z component of the <b>ConstraintReferenceVector</b> expressed in the <b>ConstraintCoordinateSystem</b> . Used for the following axis systems: <b>Lo-</b> <b>calAlignedConstrained</b> .		
	<b>Data Type</b>	Real	
	<b>Allowed Values</b>	-# < Real < # (norm of <b>ConstraintReferenceVec-</b> tor>= 1e-9)	
	<b>Access</b>	set	
	<b>Default Value</b>	1	
	<b>Units</b>	N/A	
	<b>Interfaces</b>	gui,script	
<b>Con-</b> <b>straint Co-</b> <b>ordinate</b> <b>System</b>	The coordinate system for the <b>ConstraintReferenceVector</b> . Used for the following axis sytems: <b>LocalAlignedConstrained</b> .		
	<b>Data Type</b>	Resource	
	<b>Allowed Values</b>	<b>CoordinateSystem</b>	
	<b>Access</b>	set	
	<b>Default Value</b>	<b>EarthMJ2000Eq</b>	
	<b>Units</b>	N/A	
	<b>Interfaces</b>	gui,script	

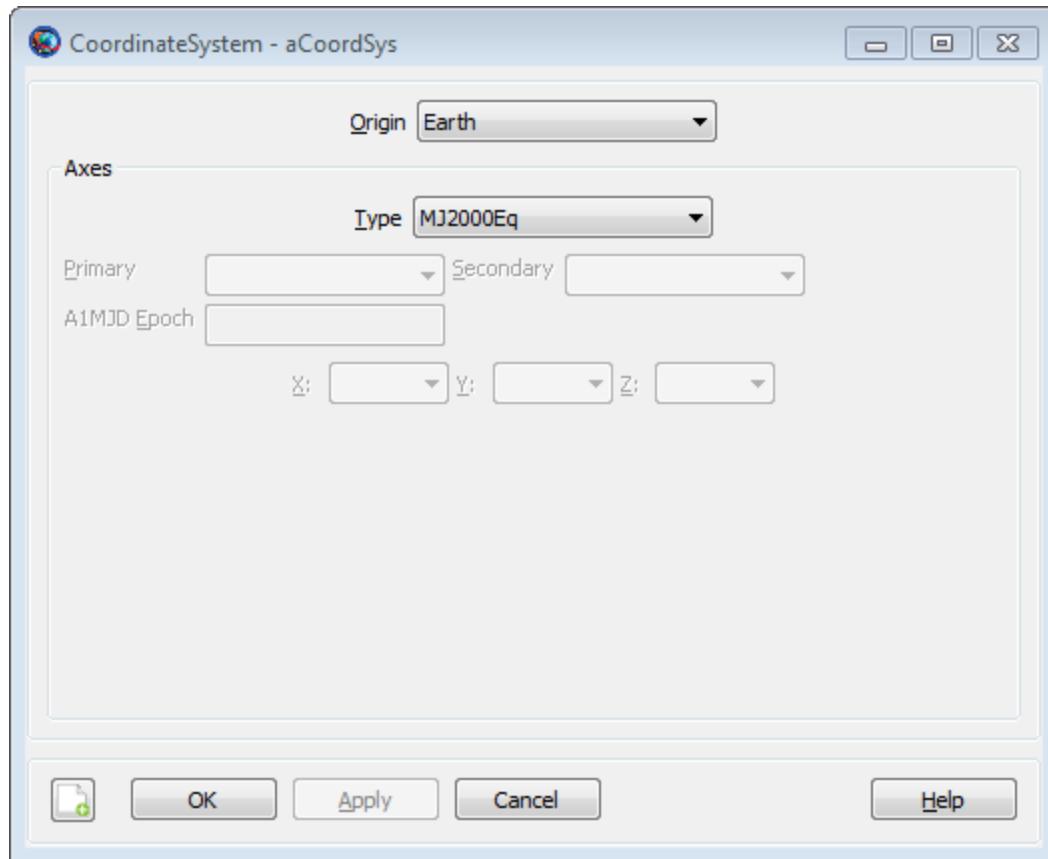
Field	Description
<b>Epoch</b>	The reference epoch for the <b>CoordinateSystem</b> . This field is only used for <b>TOE</b> and <b>MOE</b> axis types.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> A1 Modified Julian epoch.</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 21545</p> <p><b>Units</b> Modified Julian Date</p> <p><b>Interfaces</b> GUI, script</p>
<b>Origin</b>	The origin of the <b>CoordinateSystem</b> .
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> <b>CelestialBody</b>, <b>Spacecraft</b>, <b>LibrationPoint</b>, <b>Barycenter</b>, <b>SolarSystemBarycenter</b>, <b>GroundStation</b></p> <p><b>Access</b> set</p> <p><b>Default Value</b> <b>Earth</b></p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>Primary</b>	The primary body for an <b>ObjectReferenced</b> axis system. This field is only used if <b>Axes = ObjectReferenced</b> . See the discussion below for more information on how <b>Primary</b> and <b>Secondary</b> are used to compute <b>ObjectReferenced</b> axes.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> <b>CelestialBody</b>, <b>Spacecraft</b>, <b>LibrationPoint</b>, <b>Barycenter</b>, <b>SolarSystemBarycenter</b>, <b>GroundStation</b></p> <p><b>Access</b> set</p> <p><b>Default Value</b> <b>Earth</b></p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>ReferenceObject</b>	The reference object for a <b>LocalAlignedConstrained</b> axis system. The axes are computed such that the <b>AlignmentVector</b> in the body frame is aligned with the vector pointing from the <b>Origin</b> to the <b>ReferenceObject</b> .
	<p><b>Data Type</b> Resource</p> <p><b>Allowed Values</b> A Resource that has coordinates. For example: <b>CelestialBody</b>, <b>Spacecraft</b>, <b>LibrationPoint</b>, <b>Barycenter</b>, <b>SolarSystemBarycenter</b>, <b>GroundStation</b>.</p> <p><b>Access</b> set</p> <p><b>Default Value</b> <b>Luna</b></p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> gui,script</p>

Field	Description
<b>Se- condary</b>	The secondary body for an <b>ObjectReferenced</b> axis system. This field is only used if <b>Axes = ObjectReferenced</b> . See the discussion below for more information on how <b>Primary</b> and <b>Secondary</b> are used to compute <b>ObjectReferenced</b> axes.
<b>Data Type</b>	String
<b>Allowed Values</b>	CelestialBody, Spacecraft, LibrationPoint, Barycenter, SolarSystemBarycenter, GroundStation
<b>Access</b>	set
<b>Default Value</b>	Luna
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>XAxis</b>	The x-axis definition for an <b>ObjectReferenced</b> axis system. This field is only used if <b>Axes = ObjectReferenced</b> . See the discussion below for more information on how the axes are computed for <b>ObjectReferenced</b> axis systems.
<b>Data Type</b>	String
<b>Allowed Values</b>	R,V, N, -R, -V, -N, or empty
<b>Access</b>	set
<b>Default Value</b>	R
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>YAxis</b>	The y-axis definition for an <b>ObjectReferenced</b> axis system. This field is only used if <b>Axes = ObjectReferenced</b> . See the discussion below for more information on how the axes are computed for <b>ObjectReferenced</b> axis systems.
<b>Data Type</b>	String
<b>Allowed Values</b>	R,V, N, -R, -V,-N, or empty
<b>Access</b>	set
<b>Default Value</b>	No Default
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>Zaxis</b>	The z-axis for an <b>ObjectReferenced</b> axis system. This field is only used if <b>Axes = ObjectReferenced</b> . See the discussion below for more information on how the axes are computed for <b>ObjectReferenced</b> axis systems.
<b>Data Type</b>	String
<b>Allowed Values</b>	R,V, N, -R, -V,-N, or empty
<b>Access</b>	set
<b>Default Value</b>	N
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

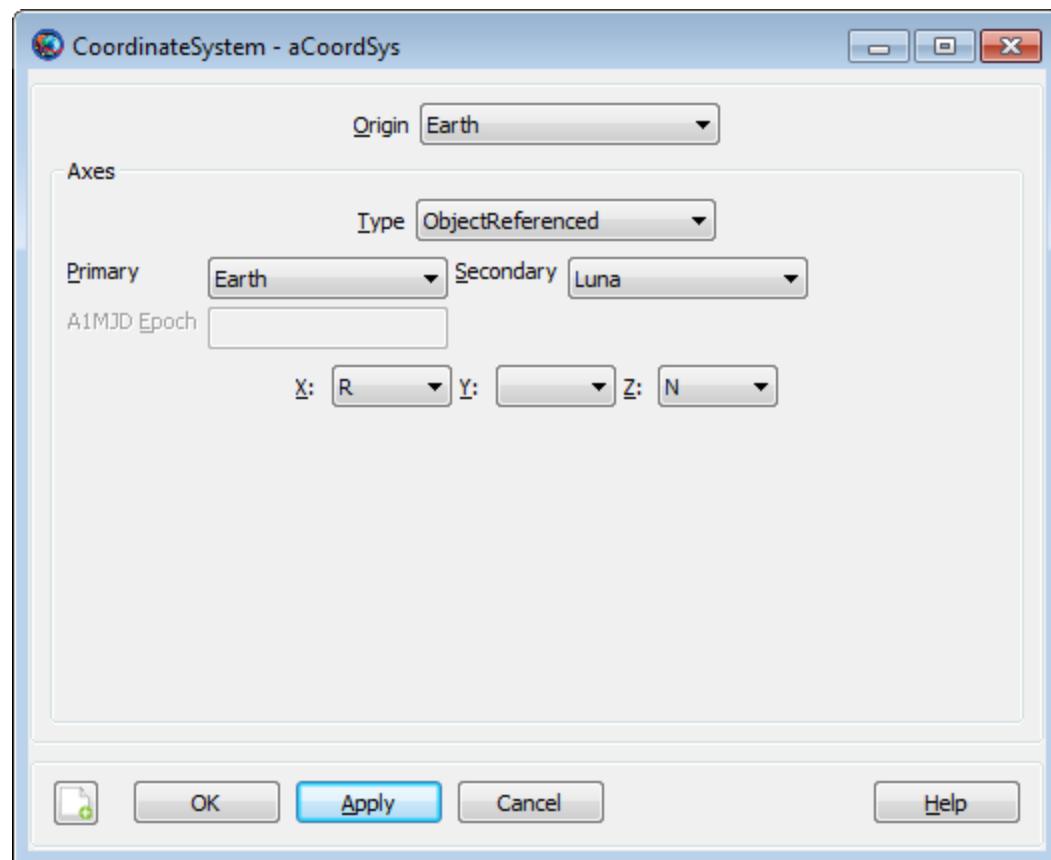
## GUI



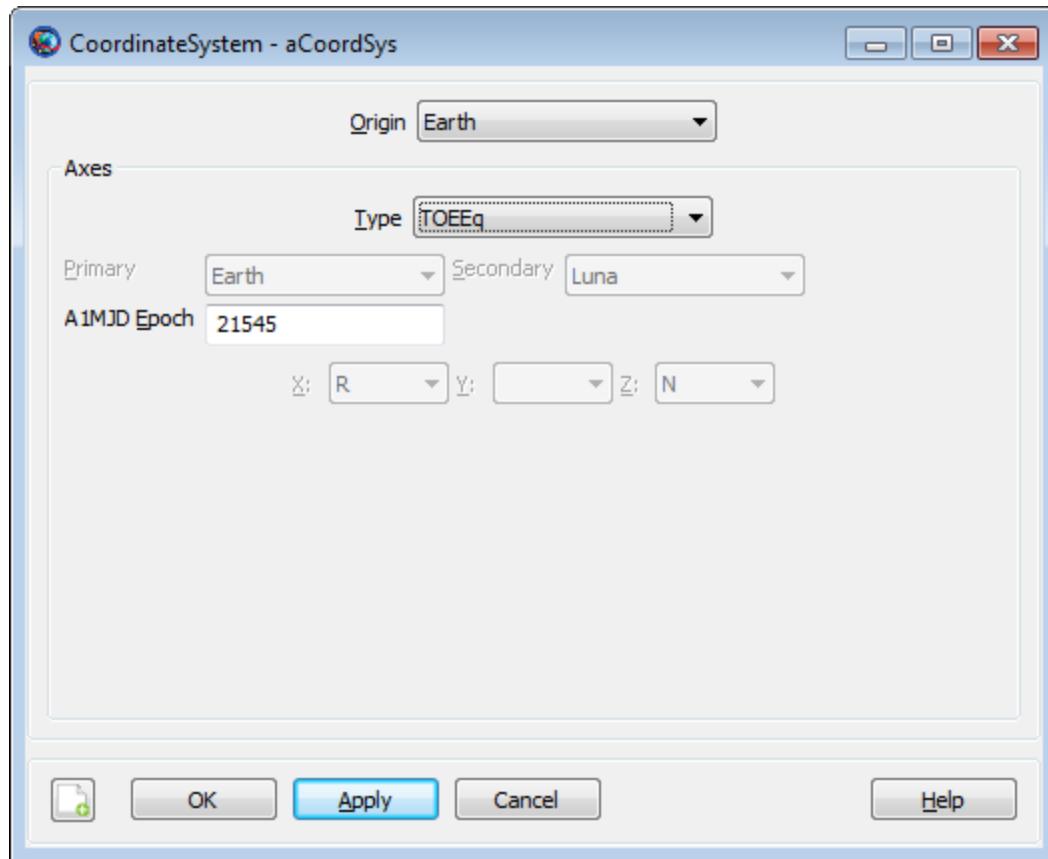
The **New Coordinate System** dialog box shown above appears when you add a new coordinate system in the **Resource Tree**. You provide a name for the new **CoordinateSystem** in the **Coordinate System Name** box and configure the **CoordinateSystem** by selecting the **Origin** and **Axes** types along with other settings. Some settings, such as **Primary** and **Secondary**, are only active for particular **Axes** types and those dependencies are described below.



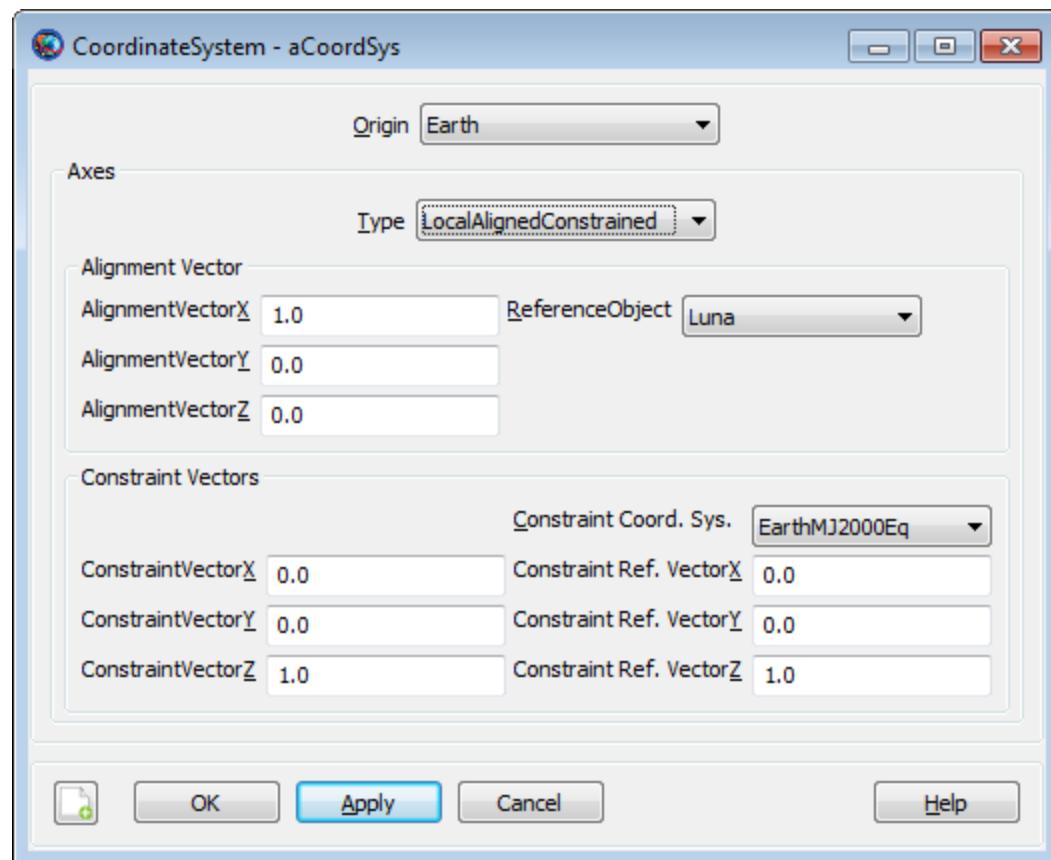
When editing an existing **CoordinateSystem**, you use the **CoordinateSystem** dialog box. The default configuration is shown above.



If you select **ObjectReferenced** for the **Axes** type, then the **Primary**, **Secondary**, **X**, **Y**, and **Z** fields are activated. You can use the **ObjectReferenced** axis system to define coordinates based on the motion of two space objects such as **Spacecraft**, **Celestial-Bodies**, or **Barycenters** to name a few. See the discussion below for a detailed definition of the **ObjectReferenced** axis system.



If you select **TOEEq**, **TOEEc**, **MOEEq**, or **MOEEc** as the axis type, then the **A1MJD Epoch** field is activated. Use the **A1MJD Epoch** field to define the reference epoch of the coordinate system.



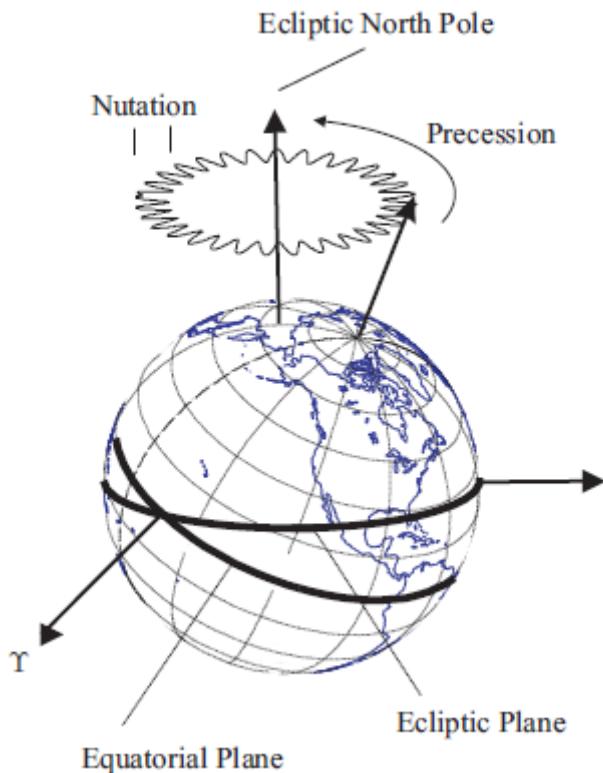
If you select **LocalAlignedConstrained** as the axes **Type**, then **CoordinateSystem** dialog displays the fields illustrated above for configuring the axes.

## Remarks

### Computation of J2000-Based Axes using IAU76/FK5 Reduction

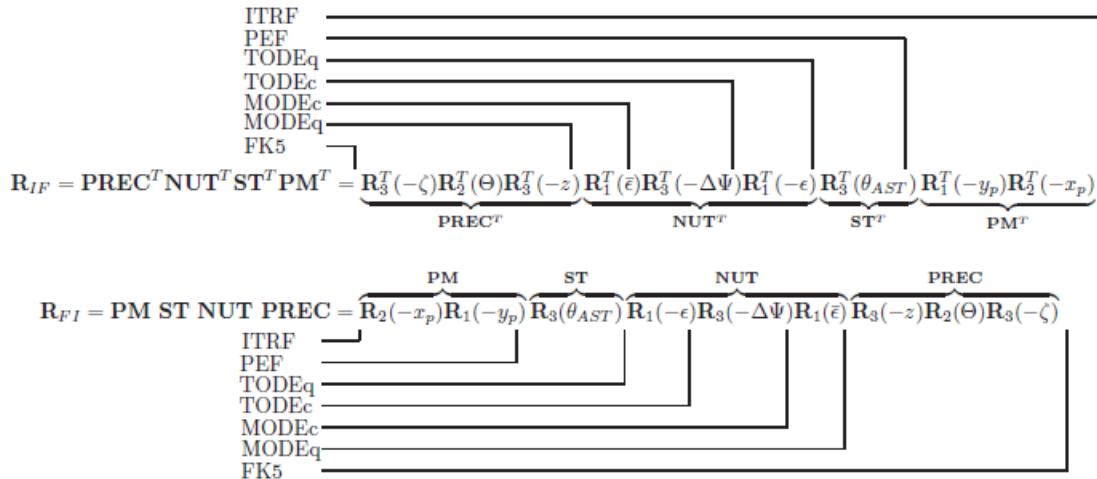
FK5 reduction is the transformation that rotates a vector expressed in the **MJ2000Eq** system to the **EarthFixed CoordinateSystem**. There are many coordinate systems that are intermediate rotations in FK5 reduction and this section describes how the following axes types are computed: **MJ2000Eq**, **MJ2000Ec**, **EarthFixed**, **MODEq**, **MODEc**, **TODEq**, **TODEc**, **MODEq**, **MODEc**, **TODEq**, and **TODEc** axes systems.

The time varying orientation of the Earth is complex due to interactions between the Earth and its external environment (the Sun and Moon and Planets) and internal dynamics. The orientation cannot currently be modelled to the accuracy required by many space applications and FK5 reduction is a combination of dynamical modeling along with daily corrections from empirical observations. The figure below illustrates components of motion of the Earth with respect to inertial space. The primary components of the motion of the Earth with respect to inertial space are Precession, Nutation, Sidereal time and, Polar Motion.



The principal moment of inertia is defined as the Celestial Ephemeris Pole. Due to the fact that Earth's mass distribution changes with time, the Celestial Ephemeris Pole is not constant with respect to the Earth's surface. Precession is defined as the coning motion that the Celestial Ephemeris Pole makes around the ecliptic north pole. The other principal component of the motion of the Celestial Ephemeris Pole is called nutation and is the oscillation in the angle between the Celestial Ephemeris Pole and the north ecliptic pole. The theory of Precession and Nutation come from dynamical models of the Earth's motion. The Sidereal time is the rotation of the Earth about the Celestial Ephemeris Pole. The sidereal time model is a combination of theory and observation. The Earth's spin axis direction is not constant with respect to the Earth's crust and its motion is called Polar Motion. A portion of polar motion is due to complicated dynamics, and a portion is due to unmodelled errors in nutation. Polar motion is determined from observation.

The True of Date (TOD) systems and Mean of Date (MOD) systems are intermediate coordinate systems in FK5 reduction and are commonly used in analysis. The details of the computations are contained in the GMAT mathematical specification and the figure below is included here for summary purposes. The following abbreviations are used in the figure. PM: Polar Motion, ST: Sideral Time, NUT: Nutation, PREC: Precession, ITRF: International Terrestrial Reference Frame (Earth Fixed), PEF: Pseudo Earth Fixed, TOD-Eq: True of Date Equator, TODEc: True of Date Ecliptic, MODEc: Mean of Date Ecliptic, MODEq: Mean of Date Equator, FK5: J2000 Equatorial Inertial (IAU-1976/1980).



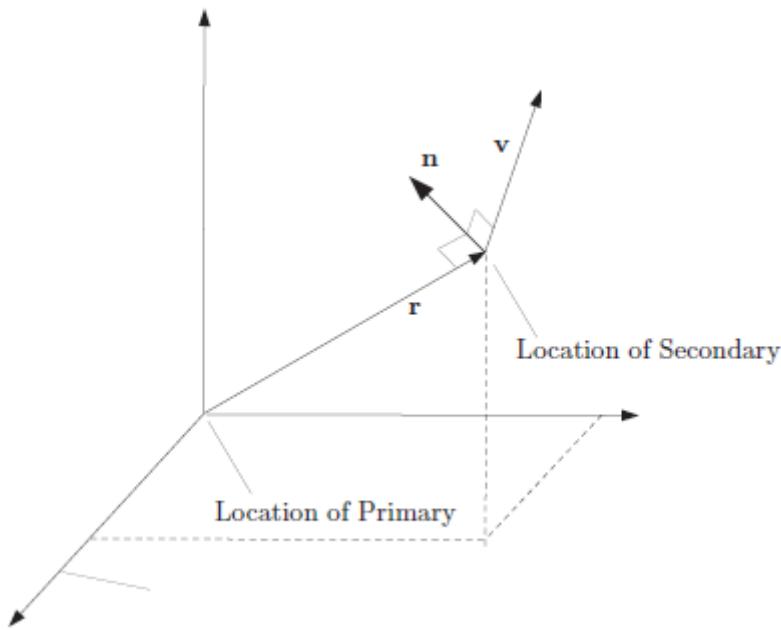
### Computation of ICRF and ITRF Axes using IAU2000 Conventions

The computation for the International Celestial Reference Frame (**ICRF**) and the International Terrestrial Reference Frame (ITRF) are computed using the IAU 2000A theory with the 2006 update to precession. GMAT uses the Celestial Intermediate Origin (CIO) method of transformation which avoids issues associated with precession and nutation. In the CIO model, the Celestial Intermediate Pole unit vector is modeled using the variables X and S and the CIO locator, s. For performance reasons, GMAT interpolates X, Y, and s, from precomputed values stored in the file named **ICRF\_Table.txt** distributed with GMAT.

GMAT models the rotation from **ICRF** to **MJ200Eq** by rotating through the **EarthFixed** frame which is identical for both the old (1976) and new (2000) theories. For performance reasons, the conversion from **ICRF** to **MJ2000Eq** is interpolated from pre-computed values of the Euler axis and angle between those frames. Note that GMAT does not currently support the IAU2000 body fixed frame for Earth and that model will be included in a future release.

### Computation of ObjectReference Axis System

An **ObjectReferenced** axis system is defined by the motion of one object with respect to another object. The figure below defines the six principal directions of an **Object Referenced** axis system. One is the relative position of the secondary object with respect to the primary object, denoted by  $\mathbf{r}$ , expressed in the inertial frame. The second is the relative velocity, denoted here by  $\mathbf{v}$ , of the secondary object with respect to the primary, expressed in the inertial frame. The third direction is the vector normal to the direction of motion which is denoted by  $\mathbf{n}$  and is calculated using  $\mathbf{n} = \mathbf{r} \times \mathbf{v}$ . The remaining three directions are the negative of the first three yielding the complete set:  $\{\mathbf{R}, -\mathbf{R}, \mathbf{V}, -\mathbf{V}, \mathbf{N}, -\mathbf{N}\}$ .



You define an **Object Referenced** axis system by defining two axes from the three available [X, Y, and Z] using the six available options {R,-R, V,-V, N,-N}. Given two directions, GMAT constructs an orthogonal, right-handed **CoordinateSystem**. For example, if you choose the x-axis to be in the direction of R and the z-axis to be in the direction of N, GMAT completes the right-handed set by setting the y-axis in the direction of NxR. If you choose permutations that result in a non-orthogonal or left-handed **CoordinateSystem**, GMAT will throw an error message.



### Warning

GMAT currently assumes that terms involving the cross and dot product of acceleration are zero when computing **ObjectReferenced** rotation matrices.

## Overview of Built-in Coordinate Systems

Name	Origin	Axes	Description
<b>EarthMJ2000Eq</b>	<b>Earth</b>	<b>MJ2000Eq</b>	An Earth equator inertial system based on IAU-1976/FK5 theory with 1980 update to nutation.
<b>EarthMJ2000Ec</b>	<b>Earth</b>	<b>MJ2000Ec</b>	An Earth ecliptic inertial system based on IAU-1976/FK5 theory with 1980 update to nutation.
<b>EarthFixed</b>	<b>Earth</b>	<b>Body-Fixed</b>	An Earth fixed system based on IAU-1976/FK5 theory with 1980 update to nutation.
<b>EarthICRF</b>	<b>Earth</b>	<b>ICRF</b>	An Earth equator inertial system based on IAU-2000 theory with 2006 update to precession.

## Description of Axes Types

Axes Name	Origin	Base Type	Description
	Limi-	ta-	tions
<b>BodyFixed</b>	Celestial Body or Spacecraft	IAU-1976 FK5	<p>The <b>BodyFixed</b> axis system is referenced to the body equator and the prime meridian of the body. See the <a href="#">Remarks for Celestial body models</a> for axis system definitions for celestial bodies.</p> <p>When <b>Origin</b> is a <b>Spacecraft</b>, the axes are computed using the <b>Spacecraft</b>'s attitude model. Note: not all attitude models compute body rates. In the case that body rates are not available on a spacecraft, a request for velocity transformations using a <b>BodyFixed</b> axis system will result in an error.</p>
<b>BodyInertial</b>	Celestial Body	IAU-1976 FK5	An inertial system referenced to the equator ( at the J2000 epoch ) of the celestial body selected as the origin of the <b>CoordinateSystem</b> . Because the <b>BodyInertial</b> axis system uses different theories for different bodies, the following definitions describe only the nominal axis configurations. The x-axis points along the line formed by the intersection of the bodies equator and earth's mean equator at J2000. The z-axis points along the body's spin axis direction at the J2000 epoch. The y-axis completes the right-handed set. For Earth, the <b>BodyInertial</b> axis system is identical to the <b>MJ2000Eq</b> system. See the <a href="#">Remarks for Celestial body models</a> for axis system definitions for all other celestial bodies.
<b>BodySpinSun</b>	Celestial Body	IAU-1976 FK5	A celestial body spin-axis-referenced system. The x-axis points from the celestial body to the Sun. The y-axis is computed as the cross product of the x-axis and the body's spin axis. The z-axis completes the right-handed set.
<b>Equator</b>	Celestial Body	IAU-1976 FK5	A true of date equator axis system for the celestial body selected as the origin. The <b>Equator</b> system is defined by the body's equatorial plane and its intersection with the ecliptic plane, at the current epoch. The current epoch is defined by the context of use and usually comes from the spacecraft or graphics epoch. See the <a href="#">Remarks for Celestial body models</a> for axis system definitions for celestial bodies.

Axes Name	Origin	Base Type	Description
		Limi- ta- tions	
<b>GSE</b>	None	IAU-1976 FK5	The Geocentric Solar Ecliptic system. The x-axis points from Earth to the Sun. The z-axis is defined as the cross product $R \times V$ where R and V are earth's position and velocity with respect to the sun respectively. The y-axis completes the right-handed set. The <b>GSE</b> axes are computed using the relative motion of the Earth and Sun even if the origin is not Earth.
<b>GSM</b>	None	IAU-1976 FK5	The Geocentric Solar Magnetic system. The x-axis points from Earth to the Sun. The z-axis is defined to be orthogonal to the x-axis and lies in the plane of the x-axis and Earth's magnetic dipole vector. The y-axis completes the right-handed set. The <b>GSM</b> axes are computed using the relative motion of the Earth and Sun even if the origin is not Earth.
<b>ICRF</b>	None	IAU-2000	An inertial coordinate system. The axes are close to the mean Earth equator and pole at the J2000 epoch, and at the Earth's surface, the RSS difference between vectors expressed in <b>MJ2000Eq</b> and <b>ICRF</b> is less than 1 m. Note that since <b>MJ2000Eq</b> and <b>ICRF</b> are imperfect realizations of inertial systems, the transformation between them is time varying. This axis system is computed using IAU-2000A theory with 2006 update for precession.

Axes Name	Origin	Base Type	Description
	Limi- ta- tions		
<b>LocalAligned-Constrained</b>	None	IAU-1976 FK5	The <b>LocalAlignedConstrained</b> axis system is an aligned constrained system based on the position of the <b>ReferenceObject</b> with respect to the <b>Origin</b> and is computed using the well known Triad algorithm. The axes are computed such that the <b>AlignmentVector</b> , defined as the components of the alignment vector expressed in the <b>LocalAligned-Constrained</b> system, is aligned with the position of the <b>ReferenceBody</b> w/r/t the origin. The rotation about the <b>AlignmentVector</b> is resolved by minimizing the angle between the <b>ConstraintVector</b> , defined as the constraint vector expressed in the <b>LocalAlignedConstrained</b> system, and the <b>ConstraintReferenceVector</b> , defined as the constraint reference vector expressed in the <b>ConstraintCoordinateSystem</b> . The alignment vectors and the constraint vectors cannot have zero length. Similarly, the cross products of the constraint vector and alignment vector cannot have zero length.
<b>MJ2000Ec</b>	None	IAU-1976 FK5	An inertial coordinate system. The x-axis points along the line formed by the intersection of the Earth's mean equator and the mean ecliptic plane at the J2000 epoch. The z-axis is normal to the mean ecliptic plane at the J2000 Epoch and the y-axis completes the right-handed set. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
<b>MJ2000Eq</b>	None	IAU-1976 FK5	An inertial coordinate system. The nominal x-axis points along the line formed by the intersection of the Earth's mean equatorial plane and the mean ecliptic plane (at the J2000 epoch), in the direction of Aries. The z-axis is normal to the Earth's mean equator at the J2000 epoch and the y-axis completes the right-handed system. The mean planes of the ecliptic and equator, at the Jff2000 epoch, are computed using IAU-1976/FK5 theory with 1980 update for nutation.

Axes Name	Origin	Base Type	Description
	Limi- ta- tions		
<b>MODEc</b>	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to the mean ecliptic at the current epoch. The current epoch is defined by the context of use and usually comes from the spacecraft or graphics epoch. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
<b>MODEq</b>	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to Earth's mean equator at the current epoch. The current epoch is defined by the context of use and usually comes from the spacecraft or graphics epoch. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
<b>MOEEc</b>	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to the mean ecliptic at the reference epoch. The reference epoch is defined on the <b>CoordinateSystem</b> object. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
<b>MOEEq</b>	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to Earth's mean equator at the reference epoch. The reference epoch is defined on the <b>CoordinateSystem</b> object. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
<b>ObjectRefer- enced</b>	None	IAU-1976 FK5	An <b>ObjectReferenced</b> system is a <b>CoordinateSystem</b> whose axes are defined by the motion of one object with respect to another object. See the discussion above for a detailed description of the <b>ObjectReferenced</b> axis system.
<b>TEME</b>	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to Earth's true equator and mean equinox at the current epoch. The current epoch is defined by the context of use and usually comes from the spacecraft or graphics epoch. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation. TEME axes can only be used with an Earth-centered coordinate system.

Axes Name	Origin	Base Type	Description
	Limi- ta- tions		
<b>TODEc</b>	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to Earth's true ecliptic at the current epoch. The current epoch is defined by the context of use and usually comes from the spacecraft or graphics epoch. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
<b>TOEEc</b>	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to the true ecliptic at the reference epoch. The reference epoch is defined on the <b>CoordinateSystem</b> object. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
<b>TODEq</b>	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to Earth's true equator at the current epoch. The current epoch is defined by the context of use and usually comes from the spacecraft or graphics epoch. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
<b>TOEEq</b>	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to Earth's true equator at the reference epoch. The reference epoch is defined on the <b>CoordinateSystem</b> object. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
<b>Topocentric</b>	Earth	IAU-1976 FK5	A <b>GroundStation</b> -based coordinate system. The y-axis points due East and the z-axis is normal to the local horizon. The x-axis completes the right handed set.

## Examples

Define a **Spacecraft**'s state in **EarthFixed** coordinates.

```
Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = EarthFixed
aSpacecraft.X = 7100
aSpacecraft.Y = 0
aSpacecraft.Z = 1300
aSpacecraft.VX = 0
aSpacecraft.VY = 7.35
aSpacecraft.VZ = 1
```

Report a **Spacecraft**'s state in **GroundStation Topocentric** coordinates.

```
Create Spacecraft aSat
```

```
Create Propagator aProp
Create GroundStation aStation

Create CoordinateSystem stationTopo
stationTopo.Origin = aStation
stationTopo.Axes   = Topocentric

Create ReportFile aReport
aReport.Filename = 'ReportFile1.txt'
aReport.Add = {aSat.stationTopo.X aSat.stationTopo.Y aSat.stationTopo.Z ...
               aSat.stationTopo.VX aSat.stationTopo.VY aSat.stationTopo.VZ}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedSecs = 8640.0}
```

View a trajectory in an **ObjectReferenced**, rotating-LibrationPoint system.

```
% Create the Earth-Moon Barycenter and Libration Point
Create Barycenter EarthMoonBary
EarthMoonBary.BodyNames = {Earth,Luna};

Create LibrationPoint SunEarthMoonL1
SunEarthMoonL1.Primary    = Sun;
SunEarthMoonL1.Secondary = EarthMoonBary
SunEarthMoonL1.Point      = L1;

% Create the coordinate system
Create CoordinateSystem RotatingSEML1Coord
RotatingSEML1Coord.Origin    = SunEarthMoonL1
RotatingSEML1Coord.Axes      = ObjectReferenced
RotatingSEML1Coord.XAxis    = R
RotatingSEML1Coord.ZAxis    = N
RotatingSEML1Coord.Primary  = Sun
RotatingSEML1Coord.Secondary = EarthMoonBary

% Create the spacecraft and propagator
Create Spacecraft aSpacecraft
aSpacecraft.DateFormat      = UTCGregorian
aSpacecraft.Epoch           = '09 Dec 2005 13:00:00.000'
aSpacecraft.CoordinateSystem = RotatingSEML1Coord
aSpacecraft.X    = -32197.88223741966
aSpacecraft.Y    = 211529.1500044117
aSpacecraft.Z    = 44708.57017366499
aSpacecraft.VX   = 0.03209516489451751
aSpacecraft.VY   = 0.06100386504053736
aSpacecraft.VZ   = 0.0550442738917212

Create Propagator aPropagator
```

```
aPropagator.FM          = aForceModel
aPropagator.MaxStep = 86400
Create ForceModel aForceModel
aForceModel.PointMasses = {Earth,Sun,Luna}

% Create a 3-D graphic
Create OrbitView anOrbitView
anOrbitView.Add          = {aSpacecraft, Earth, Sun, Luna}
anOrbitView.CoordinateSystem = RotatingSEML1Coord
anOrbitView.ViewPointReference = SunEarthMoonL1
anOrbitView.ViewPointVector   = [-1500000 0 0 ]
anOrbitView.ViewDirection     = SunEarthMoonL1
anOrbitView.ViewUpCoordinateSystem = RotatingSEML1Coord
anOrbitView.Axes            = Off
anOrbitView.XYPlane         = Off

BeginMissionSequence

Propagate aPropagator(aSpacecraft, {aSpacecraft.ElapsedDays = 180})
```

## EclipseLocator

A **Spacecraft** eclipse event locator

### Description



#### Note

**EclipseLocator** is a SPICE-based subsystem that uses a parallel configuration for the solar system and celestial bodies from other GMAT components. For precision applications, care must be taken to ensure that both configurations are consistent. See [Remarks](#) for details.

An **EclipseLocator** is an event locator used to find solar eclipse events as seen by a **Spacecraft**. By default, an **EclipseLocator** generates a text event report listing the beginning and ending times of each event, along with the duration, eclipsing body, shadow type, and information about simultaneous and adjacent nested events. Eclipse location can be performed over the entire propagation interval or over a subinterval, and can optionally adjust for light-time delay and stellar aberration.

Eclipse location can be performed with one or more **CelestialBody** resources as eclipsing (or occulting) bodies. Any configured **CelestialBody** can be used as an occulting body, including user-defined ones. Any type of eclipse can be found, including total (umbra), partial (penumbra), and annular (antumbra). All selected occulting bodies are searched using the same selection for eclipse types, search interval, and search options; to customize the options per body, use multiple **EclipseLocator** resources.

By default, the **EclipseLocator** searches the entire interval of propagation of the **Spacecraft**. To search a custom interval, set **UseEntireInterval** to False and set **InitialEpoch** and **FinalEpoch** accordingly. Note that these epochs are assumed to be **Spacecraft** epochs, and so must be valid and within the **Spacecraft** ephemeris interval. If they fall outside the propagation interval of the **Spacecraft**, GMAT will display an error.

The contact locator can optionally adjust for both light-time delay and stellar aberration, though stellar aberration currently has no effect.

The event search is performed at a fixed step through the interval. You can control the step size (in seconds) by setting the **StepSize** field. An appropriate choice for step size is no greater than the duration of the minimum event you wish to find, or the minimum gap between events you want to resolve, whichever is smaller. See [Remarks](#) for details.

GMAT uses the SPICE library for the fundamental event location algorithm. As such, all celestial body data is loaded from SPICE kernels for this subsystem, rather than GMAT's own **CelestialBody** shape and orientation configuration. See [Remarks](#) for details.

Unless otherwise mentioned, **EclipseLocator** fields cannot be set in the mission sequence.

See Also: [CelestialBody](#), [Spacecraft](#), [ContactLocator](#), [FindEvents](#)

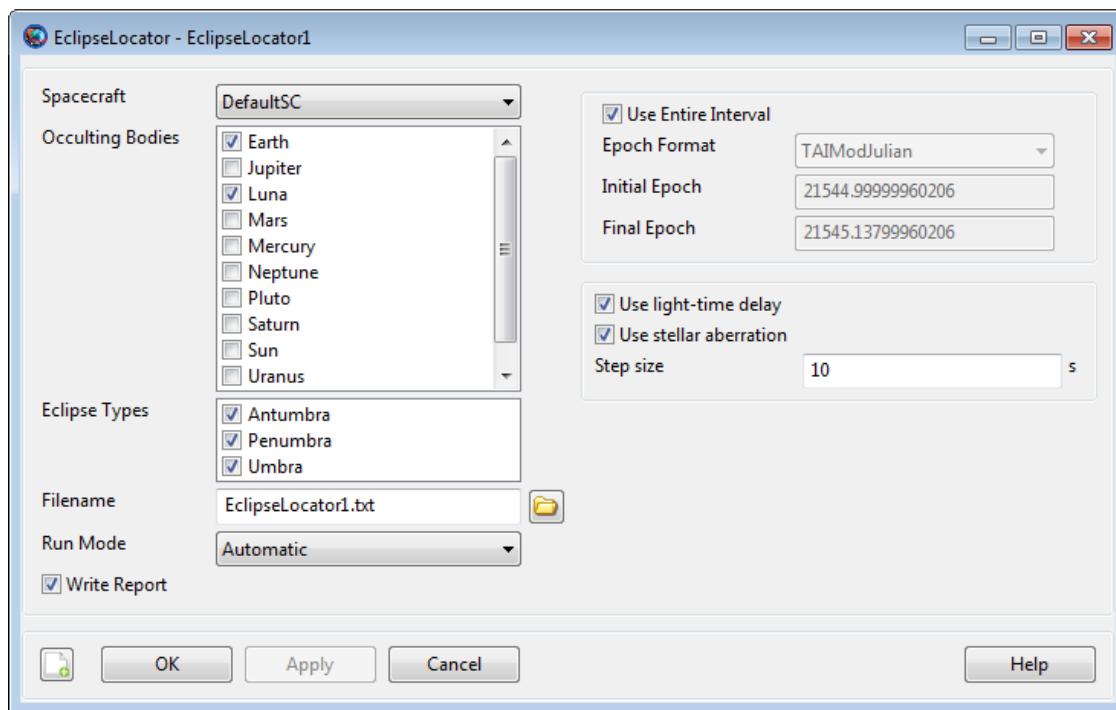
## Fields

Field	Description												
<b>EclipseTypes</b>	<p>Types of eclipses (shadows) to search for. May be Umbra (total eclipses), Penumbra (partial eclipses), or Antumbra (annular eclipses).</p> <table> <tr> <td><b>Data Type</b></td><td>Enumeration array</td></tr> <tr> <td><b>Allowed Values</b></td><td>Antumbra, Penumbra, Umbra</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>{Antumbra, Penumbra, Umbra}</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Enumeration array	<b>Allowed Values</b>	Antumbra, Penumbra, Umbra	<b>Access</b>	set	<b>Default Value</b>	{Antumbra, Penumbra, Umbra}	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Enumeration array												
<b>Allowed Values</b>	Antumbra, Penumbra, Umbra												
<b>Access</b>	set												
<b>Default Value</b>	{Antumbra, Penumbra, Umbra}												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>Filename</b>	<p>Name and path of the eclipse report file. This field can be set in the mission sequence.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Valid file path</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>'EclipseLocator.txt'</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Valid file path	<b>Access</b>	set	<b>Default Value</b>	'EclipseLocator.txt'	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Valid file path												
<b>Access</b>	set												
<b>Default Value</b>	'EclipseLocator.txt'												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>FinalEpoch</b>	<p>Last epoch to search for eclipses, in the format specified by <b>InputEpochFormat</b>. The epoch must be a valid epoch in the <b>Spacecraft</b> ephemeris interval. This field can be set in the mission sequence.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Valid epoch in available spacecraft ephemeris</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>'21545.138'</td></tr> <tr> <td><b>Units</b></td><td>Modified Julian epoch formats: days</td></tr> <tr> <td><b>Interfaces</b></td><td>Gregorian epoch formats: N/A GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Valid epoch in available spacecraft ephemeris	<b>Access</b>	set	<b>Default Value</b>	'21545.138'	<b>Units</b>	Modified Julian epoch formats: days	<b>Interfaces</b>	Gregorian epoch formats: N/A GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Valid epoch in available spacecraft ephemeris												
<b>Access</b>	set												
<b>Default Value</b>	'21545.138'												
<b>Units</b>	Modified Julian epoch formats: days												
<b>Interfaces</b>	Gregorian epoch formats: N/A GUI, script												

Field	Description												
<b>InitialEpoch</b>	<p>First epoch to search for eclipses, in the format specified by <b>InputEpochFormat</b>. The epoch must be a valid epoch in the <b>Spacecraft</b> ephemeris interval. This field can be set in the mission sequence.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Valid epoch in available spacecraft ephemeris</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>'21545'</td></tr> <tr> <td><b>Units</b></td><td>Modified Julian epoch formats: days</td></tr> <tr> <td><b>Interfaces</b></td><td>Gregorian epoch formats: N/A GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Valid epoch in available spacecraft ephemeris	<b>Access</b>	set	<b>Default Value</b>	'21545'	<b>Units</b>	Modified Julian epoch formats: days	<b>Interfaces</b>	Gregorian epoch formats: N/A GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Valid epoch in available spacecraft ephemeris												
<b>Access</b>	set												
<b>Default Value</b>	'21545'												
<b>Units</b>	Modified Julian epoch formats: days												
<b>Interfaces</b>	Gregorian epoch formats: N/A GUI, script												
<b>OccultingBodies</b>	<p>List of occulting bodies to search for eclipses. Can be any number of GMAT <b>CelestialBody</b>-type resources, such as <b>Planet</b>, <b>Moon</b>, <b>Asteroid</b>, etc. Note that an occulting body must have a mass (e.g. not <b>LibrationPoint</b> or <b>Barycenter</b>).</p> <table> <tr> <td><b>Data Type</b></td><td>List of <b>CelestialBody</b> resources (e.g. <b>Planet</b>, <b>Asteroid</b>, <b>Moon</b>, etc.)</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any existing <b>CelestialBody</b>-class resources</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>Empty list</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	List of <b>CelestialBody</b> resources (e.g. <b>Planet</b> , <b>Asteroid</b> , <b>Moon</b> , etc.)	<b>Allowed Values</b>	Any existing <b>CelestialBody</b> -class resources	<b>Access</b>	set	<b>Default Value</b>	Empty list	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	List of <b>CelestialBody</b> resources (e.g. <b>Planet</b> , <b>Asteroid</b> , <b>Moon</b> , etc.)												
<b>Allowed Values</b>	Any existing <b>CelestialBody</b> -class resources												
<b>Access</b>	set												
<b>Default Value</b>	Empty list												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>RunMode</b>	<p>Mode of event location execution. 'Automatic' triggers event location to occur automatically at the end of the run. 'Manual' limits execution only to the <b>FindEvents</b> command. 'Disabled' turns off event location entirely.</p> <table> <tr> <td><b>Data Type</b></td><td>Enumeration</td></tr> <tr> <td><b>Allowed Values</b></td><td>Automatic, Manual, Disabled</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>'Automatic'</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Enumeration	<b>Allowed Values</b>	Automatic, Manual, Disabled	<b>Access</b>	set	<b>Default Value</b>	'Automatic'	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Enumeration												
<b>Allowed Values</b>	Automatic, Manual, Disabled												
<b>Access</b>	set												
<b>Default Value</b>	'Automatic'												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>Spacecraft</b>	<p>The observing <b>Spacecraft</b> resource to search for eclipses.</p> <table> <tr> <td><b>Data Type</b></td><td><b>Spacecraft</b> resource</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any existing <b>Spacecraft</b> resource</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>First configured <b>Spacecraft</b> resource</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	<b>Spacecraft</b> resource	<b>Allowed Values</b>	Any existing <b>Spacecraft</b> resource	<b>Access</b>	set	<b>Default Value</b>	First configured <b>Spacecraft</b> resource	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
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<b>Access</b>	set												
<b>Default Value</b>	First configured <b>Spacecraft</b> resource												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

Field	Description												
<b>StepSize</b>	<p>Step size of event locator. See <a href="#">Remarks</a> for discussion of appropriate values.</p> <table> <tr> <td data-bbox="649 344 878 382"><b>Data Type</b></td><td data-bbox="926 344 992 382">Real</td></tr> <tr> <td data-bbox="649 388 878 426"><b>Allowed Values</b></td><td data-bbox="926 388 1106 426"><b>StepSize</b> &gt; 0</td></tr> <tr> <td data-bbox="649 432 878 470"><b>Access</b></td><td data-bbox="926 432 972 470">set</td></tr> <tr> <td data-bbox="649 477 878 515"><b>Default Value</b></td><td data-bbox="926 477 972 515">10</td></tr> <tr> <td data-bbox="649 521 878 559"><b>Units</b></td><td data-bbox="926 521 953 559">s</td></tr> <tr> <td data-bbox="649 566 878 604"><b>Interfaces</b></td><td data-bbox="926 566 1073 604">GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	<b>StepSize</b> > 0	<b>Access</b>	set	<b>Default Value</b>	10	<b>Units</b>	s	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	<b>StepSize</b> > 0												
<b>Access</b>	set												
<b>Default Value</b>	10												
<b>Units</b>	s												
<b>Interfaces</b>	GUI, script												
<b>UseEntireInterval</b>	<p>Search the entire available <b>Target</b> ephemeris interval. This field can be set in the mission sequence.</p> <table> <tr> <td data-bbox="649 671 878 709"><b>Data Type</b></td><td data-bbox="926 671 1037 709">Boolean</td></tr> <tr> <td data-bbox="649 715 878 753"><b>Allowed Values</b></td><td data-bbox="926 715 1067 753">true, false</td></tr> <tr> <td data-bbox="649 760 878 798"><b>Access</b></td><td data-bbox="926 760 972 798">set</td></tr> <tr> <td data-bbox="649 804 878 842"><b>Default Value</b></td><td data-bbox="926 804 985 842">true</td></tr> <tr> <td data-bbox="649 849 878 887"><b>Units</b></td><td data-bbox="926 849 985 887">N/A</td></tr> <tr> <td data-bbox="649 893 878 931"><b>Interfaces</b></td><td data-bbox="926 893 1073 931">GUI, script</td></tr> </table>	<b>Data Type</b>	Boolean	<b>Allowed Values</b>	true, false	<b>Access</b>	set	<b>Default Value</b>	true	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Boolean												
<b>Allowed Values</b>	true, false												
<b>Access</b>	set												
<b>Default Value</b>	true												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>UseLightTimeDelay</b>	<p>Use light-time delay in the event-finding algorithm.</p> <table> <tr> <td data-bbox="649 969 878 1007"><b>Data Type</b></td><td data-bbox="926 969 1037 1007">Boolean</td></tr> <tr> <td data-bbox="649 1013 878 1051"><b>Allowed Values</b></td><td data-bbox="926 1013 1067 1051">true, false</td></tr> <tr> <td data-bbox="649 1058 878 1096"><b>Access</b></td><td data-bbox="926 1058 972 1096">set</td></tr> <tr> <td data-bbox="649 1102 878 1140"><b>Default Value</b></td><td data-bbox="926 1102 985 1140">true</td></tr> <tr> <td data-bbox="649 1146 878 1184"><b>Units</b></td><td data-bbox="926 1146 985 1184">N/A</td></tr> <tr> <td data-bbox="649 1191 878 1229"><b>Interfaces</b></td><td data-bbox="926 1191 1073 1229">GUI, script</td></tr> </table>	<b>Data Type</b>	Boolean	<b>Allowed Values</b>	true, false	<b>Access</b>	set	<b>Default Value</b>	true	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Boolean												
<b>Allowed Values</b>	true, false												
<b>Access</b>	set												
<b>Default Value</b>	true												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>UseStellarAberration</b>	<p>Use stellar aberration in addition to light-time delay in the event-finding algorithm. Light-time delay must be enabled. Stellar aberration currently has no effect on eclipse searches.</p> <table> <tr> <td data-bbox="649 1322 878 1360"><b>Data Type</b></td><td data-bbox="926 1322 1037 1360">Boolean</td></tr> <tr> <td data-bbox="649 1366 878 1404"><b>Allowed Values</b></td><td data-bbox="926 1366 1067 1404">true, false</td></tr> <tr> <td data-bbox="649 1410 878 1448"><b>Access</b></td><td data-bbox="926 1410 972 1448">set</td></tr> <tr> <td data-bbox="649 1455 878 1493"><b>Default Value</b></td><td data-bbox="926 1455 985 1493">true</td></tr> <tr> <td data-bbox="649 1499 878 1537"><b>Units</b></td><td data-bbox="926 1499 985 1537">N/A</td></tr> <tr> <td data-bbox="649 1543 878 1581"><b>Interfaces</b></td><td data-bbox="926 1543 1073 1581">GUI, script</td></tr> </table>	<b>Data Type</b>	Boolean	<b>Allowed Values</b>	true, false	<b>Access</b>	set	<b>Default Value</b>	true	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Boolean												
<b>Allowed Values</b>	true, false												
<b>Access</b>	set												
<b>Default Value</b>	true												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>WriteReport</b>	<p>Write an event report when event location is executed. This field can be set in the mission sequence.</p> <table> <tr> <td data-bbox="649 1657 878 1695"><b>Data Type</b></td><td data-bbox="926 1657 1037 1695">Boolean</td></tr> <tr> <td data-bbox="649 1702 878 1740"><b>Allowed Values</b></td><td data-bbox="926 1702 1067 1740">true, false</td></tr> <tr> <td data-bbox="649 1746 878 1784"><b>Access</b></td><td data-bbox="926 1746 972 1784">set</td></tr> <tr> <td data-bbox="649 1790 878 1828"><b>Default Value</b></td><td data-bbox="926 1790 985 1828">true</td></tr> <tr> <td data-bbox="649 1835 878 1873"><b>Units</b></td><td data-bbox="926 1835 985 1873">N/A</td></tr> <tr> <td data-bbox="649 1879 878 1917"><b>Interfaces</b></td><td data-bbox="926 1879 1073 1917">GUI, script</td></tr> </table>	<b>Data Type</b>	Boolean	<b>Allowed Values</b>	true, false	<b>Access</b>	set	<b>Default Value</b>	true	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Boolean												
<b>Allowed Values</b>	true, false												
<b>Access</b>	set												
<b>Default Value</b>	true												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

## GUI



The default **EclipseLocator** GUI for a new resource is shown above. You can choose one **Spacecraft** from the list, which is populated by all the **Spacecraft** resources currently configured in the mission. In the **Occulting Bodies** list, you can check the box next to all **CelestialBody** resources you want to search for eclipses. This list shows all celestial bodies currently configured in the mission.

In the **Eclipse Types** list, choose the types of eclipses to search for. Note that each selection will increase the duration of the search.

You can configure the output via **Filename**, **Run Mode**, and **Write Report** near the bottom. If **Write Report** is enabled, a text report will be written to the file specified in **Filename**. The search will execute during **FindEvents** commands (for **Manual** or **Automatic** modes) and automatically at the end of the mission (for **Automatic** mode), depending on the **Run Mode**.

You can configure the search interval via the options in the upper right. Uncheck **Use Entire Interval** to set the search interval manually. See the [Remarks](#) section for considerations when setting the search interval.

You can control the search algorithm via the options in the bottom right. Configure light-time and stellar aberration via the check boxes next to each, and select the signal direction via the **Light-time direction** selection.

To control the fidelity and execution time of the search, set the **Step size** appropriately. See the [Remarks](#) section for details.

## Remarks

### Data configuration

The **EclipseLocator** implementation is based on the [NAIF SPICE toolkit](#), which uses a different mechanism for environmental data such as celestial body shape and orientation, planetary ephemerides, body-specific frame definitions, and leap seconds. Therefore, it is necessary to maintain two parallel configurations to ensure that the event location results are consistent with GMAT's own propagation and other parameters. The specific data to be maintained is:

- Planetary shape and orientation:
  - GMAT core: **CelestialBody.EquatorialRadius**, **Flattening**, **SpinAxisRAConstant**, **SpinAxisRARate**, etc.
  - ContactLocator: **SolarSystem.PCKFilename**,  
**CelestialBody.PlanetarySpiceKernelName**
- Planetary ephemeris:
  - GMAT core: **SolarSystem.DEFilename**, or (**SolarSystem.SPKFilename**,  
**CelestialBody.OrbitSpiceKernelName**, **CelestialBody.NAIFId**)
  - ContactLocator: **SolarSystem.SPKFilename**,  
**CelestialBody.OrbitSpiceKernelName**, **CelestialBody.NAIFId**
- Body-fixed frame:
  - GMAT core: built-in
  - ContactLocator: **CelestialBody.SpiceFrameId**,  
**CelestialBody.FrameSpiceKernelName**
- Leap seconds:
  - GMAT core: startup file **LEAP\_SECS\_FILE** setting
  - ContactLocator: **SolarSystem.LSKFilename**

See **SolarSystem** and **CelestialBody** for more details.

### Search interval

The **EclipseLocator** search interval can be specified either as the entire ephemeris interval of the **Spacecraft**, or as a user-defined interval. If **UseEntireInterval** is true, the search is performed over the entire ephemeris interval of the **Spacecraft**, including any gaps or discontinuities. If **UseEntireInterval** is false, the provided **InitialEpoch** and **FinalEpoch** are used to form the search interval directly. The user must ensure than the provided interval results in valid **Spacecraft** and **CelestialBody** ephemeris epochs.

### Run modes

The **EclipseLocator** works in conjunction with the **FindEvents** command: the **EclipseLocator** resource defines the configuration of the event search, and the **FindEvents** command executes the search at a specific point in the mission sequence. The mode of interaction is defined by **EclipseLocator.RunMode**, which has three options:

- Automatic: All **FindEvents** commands are executed as-is, plus an additional **FindEvents** is executed automatically at the end of the mission sequence.
- Manual: All **FindEvents** commands are executed as-is.
- Disabled: **FindEvents** commands are ignored.

## Search algorithm

The **EclipseLocator** uses the NAIF SPICE GF (geometry finder) subsystem to perform event location. Specifically, the following call is used for the search:

- [gfoclt\\_c](#): For third-body occultation searches

This function implements a fixed-step search method through the interval, with an embedded root-location step if an event is found. **StepSize** should be set equal to the length of the minimum-duration event to be found, or equal to the length of the minimum-duration gap between events, whichever is smaller. To guarantee location of 10-second eclipses, or 10-second gaps between adjacent eclipses, set **StepSize** = 10.

For details, see the reference documentation for the function linked above.

## Report format

When **WriteReport** is enabled, the **EclipseLocator** outputs an event report at the end of each search execution. The report contains the following data:

- Spacecraft name
- For each event:
  - Event start time (UTC)
  - Event stop time (UTC)
  - Event duration (s)
  - Occulting body name
  - Eclipse type
  - Total event number
  - Total duration
- Number of individual events
- Number of total events
- Maximum total duration
- Eclipse number of total duration

The report makes the distinction between an *individual* event and a *total* event.

- An *individual event* is a single continuous event of a single type (umbra, penumbra, etc.) from a single occulting body. Individual events can be nested for a single occulting body, such as a penumbra event followed immediately by an umbra event, or they can be nested from multiple occulting bodies, such as a Luna eclipse occurring in the middle of an Earth eclipse.
- A *total event* is the entire set of nested individual events. The total event is given a single number, and the total duration is reported in the output file.

## Event location with SPK propagator

When using the SPK propagator, you load one or more SPK ephemeris files using the `Spacecraft.OrbitSpiceKernelName` field. For the purposes of event location, this field causes the appropriate ephemeris files to be loaded automatically on run, and so use of the Propagation command is not necessary. This is an easy way of performing event location on an existing SPK ephemeris file. See the example below.

## Examples

Perform a basic eclipse search in LEO:

```
SolarSystem.EphemerisSource = 'DE421'

Create Spacecraft sat
sat.DateFormat = UTCGregorian
sat.Epoch = '15 Sep 2010 16:00:00.000'
sat.CoordinateSystem = EarthMJ2000Eq
sat.DisplayStateType = Keplerian
sat.SMA = 6678.14
sat.ECC = 0.001
sat.INC = 0
sat.RAAN = 0
sat.AOP = 0
sat.TA = 180

Create ForceModel fm
fm.CentralBody = Earth
fm.PrimaryBodies = {Earth}
fm.GravityField.Earth.PotentialFile = 'JGM2.cof'
fm.GravityField.Earth.Degree = 0
fm.GravityField.Earth.Order = 0
fm.GravityField.Earth.TideModel = 'None'
fm.Drag.AtmosphereModel = None
fm.PointMasses = {}
fm.RelativisticCorrection = Off
fm.SRP = Off

Create Propagator prop
prop.FM = fm
prop.Type = RungeKutta89

Create EclipseLocator el
el.Spacecraft = sat
el.Filename = 'Simple.report'
el.OccultingBodies = {Earth}
el.EclipseTypes = {'Umbra', 'Penumbra', 'Antumbra'}

BeginMissionSequence

Propagate prop(sat) {sat.ElapsedSecs = 10800}
```

Perform an eclipse event search from a Mars orbiter, with Phobos, Earth, and Moon eclipses:

```
% Mars orbiter with annular eclipses of Earth and Moon.

SolarSystem.EphemerisSource = 'SPICE'
```

```
SolarSystem.SPKFilename = 'de421.bsp'

Mars.NAIFId = 499
Mars.OrbitSpiceKernelName = {'../data/planetary_ephem/spk/mar063.bsp'}

Create Spacecraft sat
sat.DateFormat = UTCGregorian
sat.Epoch = '10 May 1984 00:00:00.000'
sat.CoordinateSystem = MarsMJ2000Eq
sat.DisplayStateType = Keplerian
sat.SMA = 6792.38
sat.ECC = 0
sat.INC = 45
sat.RAAN = 0
sat.AOP = 0
sat.TA = 0

Create ForceModel fm
fm.CentralBody = Mars
fm.PrimaryBodies = {Mars}
fm.GravityField.Mars.PotentialFile = 'Mars50c.cof'
fm.GravityField.Mars.Degree = 0
fm.GravityField.Mars.Order = 0
fm.Drag.AtmosphereModel = None
fm.PointMasses = {}
fm.RelativisticCorrection = Off
fm.SRP = Off

Create Propagator prop
prop.FM = fm
prop.Type = RungeKutta89

Create CoordinateSystem MarsMJ2000Eq
MarsMJ2000Eq.Origin = Mars
MarsMJ2000Eq.Axes = MJ2000Eq

Create Moon Phobos
Phobos.CentralBody = 'Mars'
Phobos.PosVelSource = 'SPICE'
Phobos.NAIFId = 401
Phobos.OrbitSpiceKernelName = {'mar063.bsp'}
Phobos.SpiceFrameId = 'IAU_PHOBOS'
Phobos.EquatorialRadius = 13.5
Phobos.Flattening = 0.3185185185186
Phobos.Mu = 7.093399e-004

Create Moon Deimos
Deimos.CentralBody = 'Mars'
Deimos.PosVelSource = 'SPICE'
```

```
Deimos.NAIFId = 402
Deimos.OrbitSpiceKernelName = {'mar063.bsp'}
Deimos.EquatorialRadius = 7.5
Deimos.SpiceFrameId = 'IAU_DEIMOS'
Deimos.Flattening = 0.30666666666666664
Deimos.Mu = 1.588174e-004

Create EclipseLocator ec
ec.Spacecraft = sat
ec.OccultingBodies = {Mercury, Venus, Earth, Luna, Mars, Phobos, Deimos}
ec.Filename = 'EarthTransit.report'

BeginMissionSequence

Propagate prop(sat) {sat.ElapsedDays = 2}
```

Perform eclipse location on an existing SPK ephemeris file:

```
SolarSystem.EphemerisSource = 'DE421'

Create Spacecraft sat
sat.OrbitSpiceKernelName = {'../data/vehicle/ephem/spk/Events_Simple.bsp'}

Create EclipseLocator cl
cl.Spacecraft = sat
cl.OccultingBodies = {Earth}
cl.Filename = 'SPKPropagation.report'

BeginMissionSequence
```

## ElectricTank

A model of a tank containing fuel for an electric propulsion system

### Description

An **ElectricTank** is a model of a tank and is required for finite burns employing an electric propulsion system. To use an **ElectricTank**, you must first create the tank, and then attach it to the desired **Spacecraft** and associate it with an **ElectricThruster** as shown in the example below. Additionally you must create a **SolarPowerSystem** or **NuclearPowerSystem** and attach it to the **Spacecraft**.

For a complete description of how to configure all Resources required for electric propulsion modeling, see the Tutorial named *Electric Propulsion*

See Also [ElectricThruster](#),[NuclearPowerSystem](#),[SolarPowerSystem](#)

### Fields

Field	Description
<b>AllowNegativeFuelMass</b>	This field allows the <b>ElectricTank</b> to have negative fuel mass which can be useful in optimization and targeting sequences before convergence has occurred. This field cannot be modified in the Mission Sequence.  <b>Data Type</b> Boolean <b>Allowed Values</b> true, false <b>Access</b> set <b>Default Value</b> false <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>DirectionX</b>	X-component of the primary direction of the <b>ElectricTank's</b> orientation in the body frame. Used in conjunction with the secondary direction elements to calculate the orientation.  <b>Data Type</b> Real <b>Allowed Values</b> Real number <b>Access</b> set <b>Default Value</b> 0 <b>Units</b> N/A <b>Interfaces</b> script

Field	Description
<b>DirectionY</b>	<p>Y-component of the primary direction of the <b>ElectricTank's</b> orientation in the body frame. Used in conjunction with the secondary direction elements to calculate the orientation.</p>
	<b>Data Type</b> Real
	<b>Allowed Values</b> Real number
	<b>Access</b> set
	<b>Default Value</b> 0
	<b>Units</b> N/A
	<b>Interfaces</b> script
<b>DirectionZ</b>	<p>Z-component of the primary direction of the <b>ElectricTank's</b> orientation in the body frame. Used in conjunction with the secondary direction elements to calculate the orientation.</p>
	<b>Data Type</b> Real
	<b>Allowed Values</b> Real number
	<b>Access</b> set
	<b>Default Value</b> 1
	<b>Units</b> N/A
	<b>Interfaces</b> script
<b>FuelCenterOfMassX</b>	<p>The X component of the fuel center of mass in hardware coordinate system.</p>
	<b>Data Type</b> Real
	<b>Allowed Values</b> Any Real number
	<b>Access</b> set, get
	<b>Default Value</b> 0.0
	<b>Units</b> meters
	<b>Interfaces</b> GUI, script
<b>FuelCenterOfMassY</b>	<p>The Y component of the fuel center of mass in hardware coordinate system.</p>
	<b>Data Type</b> Real
	<b>Allowed Values</b> Any Real number
	<b>Access</b> set, get
	<b>Default Value</b> 0.0
	<b>Units</b> meters
	<b>Interfaces</b> GUI, script

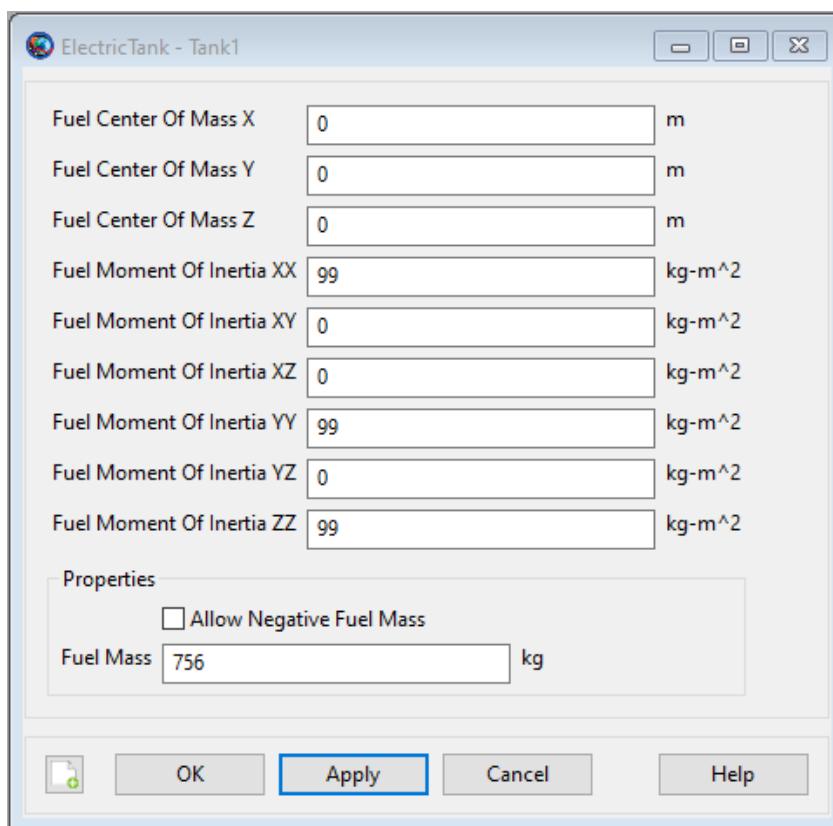
<b>Field</b>	<b>Description</b>
<b>FuelCenterOfMassZ</b>	The Z component of the fuel center of mass in hardware coordinate system.  <b>Data Type</b> Real <b>Allowed Values</b> Any Real number <b>Access</b> set, get <b>Default Value</b> 0.0 <b>Units</b> meters <b>Interfaces</b> GUI, script
<b>FuelMass</b>	The mass of fuel in the tank.  <b>Data Type</b> Real <b>Allowed Values</b> Real > 0 <b>Access</b> set, get <b>Default Value</b> 756 <b>Units</b> kg <b>Interfaces</b> GUI, script
<b>FuelMomentOfInertiaXX</b>	The XX component of the fuel moment of inertia.  <b>Data Type</b> Real <b>Allowed Values</b> Real $\geq 0$ <b>Access</b> set, get <b>Default Value</b> 99 <b>Units</b> Kg-m <sup>2</sup> <b>Interfaces</b> GUI, script
<b>FuelMomentOfInertiaXY</b>	The XY component of the fuel moment of inertia.  <b>Data Type</b> Real <b>Allowed Values</b> Real $\geq 0$ <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> Kg-m <sup>2</sup> <b>Interfaces</b> GUI, script
<b>FuelMomentOfInertiaXZ</b>	The XZ component of the fuel moment of inertia.  <b>Data Type</b> Real <b>Allowed Values</b> Real $\geq 0$ <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> Kg-m <sup>2</sup> <b>Interfaces</b> GUI, script

Field	Description
<b>FuelMomentOfInertiaYY</b>	The YY component of the fuel moment of inertia.
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real >= 0
<b>Access</b>	set, get
<b>Default Value</b>	99
<b>Units</b>	Kg-m^2
<b>Interfaces</b>	GUI, script
<b>FuelMomentOfInertiaYZ</b>	The YZ component of the fuel moment of inertia.
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real >= 0
<b>Access</b>	set, get
<b>Default Value</b>	0
<b>Units</b>	Kg-m^2
<b>Interfaces</b>	GUI, script
<b>FuelMomentOfInertiaZZ</b>	The ZZ component of the fuel moment of inertia.
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real >= 0
<b>Access</b>	set, get
<b>Default Value</b>	99
<b>Units</b>	Kg-m^2
<b>Interfaces</b>	GUI, script
<b>HWOriginInBCSX</b>	X-component of the origin of the hardware's coordinate system expressed in the spacecraft's body coordinate system.
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real
<b>Access</b>	set
<b>Default Value</b>	0
<b>Units</b>	N/A
<b>Interfaces</b>	script
<b>HWOriginInBCSY</b>	Y-component of the origin of the hardware's coordinate system expressed in the spacecraft's body coordinate system.
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real
<b>Access</b>	set
<b>Default Value</b>	0
<b>Units</b>	N/A
<b>Interfaces</b>	script

Field	Description												
<b>HWOiginBCSZ</b>	<p>Z-component of the origin of the hardware's coordinate system expressed in the spacecraft's body coordinate system.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real	<b>Access</b>	set	<b>Default Value</b>	0	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real												
<b>Access</b>	set												
<b>Default Value</b>	0												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>SecondDirectionX</b>	<p>X-component of the vector, expressed in the body frame, used to resolve the hardware's orientation about the direction vector.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real	<b>Access</b>	set	<b>Default Value</b>	0	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real												
<b>Access</b>	set												
<b>Default Value</b>	0												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>SecondDirectionY</b>	<p>Y-component of the vector, expressed in the body frame, used to resolve the hardware's orientation about the direction vector.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>-1</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real	<b>Access</b>	set	<b>Default Value</b>	-1	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real												
<b>Access</b>	set												
<b>Default Value</b>	-1												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>SecondDirectionZ</b>	<p>Z-component of the vector, expressed in the body frame, used to resolve the hardware's orientation about the direction vector.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real	<b>Access</b>	set	<b>Default Value</b>	0	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real												
<b>Access</b>	set												
<b>Default Value</b>	0												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												

## GUI

The **ElectricTank** dialog box allows you to specify properties of a fuel tank. The layout of the **ElectricTank** dialog box is shown below.



## Remarks

### Use of ElectricTank Resource in Conjunction with Maneuvers

An **ElectricTank** is used in conjunction with finite maneuvers. To implement a finite maneuver, you must first create both an **ElectricThruster** and a **FiniteBurn** resource. You must also associate the **ElectricTank** with the **ElectricThruster** resource and you must associate the **ElectricThruster** with the **FiniteBurn** resource. The finite maneuver is implemented using the **BeginFiniteBurn/EndFiniteBurn** commands. See the **Begin-FiniteBurn/EndFiniteBurn** command documentation for worked examples on how the **ElectricTank** resource is used in conjunction with finite maneuvers.

For a complete description of how to configure all Resources required for electric propulsion modeling, see the Tutorial named [Electric Propulsion](#)

### Orientation of the ElectricTank Resource

The **ElectricTank** supports orientation and location settings. The location is the position of the origin of the hardware frame, expressed in the spacecraft body coordinate frame. The orientation is represented as a direction cosine matrix that is initially computed from two non-collinear vectors, provided by the user as **Direction** and **Second-Direction** components. The three axes for the hardware coordinate frame expressed in Body coordinates are computed as follows:

1. Normalize **z** & **v**, where **z** is represented by **Direction** and **v** is the **SecondDirection** vector.

2. Compute the normal  $\mathbf{N} = \mathbf{z} \times \mathbf{v}$  and its magnitude  $m$ .
3. Verify magnitude of  $\mathbf{N}$  isn't 0.0, send message if it is too close. This will happen if one of the input vectors is a zero vector or if the two vectors are co-linear, including the case where they point in opposite directions.
4.  $\mathbf{x} = \mathbf{N} / m$
5.  $\mathbf{y} = \mathbf{z} \times \mathbf{x}$
6. The rotation matrix  $\mathbf{R}_{\text{sb}}$  is constructed with  $\mathbf{x}$  on the first row,  $\mathbf{y}$  on the second, and  $\mathbf{z}$  on the third. This matrix rotates vectors from the body frame to the hardware frame.

### Behavior When Configuring Tank and Attached Tank Properties

Create a default **ElectricTank** and attach it to a **Spacecraft** and **ElectricThruster**.

```
% Create the ElectricTank Resource
Create ElectricTank aTank
aTank.AllowNegativeFuelMass = false
aTank.FuelMass = 756

% Create an ElectricThruster and assign it a ElectricTank
Create ElectricThruster aThruster
aThruster.Tank = {aTank}

% Add the ElectricTank and Thruster to a Spacecraft
Create Spacecraft aSpacecraft
aSpacecraft.Tanks = {aTank}
aSpacecraft.Thrusters = {aThruster}
```

As exhibited below, there are some subtleties associated with setting and getting parent vs. cloned resources. In the example above, **aTank** is the parent **ElectricTank** resource and the field **aSpacecraft.Tanks** is populated with a cloned copy of **aTank**.

Create a second spacecraft and attach a fuel tank using the same procedure used in the previous example. Set the **FuelMass** in the parent resource, **aTank**, to 900 kg.

```
% Add the ElectricTank and ElectricThruster to a second Spacecraft
Create Spacecraft bSpacecraft
bSpacecraft.Tanks = {aTank}
bSpacecraft.Thrusters = {aThruster}
aTank.FuelMass = 900      %Can be performed in both resource and
                           %command modes
```

Note that in the example above, setting the value of the parent resource, **aTank**, changes the fuel mass value in both cloned fuel tank resources. More specifically, the value of both **aSpacecraft.aTank.FuelMass** and **bSpacecraft.aTank.FuelMass** are both now equal to the new value of 900 kg. We note that the assignment command for the parent resource, **aTank.FuelMass**, can be performed in both resource and command modes.

To change the value of the fuel mass in only the first created spacecraft, **aSpacecraft**, we do the following.

```
% Create the Fuel Tank Resource
BeginMissionSequence
aTank.FuelMass = 756 %Fuel tank mass in both s/c set back to default
aSpacecraft.aTank.FuelMass = 1000 %Can only be performed in command mode.
```

As a result of the commands in the previous example, the value of aSpacecraft.aTank.FuelMass is 1000 kg and the value of bSpacecraft.aTank.FuelMass is 756 kg. We note that the assignment command for the cloned resource, aSpacecraft.aTank.FuelMass, can only be performed in command mode.

### Caution: Value of AllowNegativeFuelMass Flag Can Affect Iterative Processes

By default, GMAT will not allow the fuel mass to be negative. However, occasionally in iterative processes such as targeting, a solver will try values of a maneuver parameter that result in total fuel depletion. Using the default tank settings, this will throw an exception stopping the run unless you set the **AllowNegativeFuelMass** flag to true. GMAT will not allow the the total spacecraft mass to be negative. If DryMass + FuelMass is negative GMAT will throw an exception and stop.

### Examples

Create a default **ElectricTank** and attach it to a **Spacecraft** and **ElectricThruster**.

```
% Create the ElectricTank Resource
Create ElectricTank aTank
aTank.AllowNegativeFuelMass = false
aTank.FuelMass = 756

% Create an ElectricThruster and assign it a ElectricTank
Create ElectricThruster aThruster
aThruster.Tank = {aTank}

% Add the ElectricTank and ElectricThruster to a Spacecraft
Create Spacecraft aSpacecraft
aSpacecraft.Tanks = {aTank}
aSpacecraft.Thrusters = {aThruster}

BeginMissionSequence
```

## ElectricThruster

An electric thruster model

### Description

The **ElectricThruster** resource is a model of an electric thruster which supports several models for thrust and mass flow computation. The **ElectricThruster** model also allows you to specify properties such as a duty cycle and scale factor and to connect an **ElectricThruster** with an **ElectricTank**. You can flexibly define the direction of the thrust by specifying the thrust components in coordinate systems such as (locally defined) **SpacecraftBody** or **LVLH**, or by choosing any configured **CoordinateSystem** resource.

For a complete description of how to configure all Resources required for electric propulsion modeling, see the Tutorial named *Electric Propulsion*

See Also [ElectricTank](#), [NuclearPowerSystem](#), [SolarPowerSystem](#)

### Fields

Field	Description
<b>Axes</b>	Allows the user to define a spacecraft centered set of axes for the <b>ElectricThruster</b> . This field cannot be modified in the Mission Sequence
	<b>Data Type</b> Reference Array <b>Allowed Values</b> <b>VNB</b> , <b>LVLH</b> , <b>MJ2000Eq</b> , <b>SpacecraftBody</b> <b>Access</b> set <b>Default Value</b> <b>VNB</b> <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>ConstantThrust</b>	Thrust value used <b>ThrustModel</b> is set to <b>ConstantThrustAndIsp</b> .
	<b>Data Type</b> Real <b>Allowed Values</b> Real > 0 <b>Access</b> set, get <b>Default Value</b> 0.237 <b>Units</b> N <b>Interfaces</b> GUI, script

Field	Description
<b>CoordinateSystem</b>	Determines what coordinate system the orientation parameters, <b>ThrustDirection1</b> , <b>ThrustDirection2</b> , and <b>ThrustDirection3</b> refer to. This field cannot be modified in the Mission Sequence.
	<p><b>Data Type</b> Reference Array</p> <p><b>Allowed Values</b> <b>Local</b>, <b>EarthMJ2000Eq</b>, <b>EarthMJ2000Ec</b>, <b>EarthFixed</b>, or any user defined system</p> <p><b>Access</b> set</p> <p><b>Default Value</b> <b>Local</b></p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>DecrementMass</b>	Flag which determines if the <b>FuelMass</b> is to be decremented as it used. This field cannot be modified in the Mission Sequence.
	<p><b>Data Type</b> Boolean</p> <p><b>Allowed Values</b> true, false</p> <p><b>Access</b> set</p> <p><b>Default Value</b> false</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>DutyCycle</b>	Fraction of time that the thrusters are on during a maneuver. The thrust applied to the spacecraft is scaled by this amount. Note that this scale factor also affects mass flow rate.
	<p><b>Data Type</b> Real Number</p> <p><b>Allowed Values</b> <math>0 \leq \text{Real} \leq 1</math></p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 1</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>FixedEfficiency</b>	Thruster efficiency. Only used when <b>ThrustModel</b> is <b>FixedEfficiency</b> .
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> <math>\text{Real} &gt; 0</math></p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 0.7</p> <p><b>Units</b> Decimal Percent</p> <p><b>Interfaces</b> GUI, script</p>

Field	Description
<b>GravitationalAccel</b>	<p>Value of the gravitational acceleration used for the FuelTank/Thruster calculations.</p> <p><b>Data Type</b> Real Number  <b>Allowed Values</b> Real &gt; 0  <b>Access</b> set, get  <b>Default Value</b> 9.81  <b>Units</b> m/s<sup>2</sup>  <b>Interfaces</b> GUI, script</p>
<b>HWOriginInBCSX</b>	<p>X-component of the origin of the hardware's coordinate system expressed in the spacecraft's body coordinate system.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> meters  <b>Interfaces</b> script</p>
<b>HWOriginInBCSY</b>	<p>Y-component of the origin of the hardware's coordinate system expressed in the spacecraft's body coordinate system.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> meters  <b>Interfaces</b> script</p>
<b>HWOriginInBCSZ</b>	<p>Z-component of the origin of the hardware's coordinate system expressed in the spacecraft's body coordinate system.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> meters  <b>Interfaces</b> script</p>
<b>Isp</b>	<p>Thruster specific impulse. Only used when <b>ThrustModel</b> is set to <b>FixedEfficiency</b> or <b>ConstantThrustAndIsp</b>.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real &gt; 0  <b>Access</b> set, get  <b>Default Value</b> 4200  <b>Units</b> seconds  <b>Interfaces</b> GUI, script</p>

Field	Description
<b>MassFlowCoeff1</b>	<p>Mass flow coefficient.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real Number  <b>Access</b> set, get  <b>Default Value</b> -0.004776  <b>Units</b> See <a href="#">Mathematical Models</a>  <b>Interfaces</b> GUI, script</p>
<b>MassFlowCoeff2</b>	<p>Mass flow coefficient.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real Number  <b>Access</b> set, get  <b>Default Value</b> 0.05717  <b>Units</b> See <a href="#">Mathematical Models</a>  <b>Interfaces</b> GUI, script</p>
<b>MassFlowCoeff3</b>	<p>Mass flow coefficient.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real Number  <b>Access</b> set, get  <b>Default Value</b> -0.09956  <b>Units</b> See <a href="#">Mathematical Models</a>  <b>Interfaces</b> GUI, script</p>
<b>MassFlowCoeff4</b>	<p>Mass flow coefficient.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real Number  <b>Access</b> set, get  <b>Default Value</b> 0.03211  <b>Units</b> See <a href="#">Mathematical Models</a>  <b>Interfaces</b> GUI, script</p>
<b>MassFlowCoeff5</b>	<p>Mass flow coefficient.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real Number  <b>Access</b> set, get  <b>Default Value</b> 2.13781  <b>Units</b> See <a href="#">Mathematical Models</a>  <b>Interfaces</b> GUI, script</p>

Field	Description
<b>MaximumUsablePower</b>	The maximum power the thruster can use to generate thrust. Power provided above MaximumUsablePower is not used in the thrust model.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Real &gt; 0, Real &lt; MinimumUsablePower</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 7.266</p> <p><b>Units</b> kW</p> <p><b>Interfaces</b> GUI, script</p>
<b>MinimumUsablePower</b>	The minimum power the thruster can use to generate thrust. If power provided to thruster is below MinimumUsablePower, no thrust is generated.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Real &gt; 0, Real &gt; MinimumUsablePower</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 0.638</p> <p><b>Units</b> kW</p> <p><b>Interfaces</b> GUI, script</p>
<b>MixRatio</b>	The mixture ratio employed to draw fuel from multiple tanks. For example, if there are two tanks and <b>MixRatio</b> is set to [2 1], then twice as much fuel will be drawn from tank one as from tank 2 in the <b>Tank</b> list. Note, if a MixRatio is not supplied, fuel is drawn from tanks in equal amounts, (the <b>MixRatio</b> is set to a vector of ones the same length as the <b>Tank</b> list).
	<p><b>Data Type</b> Array</p> <p><b>Allowed Values</b> Array of real numbers with same length as number of tanks in the <b>Tank</b> array</p> <p><b>Access</b> set</p> <p><b>Default Value</b> [1]</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>

Field	Description
<b>Origin</b>	<p>This field, used in conjunction with the <b>Axes</b> field, allows the user to define a spacecraft centered set of axes for the <b>ElectricThruster</b>. <b>Origin</b> has no affect when a <b>Local</b> coordinate system is used and the <b>Axes</b> are set to <b>MJ2000Eq</b> or <b>SpacecraftBody</b>. This field cannot be modified in the Mission Sequence.</p>
<b>Data Type</b>	Reference Array
<b>Allowed Values</b>	Sun, Mercury, Venus, Earth, Luna, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto
<b>Access</b>	set
<b>Default Value</b>	Earth
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>Tanks</b>	<p><b>ElectricTank</b> from which the <b>ElectricThruster</b> draws propellant from. In a script command, an empty list, e.g., Thruster1.Tank = {}, is NOT allowed. Via the script, if you wish to indicate that no <b>ElectricTank</b> is associated with an <b>ElectricThruster</b>, do not include commands such as Thruster1.Tank = ... in your script. This field cannot be modified in the Mission Sequence.</p>
<b>Data Type</b>	Reference Array
<b>Allowed Values</b>	User defined list of <b>FuelTank(s)</b> .
<b>Access</b>	set
<b>Default Value</b>	N/A
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>ThrustCoeff1</b>	Thrust coefficient.
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real Number
<b>Access</b>	set, get
<b>Default Value</b>	-5.19082
<b>Units</b>	See <a href="#">Mathematical Models</a>
<b>Interfaces</b>	GUI, script
<b>ThrustCoeff2</b>	Thrust coefficient.
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real Number
<b>Access</b>	set, get
<b>Default Value</b>	2.96519
<b>Units</b>	See <a href="#">Mathematical Models</a>
<b>Interfaces</b>	GUI, script

Field	Description
<b>ThrustCoeff3</b>	Thrust coefficient.  <b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> -14.41789 <b>Units</b> See <a href="#">Mathematical Models</a> <b>Interfaces</b> GUI, script
<b>ThrustCoeff4</b>	Thrust coefficient.  <b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> 54.05382 <b>Units</b> See <a href="#">Mathematical Models</a> <b>Interfaces</b> GUI, script
<b>ThrustCoeff5</b>	Thrust coefficient.  <b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> -0.00100092 <b>Units</b> See <a href="#">Mathematical Models</a> <b>Interfaces</b> GUI, script
<b>ThrustDirection1</b>	X component of the spacecraft thrust vector direction.  <b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> 1 <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>ThrustDirection2</b>	Y component of the spacecraft thrust vector direction.  <b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> 1 <b>Units</b> N/A <b>Interfaces</b> GUI, script

Field	Description
<b>ThrustDirection3</b>	Z component of the spacecraft thrust vector direction.  <b>Data Type</b> Real <b>Allowed Values</b> Real Number <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>ThrustModel</b>	The type of thruster model. See <a href="#">Mathematical Models</a> for a detailed description of the options.  <b>Data Type</b> String <b>Allowed Values</b> <b>ThrustMassPolynomial</b> , <b>ConstantThrustAndIsp</b> , <b>FixedEfficiency</b> <b>Access</b> set, get <b>Default Value</b> <b>ThrustMassPolynomial</b> <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>ThrustScaleFactor</b>	<b>ThrustScaleFactor</b> is a scale factor that is multiplied by the thrust vector, for a given thruster, before the thrust vector is added into the total acceleration. Note that the value of this scale factor does not affect the mass flow rate.  <b>Data Type</b> Real Number <b>Allowed Values</b> Real $\geq 0$ <b>Access</b> set, get <b>Default Value</b> 1 <b>Units</b> N/A <b>Interfaces</b> GUI, script

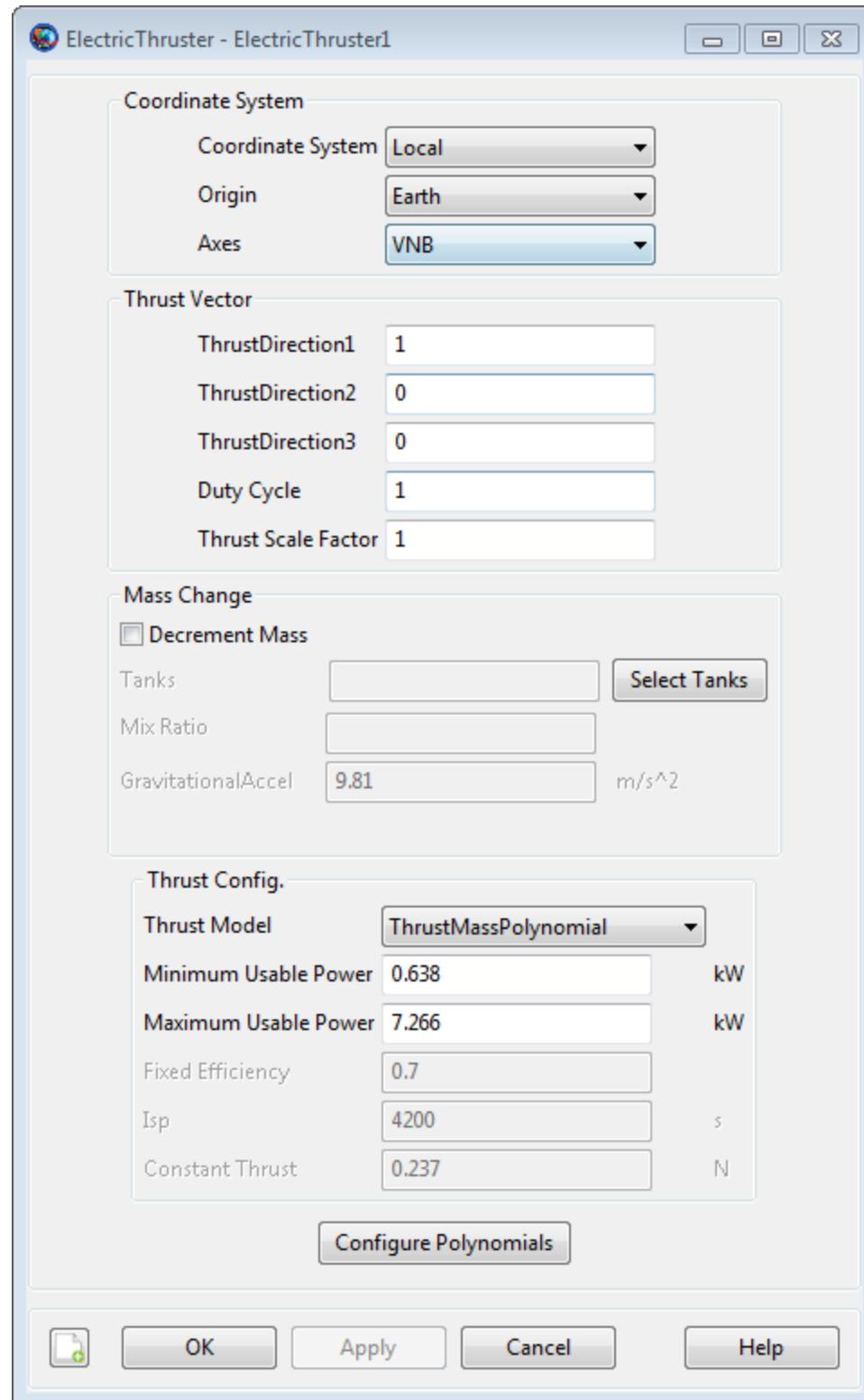
## Interactions

Command or Re- source	Description
<b>BeginFinite- Burn/EndFinite- Burn command</b>	Use these commands, which require a <b>Spacecraft</b> and a <b>Finite- Burn</b> name as input, to implement a finite burn.
<b>ElectricTank</b> <b>source</b>	re- This resource contains the fuel used to power the <b>ElectricThruster</b> specified by the <b>FiniteBurn</b> resource.
<b>FiniteBurn</b> <b>source</b>	re- When using the <b>BeginFiniteBurn/EndFiniteBurn</b> commands, you must specify which <b>FiniteBurn</b> resource to implement. The <b>FiniteBurn</b> resource specifies which <b>ElectricThruster(s)</b> to use for the finite burn.
<b>Spacecraft</b> <b>source</b>	re- When using the <b>BeginFiniteBurn/EndFiniteBurn</b> commands, you must specify which <b>Spacecraft</b> to apply the finite burn to.

Command or Re- source	Description
<b>Propagate com-</b>	In order to implement a non-zero finite burn, a <b>Propagate</b> statement must occur within the <b>BeginFiniteBurn</b> and <b>EndFiniteBurn</b> statements.

## GUI

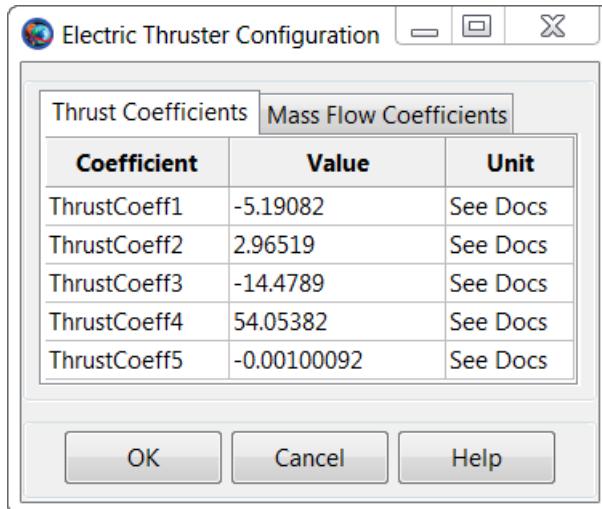
The **ElectricThruster** dialog box allows you to specify properties of an **ElectricThruster** including the **Coordinate System** of the thrust acceleration direction vector, the thrust magnitude and Isp coefficients, and choice of **ElectricTank**. The layout of the **Electric-Thruster** dialog box is shown below.



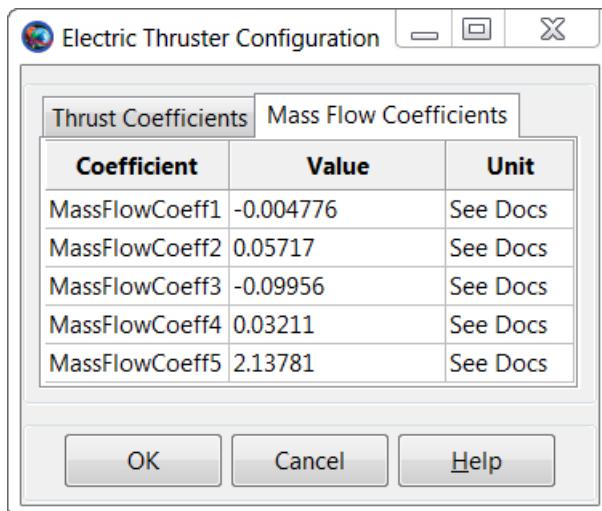
When configuring the **Coordinate System** field, you can choose between existing coordinate systems or use locally defined coordinate systems. The **Axes** field is only ac-

tive if **Coordinate System** is set to **Local**. The **Origin** field is only active if **Coordinate System** is set to **Local** and **Axes** is set to either **VNB** or **LVLH**.

Selecting the **Configure Polynomials** button brings up the following dialog box where you may input the coefficients for the **ElectricThruster** polynomial.



Similarly, clicking the **Configure Polynomials** also allows you to edit mass flow coefficients as shown below.



## Remarks

### Mathematical Models

The **ElectricThruster** model supports several models for computation of thrust and mass flow rate and the model used is set by the **ThrustModel** field. When **ThrustModel** is set to **ThrustMassPolynomial**, the following polynomials are used to compute thrust and mass flow rate

$$\dot{m} = f_d(C_{m5}P^4 + C_{m4}P^3 + C_{m3}P^2 + C_{m2}P + C_{m1})$$

$$\bar{T} = f_d f_s (C_{t5}P^4 + C_{t4}P^3 + C_{t3}P^2 + C_{t2}P + C_{t1}) R_{iT} \hat{T}$$

where P is the power provided to the thruster which is computed using the power logic defined on the **FiniteBurn** resource, f\_d is duty cycle, f\_s is thrust scale factor, R\_iT is the rotation matrix from the thrust coordinate system to the inertial system, and T\_hat is the thrust unit vector. By industry convention, the mass flow rate and thrust polynomial equations are in mg/s and milli-Newtons respectively. GMAT internally converts the units to be consistent with the equations of motion.

When **ThrustModel** is set to **ConstantThrustAndIsp**, the following polynomials are used to compute thrust and mass flow rate

$$\dot{m} = f_d \frac{C_{t1}}{I_{sp} g_0}$$

$$\bar{T} = f_d f_s C_{t1} R_{iT} \hat{T}$$

where C\_t1 is set using the **ConstantThrust** field, Isp is set using the **Isp** field, f\_d is duty cycle, f\_s is thrust scale factor, R\_iT is the rotation matrix from the thrust coordinate system to the inertial system, and T\_hat is the thrust unit vector. Note, by industry convention, the mass flow rate and thrust polynomial equations are in mg/s and milli-Newtons respectively. GMAT internally converts the units to be consistent with the equations of motion.

When **ThrustModel** is set to **FixedEfficiency**, the following polynomials are used to compute thrust and mass flow rate

$$\dot{m} = f_d \frac{2\eta P}{(I_{sp} g_0)^2}$$

$$\bar{T} = f_d f_s \frac{2\eta P}{I_{sp} g_0} R_{iT} \hat{T}$$

where P is the power provided to the thruster which is computed from the power logic defined on the **FiniteBurn** Resource. "Eta" is the **FixedEfficiency** setting, f\_d is duty cycle, f\_s is thrust scale factor, R\_iT is the rotation matrix from the thrust coordinate system to the inertial system, and T\_hat is the thrust unit vector.

### Use of Thruster Resource in Conjunction With Maneuvers

An **ElectricThruster** resource is used only in association with finite maneuvers. To implement a finite maneuver, you must first create both an **ElectricTank** and a **FiniteBurn** resource. You must also associate an **ElectricTank** with the **ElectricThruster** resource and you must associate an **ElectricThruster** with the **FiniteBurn** resource. The actual finite maneuver is implemented using the **BeginFiniteBurn/EndFiniteBurn** commands.

For a complete description of how to configure all Resources required for electric propulsion modeling, see the Tutorial named [Electric Propulsion](#)

## Local Coordinate Systems

Here, a Local coordinate system is defined as one that we configure "locally" using the **ElectricThruster** resource interface as opposed to defining a coordinate system using the **Coordinate Systems** folder in the **Resources** Tree.

To configure a local coordinate system, you must specify the coordinate system of the input thrust acceleration direction vector, **ThrustDirection1-3**. If you choose a local coordinate system, the four choices available, as given by the **Axes** sub-field, are **VNB**, **LVLH**, **MJ2000Eq**, and **SpacecraftBody**. **VNB** or Velocity-Normal-Binormal is a non-inertial coordinate system based upon the motion of the spacecraft with respect to the **Origin** sub-field. For example, if the **Origin** is chosen as Earth, then the X-axis of this coordinate system is along the velocity of the spacecraft with respect to the Earth, the Y-axis is along the instantaneous orbit normal (with respect to the Earth) of the spacecraft, and the Z-axis completes the right-handed set.

Similarly, Local Vertical Local Horizontal or **LVLH** is also a non-inertial coordinate system based upon the motion of the spacecraft with respect to the **Origin** sub-field. Again, if we choose Earth as the origin, then the X-axis of this coordinate system is the position of the spacecraft with respect to the Earth, the Z-axis is the instantaneous orbit normal (with respect to the Earth) of the spacecraft, and the Y-axis completes the right-handed set.

**MJ2000Eq** is the J2000-based Earth-centered Earth mean equator inertial coordinate system. Note that the **Origin** sub-field is not needed to define this coordinate system.

**SpacecraftBody** is the attitude system of the spacecraft. Since the thrust is applied in this system, GMAT uses the attitude of the spacecraft, a spacecraft attribute, to determine the inertial thrust direction. Note that the **Origin** sub-field is not needed to define this coordinate system.

## Caution Regarding Force Model Discontinuities

Note that when modelling shadows on a **SolarPowerSystem** Resource, it is possible that there is not enough power available to power an **ElectricThruster**. This occurs when the power available from the **SolarPowerSystem**, or the power distributed to the thruster, is less than **MinimumUsablePower**. When this occurs, the thruster model turns off thrust and this can cause a discontinuity in the force model. To avoid this, you must propagate to the boundary and switch propagators, or configure the **Propagator** to continue propagating if a poor step occurs.

## Examples

Create a default **ElectricTank** and an **ElectricThruster** that allows for fuel depletion, assign the **ElectricThruster** the default **ElectricTank**, and attach both to a **Spacecraft**.

```
% Create an ElectricTank Resource  
Create ElectricTank anElectricTank
```

```
% Create an Electric Thruster Resource
Create ElectricThruster anElectricThruster
anElectricThruster.CoordinateSystem = Local
anElectricThruster.Origin = Earth
anElectricThruster.Axes = VNB
anElectricThruster.ThrustDirection1 = 1
anElectricThruster.ThrustDirection2 = 0
anElectricThruster.ThrustDirection3 = 0
anElectricThruster.DutyCycle = 1
anElectricThruster.ThrustScaleFactor = 1
anElectricThruster.DecrementMass = true
anElectricThruster.Tank = {anElectricTank}
anElectricThruster.GravitationalAccel = 9.810000000000001
anElectricThruster.ThrustModel = ThrustMassPolynomial
anElectricThruster.MaximumUsablePower = 7.266
anElectricThruster.MinimumUsablePower = 0.638
anElectricThruster.ThrustCoeff1 = -5.19082
anElectricThruster.ThrustCoeff2 = 2.96519
anElectricThruster.ThrustCoeff3 = -14.4789
anElectricThruster.ThrustCoeff4 = 54.05382
anElectricThruster.ThrustCoeff5 = -0.00100092
anElectricThruster.MassFlowCoeff1 = -0.004776
anElectricThruster.MassFlowCoeff2 = 0.05717
anElectricThruster.MassFlowCoeff3 = -0.09956
anElectricThruster.MassFlowCoeff4 = 0.03211
anElectricThruster.MassFlowCoeff5 = 2.13781
anElectricThruster.FixedEfficiency = 0.7
anElectricThruster.Isp = 4200
anElectricThruster.ConstantThrust = 0.237

% Create a SolarPowerSystem Resource
Create SolarPowerSystem aSolarPowerSystem

% Create a Spacecraft Resource and attach hardware
Create Spacecraft DefaultSC
DefaultSC.Tanks = {anElectricTank}
DefaultSC.Thrusters = {anElectricThruster}
DefaultSC.PowerSystem = aSolarPowerSystem

BeginMissionSequence
```

## FiniteBurn

A finite burn

### Description

The **FiniteBurn** resource is used when continuous propulsion is desired. Impulsive burns happen instantaneously through the use of the **Maneuver** command, while finite burns occur continuously starting at the **BeginFiniteBurn** command and lasting until the **EndFiniteBurn** command is reached in the mission sequence. In order to apply a non-zero **Finite Burn**, there must be a **Propagate** command between the **BeginFiniteBurn** and **EndFiniteBurn** commands.

See Also: [ChemicalTank](#), [ChemicalThruster](#), [Spacecraft](#), [BeginFiniteBurn](#), [EndFiniteBurn](#), [Calculation Parameters](#)

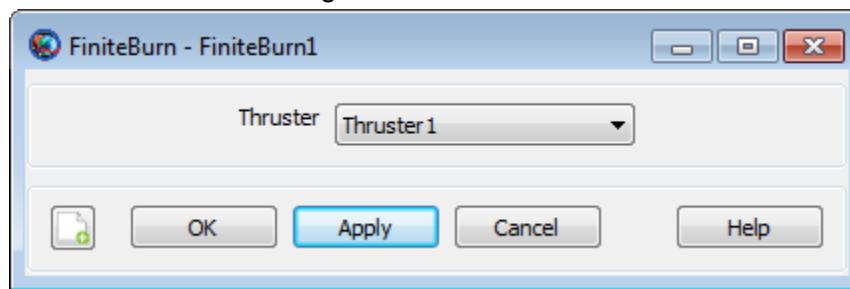
### Fields

Field	Description
<b>Thrusters</b>	The <b>Thruster</b> field allows the selection of which <b>Thruster</b> , from a list of previously created thrusters, to use when applying a finite burn. Currently, using the GUI, you can only select one <b>Thruster</b> to attach to a <b>FiniteBurn</b> resource. Using the scripting interface, you may attach multiple thrusters to a <b>FiniteBurn</b> resource. Using the scripting interface, you may attach multiple thrusters to a <b>FiniteBurn</b> resource. In a script command, an empty list, e.g., <code>FiniteBurn1.Thruster={}</code> , is allowed but is of limited utility since the GUI will automatically associate a <b>ChemicalThruster</b> , if one has been created, with the <b>FiniteBurn</b> . This field cannot be modified in the Mission Sequence.
<b>Data Type</b>	Reference Array
<b>Allowed Values</b>	A list of <b>Thrusters</b> created by user. Can be a list of <b>ChemicalThrusters</b> or <b>ElectricThrusters</b> but you cannot mix chemical and electric thrusters.
<b>Access</b>	set
<b>Default Value</b>	No Default
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script, or only one

Field	Description
<b>VectorFormat</b>	Deprecated. Allows you to define the format of the finite burn thrust direction. This field has no effect. The finite burn thrust direction, as specified in the <b>Thruster</b> resource, is always given in Cartesian format. Note: You can use GMAT scripting to convert from other representations to Cartesian and then set the Cartesian format.
<b>Data Type</b>	Enumeration
<b>Allowed Values</b>	Cartesian, Spherical
<b>Access</b>	set
<b>Default Value</b>	Cartesian
<b>Units</b>	N/A
<b>Interfaces</b>	script

## GUI

The **FiniteBurn** dialog box allows you to specify which thruster to use for the finite burn. The layout of the **FiniteBurn** dialog box is shown below.



## Remarks

### Configuring a FiniteBurn

To perform a finite burn, the **FiniteBurn** resource itself and a number of related resources and commands must be properly configured. You must associate a specific **ChemicalThruster** hardware resource with a created **FiniteBurn**. You must associate a specific **ChemicalTank** hardware resource with the chosen **ChemicalThruster**. Finally, you must attach both the chosen **Thrusters** and **Tanks** to the desired **Spacecraft**. See the example below for additional details.

### FiniteBurn Using Multiple Thrusters

Using the GUI, a **FiniteBurn** resource must be associated with exactly one **Thruster**.

Using the scripting interface, one can assign multiple thrusters to a single **FiniteBurn** resource.

## Interactions

Field	Description
<b>Spacecraft</b> <b>re-</b> source	Must be created in order to apply any burn.
<b>Thruster</b> <b>re-</b> source	As discussed in the <b>Remarks</b> , every <b>FiniteBurn</b> resource must be associated with at least one <b>ChemicalThruster</b> or <b>ElectricThruster</b> . Any thruster created in the resource tree can be incorporated into a <b>FiniteBurn</b> but thruster types cannot be mixed.
<b>ChemicalTank</b> resource	To perform a finite burn, a <b>Tank</b> must be attached to the <b>Spacecraft</b> . (A <b>ChemicalTank</b> is needed to provide pressure and temperature data used when modeling the thrust and specific impulse. A <b>Tank</b> is also needed if you want to model mass depletion.)
<b>BeginFinite- Burn</b> and <b>EndFiniteBurn</b> command	After a <b>FiniteBurn</b> is created, to apply it in the mission sequence, a <b>BeginFiniteBurn</b> and <b>EndFiniteBurn</b> command must be appended to the mission tree.
<b>Propagate</b> command	In order to apply a non-zero finite burn, there must be a <b>Propagate</b> command between the <b>BeginFiniteBurn</b> and <b>EndFiniteBurn</b> commands.

## Reporting FiniteBurn Parameters

GMAT now supports finite burn parameters that report the thrust component data for a finite burn. The parameters include total thrust from all thrusters in the three coordinate directions, the total acceleration from all thrusters in the three coordinate directions, and the total mass flow rate from all thrusters. Currently, by default the total thrust and total acceleration parameters in the three coordinate directions are reported only in the J2000 system and do not support any other coordinate system dependency. Furthermore, you can now also report out any thruster's individual parameters such as thrust magnitude, Isp and mass flow rate. See the [Calculation Parameters](#) reference for definitions of these finite burn and thruster specific parameters. Also see the [Examples](#) section for an example that shows how to report the finite burn and individual thruster specific parameters to a report file.

## Examples

Configure a chemical finite burn. Create a default **Spacecraft** and **ChemicalTank** Resource; Create a default **ChemicalThruster** that allows for fuel depletion from the default **ChemicalTank**; Attach **ChemicalTank** and **ChemicalThruster** to the **Spacecraft**; Create default **ForceModel** and **Propagator**; Create a **Finite Burn** that uses the default thruster and apply a 30 minute finite burn to the spacecraft.

```
% Create a default Spacecraft and ChemicalTank Resource
Create Spacecraft DefaultSC
Create ChemicalTank FuelTank1

% Create a default ChemicalThruster. Allow for fuel depletion from
```

```
% the default ChemicalTank.  
Create ChemicalThruster Thruster1  
Thruster1.DecrementMass = true  
Thruster1.Tank = {FuelTank1}  
  
% Attach ChemicalTank and ChemicalThruster to the spacecraft  
DefaultSC.Thrusters = {Thruster1}  
DefaultSC.Tanks = {FuelTank1}  
  
% Create default ForceModel and Propagator  
Create ForceModel DefaultProp_ForceModel  
Create Propagator DefaultProp  
DefaultProp.FM = DefaultProp_ForceModel  
  
% Create a Finite Burn that uses the default thruster  
Create FiniteBurn FiniteBurn1  
FiniteBurn1.Thrusters = {Thruster1}  
  
BeginMissionSequence  
  
% Implement 30 minute finite burn  
BeginFiniteBurn FiniteBurn1(DefaultSC)  
Propagate DefaultProp(DefaultSC) {DefaultSC.ElapsedSecs = 1800}  
EndFiniteBurn FiniteBurn1(DefaultSC)
```

This example shows how to report finite burn parameters such as total acceleration (from all thrusters), total thrust (from all thrusters) in the three coordinate directions. We also report total mass flow rate from all thrusters. Additionally, individual thruster specific parameters such as thruster mass flow rate, thrust magnitude and thruster Isp are also reported. Note that in the generated report, all finite burn and thruster parameters are reported as zeros when thrusters are not turned on.

```
Create Spacecraft aSat  
  
Create ChemicalTank aFuelTank  
  
Create ChemicalThruster aThruster  
aThruster.DecrementMass = true  
aThruster.Tank = {aFuelTank}  
aThruster.C1 = 1000 % Constant Thrust  
aThruster.K1 = 300 % Constant Isp  
  
aSat.Thrusters = {aThruster}  
aSat.Tanks = {aFuelTank}  
  
Create ForceModel aFM  
aFM.CentralBody = Earth  
aFM.PointMasses = {Earth}
```

```
Create Propagator aProp
aProp.FM = aFM

Create FiniteBurn aFB
aFB.Thrusters = {aThruster}

Create ReportFile rf
rf.Add = {aSat.UTCGregorian, aFB.TotalAcceleration1, aFB.TotalAcceleration2, ...
aFB.TotalAcceleration3, aFB.TotalMassFlowRate, aFB.TotalThrust1, ...
aFB.TotalThrust2, aFB.TotalThrust3, aSat.aThruster.MassFlowRate, ...
aSat.aThruster.ThrustMagnitude, aSat.aThruster.Isp}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedSecs = 1000}

% Do a Finite-Burn for 1800 Secs
BeginFiniteBurn aFB(aSat)
Propagate aProp(aSat) {aSat.ElapsedSecs = 1800}
EndFiniteBurn aFB(aSat)

Propagate aProp(aSat) {aSat.ElapsedSecs = 1000}
```

## FieldOfView

Models the mask, or field-of-view, of a hardware **Resource**.

### Description

GMAT supports three field-of-view **Resources** including **ConicalFOV**, **RectangularFOV**, and **CustomFOV**. These **Resources** are used to model masks of sensors and antenna (in graphics currently) and can be added to the selected hardware **Resources**. See the **Remarks** section for a detailed discussion of each field-of-view **Resource**.

See Also: [Antenna](#)

### Fields

Field	Description												
<b>Alpha</b>	<p>The transparency of the sensor field-of-view in the graphics display.</p> <table> <tr> <td><b>Data Type</b></td><td>Integer</td></tr> <tr> <td><b>Allowed Values</b></td><td>0 to 255. 0 represents fully transparent, 255 represents fully opaque.</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Integer	<b>Allowed Values</b>	0 to 255. 0 represents fully transparent, 255 represents fully opaque.	<b>Access</b>	set	<b>Default Value</b>	0	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Integer												
<b>Allowed Values</b>	0 to 255. 0 represents fully transparent, 255 represents fully opaque.												
<b>Access</b>	set												
<b>Default Value</b>	0												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>AngleWidth</b>	<p>Maximum clock angle distance from reference point (+X axis of Hardware coordinate frame) for points in the field of view. Only applies to <b>RectangularFOV Resource</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>0 to 180</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>30</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	0 to 180	<b>Access</b>	set	<b>Default Value</b>	30	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	0 to 180												
<b>Access</b>	set												
<b>Default Value</b>	30												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>AngleHeight</b>	<p>Maximum cone angle distance from the boresight (+Z axis of Hardware coordinate frame) for points within the field of view. Only applies to <b>RectangularFOV Resource</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>0 to 90</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>10</td></tr> <tr> <td><b>Units</b></td><td>degrees</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	0 to 90	<b>Access</b>	set	<b>Default Value</b>	10	<b>Units</b>	degrees	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	0 to 90												
<b>Access</b>	set												
<b>Default Value</b>	10												
<b>Units</b>	degrees												
<b>Interfaces</b>	script												

Field	Description
<b>Azimuth</b>	<p>Array containing azimuth angles for each point on the perimeter of the field of view. This array is used in conjunction with either ConeAngles or Elevation. Only applies to <b>CustomFOV Resource</b>.</p> <p><b>Data Type</b> Real array  <b>Allowed Values</b> Real array, each element is in the range 0 to 360.  <b>Access</b> set,  <b>Default Value</b> empty array  <b>Units</b> Degrees  <b>Interfaces</b> script</p>
<b>ClockAngles</b>	<p>Array containing cone angles for each point on the perimeter of the field of view. This array is used in conjunction with ClockAngles. Only applies to <b>CustomFOV Resource</b>.</p> <p><b>Data Type</b> Real array  <b>Allowed Values</b> Real array, each element is in the range -180 to 180.  <b>Access</b> set,  <b>Default Value</b> empty array  <b>Units</b> Degrees  <b>Interfaces</b> script</p>
<b>Color</b>	<p>The color of the sensor field-of-view displayed in graphics.</p> <p><b>Data Type</b> Integer array or string  <b>Allowed Values</b> Valid predefined color or a triplet of integers representing a red, green or blue value ranging from 0 to 255.  <b>Access</b> set  <b>Default Value</b> [0 0 0] or Black  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>ConeAngles</b>	<p>Array containing cone angles for each point on the perimeter of the field of view. This array is used in conjunction with ClockAngles. Only applies to <b>CustomFOV Resource</b>.</p> <p><b>Data Type</b> Real array  <b>Allowed Values</b> RealArray, each element is in the range 0 to 180  <b>Access</b> set  <b>Default Value</b> empty array  <b>Units</b> Degrees  <b>Interfaces</b> script</p>

<b>Field</b>	<b>Description</b>												
<b>Elevation</b>	<p>Array containing elevation angles for each point on the perimeter of the field of view. Note that the elevation is relative to the plane tangent to the sensor's boresight direction. This array is used in conjunction with either Azimuth or ClockAngles. Only applies to <b>CustomFOV Resource</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real array</td></tr> <tr> <td><b>Allowed Values</b></td><td>RealArray, each element is in the range -90 to 90</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>empty array</td></tr> <tr> <td><b>Units</b></td><td>Degrees</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real array	<b>Allowed Values</b>	RealArray, each element is in the range -90 to 90	<b>Access</b>	set	<b>Default Value</b>	empty array	<b>Units</b>	Degrees	<b>Interfaces</b>	script
<b>Data Type</b>	Real array												
<b>Allowed Values</b>	RealArray, each element is in the range -90 to 90												
<b>Access</b>	set												
<b>Default Value</b>	empty array												
<b>Units</b>	Degrees												
<b>Interfaces</b>	script												
<b>FieldOfViewAngle</b>	<p>The half angle of the conical sensor yield of view. Only applies to <b>ConicalFOV Resource</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td><math>0 &lt; \text{FieldOfViewAngle} \leq 90</math></td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>30</td></tr> <tr> <td><b>Units</b></td><td>degrees</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	$0 < \text{FieldOfViewAngle} \leq 90$	<b>Access</b>	set	<b>Default Value</b>	30	<b>Units</b>	degrees	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	$0 < \text{FieldOfViewAngle} \leq 90$												
<b>Access</b>	set												
<b>Default Value</b>	30												
<b>Units</b>	degrees												
<b>Interfaces</b>	script												
<b>FOVFileName</b>	<p>Name and path to FOV file. Only applies to <b>CustomFOV Resource</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Text file containing a valid cone angle and clock angle on each row.</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>none</td></tr> <tr> <td><b>Units</b></td><td>Angles are in degrees.</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Text file containing a valid cone angle and clock angle on each row.	<b>Access</b>	set	<b>Default Value</b>	none	<b>Units</b>	Angles are in degrees.	<b>Interfaces</b>	script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Text file containing a valid cone angle and clock angle on each row.												
<b>Access</b>	set												
<b>Default Value</b>	none												
<b>Units</b>	Angles are in degrees.												
<b>Interfaces</b>	script												
<b>InterpolationStepSize</b>	<p>Size of steps to take when performing spherical linear interpolation for a mask file. May be set to 0.0 to disable. Only applies to <b>CustomFOV</b> and only when using Azimuth and Elevation to define the angles.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>0.0 or value between or equal to 0.2 and 180.0</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0.2 degrees</td></tr> <tr> <td><b>Units</b></td><td>Angles are in degrees.</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	0.0 or value between or equal to 0.2 and 180.0	<b>Access</b>	set	<b>Default Value</b>	0.2 degrees	<b>Units</b>	Angles are in degrees.	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	0.0 or value between or equal to 0.2 and 180.0												
<b>Access</b>	set												
<b>Default Value</b>	0.2 degrees												
<b>Units</b>	Angles are in degrees.												
<b>Interfaces</b>	script												

## Remarks

Field-of-view objects define the sensor mask (a representation of the perimeter of the field of view) for use in graphics applications. Future versions of GMAT will determine if a given vector (e.g., the spacecraft-to-Sun vector) is in the sensor field of view.



### Note

The configuration of a sensor location and orientation in the body frame is configured on the **Antenna Resource**. The orientation of the hardware object in the spacecraft body frame and the spacecraft attitude is used to perform the rotations of vectors between a reference frame and a hardware coordinate frame. By convention a sensor boresight is the +Z axis of the sensor coordinate frame.

## Configuring a ConicalFOV

A **ConicalFOV** object models a conical field of view, which can be represented by its cone angle; the angle between the boresight and the edge of the field of view. This angle remains constant, and the field of view mask can be thought of as a circle on the unit sphere.

Configure a ConicalFOV.

```
% Create the ConicalFOV object
Create ConicalFOV cone1;
cone1.FieldOfViewAngle = 60;
cone1.Color = Blue;
cone1.Alpha = 255; %the field of view is fully opaque

% Attach the FOV object to an antenna
Create Antenna antenna1;
antenna1.FieldOfView = cone1;
```

## Configuring a RectangularFOV

The **RectangularFOV Resource** models a field-of-view where the 4 corners are defined by the angular width and height limits. A RectangularFOV object models a field of view defined by limits on cone angle and and clock angle. A (cone angle, clock angle) pair defines a point on the unit sphere. Unlike a conical sensor, which assumes the cone angle is uniform for all clock angles, the cone angle is measured along a “prime meridian” lying in the X-Z plane of the Hardware coordinate frame. A positive cone angle is measured towards the +X axis, a negative cone angle is measured towards the -X axis.

Configure a RectangularFOV.

```
% Create the RectangularFOV object
Create RectangularFOV box1;
box1.AngleHeight = 20;
box1.AngleWidth = 50;
```

```

box1.Color = [255 255 0]; % Yellow
box1.Alpha = 255; %the field of view is fully opaque

% Attach the FOV object to an antenna
Create Antenna antenna1;
antenna1.FieldOfView = cone1;

```

### Configuring a CustomFOV

The **CustomFOV** models the field of view's perimeter as a sequence of points on the unit sphere, represented by a (cone, clock) or (azimuth, elevation) pair of angles. A CustomFOV can be used to model an irregular sensor field of view. Note that cone angles are measured relative to the zenith direction and elevation angles are measured relative to the horizontal plane.

There are two ways GMAT will determine the boundaries of a FOV between two defined points.

1. GMAT will treat the FOV as a polyhedron, with the boundary between the two points defined by the plane created from the two points and the origin. This approach is used if the FOV points are defined using Cone and Clock angles or if InterpolationStepSize = 0
2. GMAT will linearly interpolate between the elevation angles of the FOV at azimuth steps from 0 to 360 at steps defined by InterpolationStepSize. This approach is used if the FOV points are defined using Azimuth and Elevation angles and InterpolationStepSize is non-zero, having a default value of 0.2 degrees for InterpolationStepSize. The final mask will be the union of the user defined set of points and the points created by the interpolation



### Warning

The CustomFOV uses the Jordan Curve Thereom to determine if a point is inside of a sensor. Future versions of GMAT will expose that interface to provide sensor coverage computations. It is important that no line segments in a CustomFOV cross one another.

Configure a CustomFOV.

```

% Create a CustomFOV from a text file of cone and clock angles
Create CustomFOV fov;
fov.FOVFileName = 'ConeClockAngles.txt';

% ... or alternatively, create a CustomFOV by
fov.ClockAngles = [ 15.0 25.0 35.0];
fov.ConeAngles = [ 30.0 45.0 60.0];

% ... or alternatively, create an equivalent CustomFOV by
fov.Azimuth = [ 15.0 25.0 35.0];
fov.Elevation = [ 60.0 45.0 30.0];

```

```
% Attach the FOV object to an antenna  
Create Antenna antenna1;  
antenna1.FieldOfView = fov;
```

The example below contains contents of the mask file for the example above. The mask file consists of pairs of clock and cone angles in degrees. Clock and cone angles pairs are on a row with the clock angle first and the cone angle second. The keyword `ClockConeAngles` specifies that the angle pairs are clock and cone angles. Alternatively, the user may specify azimuth and elevation angles by using the `AzimuthElevationAngles` keyword. An angle type keyword must be present in the file.

```
ClockConeAngles
```

```
15.0 30.0  
25.0 45.0  
35.0 60.0
```

## ForceModel

Used to specify force modeling options such as gravity, drag, solar radiation pressure, and non-central bodies for propagation.

### Description

A **ForceModel** is a model of the environmental forces and dynamics that affect the motion of a spacecraft. GMAT supports numerous forces, including perturbations from point mass and spherical harmonic gravity models, atmospheric drag, solar radiation pressure, tide models, and relativistic corrections. A **ForceModel** is configured and attached to the **Propagator** object (see the **Propagator** object for differences between script and GUI configuration when configuring a **Propagator**). The **Propagator**, along with the **Propagate** command, uses a **ForceModel** to numerically solve the orbital equations of motion (forwards or backwards in time) using the forces configured in the **ForceModel** object, and may include thrust terms and mass flow in the case of powered flight. See the discussion below for detailed information on how to configure force models for your application. This resource cannot be modified in the Mission Sequence.

See Also: [Propagator](#), [FiniteBurn](#)

### Fields

Option	Description
<b>CentralBody</b>	The central body of propagation. <b>CentralBody</b> must be a celestial body and cannot be a <b>LibrationPoint</b> , <b>Barycenter</b> , <b>Spacecraft</b> , or other special point.  Data Type      Resource reference Allowed Values <b>CelestialBody</b> Access      set Default Value <b>Earth</b> Units      N/A Interfaces      GUI, script
<b>Drag</b>	Deprecated. This field has been replaced with <b>Drag.AtmosphereModel</b> .

Option	Description
<b>Drag.AtmosphereModel</b>	<p>Specifies the atmosphere model used in the drag force. This field is only active if there is a <b>Primary-Body</b>.</p>
<b>Data Type</b>	Enumeration
<b>Allowed Values</b>	<p>If <b>PrimaryBody</b> is <b>Earth</b>: <b>None</b>, <b>JacchiaRoberts</b>, <b>MSISE86</b> (with plugin), <b>MSISE90</b>, <b>NRLMSISE00</b> (with plugin)</p>
<b>Access</b>	<b>If PrimaryBody is Mars</b> : <b>None</b> , <b>MarsGRAM2005</b> (with plugin)
<b>Default Value</b>	set
<b>Units</b>	None
<b>Interfaces</b>	N/A
<b>Access</b>	GUI, script
<b>Drag.CSSISpaceWeatherFile</b>	<p>The file name of the CSSI space weather file with optional path information. See <a href="#">Remarks</a> for details on file format.</p>
<b>Data Type</b>	String
<b>Allowed Values</b>	<p>String containing name of the CSSI file with optional path information.</p>
<b>Access</b>	set
<b>Default Value</b>	'SpaceWeather-All-v1.2.txt'
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>Drag.DensityModel</b>	<p>Enabled when <b>Drag.AtmosphereModel</b> is <b>Mars-GRAM2005</b>. Specifies the Mars-GRAM density model to use. <b>Mean</b> is mean density with any optional wave model perturbations enabled by the input file. <b>High</b> is <b>Mean</b> density plus 1 standard deviation. <b>Low</b> is <b>Mean</b> density minus 1 standard deviation.</p>
<b>Data Type</b>	Enumeration
<b>Allowed Values</b>	<b>High</b> , <b>Low</b> , <b>Mean</b>
<b>Access</b>	set
<b>Default Value</b>	<b>Mean</b>
<b>Units</b>	N/A
<b>Interfaces</b>	script

Option	Description
<b>Drag.DragModel</b>	User choice of Spacecraft area model for drag computation.
	<b>Data Type</b> Enumeration <b>Allowed Values</b> <b>Spherical, SPADFile</b> <b>Access</b> set <b>Default Value</b> <b>Spherical</b> <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>Drag.F107</b>	The instantaneous value of solar flux at wavelength of 10.7 cm. This field is only active if there is a <b>PrimaryBody</b> and the current weather source is set to constant values (ConstantFluxAndGeoMag). Realistic values for this setting are $50 \leq \text{Drag.F107} \leq 400$ .
	<b>Data Type</b> Real <b>Allowed Values</b> <b>Drag.F107&gt;= 0</b> <b>Access</b> set <b>Default Value</b> 150 <b>Units</b> $10^{-22} \text{ W/m}^2/\text{Hz}$ <b>Interfaces</b> GUI, script
<b>Drag.F107A</b>	The 81-day running average value of solar flux at wavelength of 10.7 cm. This field is only active in the script if there is a <b>PrimaryBody</b> and the current weather source is set to constant values (ConstantFluxAndGeoMag). Realistic values for this setting are $50 \leq \text{Drag.F107A} \leq 400$ .
	<b>Data Type</b> Real <b>Allowed Values</b> <b>Drag.F107A&gt;=0</b> <b>Access</b> set <b>Default Value</b> 150 <b>Units</b> $10^{-22} \text{ W/m}^2/\text{Hz}$ <b>Interfaces</b> script
<b>Drag.HistoricWeatherSource</b>	Defines the source for historical flux and geomagnetic indices used in Earth density modeling.
	<b>Data Type</b> Enumeration <b>Allowed Values</b> <b>ConstantFluxAndGeoMag, CSSISpaceWeatherFile</b> <b>Access</b> set <b>Default Value</b> <b>ConstantFluxAndGeoMag</b> <b>Units</b> N/A <b>Interfaces</b> GUI, script

Option	Description
<b>Drag.InputFile</b>	<p>Enabled when <b>Drag.AtmosphereModel</b> is <b>Mars-GRAM2005</b>. Path to the Mars-GRAM input namelist file that configures the model. See the <a href="#">Mars-GRAM2005 section</a> for details on the individual settings in this file and how they are used by GMAT. Relative paths are relative to the GMAT bin directory.</p>
	<p><b>Data Type</b> String  <b>Allowed Values</b> Valid path to a Mars-GRAM input namelist file  <b>Access</b> set  <b>Default Value</b> '.../ data/atmosphere/Mars- GRAM2005/inputstd0.txt'  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>Drag.MagneticIndex</b>	<p>The geomagnetic index (Kp) used in density calculations. Kp is a planetary 3-hour-average, geomagnetic index that measures magnetic effects of solar radiation. This field is only active if there is a <b>PrimaryBody</b> and the current weather source is set to constant values (ConstantFluxAndGeoMag).</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> 0 &lt;= Real Number &lt;= 9  <b>Access</b> set  <b>Default Value</b> 3  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>Drag.PredictedWeatherSource</b>	<p>Defines the source for predicted flux and geomagnetic indices used in Earth density modeling.</p>
	<p><b>Data Type</b> Enumeration  <b>Allowed Values</b> SchattenFile, Constant- FluxAndGeoMag, CSSIS- paceWeatherFile  <b>Access</b> set  <b>Default Value</b> ConstantFluxAndGeoMag  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>

Option	Description
<b>Drag.SchattenErrorModel</b>	The error model used from the Schatten file. Schatten predicts include mean, +2 sigma, and -2 sigma models. See <a href="#">Remarks</a> for details on the file format.
<b>Data Type</b>	Enumeration
<b>Allowed Values</b>	<b>Nominal</b> , <b>PlusTwoSigma</b> , <b>MinusTwoSigma</b>
<b>Access</b>	set
<b>Default Value</b>	<b>Nominal</b>
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>Drag.SchattenFile</b>	The file name of the Schatten file with optional path information. See <a href="#">Remarks</a> for details on file format.
<b>Data Type</b>	String
<b>Allowed Values</b>	String containing name of the Schatten file with optional path information.
<b>Access</b>	set
<b>Default Value</b>	'SchattenPredict.txt'
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>Drag.SchattenTimingModel</b>	The timing model used from the Schatten file. Schatten predicts include a nominal solar cycle model, an early model, and a late model. See <a href="#">Remarks</a> for details on the file format.
<b>Data Type</b>	Enumeration
<b>Allowed Values</b>	<b>NominalCycle</b> , <b>EarlyCycle</b> , <b>LateCycle</b>
<b>Access</b>	set
<b>Default Value</b>	<b>NominalCycle</b>
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

Option	Description												
<b>ErrorControl</b>	<p>Controls how error in the current integration step is estimated. The error in the current step is computed by the selection of <b>ErrorControl</b> and compared to the value set in the <b>Accuracy</b> field to determine if the step has an acceptable error or needs to be improved. All error measurements are relative error, however, the reference for the relative error changes depending upon the selection of <b>ErrorControl</b>. <b>RSSStep</b> is the Root Sum Square (RSS) relative error measured with respect to the current step. <b>RSSState</b> is the (RSS) relative error measured with respect to the current state. <b>LargestStep</b> is the state vector component with the largest relative error measured with respect to the current step. <b>LargestState</b> is the state vector component with the largest relative error measured with respect to the current state. Setting <b>ErrorControl</b> to <b>None</b> turns off error control and the integrator takes constant steps at the value defined by the smaller of <b>InitialStepSize</b> and <b>MaxStep</b> on the numerical integrator.</p> <table> <tr> <td data-bbox="687 941 833 979"><b>Data Type</b></td><td data-bbox="964 941 1127 979">Enumeration</td></tr> <tr> <td data-bbox="687 984 899 1022"><b>Allowed Values</b></td><td data-bbox="964 984 1385 1051"><b>None</b>, <b>RSSStep</b>, <b>RSSState</b>, <b>LargestState</b>, <b>LargestStep</b></td></tr> <tr> <td data-bbox="687 1056 784 1094"><b>Access</b></td><td data-bbox="964 1056 997 1094">set</td></tr> <tr> <td data-bbox="687 1098 866 1136"><b>Default Value</b></td><td data-bbox="964 1098 1078 1136"><b>RSSStep</b></td></tr> <tr> <td data-bbox="687 1140 752 1178"><b>Units</b></td><td data-bbox="964 1140 997 1178">N/A</td></tr> <tr> <td data-bbox="687 1182 817 1220"><b>Interfaces</b></td><td data-bbox="964 1182 1095 1220">GUI, script</td></tr> </table>	<b>Data Type</b>	Enumeration	<b>Allowed Values</b>	<b>None</b> , <b>RSSStep</b> , <b>RSSState</b> , <b>LargestState</b> , <b>LargestStep</b>	<b>Access</b>	set	<b>Default Value</b>	<b>RSSStep</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Enumeration												
<b>Allowed Values</b>	<b>None</b> , <b>RSSStep</b> , <b>RSSState</b> , <b>LargestState</b> , <b>LargestStep</b>												
<b>Access</b>	set												
<b>Default Value</b>	<b>RSSStep</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>External</b>	<p>This specifies a python script from which to get dynamics data from when using an external force model. The python script may be placed in the GMAT installation userfunctions/python folder, or in any folder specified by <b>PYTHON_MODULE_PATH</b> in the GMAT startup file. The name should not include the *.py suffix. This parameter, if not empty, specifies that an external force model is to be used. See <a href="#">External Force Model</a> below for more details.</p> <table> <tr> <td data-bbox="687 1554 833 1592"><b>Data Type</b></td><td data-bbox="964 1554 1029 1592">String</td></tr> <tr> <td data-bbox="687 1596 899 1634"><b>Allowed Values</b></td><td data-bbox="964 1596 1385 1698">String containing name of the python script containing an external force model.</td></tr> <tr> <td data-bbox="687 1702 784 1740"><b>Access</b></td><td data-bbox="964 1702 997 1740">set</td></tr> <tr> <td data-bbox="687 1744 866 1782"><b>Default Value</b></td><td data-bbox="964 1744 1029 1782"><b>None</b></td></tr> <tr> <td data-bbox="687 1786 752 1824"><b>Units</b></td><td data-bbox="964 1786 997 1824">N/A</td></tr> <tr> <td data-bbox="687 1828 817 1867"><b>Interfaces</b></td><td data-bbox="964 1828 1095 1867">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	String containing name of the python script containing an external force model.	<b>Access</b>	set	<b>Default Value</b>	<b>None</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	String containing name of the python script containing an external force model.												
<b>Access</b>	set												
<b>Default Value</b>	<b>None</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

Option	Description
<b>External.DerivativesFunction</b>	This specifies the name of the function within the Python script, <b>External</b> , for GMAT to call if an external force model is being used. See <a href="#">External Force Model</a> below for more details.
<b>Data Type</b>	String
<b>Allowed Values</b>	String containing name of the python function.
<b>Access</b>	set
<b>Default Value</b>	GetDerivatives
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>External.ExcludeOtherForces</b>	When true, GMAT will only use the external python force model for integration, excluding any GMAT forces defined in the <b>ForceModel</b> . If false, the force will be applied in addition to any other forces defined within the <b>ForceModel</b> . See <a href="#">External Force Model</a> below for more details.
<b>Data Type</b>	Boolean
<b>Allowed Values</b>	true, false
<b>Access</b>	set
<b>Default Value</b>	false
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>GravityField. PrimaryBodyName.Degree</b>	The degree of the harmonic gravity field. This field is only active if there is a <b>PrimaryBody</b> .
<b>Data Type</b>	Integer
<b>Allowed Values</b>	0<=Degree<=Max Degree On File
<b>Access</b>	set
<b>Default Value</b>	4 (When loading a custom file in the GUI, GMAT sets <b>Degree</b> to the max value on the file)
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

Option	Description
<b>GravityField.</b> <i>PrimaryBodyName.Order</i>	<p>The order of the harmonic gravity field. This field is only active if there is a <b>PrimaryBody</b>.</p>
<b>Data Type</b>	Integer
<b>Allowed Values</b>	0<=Order<=Max Degree On File AND Degree <= Order
<b>Access</b>	set
<b>Default Value</b>	4 (When loading a custom file in the GUI, GMAT sets <b>Order</b> to the max value on the file)
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>GravityField.</b>	The gravity potential file. This field is only active if there
<i>PrimaryBodyName.PotentialFiles</i>	is a <b>PrimaryBody</b> . See discussion below for detailed explanation of supported file types and how to configure gravity files.
<b>Data Type</b>	String
<b>Allowed Values</b>	path and name of .cof OR .grv file
<b>Access</b>	set
<b>Default Value</b>	JGM2.cof
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>GravityField.</b>	The upper bound on the degree and order to be used
<i>PrimaryBodyName.StmLimit</i>	when calculating the State Transition Matrix (STM). The STM will not use a degree or order greater than that specified by either the <b>Degree</b> and <b>Order</b> fields or the <b>StmLimit</b> . This field has no effect on the degree or order used to calculate the state, only the STM. This field is only active if there is a <b>PrimaryBody</b> .
<b>Data Type</b>	Integer
<b>Allowed Values</b>	Int >= 0
<b>Access</b>	set
<b>Default Value</b>	100
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

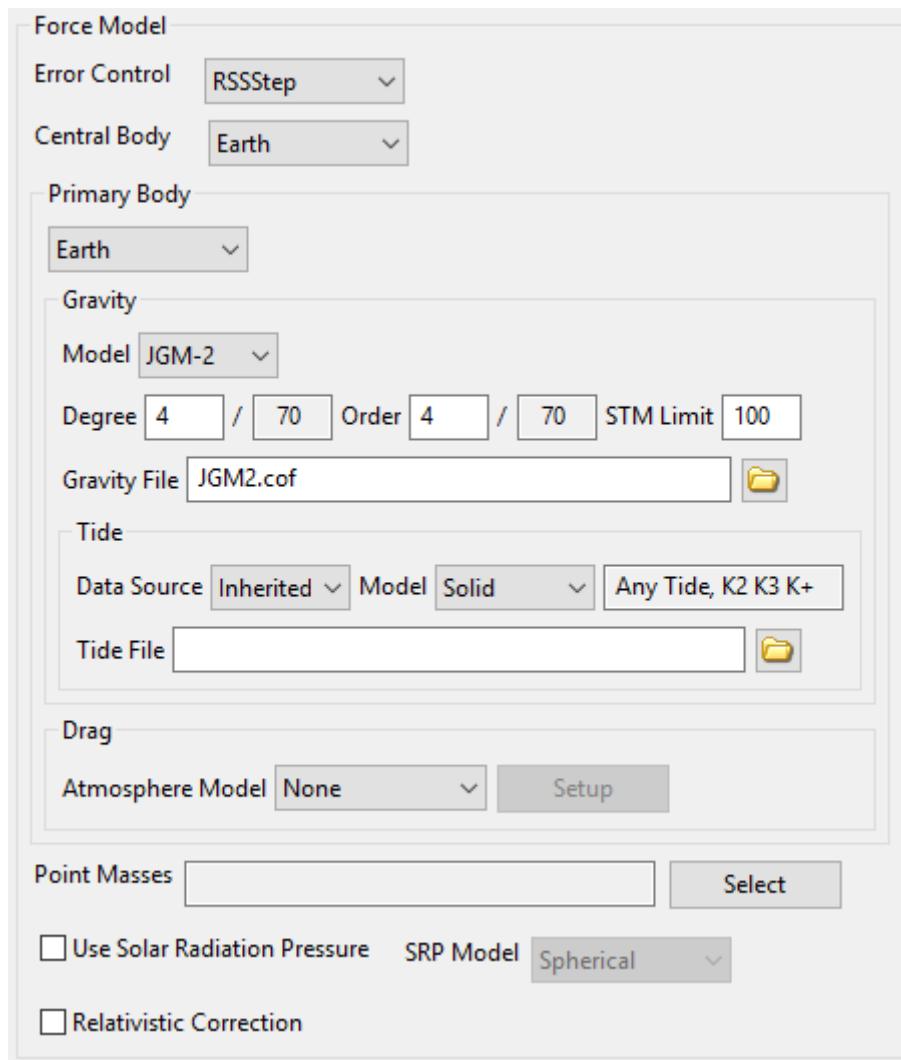
Option	Description
<b>GravityField.</b> <i>PrimaryBodyName.TideFile</i>	The tide file. This field is only active if there is a <b>PrimaryBody</b> . See discussion below for detailed explanation of supported file types and how to configure tide files.
	<b>Data Type</b> String <b>Allowed Values</b> path and name of .tide file <b>Access</b> set <b>Default Value</b> (None) <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>GravityField.</b> <i>PrimaryBodyName.TideModel</i>	Flag for type of tide model. This field is always active but only used in the dynamics when there is a harmonic gravity model for the body.
	<b>Data Type</b> Enumeration <b>Allowed Values</b> <b>None</b> , <b>Solid</b> , <b>SolidAndPole</b> <b>Access</b> set <b>Default Value</b> <b>None</b> <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>Model</b>	A GUI list of "configured" gravity files defined in the file gmat_startup_file.txt. <b>Model</b> allows you to quickly choose between gravity files distributed with GMAT. For example, if <b>PrimaryBody</b> is Earth, you can select among Earth gravity models provided with GMAT such as <b>JGM-2</b> and <b>EGM-96</b> . If you select <b>Other</b> , you can provide the path and filename for a custom gravity file.
	<b>Data Type</b> String <b>Allowed Values</b> <b>JGM2</b> , <b>JGM3</b> , <b>EGM96</b> , <b>MARS50C</b> , <b>MGNP180U</b> <b>Access</b> set,get <b>Default Value</b> <b>JGM2</b> <b>Units</b> N/A <b>Interfaces</b> GUI

Option	Description												
<b>PointMasses</b>	<p>A list of celestial bodies to be treated as point masses in the force model. A body cannot be both a <b>PrimaryBody</b> and in the <b>PointMasses</b> list. An empty list "{}" removes all points masses from the list.</p> <table> <tr> <td><b>Data Type</b></td><td>Resource array</td></tr> <tr> <td><b>Allowed Values</b></td><td>array of <b>CelestialBodies</b> not selected as a <b>PrimaryBody</b></td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>Empty List</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Resource array	<b>Allowed Values</b>	array of <b>CelestialBodies</b> not selected as a <b>PrimaryBody</b>	<b>Access</b>	set	<b>Default Value</b>	Empty List	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Resource array												
<b>Allowed Values</b>	array of <b>CelestialBodies</b> not selected as a <b>PrimaryBody</b>												
<b>Access</b>	set												
<b>Default Value</b>	Empty List												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>PrimaryBodies</b>	<p>A body modeled with a "complex" force model. A primary body can have an atmosphere and harmonic gravity model. You may assign multiple primary bodies if you wish to model harmonic gravity for multiple bodies. Please see the important <a href="#">remarks</a> below regarding the use of multiple harmonic gravity models. The force model <b>CentralBody</b> should be one of the primary bodies, and primary bodies cannot be included in the <b>PointMasses</b> field.</p> <table> <tr> <td><b>Data Type</b></td><td>Resource reference</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>CelestialBody</b> not included in <b>PointMasses</b>.</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>Earth</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Resource reference	<b>Allowed Values</b>	<b>CelestialBody</b> not included in <b>PointMasses</b> .	<b>Access</b>	set	<b>Default Value</b>	Earth	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Resource reference												
<b>Allowed Values</b>	<b>CelestialBody</b> not included in <b>PointMasses</b> .												
<b>Access</b>	set												
<b>Default Value</b>	Earth												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>RelativisticCorrection</b>	<p>Sets relativistic correction on or off.</p> <table> <tr> <td><b>Data Type</b></td><td>Enumeration</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>On, Off</b></td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>Off</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Enumeration	<b>Allowed Values</b>	<b>On, Off</b>	<b>Access</b>	set	<b>Default Value</b>	<b>Off</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Enumeration												
<b>Allowed Values</b>	<b>On, Off</b>												
<b>Access</b>	set												
<b>Default Value</b>	<b>Off</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

Option	Description
<b>SRP</b>	<p>Sets SRP force on or off. See the Remarks section for a detailed explanation of SRP configuration. The SRP model used is set in the SRP.Model field.</p>
	<p><b>Data Type</b> Enumeration  <b>Allowed Values</b> On, Off  <b>Access</b> set  <b>Default Value</b> Off  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>SRP.Flux</b>	<p>The value of SRP flux at 1 AU. This field is only active in the script if <b>SRP</b> is on.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> 1200 &lt; <b>SRP.Flux</b> &lt; 1450  <b>Access</b> set  <b>Default Value</b> 1367  <b>Units</b> W/m<sup>2</sup>  <b>Interfaces</b> script</p>
<b>SRP.Flux_Pressure</b>	<p>The solar flux at 1 AU divided by the speed of light. This field is only active in the script if SRP is on. See the Remarks section for a detailed explanation of SRP configuration.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> 4.33e-6 &lt; <b>SRP.Flux_Pressure</b> &lt; 4.84e-6  <b>Access</b> set  <b>Default Value</b> 4.55982118135874e-006  <b>Units</b> W *s/m<sup>3</sup>  <b>Interfaces</b> script</p>
<b>SRP.SRPModel</b>	<p>User choice of Spacecraft area model for SRP computation.</p>
	<p><b>Data Type</b> Enumeration  <b>Allowed Values</b> Spherical, SPADFile, NPlate  <b>Access</b> set  <b>Default Value</b> Spherical  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>

Option	Description
<b>SRP.Nominal_Sun</b>	The value of one Astronomical Unit in km used in scaling SRP.Flux, which is flux at 1 AU, to the flux at space-craft distance from sun. This field is only active in the script if SRP is on. See the Remarks section for a detailed explanation of SRP configuration.

**Data Type** Real  
**Allowed Values** 135e6<**Nominal\_Sun**<165e6  
**Access** set  
**Default Value** 149597870.691  
**Units** km  
**Interfaces** script

**GUI**

Settings for the **ForceModel** object.

## Remarks

### Overview of Primary Body/Central Body and Field Interactions

In GMAT, a primary body is a celestial body that is modeled with a complex force model which may include a spherical harmonic gravity model, tides, or drag. A body cannot appear in both the **PrimaryBodies** and **PointMasses** fields. GMAT allows multiple primary bodies in the force model, but restricts the model to a single primary body for orbit determination.

GMAT currently requires that the primary body is either the same as the **CentralBody** or set to **None** in the GUI. If you change the **CentralBody** in the GUI, GMAT changes the primary body to **None**, and you can then select between **None** and the central body. When you select a primary body in the GUI, the **Gravity** and **Drag** fields activate and allow you to select models for those forces consistent with the body selected in the **PrimaryBodies** field. For example, if you select Earth as the primary body, you can only select Earth drag models in the **Drag.AtmosphereModel** field. See the field list above for available models.

### Configuring Gravitational Models

GMAT supports point mass gravity, spherical harmonic, and tide modeling for all celestial bodies. On a **Propagator**, all celestial bodies are classified into two mutually exclusive categories: **PrimaryBodies**, and **Point Masses**. To model a body as a point mass, add it to the **PointMasses** list. When a primary body is selected on the GUI, the **CentralBody** and primary body must be the same.

Bodies modeled as **PointMasses** use the gravitational parameter defined on the body (i.e. Earth.Mu) in the equations of motion. Bodies defined as **PrimaryBodies** use the constants defined on the potential file in the equations of motion. GMAT supports two gravity file formats: the .cof format, and the STK .grv format. You can provide a custom potential file for your application as long as it is one of the supported formats. Potential files defined in the startup file are available in the **Model** list in the GUI. For example, the following lines in the startup file configure GMAT so that EGM96 is an available option for **Model** in the GUI when the primary body is Earth:

```
EARTH_POT_PATH      = DATA_PATH/gravity/earth/  
EGM96_FILE          = EARTH_POT_PATH/EGM96.cof
```

Below is an example script snippet for configuring a custom gravity model.

```
Create ForceModel aForceModel  
  
aForceModel.CentralBody = Earth  
aForceModel.PrimaryBodies = {Earth}  
aForceModel.GravityField.Earth.Degree = 21  
aForceModel.GravityField.Earth.Order  = 21  
aForceModel.GravityField.Earth.PotentialFile = 'c:\MyData\file.cof'
```

## Using Multiple Harmonic Gravity Models

GMAT permits modeling non-spherical harmonic gravity models for multiple bodies simultaneously. This is an advanced capability that should only be used with caution, as it is easy to unknowingly misconfigure it and obtain inaccurate results. The user should note that there are few instances in the solar system where this capability is needed and should first consider if its use is appropriate or necessary. A critical aspect of this feature is the correct choice of the central body of the force model, which should generally be the body whose sphere of influence contains the trajectory. If choosing to use this feature, the user should choose the **ForceModel CentralBody** carefully and may wish to examine the results under different assumptions of the central body.

In the case of trajectory design and optimization, the common best practice is not to use multiple harmonic gravity models, but instead to segment the trajectory by sphere of influence, using force models employing only one primary body in each sphere of influence. The **Ex\_LunarTransfer** and **Ex\_MarsBPlane** sample scripts are good examples of this.

The current release of GMAT allows multiple harmonic gravity models for trajectory design and mission planning work, but restricts the use of harmonic gravity models to a single central body setting when performing orbit determination related tasks.

The script excerpt below shows an example of how to configure harmonic gravity modeling for both the Earth and Moon (Luna) simultaneously.

```
Create ForceModel FM

FM.CentralBody          = Earth;
FM.PrimaryBodies        = {Earth, Luna};
FM.PointMasses          = {Sun, Venus, Jupiter, Saturn};
FM.GravityField.Earth.Degree = 12;
FM.GravityField.Earth.Order = 12;
FM.GravityField.Earth.TideModel = 'None';
FM.GravityField.Earth.PotentialFile = 'EGM96.cof';
FM.GravityField.Luna.Degree = 50;
FM.GravityField.Luna.Order = 50;
FM.GravityField.Luna.PotentialFile = 'grgm900c.cof';
FM.GravityField.Luna.TideModel = 'None';
FM.SRP                  = On
FM.ErrorControl         = 'None'
```

## Force Model Settings and Choice of CentralBody can Greatly Affect Accuracy of Results



### Warning

Sometimes, even when you might not think so, you must include gravitational forces from other bodies in the solar system in the force model. When GMAT propagates a **Spacecraft**, the **CentralBody** parameter is used as the basis for the numerical integration. In particular, GMAT uses the “relative” equations of motion of the satellite with respect to the **CentralBody**. This equation involves terms from the Sun and other planets in the solar system. (See, for example, A. E. Roy, Orbital Motion 2e, Section 6.2, on the Equations of Relative Motion). If the GMAT user **Spacecraft** is in a multi-body orbit regime, or the user is switching the **CentralBody**, or is using a non-recommended (as explained below) **CentralBody**, *the user must include gravitational forces from other bodies in the solar system in the Force Model*. Note that best practice is also to use the **CentralBody** associated with the dominant gravitational force on your **Spacecraft**. For example, if your **Spacecraft** is in low lunar orbit, the moon’s gravity will be the dominant gravitational force. Thus, you should use the Moon as the **CentralBody** and not the Earth. One can also consider switching central bodies during your propagation as your **Spacecraft** approaches different spheres of influence.

## Overview of Tide Model Field Interactions

By default, the tide data source is set to **None** and the tide model selector is disabled if no tide model is selected. To use a tide model, first the tide data source must be changed to either **Inherited** or **Tide File**, at which point the Tide Model selector becomes enabled to select from the tide models supported by the tide data source. See the field list above for available models. The **Inherited** option indicates that the data for the tide model is provided either by the gravity potential file or the data is built into GMAT. The tide data contained in a gravity potential file has precedence over any built-in values. The **Tide File** option enables the file selector to choose a file containing the Love numbers to be used as the data source for the tide model. The tide data contained in a tide file has precedence over all other tide data sources.

## Configuring Tide Models

GMAT supports solid tide modeling for all central bodies, and both solid and pole tide modeling for the Earth. Tide models can only be used if a **PrimaryBody** is set. GMAT contains built-in values for both solid and pole tides for the Earth. External files can also be used to provide the Love numbers to be used in the tide model, either from a gravity file that supports tides, or a separate tide file.

If a gravity file with Love numbers is provided, those Love numbers will be used for the solid tide model calculations. If a tide file is provided, the Love numbers in the tide file will be used. If both a gravity file with Love numbers and a tide file are provided, the Love numbers from both files will be used, with the Love numbers in the tide file having

precedence over the gravity file. Only if no tide file is provided and the gravity potential file has no love numbers are GMAT's default Love numbers used for the Earth. GMAT's built-in values are the only data source for pole tides.

Below is an example script snippet for configuring a custom gravity model including Lunar solid tides.

```
Create ForceModel aForceModel  
  
aForceModel.CentralBody = Luna  
aForceModel.PrimaryBodies = {Luna}  
aForceModel.GravityField.Luna.Degree = 21  
aForceModel.GravityField.Luna.Order = 21  
aForceModel.GravityField.Luna.PotentialFile = 'c:\MyData\file.cof'  
aForceModel.GravityField.Luna.TideFile = 'c:\MyData\file.tide'  
aForceModel.GravityField.Luna.TideModel = 'Solid'
```

Tide files use the .tide file extension. You can provide a custom tide file for your application as long as it is in the supported format. Tide files contain the Love numbers to be used to model the solid tides. Tide files can include the k<sub>2</sub>, k<sub>3</sub>, and k<sub>+</sub> coefficients. The format used by the tide file is 'k {degree} {order} {value}' or 'kplus {order} {value}' for k<sub>+</sub>.

Below is a sample tide file using the built-in values that GMAT uses for the Earth's Love numbers

```
k 2 0 0.30190  
k 2 1 0.29830  
k 2 2 0.30102  
k 3 0 0.093  
k 3 1 0.093  
k 3 2 0.093  
k 3 3 0.094  
kplus 0 -0.00087  
kplus 1 -0.00079  
kplus 2 -0.00057
```

## Zero Tide and Tide Free Models

The selection of a tide model is closely linked to the gravitational potential model that is used. Some gravitational potential models incorporate some tidal effects into the gravitational potential model. Two common ways gravitational models handle modeling tidal forces are by being tide-free and zero-tide. Tide free gravitational models contain no effects of tidal forces in the gravitational potential, while zero tide gravitational models contain the permanent (time-independent) effect of tides on the potential. For STK .grv files, the "IncludesPermTides" keyword is recognized to identify if the gravitational potential model includes permanent tide effects, however the coefficients in the "TideFree-Values" and "ZeroTideValues" keyword blocks are currently ignored.



## Caution

Caution: If a zero tide gravitational model is used with the **Solid** or **SolidAndPole** tide options, the effect of permanent tides is double counted and may yield inaccurate results. For further a more in-depth discussion, please consult the *IERS Conventions (2010)*. GMAT does not convert between a zero tide and tide free potential, therefore the user must pay attention to which potential they intend on using, particularly when modeling solid tides.

## Configuring Drag Models

GMAT supports many density models for Earth including **Jacchia-Roberts** and various MSISE models. Density models for non-Earth bodies -- the Mars-GRAM model for example -- are included using custom plug-in components and are currently only supported in the script interface. With any density model, the user also has the choice of using either a spherical spacecraft area model or a SPAD file for the spacecraft area computation. Spacecraft area modeling is selected using the **Drag.DragModel** parameter. More details of SPAD area modeling can be found in [Spacecraft Ballistic/Mass Properties](#)

To configure Earth density models, select Earth as the primary body, In the GUI, this activates the **AtmosphereModel** list. You can configure the solar flux values using the **Setup** button next to the **AtmosphereModel** list after you have selected an atmosphere model. Below is an example script snippet for configuring the **NRLMSISE00** density model.

```
Create ForceModel aForceModel  
  
aForceModel.PrimaryBodies = {Earth}  
aForceModel.Drag.AtmosphereModel = NRLMSISE00
```



## Caution

Caution: GMAT uses the original single precision FORTAN code developed by the scientists who created the MSISE models. At low altitudes, the single precision density can cause numeric issues in the double precision integrator step size control and integration can be unacceptably slow. You can avoid the performance issue by using either fixed step integration or by using a relatively high **Accuracy** value such as 1e-8. You may need to experiment with the **Accuracy** setting to a value acceptable for your application.

Note that when you select **None** for **Drag.AtmosphereModel**, the fields associated with density configuration, such as **Drag.F107**, **Drag.F107A**, and **Drag.MagneticIndex** and others are inactive and must be removed from your script file to avoid parsing errors. When working in the GUI, this is performed automatically.

The table below describes the limits on altitude for drag models supported by GMAT.

Model	Theoretical Altitude (h) Limits	Comments
<b>MSISE86</b>	$90 < h < 1000$	GMAT will not allow propagation below 90 km altitude.
<b>MSISE90</b>	$0 < h < 1000$	GMAT will allow propagation below 0 km altitude but results are non-physical.
<b>NRLMSISE00</b>	$0 < h < 1000$	GMAT will allow propagation below 0 km altitude but results are non-physical.
<b>JacchiaRoberts</b>	$h > 100$	GMAT will not allow propagation below 100 km altitude.

## MarsGRAM2005

When **PrimaryBody** is **Mars**, you can choose Mars-GRAM 2005 as your atmosphere model. This model is only available when the libMarsGRAM plugin is available and enabled in the GMAT startup file.



### Warning

As of version R2015a, you can only have one unique Mars-GRAM force model configuration in a given script. If you include multiple propagators with Mars-GRAM force models with different Mars-GRAM configurations, the different configurations are not honored, and all of the propagators will use the same configuration for Mars-GRAM.

When using the **MarsGRAM2005** atmosphere model, three new fields are available in the script language (but not the GUI):

- **Drag.InputFile**
- **Drag.DensityModel**

See the [Fields section](#) for details on these fields.

In addition, the space weather fields are treated as follows:

- **Drag.F107**: value of 10.7 cm solar flux at 1 AU, as documented in the [Fields section](#)
- **Drag.F107A**: not used
- **Drag.MagneticIndex**: not used

The Mars-GRAM 2005 input file is a text file in FORTRAN NAMELIST format. Most variables in this file are passed directly to the Mars-GRAM model and are used as intended. However, some are replaced internally by GMAT-supplied values. The following table lists those input variables that are handled specially.

Input Variable	GMAT usage
(Unlisted)	Passed through to Mars-GRAM 2005 model

Input Variable	GMAT usage
DATADIR	Always '.../data/atmosphere/MarsGRAM2005/bin-Files'
GCMDIR	Always '.../data/atmosphere/MarsGRAM2005/bin-Files'
IERT	Always 1 (Earth-receive time)
IUTC	Always 0 (TT time)
MONTH	Replaced by current propagation epoch
MDAY	Replaced by current propagation epoch
MYEAR	Replaced by current propagation epoch
NPOS	Always 1
IHR	Replaced by current propagation epoch
IMIN	Replaced by current propagation epoch
ISEC	Replaced by current propagation epoch
LonEW	Always 1 (positive East)
F107	Replaced by value of <b>Drag.F107</b>
FLAT	Replaced by current propagation state
FLON	Replaced by current propagation state
FHGT	Replaced by current propagation state
MOLAheights	Always 0 (reference ellipsoid)
iup	Always 0 (no output)
ipclat	Always 0 (planetographic input)
requa	Replaced by value of <b>Mars.EquatorialRadius</b>
rpole	Replaced by GMAT's value of Mars polar radius (calculated from <b>Mars.EquatorialRadius</b> and <b>Mars.Flattening</b> )

The input file is read by the Mars-GRAM 2005 model code, which has limited error checking. If the input file or data files are incorrect or missing, GMAT may exhibit unintended behavior. Note that local winds returned by the Mars-GRAM 2005 model are not included in GMAT's drag model.

### Space Weather Data for Earth Atmospheric Density Models

GMAT supports several space weather input types for drag modeling including constant flux and geomagnetic index values, a historical data file, and a predicted data file. You can separately configure the data used for historical data and predicted data. For historical data you can choose between constant values and a CSSI space weather file. For predicted data you can choose between constant values, a CSSI space weather file, and a Schatten predict file. Each of those sources is discussed in detail below.

The precedence for data source is determined by the current propagation epoch (i.e. the epoch when density is evaluated), and the epochs contained on the data files. The following rules are applied:

- If both historical data and predicted data sources are set to **ConstantFluxAndGeoMag**, then constant values are always used.
- If you have selected a CSSI file as the historical data source and the current propagation epoch falls before the last row of data in the CSSI file's observed data block, then the CSSI data is used. If the current propagation epoch is later than the last record in the CSSI observed data block, the specified predicted data source is used. If the propagation epoch is before the first observed data record the first record in the file is used.
- If you have selected the Schatten file as the predicted data source and a CSSI file as the historic source, GMAT will switch to the Schatten file at the end of the observed data block in the CSSI data file.
- If you have selected the Schatten file as the predicted data source and **ConstantFluxAndGeoMag** as the historic source, GMAT will switch to the Schatten data file at the start of the Schatten data records.
- The Schatten file option may not be used as a historic space weather source.

## Constant Values

GMAT supports constant flux and geomagnetic index values for all Earth density models. You configure GMAT to use those values for historical and predicted data as shown below using NRLMSISE00 for the example.

```
Create ForceModel aForceModel

aForceModel.Drag.AtmosphereModel = NRLMSISE00
aForceModel.Drag.HistoricWeatherSource = 'ConstantFluxAndGeoMag'
aForceModel.Drag.PredictedWeatherSource = 'ConstantFluxAndGeoMag'
aForceModel.Drag.F107 = 150
aForceModel.Drag.F107A = 150
aForceModel.Drag.MagneticIndex = 3
```

## CSSI Space Weather Data

You can provide a Center for Space Standards and Innovation (CSSI) file for historical and predicted space weather data. The CCSI file format is described in detail at the [Celestrak](#) website and the files are available for download at that site and [here](#). You can configure GMAT to use the CCSI file for historical and predicted data as shown below.

```
Create ForceModel aForceModel

aForceModel.Drag.AtmosphereModel = NRLMSISE00
aForceModel.Drag.HistoricWeatherSource = 'CSSISpaceWeatherFile'
aForceModel.Drag.PredictedWeatherSource = 'CSSISpaceWeatherFile'
aForceModel.Drag.CSSISpaceWeatherFile = 'SpaceWeather-All-v1.2.txt'
```

You can provide a full or relative path to the file, or put the file in GMAT's data file folders documented in the startup file help.

## Schatten Space Weather Data

You configure GMAT to use Schatten predicted data as shown below. Schatten data files may only be used as predicted space weather data.

```
Create ForceModel aForceModel

aForceModel.Drag.AtmosphereModel = NRLMSISE00
aForceModel.Drag.PredictedWeatherSource = 'SchattenFile'
aForceModel.Drag.SchattenFile = 'SchattenPredict.txt'
aForceModel.Drag.SchattenErrorModel = 'Nominal'
aForceModel.Drag.SchattenTimingModel = 'NominalCycle'
```

The Schatten file is distributed by the Flight Dynamics Facility (FDF) at Goddard Space Flight Center and made accessible at the Community Coordinated Modeling Center (CCMC) website. You can access current and past Schatten data files at the [https://iswa.ccmc.gsfc.nasa.gov/iswa\\_data\\_tree/model/solar/FDF/SchattenSolarFluxPrediction/](https://iswa.ccmc.gsfc.nasa.gov/iswa_data_tree/model/solar/FDF/SchattenSolarFluxPrediction/) URL. Note that when downloading Schatten files from the CCMC, you must manually add the BEGIN\_DATA and END\_DATA tags as shown in the example below.

You can provide a full or relative path to the file, or put the file in GMAT's data file folders documented in the startup file help. Additionally you can choose between **Nominal**, **PlusTwoSigma**, and **MinusTwoSigma** for the **SchattenErrorModel**, and between **NominalCycle**, **EarlyCycle**, and **LateCycle** for the **SchattenTimingModel**. Note that GMAT reads the raw file containing all permutation of mean, +2 sigma, and -2 sigma, and nominal, early and late solar cycles. The files from the FDF must be modified to include keywords that indicate when data starts and ends as shown below:

	NOMINAL TIMING				EARLY TIMING				LATE TIMING					
	mo.	yr.	mean	+2sig	-2sig	ap	mean	+2sig	-2sig	ap	mean	+2sig	-2sig	ap
BEGIN_DATA														
2	2011	92	107	76	9	105	125	85	10	77	87	66	8	
3	2011	93	110	77	9	106	128	86	10	79	89	67	8	
4	2011	95	112	78	9	108	129	87	10	80	92	69	8	
END_DATA														

Data must be formatted according to FORMAT(I3,I5,I6,11I5), and no comments or blank lines can occur between the BEGIN\_DATA and END\_DATA keywords.

## Configuring SRP Models

GMAT supports a spherical SRP model, and a SPAD file for high fidelity SRP modeling. Both models use a dual cone model for central body shadowing of the spacecraft. See the [Spacecraft Ballistic/Mass Properties](#) documentation for configuring a SPAD file for a spacecraft. The script snippet below shows how to configure two **ForceModels**, one that uses **Spherical** area modeling (the default), and one that uses a **SPADFile**.

```
% A spherical SRP model
Create ForceModel aForceModel_1

aForceModel_1.PrimaryBodies = {Earth}
```

```
aForceModel_1.SRP = On
aForceModel_1.SRP.SRPMODEL = Spherical

% A SPAD SRP model
Create ForceModel aForceModel_2

aForceModel_2.PrimaryBodies = {Earth}
aForceModel_2.SRP = On
aForceModel_2.SRP.SRPMODEL = SPADFILE
```

You can define the solar flux using two approaches which are currently only supported in the script interface. One approach is to define the flux value using the **SRP.Flux** field and the value of an astronomical unit (in km) using the **Nominal\_Sun** field as shown in the following example.

```
Create ForceModel aForceModel

aForceModel.PrimaryBodies = {Earth}
aForceModel.SRP = On
aForceModel.SRP.Flux = 1367
aForceModel.SRP.Nominal_Sun = 149597870.691
```

An alternative approach is to define the flux pressure at 1 astronomical unit using the **Flux\_Pressure** field as shown below..

```
Create ForceModel aForceModel

aForceModel.PrimaryBodies = {Earth}
aForceModel.SRP = On
aForceModel.SRP.Flux_Pressure = 4.53443218374393e-006
aForceModel.SRP.Nominal_Sun = 149597870.691
```

If you mix flux settings, as shown in the example below, GMAT will use the last approach in the script. Here, GMAT will use the **Flux\_Pressure** setting.

```
Create ForceModel aForceModel

aForceModel.PrimaryBodies = {Earth}
aForceModel.SRP = On
aForceModel.SRP.Flux = 1370
aForceModel.SRP.Nominal_Sun = 149597870
aForceModel.SRP.Flux_Pressure = 4.53443218374393e-006
```



### Caution

Caution: GMAT's default option for configuring solar flux for an SRP model is to use **SRP.Flux** and **Nominal\_Sun** fields. If you initially configured the **Flux\_Pressure** field, when you save your mission via the save button in the toolbar, GMAT will write out **SRP.Flux** and **Nominal\_Sun** values consistent with your setting of **Flux\_Pressure**.

## Variational Equations and the STM

GMAT can optionally propagate the orbit State Transition Matrix (STM). For more information on how to configure GMAT to compute the STM, see the Propagate command documentation.



### Caution

Caution: GMAT allows you to propagate the State Transition Matrix (STM) along with the orbital state. However, not all variational terms are implemented for STM propagation. The following are implemented: point mass perturbation, spherical harmonics (with tide models), drag, and solar radiation pressure. The following are NOT implemented: relativistic terms and finite burns. Additionally, the SRP variational term does not include the partial derivative of the percent shadow with respect to orbital state. This approximation is acceptable for orbits with short penumbra durations but is inaccurate for orbits that spend relatively long periods of time in penumbra.

## External Force Model

This feature expands the capability of GMAT **ForceModels** by allowing the use of external, python-defined force models in GMAT integrators. Python scripts may be added to the Python userfunctions folder, or any other folder specified in the GMAT startup file with **PYTHON\_MODULE\_PATH**. Additionally, the GMAT [python interface](#) must be configured. To use an external force model, create a python script containing a function that GMAT will call during the orbit integration. By default, this function should be called `GetDerivatives()`, but the function name can be changed using the **ForceModel.External.DerivativesFunction** parameter. This function must take in four parameters in the order described below. The python names of these parameters can be changed by the user within the python function definition:

- state: list, The propagation state vector. The size and contents of this vector can vary and depend on the user **ForceModel** and **Propagator** configuration. Contains only floating point values.
- epoch: float, The current epoch in **A1ModJulian** format.
- description: list, A list of strings that describe each state vector item. The size and order of this list matches that of the state vector.
- order: int (1,2), The order of the derivatives to be calculated by the ExternalForceModel. If order is 1, the values returned should be first order derivatives of the state vector. If order is 2, the values returned should be the second order derivatives. Most GMAT integrators use only 1st order derivatives. Currently, the only integrator that uses 2nd order derivatives is RungeKutta68.

The derivatives function must return a list of floats that matches the size of the state vector. Use the table below to help you determine what GMAT expects to receive from the derivatives function. Be sure the list returned from the derivatives function is in the same order as specified in the state parameter list description passed to the function. Any matrices (like the **A** matrix) to be returned must first be reshaped into linear arrays and appended to the state derivatives in the proper order.

State Component	What GMAT Provides	What to Return from the Derivatives Function	Comments
CartesianState	Position and velocity in the central body inertial (J2000 axes) frame	For a first-order integrator, return [vx, vy, vz, ax, ay, az], where [ax, ay, az] are the acceleration components of the external force in inertial coordinates. For a second-order integrator, return [ax, ay, az, 0, 0, 0].	Velocity components of the returned list are ignored; GMAT will automatically substitute the velocity from the state vector. You may return zero for the velocity components. Most GMAT integrators are first-order integrators. RungeKutta68 is the only second-order integrator currently implemented.
TotalMass	Current space-craft mass (kg)	The mass flow rate, dm/dt	Units are kg/sec.
STM (State Transition Matrix)	State transition matrix $\Phi_i$ from $t_{i-1}$ to $t_i$ , such that $\Phi_i = \Phi(t_{i-1}, t_i)$ .	The A matrix	See the GMAT Math Specification, Section 4.1.3 and Eq. 4.14 for a definition of the A matrix.
Covariance	A 6x6 placeholder matrix.	A 6x6 placeholder matrix. These values can be anything (zeros are recommended), and must be returned by the user in the appropriate locations of the partials vector, but they have no effect on the covariance propagation.	The external force model currently has no effect on covariance propagation. If using an external force model and propagating the covariance, an additional 6x6 matrix labeled "Covariance" will be included in the state. This matrix should be ignored. However, the user must pad out the returned partial derivatives vector with 36 placeholder elements.



### Note

When returning 1st order derivatives, GMAT will ignore the first three values. These values correspond to Cartesian velocity of the first **Spacecraft** in the state vector. These values are taken from the current state vector internally by GMAT. It is recommended users return [0.0, 0.0, 0.0] for these values.



## Note

Since the external force model necessitates using an external python script, a user can connect this script to GMAT's python API. This allows for a variety of features including giving the user access to various spacecraft parameters from inside the derivatives function. A note of caution, spacecraft parameters accessed through the API from within an external force model function, may not always be up to date. Internal spacecraft objects are not updated every step as various integrators perform sub steps in which state data may be changed. The GMAT spacecraft object will only be updated after completing a full step. Any data that is contained in the state vector parameter should only be accessed from the state vector parameter passed in directly to the external force model derivatives function. However, any data not passed directly into the derivatives function is safe to access from the API.

## Examples

A **ForceModel** for point mass propagation.

```
Create Spacecraft aSat
Create ForceModel aForceModel

aForceModel.CentralBody = Earth
aForceModel.PointMasses = {Earth}

Create Propagator aProp

aProp.FM = aForceModel

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = .2}
```

A **ForceModel** for high fidelity low Earth orbit propagation.

```
Create Spacecraft aSat
Create ForceModel aForceModel

aForceModel.CentralBody = Earth
aForceModel.PrimaryBodies = {Earth}
aForceModel.PointMasses = {Sun, Luna}
aForceModel.SRP = On
aForceModel.RelativisticCorrection = On
aForceModel.ErrorControl = RSSStep
aForceModel.GravityField.Earth.Degree = 20
aForceModel.GravityField.Earth.Order = 20
aForceModel.GravityField.Earth.PotentialFile = 'EGM96.cof'
aForceModel.GravityField.Earth.TideModel = 'None'
aForceModel.Drag.AtmosphereModel = MSISE90
```

```
aForceModel.Drag.F107 = 150
aForceModel.Drag.F107A = 150
aForceModel.Drag.MagneticIndex = 3
aForceModel.SRP.Flux = 1359.388569998901
aForceModel.SRP.SRPMODEL = Spherical;
aForceModel.SRP.Nominal_Sun = 149597870.691

Create Propagator aProp

aProp.FM = aForceModel

BeginMissionSequence

Propagate aProp(aSat){aSat.ElapsedDays = .2}
```

A **ForceModel** that uses a SPAD SRP File.

```
Create Spacecraft aSpacecraft

aSpacecraft.DryMass = 2000
aSpacecraft.SPADSRPFile = '..\data\vehicle\spad\SphericalModel.spo'
aSpacecraft.SPADSRPScaleFactor = 1

Create ForceModel aFM

aFM.SRP = On
aFM.SRP.SRPMODEL = SPADFile

Create Propagator aProp

aProp.FM = aFM

BeginMissionSequence

Propagate aProp(aSpacecraft) {aSpacecraft.ElapsedDays = 0.2}
```

A **ForceModel** for high fidelity lunar orbit propagation.

```
Create Spacecraft moonSat

moonSat.DateFormat = UTCGregorian
moonSat.EPOCH = 01 Jun 2004 12:00:00.000
moonSat.COORDINATESYSTEM = MoonMJ2000Eq
moonSat.DISPLAYSTATETYPE = Cartesian
moonSat.X = -1486.792117191545200
moonSat.Y = 0.0
moonSat.Z = 1486.792117191543000
moonSat.VX = -0.142927729144255
moonSat.VY = -1.631407624437537
moonSat.VZ = 0.142927729144255
```

```
Create CoordinateSystem MoonMJ2000Eq  
  
MoonMJ2000Eq.Origin = Luna  
MoonMJ2000Eq.Axes    = MJ2000Eq  
  
Create ForceModel MoonLP165P  
  
MoonLP165P.CentralBody = Luna  
MoonLP165P.PrimaryBodies = {Luna}  
MoonLP165P.SRP = On  
MoonLP165P.SRP.Flux = 1367  
MoonLP165P.SRP.Nominal_Sun = 149597870.691  
MoonLP165P.Gravity.Luna.PotentialFile = ../data/gravity/luna/LP165P.cof  
MoonLP165P.Gravity.Luna.Degree = 20  
MoonLP165P.Gravity.Luna.Order = 20  
  
Create Propagator RKV89  
  
RKV89.FM = MoonLP165P  
  
BeginMissionSequence  
  
Propagate RKV89(moonSat) {moonSat.ElapsedSecs = 300}
```

### A **ForceModel** using an **ExternalForceModel**.

```
Create Spacecraft aSat  
  
Create ForceModel ExternalForceModel  
ExternalForceModel.External = SimpleExternalForceModel;  
ExternalForceModel.External.ExcludeOtherForces = true;  
  
Create Propagator aProp  
aProp.FM = ExternalForceModel  
  
BeginMissionSequence  
  
Propagate aProp(aSat) {aSat.ElapsedDays = .2}
```

## Formation

A collection of spacecraft.

### Description

A **Formation** resource allows you to combine spacecraft in a “container” object and then GMAT’s propagation subsystem will model the collection of spacecraft as a coupled dynamic system. You can only propagate **Formation** resources using numerical-integrator type propagators. This resource cannot be modified in the Mission Sequence.

See Also: [Propagate](#), [Color](#)

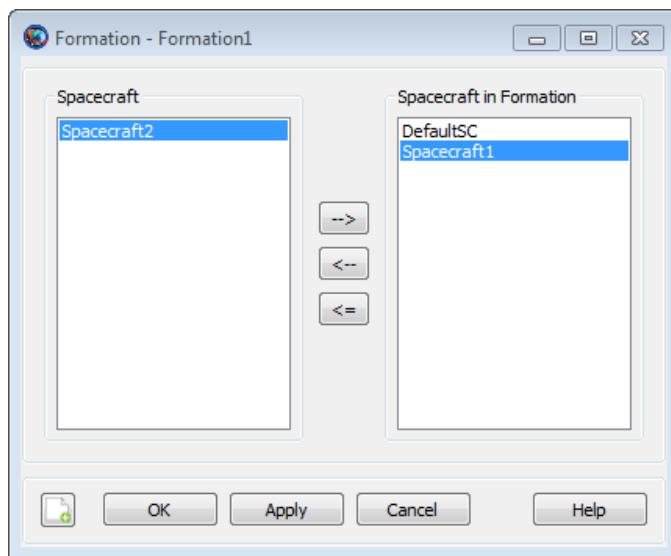
### Fields

Field	Description
<b>Add</b>	Adds a list of <b>Spacecraft</b> to the <b>Formation</b> . The list cannot be empty.  Data Type              Resource array Allowed Values        array of spacecraft Access                  set Default Value         empty list Units                   N/A Interfaces            GUI, script

### GUI

To create a simple **Formation** and configure its **Spacecraft**, in the **Resource Tree**:

1. Right-click the **Spacecraft** folder and select **Add Spacecraft**.
2. Right click the **Formations** folder and select **Add Formation**.
3. Double-click **Formation1** to open its dialog box.
4. Click the right-arrow button twice to add **DefaultSC** and **Spacecraft1** to **Formation1**.
5. Click **Ok**.



### Note

A **Spacecraft** can only be added to one Formation.

### Remarks

A **Formation** is a container object that allows you to model a group of **Spacecraft** as a coupled system. You can add **Spacecraft** to a **Formation** using the **Add** field as shown in the script examples below or in the GUI example above. The primary reasons to use a **Formation Resource** are (1) to simplify the propagation of multiple spacecraft and (2) for performance reasons. You can only add a spacecraft to a one formation, and you cannot add a formation to a formation. GMAT's propagation subsystem models **Formations** as a coupled dynamic system. Once spacecraft have been added to a **Formation**, you can easily propagate all of the spacecraft by simply including the formation in the **Propagate** command statement like this:

```
Propagate aPropagator(aFormation) {aSat1.ElapsedSecs = 12000.0}
```

You can only propagate **Formation** resources using numerical-integrator type propagators. GMAT does not support propagation of the orbit state transition matrix when propagating formations.

When propagating a **Formation**, all spacecraft in the **Formation** must have equivalent epochs. GMAT will allow you to separately propagate a **Spacecraft** that has been added to a **Formation**, like this:

```
aFormation.Add = {aSat1, aSat2}  
Propagate aPropagator(aSat1) {aSat1.ElapsedSecs = 12000.0}
```

However, when a **Formation** is propagated, if the epochs of all **Spacecraft** in the **Formation** are not equivalent to a tolerance of a few microseconds, **GMAT** will throw an error and execution will stop.

## Setting Colors On Spacecrafts In Formation Resource

If you want to set unique colors on spacecraft trajectories that are nested in the **Formation** resource, then change colors through either the **Spacecraft** resource or the **Propagate** command. See the [Color](#) documentation for discussion and examples on how to set unique colors on **Spacecraft** resource and **Propagate** command.

### Examples

Create two **Spacecraft**, add them to a **Formation**, and propagate the **Formation**.

```
Create Spacecraft aSat1 aSat2  
  
Create Formation aFormation  
aFormation.Add = {aSat1, aSat2}  
  
Create Propagator aPropagator  
  
BeginMissionSequence  
  
Propagate aPropagator(aFormation) {aSat1.ElapsedSecs = 12000.0}
```

## GroundStation

A ground station model.

### Description

A **GroundStation** models a facility fixed to the surface of a **CelestialBody**. There are several state representations available for defining the location of a ground station including Cartesian and spherical. This resource cannot be modified in the mission sequence.

See Also: [ContactLocator](#), [CoordinateSystem](#), [Color](#)

### Fields

Field	Description	
<b>AddHardware</b>	List of all <b>Transmitter</b> , <b>Receiver</b> , and <b>Antenna</b> hardware used by ground station	
	<b>Data Type</b>	Object Array
	<b>Allowed Values</b>	Each element in the list has to be a valid <b>Transmitter</b> , <b>Receiver</b> , or <b>Antenna</b>
	<b>Access</b>	set
	<b>Default Value</b>	None
	<b>Units</b>	N/A
<b>Altitude</b>	Interfaces	script
	The altitude of the station with respect to the <b>HorizonReference</b> .	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	-# < Real < #
	<b>Access</b>	set
	<b>Default Value</b>	0
<b>CentralBody</b>	<b>Units</b>	km
	Interfaces	GUI, script
	The central body of the <b>GroundStation</b> .	
	<b>Data Type</b>	String
	<b>Allowed Values</b>	<b>Earth</b> . Configured celestial body.
	<b>Access</b>	set

Field	Description												
<b>DataSource</b>	<p>Source of where to get <b>Temperature</b>, <b>Pressure</b>, <b>Humidity</b>, and <b>MinimumElevationAngle</b>. If the value is Constant, then the values of these parameters, as set in the <b>GroundStation</b> resource, remain constant for all relevant measurements. Currently, the value of Constant is the only allowed value.</p> <table> <tr> <td><b>Data Type</b></td><td>Enumeration</td></tr> <tr> <td><b>Allowed Values</b></td><td>Constant</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>Constant</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Enumeration	<b>Allowed Values</b>	Constant	<b>Access</b>	set	<b>Default Value</b>	<b>Constant</b>	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Enumeration												
<b>Allowed Values</b>	Constant												
<b>Access</b>	set												
<b>Default Value</b>	<b>Constant</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>ErrorModels</b>	<p>User-defined list of <b>ErrorModel</b> objects that describe the measurement error models used for this <b>GroundStation</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>StringList</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any valid user-defined <b>ErrorModel</b> resource</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>None</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	StringList	<b>Allowed Values</b>	Any valid user-defined <b>ErrorModel</b> resource	<b>Access</b>	set	<b>Default Value</b>	<b>None</b>	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	StringList												
<b>Allowed Values</b>	Any valid user-defined <b>ErrorModel</b> resource												
<b>Access</b>	set												
<b>Default Value</b>	<b>None</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>HorizonMaskFileName</b>	<p>Path to an external file specifying angle pairs that describe an orientation-dependent horizon mask profile. The mask is only used by the <b>ContactLocator</b> resource and has no effect on estimation or simulation. See Remarks below for more details on the contents and formatting of this file.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Path to an existing text mask file</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>None</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Path to an existing text mask file	<b>Access</b>	set	<b>Default Value</b>	<b>None</b>	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Path to an existing text mask file												
<b>Access</b>	set												
<b>Default Value</b>	<b>None</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>HorizonReference</b>	<p>The system used for the horizon. <b>Sphere</b> is equivalent to Geocentric, <b>Ellipsoid</b> is equivalent to Geodetic.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>Sphere</b>, <b>Ellipsoid</b></td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>Sphere</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	<b>Sphere</b> , <b>Ellipsoid</b>	<b>Access</b>	set	<b>Default Value</b>	<b>Sphere</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	<b>Sphere</b> , <b>Ellipsoid</b>												
<b>Access</b>	set												
<b>Default Value</b>	<b>Sphere</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

Field	Description												
<b>Humidity</b>	<p>Humidity at ground station used to calculate tropospheric correction for the HopfieldSaastamoinen model. GMAT only uses this value if <b>DataSource</b> is set to Constant.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>0.0 &lt;= Real &lt;=100.0</b></td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td><b>55</b></td></tr> <tr> <td><b>Units</b></td><td>percentage</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	<b>0.0 &lt;= Real &lt;=100.0</b>	<b>Access</b>	set, get	<b>Default Value</b>	<b>55</b>	<b>Units</b>	percentage	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	<b>0.0 &lt;= Real &lt;=100.0</b>												
<b>Access</b>	set, get												
<b>Default Value</b>	<b>55</b>												
<b>Units</b>	percentage												
<b>Interfaces</b>	script												
<b>Id</b>	<p>Id of the <b>GroundStation</b> used in simulation and estimation</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>May contain letters, integers, dashes, underscores</td></tr> <tr> <td><b>Access</b></td><td>set,</td></tr> <tr> <td><b>Default Value</b></td><td>StationId</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	May contain letters, integers, dashes, underscores	<b>Access</b>	set,	<b>Default Value</b>	StationId	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	May contain letters, integers, dashes, underscores												
<b>Access</b>	set,												
<b>Default Value</b>	StationId												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>IonosphereModel</b>	<p>Specification of ionospheric model used in the light time calculations.</p> <table> <tr> <td><b>Data Type</b></td><td>Enumeration</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>'None', 'IRI2007','TRK-2-23'</b></td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>'None'</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Enumeration	<b>Allowed Values</b>	<b>'None', 'IRI2007','TRK-2-23'</b>	<b>Access</b>	set	<b>Default Value</b>	<b>'None'</b>	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Enumeration												
<b>Allowed Values</b>	<b>'None', 'IRI2007','TRK-2-23'</b>												
<b>Access</b>	set												
<b>Default Value</b>	<b>'None'</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>Latitude</b>	<p>The latitude of the station with respect to <b>HorizonReference</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>-90 &lt; Real &lt; 90</b></td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>0</b></td></tr> <tr> <td><b>Units</b></td><td>deg.</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	<b>-90 &lt; Real &lt; 90</b>	<b>Access</b>	set	<b>Default Value</b>	<b>0</b>	<b>Units</b>	deg.	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	<b>-90 &lt; Real &lt; 90</b>												
<b>Access</b>	set												
<b>Default Value</b>	<b>0</b>												
<b>Units</b>	deg.												
<b>Interfaces</b>	GUI, script												

Field	Description												
<b>Location1</b>	<p>The first component of the <b>GroundStation</b> location. When <b>StateType</b> is <b>Cartesian</b>, <b>Location1</b> is the x-component of station location in the body-fixed system. When <b>StateType</b> is <b>Spherical</b> or <b>Elliposoid</b>, <b>Location1</b> is the <b>Latitude</b> (deg.) of the <b>GroundStation</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-# &lt; Real &lt; # for <b>Cartesian</b>, See <b>Longitude</b>, <b>Latitude</b>, <b>Altitude</b> for others.</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>6378.1363</td></tr> <tr> <td><b>Units</b></td><td>see description</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-# < Real < # for <b>Cartesian</b> , See <b>Longitude</b> , <b>Latitude</b> , <b>Altitude</b> for others.	<b>Access</b>	set	<b>Default Value</b>	6378.1363	<b>Units</b>	see description	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-# < Real < # for <b>Cartesian</b> , See <b>Longitude</b> , <b>Latitude</b> , <b>Altitude</b> for others.												
<b>Access</b>	set												
<b>Default Value</b>	6378.1363												
<b>Units</b>	see description												
<b>Interfaces</b>	GUI, script												
<b>Location2</b>	<p>The second component of the <b>GroundStation</b> location. When <b>StateType</b> is <b>Cartesian</b>, <b>Location2</b> is the y-component of station location in the body-fixed system. When <b>StateType</b> is <b>Spherical</b> or <b>Elliposoid</b>, <b>Location2</b> is the <b>Longitude</b> (deg.) of the <b>GroundStation</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-# &lt; Real &lt; # for <b>Cartesian</b>, See <b>Longitude</b>, <b>Latitude</b>, <b>Altitude</b> for others.</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>see description</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-# < Real < # for <b>Cartesian</b> , See <b>Longitude</b> , <b>Latitude</b> , <b>Altitude</b> for others.	<b>Access</b>	set	<b>Default Value</b>	0	<b>Units</b>	see description	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-# < Real < # for <b>Cartesian</b> , See <b>Longitude</b> , <b>Latitude</b> , <b>Altitude</b> for others.												
<b>Access</b>	set												
<b>Default Value</b>	0												
<b>Units</b>	see description												
<b>Interfaces</b>	GUI, script												
<b>Location3</b>	<p>The third component of the <b>GroundStation</b> location. When <b>StateType</b> is <b>Cartesian</b>, <b>Location3</b> is the z-component of station location in the body-fixed system. When <b>StateType</b> is <b>Spherical</b> or <b>Elliposoid</b>, <b>Location3</b> is the height (km) of the <b>GroundStation</b> above the reference shape.</p> <table> <tr> <td><b>Data Type</b></td><td>Reals</td></tr> <tr> <td><b>Allowed Values</b></td><td>-# &lt; Real &lt; # for <b>Cartesian</b>, See <b>Longitude</b>, <b>Latitude</b>, <b>Altitude</b> for others.</td></tr> <tr> <td><b>Access</b></td><td>set,</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>see description</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Reals	<b>Allowed Values</b>	-# < Real < # for <b>Cartesian</b> , See <b>Longitude</b> , <b>Latitude</b> , <b>Altitude</b> for others.	<b>Access</b>	set,	<b>Default Value</b>	0	<b>Units</b>	see description	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Reals												
<b>Allowed Values</b>	-# < Real < # for <b>Cartesian</b> , See <b>Longitude</b> , <b>Latitude</b> , <b>Altitude</b> for others.												
<b>Access</b>	set,												
<b>Default Value</b>	0												
<b>Units</b>	see description												
<b>Interfaces</b>	GUI, script												

Field	Description
<b>Longitude</b>	<p>The longitude of the station.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> value &gt;=0  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> deg.  <b>Interfaces</b> GUI, script</p>
<b>MinimumElevationAngle</b>	<p>Minimum elevation angle constraint for use with <b>ContactLocator</b>. If the ground station also has an Antenna with a <b>FieldOfView</b> mask attached, times computed by the contact locator are restricted to those satisfying both the minimum elevation angle criteria and the field-of-view mask simultaneously.</p> <p>For tracking data measurement and estimation, this is minimum allowed elevation angle for the signal transmitted from spacecraft to ground station. During simulation, measurements are only generated if the spacecraft elevation from the ground station exceeds this value. During estimation, measurements must exceed this value to be admitted for processing by the estimator.</p> <p>GMAT only uses this value if <b>DataSource</b> is set to Constant.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> -90 # <b>MinimumElevationAngle</b> # 90  <b>Access</b> set  <b>Default Value</b> 7  <b>Units</b> deg  <b>Interfaces</b> GUI, script</p>
<b>OrbitColor</b>	<p>Allows you to select available colors for a user-defined <b>GroundStation</b>. The <b>GroundStation</b> object is drawn on a spacecraft's ground track plot created by <b>GroundTrackPlot</b> 2D graphics display resource. The colors can be identified through a string or an integer array. For example: Setting groundstation's color to red can be done in following two ways: <code>GroundStation.OrbitColor = Red</code> or <code>GroundStation.OrbitColor = [255 0 0]</code>. This field can be modified in the Mission Sequence as well.</p> <p><b>Data Type</b> Integer Array or String  <b>Allowed Values</b> Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255.  <b>Access</b> set  <b>Default Value</b> Thistle  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>

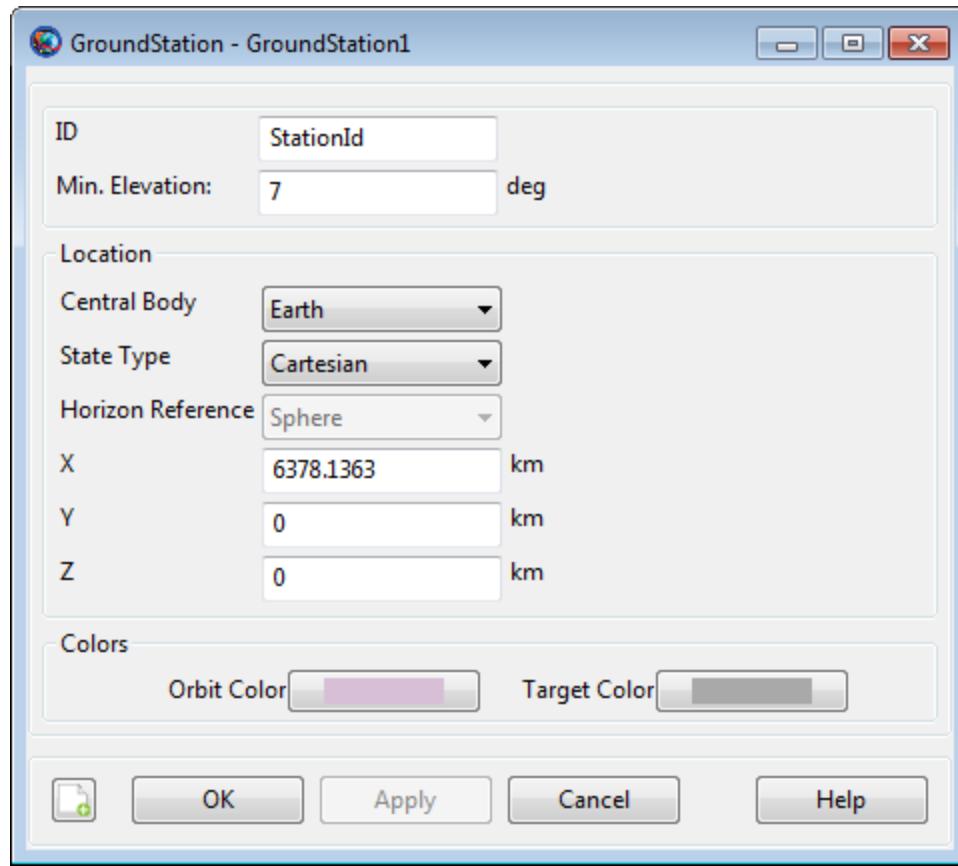
Field	Description
<b>Pressure</b>	Air pressure at ground station used to calculate tropospheric correction for the HopfieldSaastamoinen model. GMAT only uses this value if <b>DataSource</b> is set to Constant.
	<b>Data Type</b> Real <b>Allowed Values</b> <b>Real &gt;0.0</b> <b>Access</b> set, get <b>Default Value</b> <b>1013.5</b> <b>Units</b> hPa <b>Interfaces</b> script
<b>StateType</b>	The type of state used to define the location of the ground station.
	<b>Data Type</b> String <b>Allowed Values</b> <b>Cartesian, Spherical</b> <b>Access</b> set <b>Default Value</b> Cartesian <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>SpiceFrameId</b>	The station's SPICE frame ID. Note this field does not have a default, and is not saved to script, unless it is set to a specific allowed value.
	<b>Data Type</b> String or Integer <b>Allowed Values</b> Valid SPICE frame ID (text or numeric). The convention for stations is '399xyz', where 'xyz' are integers mapped to the station. For example, DSN station 'DSS-66' has Id '399066'. <b>Access</b> set <b>Default Value</b> No default. <b>Units</b> N/A <b>Interfaces</b> script

Field	Description
<b>TargetColor</b>	Allows you to select available colors for a user-defined <b>GroundStation</b> object during iterative processes such as Differential Correction or Optimization. The target color can be identified through a string or an integer array. For example: Setting groundstation's target color to yellow color can be done in following two ways: <code>GroundStation.TargetColor = Yellow</code> or <code>GroundStation.TargetColor = [255 255 0]</code> . This field can be modified in the Mission Sequence as well.
<b>Data Type</b>	Integer Array or String
<b>Allowed Values</b>	Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255.
<b>Access</b>	set
<b>Default Value</b>	DarkGray
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>Temperature</b>	Air temperature at ground station used to calculate tropospheric correction for the HopfieldSaastamoinen model. GMAT only uses this value if <b>DataSource</b> is set to Constant.
<b>Data Type</b>	Real
<b>Allowed Values</b>	<b>Real &gt;0.0</b>
<b>Access</b>	set, get
<b>Default Value</b>	<b>295.1</b>
<b>Units</b>	Kelvin
<b>Interfaces</b>	script
<b>TroposphereModel</b>	Specification of tropospheric model used in the light time calculations.
<b>Data Type</b>	Enumeration
<b>Allowed Values</b>	'None', 'HopfieldSaastamoinen', 'Marini', 'TRK-2-23'
<b>Access</b>	set
<b>Default Value</b>	<b>'None'</b>
<b>Units</b>	N/A
<b>Interfaces</b>	script

## GUI

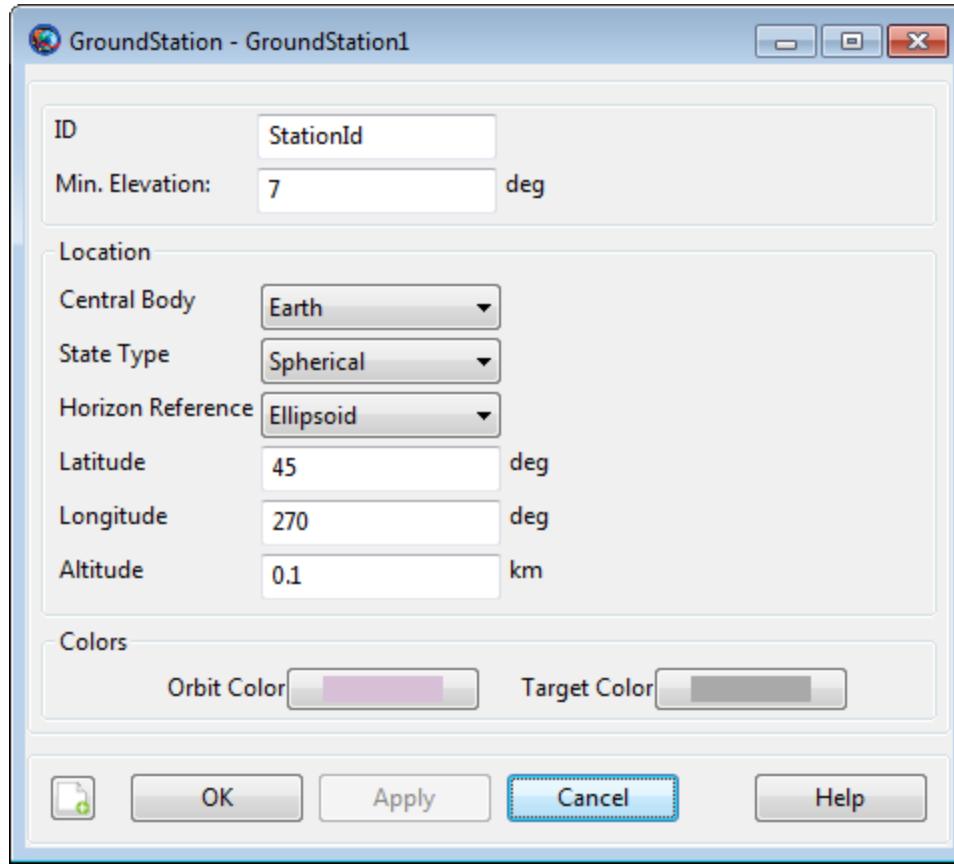
To create a **GroundStation**, starting from the **Resource Tree**:

1. Right-click the **GroundStation** folder and select **Add Ground Station**.
2. Double-click **GroundStation1**.



You can set the ground station location in several state representations. The **Cartesian** representation is illustrated above. To set the **Longitude**, **Latitude**, and **Altitude** to 45 deg., 270 deg., and 0.1 km respectively, with respect to the reference ellipsoid:

1. In the **StateType** menu, select **Spherical**.
2. In the **HorizonReference** menu, select **Ellipsoid**.
3. In the **Latitude** text box, type **45**.
4. In the **Longitude** text box, type **270**.
5. In the **Altitude** text box, type **0.1**.



## Remarks

The **GroundStation** model allows you to configure a facility by defining the location in body-fixed coordinates using one of several state representations. GMAT supports **Cartesian**, **Sphere**, and **Ellipsoid** representations and examples below show how to configure a **GroundStation** in each representation. When using the **Ellipsoid** model or **Sphere** representations, GMAT uses the physical properties - flattening and radius for example - defined on the **CelestialBody** resource to convert to Cartesian coordinates based upon a two-axis ellipsoid model.

## Ground Station Masking File

The user may specify an orientation-dependent masking file for use with the **Contact-Locator** resource. This mask is typically used to describe terrain, buildings, or other obstructions in the vicinity of the antenna which may block the signal in certain directions. The mask file consists of a keyword describing the type of angles in the file and two columns of data representing the angle pairs that describe the mask as shown in the sample below.

```
AzimuthElevationAngles
```

0.0	7.6
3.0	6.5
8.0	3.1

```
38.0  6.6
45.0  5.5
58.0  8.4
70.0  7.6
77.0  9.2
... etc ...
360.0 7.6
```

The allowed angle types are `AzimuthElevationAngles`, to specify that the file contains azimuth and elevation angle pairs, or `ClockConeAngles`, to specify that the file contains clock and cone angles.

GMAT can also read STK-format "aem" mask files, and an STK "aem" file may be assigned for use on the **HorizonMaskFileName** parameter.

### Setting Colors On a Ground Station Facility

GMAT allows you to set colors on a ground station facility that you create. The **GroundStations** are drawn on the **GroundTrackPlot** 2D graphics display. The **GroundStation** object's **OrbitColor** and **TargetColor** fields are used to set colors on a ground station facility. See the **Fields** section to read more about these two fields. Also See **Color** documentation for discussion and examples on how to set colors on a ground station facility.

### Marini Troposphere Model Data File

The Marini troposphere model utilizes a data file which contains monthly mean values for the model calculation for different locations on the Earth's surface. This data file's location is specified by the `MARINI_TROPO_FILE` property in the startup file. Each line in the data file contains a latitude longitude pair, followed by 12 values, one for each month of the year. Each value in the data file combines both the refractivity and a scale height factor into a single integer, which are both used in the Marini model. The two rightmost digits are used to obtain the scale height, while the remaining digits to the left represent the refractivity. The digits used for the scale height have the decimal point placed between the two digits, while the refractivity values have the decimal point placed at the right of its rightmost digit. For example, a value in the data file of 37068 would correspond to a refractivity of 370, and a scale height of 6.8.

The line in the data file is selected for use if it is within one degree of latitude and one degree of longitude of the ground station location. The column is then selected based on the month of the year. If the location of the ground station is within one degree of latitude and longitude of multiple locations in the data file, the first line is the one selected. If the location of the ground station is not within one degree of latitude and longitude of a location in the data file, a default value of 37068 is used instead, regardless of month. The latitude ranges from -90 to 90 degrees, while the longitude spans from 0 to 360 degrees.

### Ionosphere Modeling for Orbit Determination

The signal path for a tracking data measurement is bent as it passes through Earth's ionosphere. The magnitude of this effect depends on the signal frequency and dimin-

ishes rapidly at high frequencies. Measurements at K-band or higher frequency may often safely ignore or disable the ionosphere correction, but it is generally desirable to model ionosphere corrections for tracking at S-band or lower frequency. The ionosphere correction is also elevation-dependent and increases dramatically at low signal path elevation. At low elevation (below 5 degrees), the computed correction is likely to be inaccurate and low-elevation measurements should generally be excluded from use in estimation.

The frequency for the ionosphere correction is not retrieved from tracking data and must be set on a **Transmitter** object attached to the transmit ground station. If a Transmitter object is not supplied, a default frequency of 2000 MHz is used.



### Note

TDRS user and BRTS tracking employs different frequencies on the uplink/downlink (between the ground and TDRS) and the forward/return (between the TDRS and user or BRTS) legs. The uplink/downlink frequency for ionosphere modeling is set on the TDRS ground station Transmitter object. The forward/return frequency for ionosphere modeling is set on the BRTS ground station Transmitter object. If the BRTS does not have a Transmitter attached, the ground uplink frequency is used for computing ionosphere corrections on the forward link. Currently no media corrections (neither troposphere nor ionosphere) are included on the forward/return leg between TDRS and on-orbit users.

### TRK-2-23 Model Implementation

The use of TRK-2-23 files for Tropospheric and Ionospheric conventions requires the user to follow certain conventions. Each spacecraft should have the **NAIFId** parameter set to match their spacecraft number. For each ground station using a TRK-2-23 model, set the **Id** parameter to be the DSN station number. Additionally, each directory containing .csp and .csp.ql (quick-look) files for processing should be assigned to **Earth.DSNMediaFileDirectories** parameter as strings in an array, with each entry containing the directory path. Should a directory contain .csp and .csp.ql files with overlapping time entries, priority will be given to the data from the .csp file.

TRK-2-23 data entries include correction information for the following measurement types: ALL, DOPRNG, RANGE, DOPPLER, and VLBI. Coefficients specified as ALL can be applied to any type of measurement and are used for tropospheric corrections. Tropospheric corrections can be executed with only the seasonal.csp file, but will gain additional accuracy if monthly correction files that cover the span of the run are included. DOPRNG, RANGE, DOPPLER, and VLBI coefficients are applicable to ionospheric corrections. Since GMAT performs media corrections as a component of calculating the range measurement between two points, files must be of type DOPRNG or RANGE to be compatible with the GMAT ionospheric correction model.

Because GMAT generates Doppler measurements by first calculating the range then determining the Doppler shift, media corrections are not applied to Doppler measurements directly. For this reason, using TRK-2-23 files with corrections for solely DOPPLER mea-

surements is not supported. VLBI is also not supported, as GMAT currently does not support VLBI based measurements.

Since the ionospheric entries are defined only for the narrow windows in which the ground station has visibility of the spacecraft, users should be particularly careful to use accurate initial parameters when implementing the model. Further specifications for the TRK-2-23 data format can be found in Section 3 of Reference 1.

## Examples

Configure a **GroundStation** in Geodetic coordinates.

```
Create GroundStation aGroundStation
aGroundStation.CentralBody      = Earth
aGroundStation.StateType       = Spherical
aGroundStation.HorizonReference = Ellipsoid
aGroundStation.Location1       = 60
aGroundStation.Location2       = 45
aGroundStation.Location3       = 0.01

% or alternatively

aGroundStation.Latitude   = 60
aGroundStation.Longitude  = 45
aGroundStation.Altitude    = 0.01
```

Configure a **GroundStation** in Geocentric coordinates.

```
Create GroundStation aGroundStation
aGroundStation.CentralBody      = Earth
aGroundStation.StateType       = Spherical
aGroundStation.HorizonReference = Sphere
aGroundStation.Location1       = 59.83308194090783
aGroundStation.Location2       = 45
aGroundStation.Location3       = -15.99424674414058

% or alternatively

aGroundStation.Latitude   = 59.83308194090783
aGroundStation.Longitude  = 45
aGroundStation.Altitude    = -15.99424674414058
```

Configure a **GroundStation** in Geocentric coordinates.

```
Create GroundStation aGroundStation
aGroundStation.CentralBody = Earth
aGroundStation.StateType  = Cartesian
aGroundStation.Location1  = 2260.697433050543
aGroundStation.Location2  = 2260.697433050542
aGroundStation.Location3  = 5500.485954732006
```

Configure a **GroundStation** that, when used for navigation, will model how the RF signal is refracted in the atmosphere.

```
Create GroundStation aGroundStation  
aGroundStation.IonosphereModel      = 'IRI2007';  
aGroundStation.TroposphereModel     = 'HopfieldSaastamoinen';  
  
BeginMissionSequence;
```

Configure a **GroundStation** that, when used for navigation, will model how the RF signal is refracted in the atmosphere using TRK-2-23 data.

```
Create GroundStation aSpacecraft  
aSpacecraft.NAIFId      = -64;  
  
Create GroundStation aGroundStation  
aGroundStation.Id          = '026';  
aGroundStation.IonosphereModel = 'TRK-2-23';  
aGroundStation.TroposphereModel = 'TRK-2-23';  
  
Earth.DSNMediaFileDirectories = {'path/to/directory/Troposphere','path/to/direc  
  
BeginMissionSequence;
```

Attach a **Transmitter** and **Receiver** resource to a **GroundStation**.

```
Create Transmitter Transmitter1  
Create Receiver Receiver1  
  
Create GroundStation aGroundStation;  
aGroundStation.AddHardware = {Transmitter1, Receiver1};  
  
BeginMissionSequence;
```

## References

1. Machuzak, Berner, Pham and Stipanuk. *TRK-2-23 Media Calibration Interface*. Technical Report JPL D-16765, NASA, 2008.

## Imager

An imager with a defined field of view.

### Description

A number of GMAT resources including **Spacecraft**, and **IntrusionLocator** resource to simulate when objects pass through a spacecraft camera's field of view.

See Also: [Spacecraft](#), [IntrusionLocator](#)

### Fields

Field	Description
<b>FieldOfView</b>	Reference to optional field-of-view object which models the area visible to the antenna.  <b>Data Type</b> FOV Resource <b>Allowed Values</b> CustomFOV, ConicalFOV, or RectangularFOV Resource. <b>Access</b> set <b>Default Value</b> empty <b>Units</b> N/A <b>Interfaces</b> script
<b>DirectionX</b>	X-component of the field-of-view boresight vector expressed in spacecraft body coordinates.  <b>Data Type</b> Real <b>Allowed Values</b> Real number <b>Access</b> set <b>Default Value</b> 0 <b>Units</b> N/A <b>Interfaces</b> script
<b>DirectionY</b>	Y-component of the field-of-view boresight vector expressed in spacecraft body coordinates.  <b>Data Type</b> Real <b>Allowed Values</b> Real number <b>Access</b> set <b>Default Value</b> 0 <b>Units</b> N/A <b>Interfaces</b> script

<b>Field</b>	<b>Description</b>
<b>DirectionZ</b>	<p>Z-component of the field-of-view boresight vector expressed in spacecraft body coordinates.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real number  <b>Access</b> set  <b>Default Value</b> 1  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>SecondDirectionX</b>	<p>X-component of the vector, expressed in the body frame, used to resolve the sensor's orientation about the boresite vector.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> -1  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>SecondDirectionY</b>	<p>Y-component of the vector, expressed in the body frame, used to resolve the sensor's orientation about the boresite vector.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>SecondDirectionZ</b>	<p>Z-component of the vector, expressed in the body frame, used to resolve the sensor's orientation about the boresite vector.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> N/A  <b>Interfaces</b> script</p>

Field	Description
<b>HWOriginInBCSX</b>	X-component of the origin of the antenna's coordinate system expressed in the spacecraft's body coordinate system.
	<b>Data Type</b> Real <b>Allowed Values</b> Real <b>Access</b> set <b>Default Value</b> 0 <b>Units</b> N/A <b>Interfaces</b> script
<b>HWOriginInBCSY</b>	Y-component of the origin of the antenna's coordinate system expressed in the spacecraft's body coordinate system.
	<b>Data Type</b> Real <b>Allowed Values</b> Real <b>Access</b> set <b>Default Value</b> 0 <b>Units</b> N/A <b>Interfaces</b> script
<b>HWOriginInBCSZ</b>	Z-component of the origin of the antenna's coordinate system expressed in the spacecraft's body coordinate system.
	<b>Data Type</b> Real <b>Allowed Values</b> Real <b>Access</b> set <b>Default Value</b> 0 <b>Units</b> N/A <b>Interfaces</b> script

## Remarks

The imager model supports mask, orientation and location settings. The mask is provided by the object designated by **FieldOfView**. The location is the position of the origin of the sensor frame, expressed in the spacecraft body coordinate frame. The orientation is represented as a direction cosine matrix that is initially computed from two non-colinear vectors, provided by the user as **Direction** and **SecondDirection** components. The three axes for the sensor coordinate frame expressed in Body coordinates are computed as follow:

1. Normalize  $\mathbf{z}$  &  $\mathbf{v}$ , where  $\mathbf{z}$  is the boresight represented by **Direction** and  $\mathbf{v}$  is the **SecondDirection** vector.
2. Compute the normal  $\mathbf{N} = \mathbf{z} \times \mathbf{v}$  and its magnitude  $m$ .
3. Verify magnitude of  $\mathbf{N}$  isn't 0.0, send message if it is too close. This will happen if one of the input vectors is a zero vector or if the two vectors are co-linear, including the case where they point in opposite directions.

4.  $\mathbf{x} = \mathbf{N} / m$
5.  $\mathbf{y} = \mathbf{z} \times \mathbf{x}$
6. The rotation matrix  $\mathbf{R}_{\text{sb}}$  is constructed with  $\mathbf{x}$  on the first row,  $\mathbf{y}$  on the second, and  $\mathbf{z}$  on the third. This matrix rotates vectors from the body frame to the sensor frame.

$\mathbf{R}_{\text{sb}}$  is used as part of the chain checking if an object is in the field of view. The general approach is to have a vector from the imager to the object in a given reference frame and do a series of rotations, the last of which would use  $\mathbf{R}_{\text{sb}}$  to rotate the vector from spacecraft to imager coordinates. The default direction of the boresight is along the  $\mathbf{z}$ -axis of the body to which it is attached. Note that the default's for **Direction** and **SecondDirection** are  $[0,0,1]$  and  $[-1,0,0]$  respectively. This default orientation is selected to match the correct orientation for a **GroundStation** with an **Imager** pointed up, with **SecondDirection** matching North in the topocentric frame.

## Examples

Attach an **Imager** to a **Spacecraft Resource** type.

```
Create Imager SatImager  
  
Create Spacecraft Sat  
Sat.AddHardware = {SatImager};  
  
BeginMissionSequence;
```

Define the field-of-view, orientation, and location of an imager.

```
% Define a conical FOV  
Create ConicalFOV coneFOV;  
GMAT coneFOV.FieldOfViewAngle = 20;  
  
% Create an imager and attach a FOV  
Create Imager myImager;  
GMAT myImager.FieldOfView = coneFOV;  
  
% Define the antenna boresight direction in body coordinates  
GMAT myImager.DirectionX = 1;  
GMAT myImager.DirectionY = 0;  
GMAT myImager.DirectionZ = 0;  
  
% Define the vector to resolve orientation about boresight  
GMAT myImager.SecondDirectionX = 0;  
GMAT myImager.SecondDirectionY = 1;  
GMAT myImager.SecondDirectionZ = 0;  
  
% Define the location of antenna in body coordinates  
GMAT myImager.HWOriginInBCSX = 100;  
GMAT myImager.HWOriginInBCSY = -100;  
GMAT myImager.HWOriginInBCSZ = 0;
```

## ImpulsiveBurn

An impulsive maneuver

### Description

The **ImpulsiveBurn** resource allows the spacecraft to undergo an instantaneous Delta-V (#V), as opposed to a finite burn which is not instantaneous, by specifying the three vector components of the Delta-V. You can configure the burn by defining its coordinate system and vector component values. For **Local** coordinate systems, the user can choose the **Origin** and type of **Axes**. Depending on the mission, it may be simpler to use one coordinate system over another.

See Also [Maneuver](#), [ChemicalTank](#), [BeginFiniteBurn](#)

### Fields

Field	Description												
<b>Axes</b>	<p>Allows you to define a spacecraft centered set of axes for the impulsive burn. This field cannot be modified in the Mission Sequence.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>VNB</b>, <b>LVLH</b>, <b>MJ2000Eq</b>, <b>SpacecraftBody</b></td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>VNB</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	<b>VNB</b> , <b>LVLH</b> , <b>MJ2000Eq</b> , <b>SpacecraftBody</b>	<b>Access</b>	set	<b>Default Value</b>	<b>VNB</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	<b>VNB</b> , <b>LVLH</b> , <b>MJ2000Eq</b> , <b>SpacecraftBody</b>												
<b>Access</b>	set												
<b>Default Value</b>	<b>VNB</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>B</b>	<p>Deprecated. Z-component of the applied impulsive burn (Delta-V)</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real</td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>km/s</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real	<b>Access</b>	set, get	<b>Default Value</b>	0	<b>Units</b>	km/s	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real												
<b>Access</b>	set, get												
<b>Default Value</b>	0												
<b>Units</b>	km/s												
<b>Interfaces</b>	GUI, script												
<b>CoordinateSystem</b>	<p>Determines what coordinate system the orientation parameters, <b>Element1</b>, <b>Element2</b>, and <b>Element3</b> refer to. This field cannot be modified in the Mission Sequence.</p> <table> <tr> <td><b>Data Type</b></td><td>Reference Array</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>Local</b>, <b>EarthMJ2000Eq</b>, <b>EarthMJ2000Ec</b>, <b>EarthFixed</b>, or any user defined system</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>Local</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Reference Array	<b>Allowed Values</b>	<b>Local</b> , <b>EarthMJ2000Eq</b> , <b>EarthMJ2000Ec</b> , <b>EarthFixed</b> , or any user defined system	<b>Access</b>	set	<b>Default Value</b>	<b>Local</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Reference Array												
<b>Allowed Values</b>	<b>Local</b> , <b>EarthMJ2000Eq</b> , <b>EarthMJ2000Ec</b> , <b>EarthFixed</b> , or any user defined system												
<b>Access</b>	set												
<b>Default Value</b>	<b>Local</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

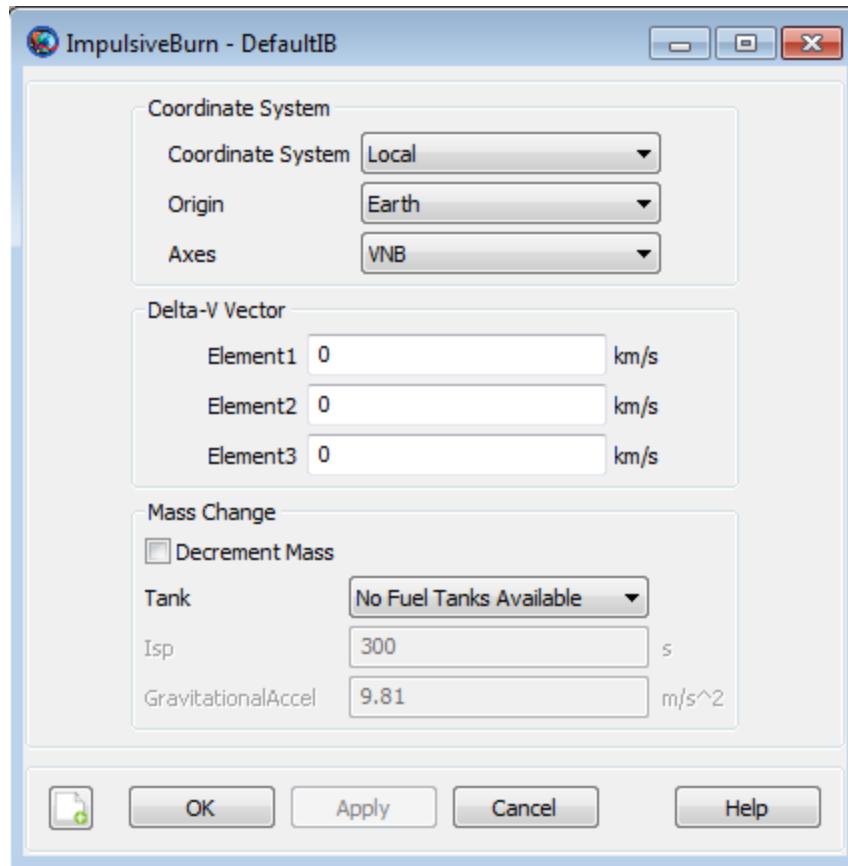
Field	Description
<b>DecrementMass</b>	Flag which determines if the <b>FuelMass</b> is to be decremented as it used. This field cannot be modified in the Mission Sequence.
	<b>Data Type</b> String <b>Allowed Values</b> true, false <b>Access</b> set <b>Default Value</b> false <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>Element1</b>	X-component of the applied impulsive burn (Delta-V)
	<b>Data Type</b> Real <b>Allowed Values</b> Real <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> km/s <b>Interfaces</b> GUI, script
<b>Element2</b>	Y-component of the applied impulsive burn (Delta-V)
	<b>Data Type</b> Real <b>Allowed Values</b> Real <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> km/s <b>Interfaces</b> GUI, script
<b>Element3</b>	Z-component of the applied impulsive burn (Delta-V)
	<b>Data Type</b> Real <b>Allowed Values</b> Real <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> km/s <b>Interfaces</b> GUI, script
<b>GravitationalAccel</b>	Value of the gravitational acceleration used to calculate fuel depletion.
	<b>Data Type</b> Real <b>Allowed Values</b> Real > 0 <b>Access</b> set, get <b>Default Value</b> 9.81 <b>Units</b> m/s^2 <b>Interfaces</b> GUI, script

Field	Description
<b>Isp</b>	<p>Value of the specific impulse of the fuel</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set, get  <b>Default Value</b> 300  <b>Units</b> s  <b>Interfaces</b> GUI, script</p>
<b>N</b>	<p>Deprecated. Y-component of the applied impulsive burn (Delta-V)</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set, get  <b>Default Value</b> 0  <b>Units</b> km/s  <b>Interfaces</b> GUI, script</p>
<b>Origin</b>	<p>The <b>Origin</b> field, used in conjunction with the <b>Axes</b> field, allows the user to define a spacecraft centered set of axes for the impulsive burn. This field cannot be modified in the Mission Sequence.</p> <p><b>Data Type</b> Reference Array  <b>Allowed Values</b> Sun, Mercury, Venus, Earth, Luna, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto  <b>Access</b> set  <b>Default Value</b> Earth  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>Tank</b>	<p><b>ChemicalTank</b> from which the <b>ChemicalThruster</b> draws propellant from. This field cannot be modified in the Mission Sequence.</p> <p><b>Data Type</b> Reference Array  <b>Allowed Values</b> User defined list of <b>ChemicalTanks</b>  <b>Access</b> set  <b>Default Value</b> N/A  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>

Field	Description	
V	Deprecated. X-component of the applied impulsive burn (Delta-V)	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real
	<b>Access</b>	set, get
	<b>Default Value</b>	0
	<b>Units</b>	km/s
	<b>Interfaces</b>	GUI, script
VectorFormat	Deprecated. Allows you to define the format of the <b>Impulsive-Burn Delta-V Vector</b> . This field has no effect. The <b>Impulsive-Burn Delta-V Vector</b> is always given in Cartesian format.	
	<b>Data Type</b>	Enumeration
	<b>Allowed Values</b>	Cartesian, Spherical
	<b>Access</b>	set
	<b>Default Value</b>	Cartesian
	<b>Units</b>	N/A
	<b>Interfaces</b>	script

## GUI

The **ImpulsiveBurn** dialog box allows you to specify properties of an **ImpulsiveBurn** including Delta-V component values and choice of **Coordinate System**. If you choose to model fuel loss associated with an impulsive burn, you must specify choice of fuel tank as well as ISP value and gravitational acceleration used to calculate fuel use. The layout of the **ImpulsiveBurn** dialog box is shown below.



The **Origin** and **Axes** fields are only relevant if **Coordinate System** is set to Local. See the Remarks for more detail on local coordinate systems.

If **Decrement Mass** is checked, then you can select the desired **ChemicalTank** used as the fuel supply for mass depletion.

## Remarks

### Local Coordinate Systems

Here, a Local **Coordinate System** is defined as one that we configure "locally" using the **ImpulsiveBurn** resource interface as opposed to defining a coordinate system using the **Coordinate Systems** folder in the **Resources Tree**.

To configure a Local **Coordinate System**, you must specify the coordinate system of the input Delta-V vector, **Element1-3**. If you choose a local **Coordinate System**, the four choices available, as given by the **Axes** sub-field, are **VNB**, **LVLH**, **MJ2000Eq**, and **SpacecraftBody**. **VNB** or Velocity-Normal-Binormal is a non-inertial coordinate system based upon the motion of the spacecraft with respect to the **Origin** sub-field. For example, if the **Origin** is chosen as Earth, then the X-axis of this coordinate system is along the velocity of the spacecraft with respect to the Earth, the Y-axis is along the instantaneous orbit normal (with respect to the Earth) of the spacecraft, and the Z-axis points away from the Earth as much as possible while remaining orthogonal to the other two axes, completing the right-handed set.

Similarly, Local Vertical Local Horizontal or **LVLH** is a non-inertial coordinate system based upon the motion of the spacecraft with respect to the body specified in the **Origin** sub-field. If you choose Earth as the origin, then the X-axis of this coordinate system points from the center of the Earth to the spacecraft, the Z-axis is along the instantaneous orbit normal (with respect to the Earth) of the spacecraft, and the Y-axis completes the right-handed set. For typical bound orbits, the Y-axis is approximately aligned with the velocity vector. In the event of a perfectly circular orbit, the Y axis is exactly along the velocity vector.

**MJ2000Eq** is the J2000-based Earth-centered Earth mean equator inertial **Coordinate System**. Note that the **Origin** sub-field is not needed to define this coordinate system.

**SpacecraftBody** is the coordinate system used by the spacecraft. Since the thrust is applied in this system, GMAT uses the attitude of the spacecraft, a spacecraft attribute, to determine the inertial thrust direction. Note that the **Origin** sub-field is not needed to define this coordinate system.

### Deprecated Field Names for an ImpulsiveBurn

Note that the standard method, as shown below, for specifying the components of an **ImpulsiveBurn** is to use the **Element1**, **Element2**, and **Element3** field names.

```
Create ImpulsiveBurn DefaultIB
DefaultIB.Element1 = -3
DefaultIB.Element2 = 7
DefaultIB.Element3 = -2
```

For this current version of GMAT, you may also use the field names **V**, **N**, and **B** in place of **Element1**, **Element2**, and **Element3**, respectively. The commands below are equivalent to the commands above.

```
Create ImpulsiveBurn DefaultIB
DefaultIB.V = -3
DefaultIB.N = 7
DefaultIB.B = -2
```

It is important to note that the **V**, **N**, **B** field names do not necessarily correspond to some Velocity, Normal, Binormal coordinate system. The coordinate system of any **ImpulsiveBurn** is always specified by the **CoordinateSystem**, **Origin**, and **Axes** fields. Because of the confusion that the **V**, **N**, **B** field names can cause, their use will not be allowed in future versions of GMAT. If you use the **V**, **N**, **B** field names in this version of GMAT, you will receive a warning message.

### Backwards-propagated Impulsive maneuvers defined using the spacecraft velocity

Examples of axes defined using the spacecraft velocity are the **VNB** and **LVLH** axes discussed above as well as some user-defined axes. The behavior when applying an impulsive maneuver using these types of axes during a backwards-propagation is subtle and requires some explanation. In the examples that follow, we will focus our discussion on a **VNB** maneuver.

As will be shown in the script samples below, an impulsive maneuver is applied during a backwards propagation using the 'BackProp' keyword. The maneuver components that you specify for a backwards propagation are used to calculate the components of the maneuver actually applied. Refer to the script sample below where a backwards-propagated impulsive maneuver is followed by the same maneuver using a normal formal propagation. The impulsive maneuver is defined so that the velocity of the spacecraft is unchanged after the script is run.

```
Create Spacecraft Sat;
Create ImpulsiveBurn myImpulsiveBurn;
GMAT myImpulsiveBurn.CoordinateSystem = Local;
GMAT myImpulsiveBurn.Origin = Earth;
GMAT myImpulsiveBurn.Axes = VNB;
myImpulsiveBurn.Element1 = 3.1
myImpulsiveBurn.Element2 = -0.1
myImpulsiveBurn.Element3 = 0.2

BeginMissionSequence
Maneuver BackProp myImpulsiveBurn(Sat);
Maneuver myImpulsiveBurn(Sat);
```

To calculate the actual maneuver components applied, GMAT, internally, uses an iterative calculation method. This iteration method works best for maneuver magnitudes that are not an appreciable fraction of the overall spacecraft velocity. In addition, for **VNB** maneuvers, the iteration method works best for maneuvers where the '**N**' and '**B**' component magnitudes are relatively small as compared to the '**V**' component magnitude. If the GMAT internal iterative method fails to converge, a warning message will be generated. Currently, there is not an easy way for the user to report out the actual applied back-propagated maneuver components. (The maneuver report outputs the user supplied **VNB** coordinates). After the back-propagated maneuver has been applied, however, we do know what the components of the maneuver are. If the **VNB** maneuver has user-supplied components, (Vx, Vy, Vz), then after the back-propagated maneuver has been applied, the **VNB** components of the maneuver are (-Vx, -Vy, -Vz).

Consider the script sample below where the '**N**' and '**B**' components of the maneuver are zero and the '**V**' component is +5 km/s. If the spacecraft velocity is (7,0,0) km/s in J2000 inertial coordinates, then after the backwards-propagated impulsive maneuver, the velocity of the spacecraft will be (2,0,0) km/s.

```
Create Spacecraft Sat;
Create ImpulsiveBurn myImpulsiveBurn;
GMAT myImpulsiveBurn.CoordinateSystem = Local;
GMAT myImpulsiveBurn.Origin = Earth;
GMAT myImpulsiveBurn.Axes = VNB;

myImpulsiveBurn.Element1 = 5
myImpulsiveBurn.Element2 = 0.0
myImpulsiveBurn.Element3 = 0.0

BeginMissionSequence
```

```
Maneuver BackProp myImpulsiveBurn(Sat);
```

Finally, we note that when mass change is modeled for a backwards-propagated impulsive maneuver, mass is added to the tank. This is done so there is no change in mass when a backwards-propagated impulsive maneuver is followed by the same maneuver using a normal forward propagation.

## Interactions

Resource	Description
<b>Spacecraft re-source</b>	Must be created in order to apply any <b>ImpulsiveBurn</b>
<b>Chemical-Tank source</b>	If you want to model mass depletion for an <b>ImpulsiveBurn</b> , attach a <b>ChemicalTank</b> to the maneuvered <b>Spacecraft</b> as a source of fuel mass.
<b>Maneuver</b>	Must use the <b>Maneuver</b> command to apply an <b>ImpulsiveBurn</b> to a <b>Spacecraft</b> .
<b>Vary command</b>	If you want to allow the <b>ImpulsiveBurn</b> components to vary in order to achieve some goal, then the <b>Vary</b> command, as part of a <b>Target</b> or <b>Optimize</b> command sequence, must be used.

## Examples

Create a default **ChemicalTank** and an **ImpulsiveBurn** that allows for fuel depletion, assign the **ImpulsiveBurn** the default **ChemicalTank**, attach the **ChemicalTank** to a **Spacecraft**, and apply the **ImpulsiveBurn** to the **Spacecraft**.

```
% Create the ChemicalTank Resource
Create ChemicalTank FuelTank1
FuelTank1.AllowNegativeFuelMass = false
FuelTank1.FuelMass = 756
FuelTank1.Pressure = 1500
FuelTank1.Temperature = 20
FuelTank1.RefTemperature = 20
FuelTank1.Volume = 0.75
FuelTank1.FuelDensity = 1260
FuelTank1.PressureModel = PressureRegulated

Create ImpulsiveBurn DefaultIB
DefaultIB.CoordinateSystem = Local
DefaultIB.Origin = Earth
DefaultIB.Axes = VNB
DefaultIB.Element1 = 0.001
DefaultIB.Element2 = 0
DefaultIB.Element3 = 0
DefaultIB.DecrementMass = true
DefaultIB.Tank = {FuelTank1}
```

```
DefaultIB.Isp = 300
DefaultIB.GravitationalAccel = 9.81000000000001

% Add the the ChemicalTank to a Spacecraft
Create Spacecraft DefaultSC
DefaultSC.Tanks = {FuelTank1}

BeginMissionSequence
Maneuver DefaultIB(DefaultSC)
```

## IntrusionLocator

A line-of-sight event locator between a target **CelestialBody** and an observer **Spacecraft**

### Description



#### Note

**IntrusionLocator** is a SPICE-based subsystem that uses a parallel configuration for the solar system and celestial bodies from other GMAT components. For precision applications, care must be taken to ensure that both configurations are consistent. See [Remarks](#) for details.

An **IntrusionLocator** is an event locator used to find line-of-sight events between a **Spacecraft** and a **CelestialBody** based on the field of view of an **Imager** attached to the Spacecraft. By default, a **IntrusionLocator** generates a text event report listing the beginning and ending times of each line-of-sight event, with intermediate times generated at the selected step size. Each piece of data also contains the coordinates of the target within the user selected coordinate system, the angular diameter, and the illumination of the target. Intrusion location can be performed over the entire propagation interval or over a subinterval, and can optionally adjust for light-time delay and stellar aberration. Intrusion location can be configured to search for times of occultation of other **CelestialBody** resources that may block line of sight, and can limit intrusion events to a specified minimum illumination for the targets.

Intrusion location can be performed between one **Spacecraft Imager (Observer)** and any number of **CelestialBody** resources (**Targets**). Each target-observer pair is searched individually, and results in a separate segment of the resulting report. All pairs must use the same interval and search options; to customize the options per pair, use multiple **IntrusionLocator** resources.

Third-body occultation searches can be included by listing a **CelestialBody** resource in the **CentralBody** field. Any configured **CelestialBody** can be used as an occulting body, including user-defined bodies.

By default, the **IntrusionLocator** searches the entire interval of propagation of the **IntrudingBodies**, after applying endpoint light-time adjustments; see [Remarks](#) for details. To search a custom interval, set **UseEntireInterval** to False and set **InitialEpoch** and **FinalEpoch** accordingly. Note that these epochs are assumed to be at the observer, and so must be valid when translated to the target via light-time delay and stellar aberration, if configured. If they fall outside the propagation interval of the **IntrudingBodies**, GMAT will display an error.

The intrusion locator can optionally adjust for both light-time delay and stellar aberration, using a signal moving in the receive direction (**Target to Observer**). The light-time direction affects the valid search interval by limiting searches near the end of the interval.

See [Remarks](#) for details. Stellar aberration is only applied for the line-of-sight portion of the search; it has no effect during occultation searches.

The event search is performed at a fixed step through the interval. You can control the step size (in seconds) by setting the **StepSize** field. An appropriate choice for step size is no greater than half the period of the line-of-sight function—that is, half the orbit period for an elliptical orbit. See [Remarks](#) for details.

GMAT uses the SPICE library for the fundamental event location algorithm. As such, all celestial body data is loaded from SPICE kernels for this subsystem, rather than GMAT's own **CelestialBody** shape and orientation configuration. See [Remarks](#) for details.

Unless otherwise mentioned, **IntrusionLocator** fields cannot be set in the mission sequence.

See Also: [CelestialBody](#), [Imager](#), [Spacecraft](#)

## Fields

Field	Description
<b>CentralBody</b>	Name of a celestial body that will be checked for intervening between the <b>Imager</b> and the targets. When this occurs, the target does not appear as intruding in the sensor intrusion report.  <b>Data Type</b> A <b>CelestialBody</b> resource (e.g. <b>Planet</b> , <b>Asteroid</b> , <b>Moon</b> , etc.) <b>Allowed Values</b> Any existing <b>CelestialBody</b> resource <b>Access</b> set <b>Default Value</b> Earth <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>Filename</b>	Name and path of the intrusion report file. This field can be set in the mission sequence.  <b>Data Type</b> String <b>Allowed Values</b> Valid file path <b>Access</b> set <b>Default Value</b> ' <i>IntrusionLocator.txt</i> ' <b>Units</b> N/A <b>Interfaces</b> GUI, script

Field	Description
<b>FinalEpoch</b>	<p>Last epoch to search for intrusions, in the format specified by <b>InputEpochFormat</b>. The epoch must map to a valid epoch in the <b>Spacecraft</b> and target <b>Intruding Body</b> ephemeris interval, including any light time. This field can be set in the mission sequence.</p>
<b>Data Type</b>	String
<b>Allowed Values</b>	Valid epoch in available spacecraft ephemeris set
<b>Access</b>	set
<b>Default Value</b>	'21545.138'
<b>Units</b>	ModifiedJulian epoch formats: days
<b>Interfaces</b>	Gregorian epoch formats: N/A GUI, script
<b>InitialEpoch</b>	<p>First epoch to search for intrusions, in the format specified by <b>InputEpochFormat</b>. The epoch must map to a valid epoch in the <b>Spacecraft</b> and target <b>Intruding Body</b> ephemeris interval, including any light time. This field can be set in the mission sequence.</p>
<b>Data Type</b>	String
<b>Allowed Values</b>	Valid epoch in available spacecraft ephemeris set
<b>Access</b>	set
<b>Default Value</b>	'21545'
<b>Units</b>	ModifiedJulian epoch formats: days
<b>Interfaces</b>	Gregorian epoch formats: N/A GUI, script
<b>IntrudingBodies</b>	<p>List of <b>CelestialBody</b> resources that are used as targets for the observers listed in the field <b>Sensors</b>. Events where these bodies are seen in the field of view of the <b>Sensors</b> will be tracked in the output file.</p>
<b>Data Type</b>	A <b>CelestialBody</b> resource list (e.g. <b>Planet</b> , <b>Asteroid</b> , <b>Moon</b> , etc.)
<b>Allowed Values</b>	Any existing <b>CelestialBody</b> resources
<b>Access</b>	set
<b>Default Value</b>	N/A
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

Field	Description
<b>MinimumPhase</b>	<p>Value to set the minimum amount of illumination a target must have to be considered intruding when in the field of view of the <b>Sensors</b>. Note that for targets that are stars, they always have an illumination value of 1.0.</p>
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	0.0 < <b>MinimumPhase</b> < 1.0
	<b>Access</b>
	set
	<b>Default Value</b>
	'0.0'
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	<p><b>ReportCoordinates</b> String to set what coordinate format the intruding bodies are reported in during an intrusion event. The SpacecraftBody coordinates use the body frame from the <b>Spacecraft</b> field. FixedGrid uses the coordinate frame provided from the <b>SpiceGridFrame-File</b> field.</p>
	<b>Data Type</b>
	String
	SpacecraftBody, FixedGrid
	<b>Access</b>
	set
	<b>Default Value</b>
	Spacecraft
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	<p><b>RunMode</b> Mode of event location execution. 'Automatic' triggers event location to occur automatically at the end of the run. 'Manual' limits execution only to the <b>FindEvents</b> command. 'Disabled' turns off event location entirely.</p>
	<b>Data Type</b>
	Enumeration
	Automatic, Manual, Disabled
	<b>Access</b>
	set
	<b>Default Value</b>
	'Automatic'
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	<p><b>Sensors</b> List of <b>Imager</b> resources to be used in checking for intrusions.</p>
	<b>Data Type</b>
	One or more <b>Imager</b> resources
	Any existing <b>Imager</b> resource attached to the <b>Spacecraft</b> entered in the <b>Spacecraft</b> field
	<b>Access</b>
	set
	<b>Default Value</b>
	N/A
	<b>Units</b>
	N/A
	<b>Interfaces</b>

Field	Description
<b>Spacecraft</b>	<p>Name of a <b>Spacecraft</b> that has the desired <b>Imager</b> resources attached to it to be used as observers.</p> <p><b>Data Type</b> A <b>Spacecraft</b> resource  <b>Allowed Values</b> Any existing <b>Spacecraft</b> resource with at least one <b>Imager</b> resource attached to it  <b>Access</b> set  <b>Default Value</b> N/A  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>SpiceGridFrame-File</b>	<p>The frame kernel files used when a FixedGrid coordinate frame is selected in the <b>ReportCoordinates</b> field.</p> <p><b>Data Type</b> String  <b>Allowed Values</b> Valid file path and name  <b>Access</b> set  <b>Default Value</b> N/A  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>StepSize</b>	<p>Time step used in the event locator. See <a href="#">Remarks</a> for discussion of appropriate values.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> <b>StepSize</b> &gt; 0  <b>Access</b> set  <b>Default Value</b> 10  <b>Units</b> s  <b>Interfaces</b> GUI, script</p>
<b>UseEntireInterval</b>	<p>Search the entire available ephemeris interval, after adjusting the end-points for light-time delay as appropriate. See <a href="#">Remarks</a> for details. This field can be set in the mission sequence.</p> <p><b>Data Type</b> Boolean  <b>Allowed Values</b> true, false  <b>Access</b> set  <b>Default Value</b> true  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>

Field	Description	
<b>UseLightTimeDelay</b>	Use light-time delay in the event-finding algorithm. The clock is always hosted on the <b>Observer</b> .	
	<b>Data Type</b>	Boolean
	<b>Allowed Values</b>	true, false
	<b>Access</b>	set
	<b>Default Value</b>	true
	<b>Units</b>	N/A
	<b>Interfaces</b>	GUI, script
<b>UseStellarAberration</b>	Use stellar aberration in addition to light-time delay in the event-finding algorithm. Light-time delay must be enabled. Stellar aberration only affects line-of-sight searches, not occultation searches.	
	<b>Data Type</b>	Boolean
	<b>Allowed Values</b>	true, false
	<b>Access</b>	set
	<b>Default Value</b>	true
	<b>Units</b>	N/A
	<b>Interfaces</b>	GUI, script
<b>WriteReport</b>	Write an event report when event location is executed. This field can be set in the mission sequence.	
	<b>Data Type</b>	Boolean
	<b>Allowed Values</b>	true, false
	<b>Access</b>	set
	<b>Default Value</b>	true
	<b>Units</b>	N/A
	<b>Interfaces</b>	GUI, script

## GUI

The default **IntrusionLocator** GUI for a new resource is shown above. One **Spacecraft** can be selected from the **Spacecraft** drop-down menu, which is populated by all the currently configured **Spacecraft** in the mission. Next, the **Central Body** is selected from the drop-down menu populated with all the currently loaded **CelestialBody** resources.

The **Intruding Bodies** checklist is used to set what **CelestialBody** the sensors will check for intrusion during the mission sequence. Multiple selections can be made. The following **Sensors** checklist is used to select which sensors to utilize for this **IntrusionLocator**. Note that these sensors will also need to be attached to the selected **Spacecraft**'s hardware list.

You can configure the output via **Filename**, **Run Mode**, and **Write Report** near the bottom. If **Write Report** is enabled, a text report will be written to the file specified in **Filename**. The search will execute during **FindEvents** commands (for **Manual** or **Au-**

**tomatic** modes) and automatically at the end of the mission (for **Automatic** mode), depending on the **Run Mode**.

You can configure the search interval via the options in the upper right. Uncheck **Use Entire Interval** to set the search interval manually. See the [Remarks](#) section for considerations when setting the search interval.

You can control the search algorithm via the options in the bottom right. Configure light-time and stellar aberration via the check boxes next to each.

To control the fidelity and execution time of the search, set the **Step size** appropriately. See the [Remarks](#) section for details.

To set the minimum phase required to count an object as intruding, set the **Minimum Phase** appropriately.

Use the **Report Coordinates** drop-down menu to select the coordinates used in the output intrusion report. If **FixedGrid** is selected, the **Spice Grid Frame File** becomes available to set the frame kernel to be used. This is set by directly entering the full path or using the browse button next to the field.

## Remarks



### Warning

The **CustomFOV** shape is currently not supported by the **IntrusionLocator**.



### Warning

The spacecraft body frame is currently not a supported coordinate system for the **ReportCoordinates** field.

## Data configuration

The **IntrusionLocator** implementation is based on the [NAIF SPICE toolkit](#), which uses a different mechanism for environmental data such as celestial body shape and orientation, planetary ephemerides, body-specific frame definitions, and leap seconds. Therefore, it is necessary to maintain two parallel configurations to ensure that the event location results are consistent with GMAT's own propagation and other parameters. The specific data to be maintained is:

- Planetary shape and orientation:
  - GMAT core: **CelestialBody.EquatorialRadius**, **Flattening**, **SpinAxisRAConstant**, **SpinAxisRARate**, etc.
  - IntrusionLocator: **SolarSystem.PCKFilename**,  
**CelestialBody.PlanetarySpiceKernelName**
- Planetary ephemeris:

- GMAT core: **SolarSystem.DEFilename**, or (**SolarSystem.SPKFilename**, **CelestialBody.OrbitSpiceKernelName**, **CelestialBody.NAIFId**)
- IntrusionLocator: **SolarSystem.SPKFilename**,  
**CelestialBody.OrbitSpiceKernelName**, **CelestialBody.NAIFId**
- Body-fixed frame:
  - GMAT core: built-in
  - IntrusionLocator: **CelestialBody.SpiceFrameId**,  
**CelestialBody.FrameSpiceKernelName**
- Leap seconds:
  - GMAT core: startup file LEAP\_SECS\_FILE setting
  - IntrusionLocator: **SolarSystem.LSKFilename**

See **SolarSystem** and **CelestialBody** for more details.

### Search interval

The **IntrusionLocator** search interval can be specified either as the entire ephemeris interval of the **Spacecraft**, or as a user-defined interval. If **UseEntireInterval** is true, the search is performed over the entire ephemeris interval of the **Spacecraft**, including any gaps or discontinuities. If **UseEntireInterval** is false, the provided **InitialEpoch** and **FinalEpoch** are used to form the search interval directly. The user must ensure than the provided interval results in valid **Spacecraft** and **CelestialBody** ephemeris epochs.

### Run modes

The **IntrusionLocator** works in conjunction with the **FindEvents** command: the **IntrusionLocator** resource defines the configuration of the event search, and the **FindEvents** command executes the search at a specific point in the mission sequence. The mode of interaction is defined by **ContactLocator.RunMode**, which has three options:

- Automatic: All **FindEvents** commands are executed as-is, plus an additional **FindEvents** is executed automatically at the end of the mission sequence.
- Manual: All **FindEvents** commands are executed as-is.
- Disabled: **FindEvents** commands are ignored.

### Search algorithm

The **IntrusionLocator** uses the NAIF SPICE GF (geometry finder) subsystem to perform event location. Specifically, the following call is used for the search:

- **gftfov\_c**: For intrusion event searches
- **gfoclt\_c**: For third-body occultation searches

These functions implement a fixed-step search method through the interval, with an embedded root-location step if an event is found. **StepSize** should be set equal to the length of the minimum-duration event to be found, or equal to the length of the minimum-duration gap between events, whichever is smaller. To guarantee location of 10-second intrusions, or 10-second gaps between adjacent intrusions, set **StepSize** = 10.

For details, see the reference documentation for the functions listed above.

## Report format

When **WriteReport** is enabled, the **IntrusionLocator** outputs an event report at the end of each search execution. The report contains the following data:

- Spacecraft name
- Sensor name
- Coordinate System name
- For each time step during an intrusion event:
  - Current time (UTC)
  - Intruding body name
  - Angular diameter of intruding body (deg)
  - "X" coordinate of intruding body in specified coordinate system (deg)
  - "Y" coordinate of intruding body in specified coordinate system (deg)
  - Intrusion event type (Intrusion Start, Intrusion, Intrusion End)

The report makes the distinction between an *individual* event and a *total* event.

- An *individual event* is a single event where an intruding body is detected within a sensor's field of view. These include intrusion starts, ends, and the events in-between occurring at the provided **StepSize**.
- A *total event* is the entire set of nested individual events. Each start of an intrusion is a new total event. In other words, the number of total events describes the number of times intruding bodies passed into the field of view of the sensors.

## Event location with SPK propagator

When using the SPK propagator, you load one or more SPK ephemeris files using the `Spacecraft.OrbitSpiceKernelName` field. For the purposes of event location, this field causes the appropriate ephemeris files to be loaded automatically on run, and so use of the Propagation command is not necessary. This is an easy way of performing event location on an existing SPK ephemeris file. See the example below.

## Examples

Perform a basic intrusion search in LEO:

```
Create Spacecraft sat
sat.AddHardware = {camera}

Create ForceModel fm;

Create Propagator prop;
prop.FM = fm;
prop.Type = RungeKutta89;

Create Imager camera;
camera.FieldOfView = cameraFOV;
camera.DirectionX = 1.0;
```

```
Create ConicalFOV cameraFOV;
cameraFOV.FieldOfViewAngle = 11.50;

Create IntrusionLocator il;
il.CentralBody = Earth;
il.Spacecraft = sat;
il.Sensors = {camera};
il.IntrudingBodies = {Luna, Sun};
il.MinimumPhase = 0.6;
il.StepSize = 30.0;
il.UseLightTimeDelay = true;
il.UseStellarAberration = true;
il.WriteReport = true;
il.RunMode = Automatic;
il.UseEntireInterval = true;
il.Filename = 'ExampleIntrusionReport.txt';
il.ReportCoordinates = 'FixedGrid';
il.SpiceGridFrameFile = '../data/hardware/FixedGrid_NewVer.tf';

BeginMissionSequence;
Propagate prop(sat) {sat.ElapsedDays = 60.0};
```

## LibrationPoint

An equilibrium point in the circular, restricted 3-body problem

### Description

A **LibrationPoint**, also called a Lagrange point, is an equilibrium point in the circular restricted three-body problem (CRTBP). There are five libration points, three of which are unstable in the CRTBP sense, and two that are stable. See the discussion below for a detailed explanation of the different libration points and for examples configuring GMAT for common libration point regimes. This resource cannot be modified in the Mission Sequence.

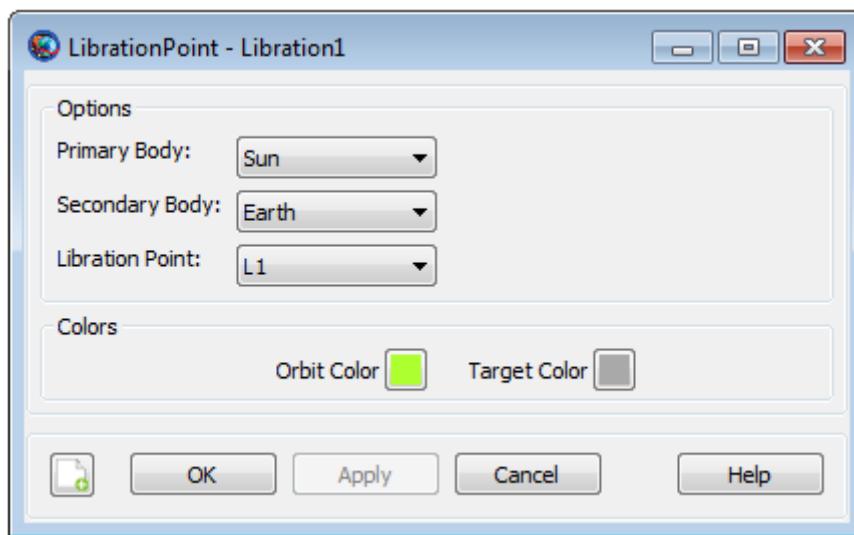
See Also: [Barycenter](#), [Color](#)

### Fields

Field	Description												
<b>OrbitCol- or</b>	<p>Allows you to set available colors on user-defined <b>LibrationPoint</b> orbits. The libration point orbits are drawn using the 3D <b>OrbitView</b> graphics displays. Colors on a <b>LibrationPoint</b> object can be set through a string or an integer array. For example: Setting a libration point's orbit color to red can be done in the following two ways: <code>LibrationPoint.OrbitColor = Red</code> or <code>LibrationPoint.OrbitColor = [255 0 0]</code>. This field can be modified in the Mission Sequence as well..</p> <table> <tr> <td><b>Data Type</b></td><td>Integer Array or String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255.</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>GreenYellow</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Integer Array or String	<b>Allowed Values</b>	Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255.	<b>Access</b>	set	<b>Default Value</b>	GreenYellow	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Integer Array or String												
<b>Allowed Values</b>	Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255.												
<b>Access</b>	set												
<b>Default Value</b>	GreenYellow												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>Point</b>	<p>The libration point index.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>L1, L2, L3, L4, or L5</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>L1</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	L1, L2, L3, L4, or L5	<b>Access</b>	set	<b>Default Value</b>	L1	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	L1, L2, L3, L4, or L5												
<b>Access</b>	set												
<b>Default Value</b>	L1												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

Field	Description
<b>Primary</b>	The primary body or barycenter.  <b>Data Type</b> String <b>Allowed Values</b> <b>CelestialBody</b> or <b>Barycenter</b> . Primary cannot be <b>SolarSystemBarycenter</b> and Primary cannot be the same as Secondary. <b>Access</b> set <b>Default Value</b> Sun <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>Se- condary</b>	The secondary body or barycenter.  <b>Secondary</b> String <b>Allowed Values</b> <b>CelestialBody</b> or <b>Barycenter</b> . Secondary cannot be <b>SolarSystemBarycenter</b> and Primary cannot be the same as Secondary. <b>Access</b> set <b>Default Value</b> Earth <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>Target- Color</b>	Allows you to set available colors on <b>LibrationPoint</b> object's perturbing orbital trajectories that are drawn during iterative processes such as Differential Correction or Optimization. The target color can be identified through a string or an integer array. For example: Setting a libration point's perturbing trajectory color to yellow can be done in following two ways: <code>LibrationPoint.TargetColor = Yellow</code> or <code>LibrationPoint.TargetColor = [255 255 0]</code> . This field can be modified in the Mission Sequence as well.  <b>Data Type</b> Integer Array or String <b>Allowed Values</b> Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255. <b>Access</b> set <b>Default Value</b> DarkGray <b>Units</b> N/A <b>Interfaces</b> GUI, script

## GUI

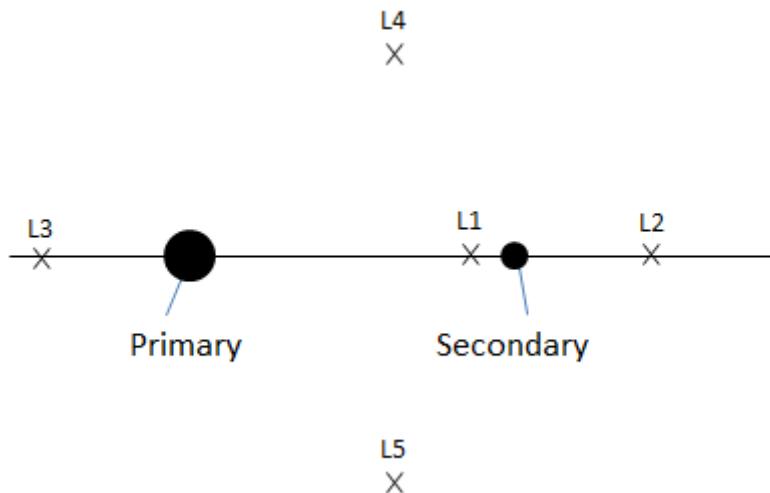


The **LibrationPoint** dialog box allows you to select the **Primary Body**, **Secondary Body**, and the libration point index. You can select from celestial bodies and barycenters. You cannot choose the **SolarSystemBarycenter** as either the **Primary** or **Secondary** and the **Primary** and **Secondary** cannot be the same object.

## Remarks

### *Overview of Libration Point Geometry*

A **LibrationPoint**, also called a Lagrange point, is an equilibrium point in the Circular Restricted Three Body Problem (CRTBP). The definitions for the libration points used in GMAT are illustrated in the figure below where the **Primary** and **Secondary** bodies are shown in a rotating frame defined with the x-axis pointing from the **Primary** to the **Secondary**. GMAT is configured for the full ephemeris problem and computes the location of the libration points by assuming that at a given instant in time, the CRTBP theory developed by Lagrange and Szebehely can be used to compute the location of the libration points using the locations of the primary and secondary from the JPL ephemerides. The three collinear points (L1, L2, and L3) are unstable (even in the CRTBP) and the triangular points (L4, and L5) are stable in CRTBP.



### Configuring a Libration Point

GMAT allows you to define the **Primary** and/or **Secondary** as a **CelestialBody** or **Barycenter** (except **SolarSystemBarycenter**). This allows you to set the **Primary** as the Sun, and the **Secondary** as the Earth-Moon barycenter for modeling Sun-Earth-Moon libration points. See the examples below for details.

### Setting Colors On Libration Point Orbits

GMAT allows you to assign colors to libration point orbits that are drawn using the **OrbitView** graphics display windows. GMAT also allows you to assign colors to perturbing libration point orbital trajectories which are drawn during iterative processes such as differential correction or optimization. The **LibrationPoint** object's **OrbitColor** and **TargetColor** fields are used to assign colors to both orbital and perturbing trajectories. See the [Fields](#) section to learn more about these two fields. Also see [Color](#) documentation for discussion and examples on how to set colors on a libration point orbit.

### Examples

Create and use an Earth-Moon **LibrationPoint**.

```
% Create the libration point and rotating libration point coordinate system
Create LibrationPoint EarthMoonL2
EarthMoonL2.Primary      = Earth
EarthMoonL2.Secondary    = Luna
EarthMoonL2.Point        = L2

Create CoordinateSystem EarthMoonRotLibCoord
EarthMoonRotLibCoord.Origin     = EarthMoonL2
EarthMoonRotLibCoord.Axes       = ObjectReferenced
EarthMoonRotLibCoord.XAxis     = R
EarthMoonRotLibCoord.ZAxis     = N
EarthMoonRotLibCoord.Primary   = Earth
```

```

EarthMoonRotLibCoord.Secondary = Luna

% Configure the spacecraft and propagator
Create Spacecraft aSat
aSat.DateFormat      = TAIModJulian
aSat.Epoch          = '25220.0006220895'
aSat.CoordinateSystem = EarthMoonRotLibCoord
aSat.DisplayStateType = Cartesian
aSat.X   = 9999.752137149568
aSat.Y   = 1.774296833900735e-007
aSat.Z   = 21000.02640446094
aSat.VX  = -1.497748388797418e-005
aSat.VY  = -0.2087816321971509
aSat.VZ  = -5.42471673237177e-006

Create ForceModel EarthMoonL2Prop_ForceModel
EarthMoonL2Prop_ForceModel.PointMasses = {Earth, Luna, Sun}
Create Propagator EarthMoonL2Prop
EarthMoonL2Prop.FM = EarthMoonL2Prop_ForceModel

% Create the orbit view
Create OrbitView ViewEarthMoonRot
ViewEarthMoonRot.Add           = {Earth, Luna, Sun,...}
                                aSat, EarthMoonL2}
ViewEarthMoonRot.CoordinateSystem = EarthMoonRotLibCoord
ViewEarthMoonRot.ViewPointReference = EarthMoonL2
ViewEarthMoonRot.ViewDirection    = EarthMoonL2
ViewEarthMoonRot.ViewScaleFactor = 5

Create Variable I

BeginMissionSequence

% Prop for 3 xz-plane crossings
For I = 1:3
    Propagate 'Prop to Y Crossing' EarthMoonL2Prop(aSat) ...
              {aSat.EarthMoonRotLibCoord.Y = 0}
EndFor

```

Create and use a Sun, Earth-Moon **LibrationPoint**.

```

% Create the Earth-Moon Barycenter and Libration Point
Create Barycenter EarthMoonBary
EarthMoonBary.BodyNames = {Earth,Luna}

Create LibrationPoint SunEarthMoonL1
SunEarthMoonL1.Primary  = Sun
SunEarthMoonL1.Secondary = EarthMoonBary
SunEarthMoonL1.Point    = L1

```

```
% Create the coordinate system
Create CoordinateSystem RotatingSEML1Coord
RotatingSEML1Coord.Origin      = SunEarthMoonL1
RotatingSEML1Coord.Axes        = ObjectReferenced
RotatingSEML1Coord.XAxis       = R
RotatingSEML1Coord.ZAxis       = N
RotatingSEML1Coord.Primary     = Sun
RotatingSEML1Coord.Secondary   = EarthMoonBary

% Create the spacecraft and propagator
Create Spacecraft aSpacecraft
aSpacecraft.DateFormat        = UTCGregorian
aSpacecraft.Epoch              = '09 Dec 2005 13:00:00.000'
aSpacecraft.CoordinateSystem  = RotatingSEML1Coord
aSpacecraft.X    = -32197.88223741966
aSpacecraft.Y    = 211529.1500044117
aSpacecraft.Z    = 44708.57017366499
aSpacecraft.VX   = 0.03209516489451751
aSpacecraft.VY   = 0.06100386504053736
aSpacecraft.VZ   = 0.0550442738917212

Create Propagator aPropagator
aPropagator.FM                = aForceModel
aPropagator.MaxStep = 86400
Create ForceModel aForceModel
aForceModel.PointMasses = {Earth,Sun,Luna}

% Create a 3-D graphic
Create OrbitView anOrbitView
anOrbitView.Add                  = {aSpacecraft, Earth, Sun, Luna}
anOrbitView.CoordinateSystem     = RotatingSEML1Coord
anOrbitView.ViewPointReference   = SunEarthMoonL1
anOrbitView.ViewPointVector      = [-1500000 0 0 ]
anOrbitView.ViewDirection        = SunEarthMoonL1
anOrbitView.ViewUpCoordinateSystem = RotatingSEML1Coord
anOrbitView.Axes                 = Off
anOrbitView.XYPlane               = Off

BeginMissionSequence

Propagate aPropagator(aSpacecraft, {aSpacecraft.ElapsedDays = 180})
```

## NuclearPowerSystem

A nuclear power system

### Description

The **NuclearPowerSystem** models a nuclear power system including power generated as function of time and distance from the sun.

For a complete description of how to configure all Resources required for electric propulsion modeling, see the Tutorial named [Electric Propulsion](#)

See Also [ElectricTank](#), [ElectricThruster](#), [SolarPowerSystem](#)

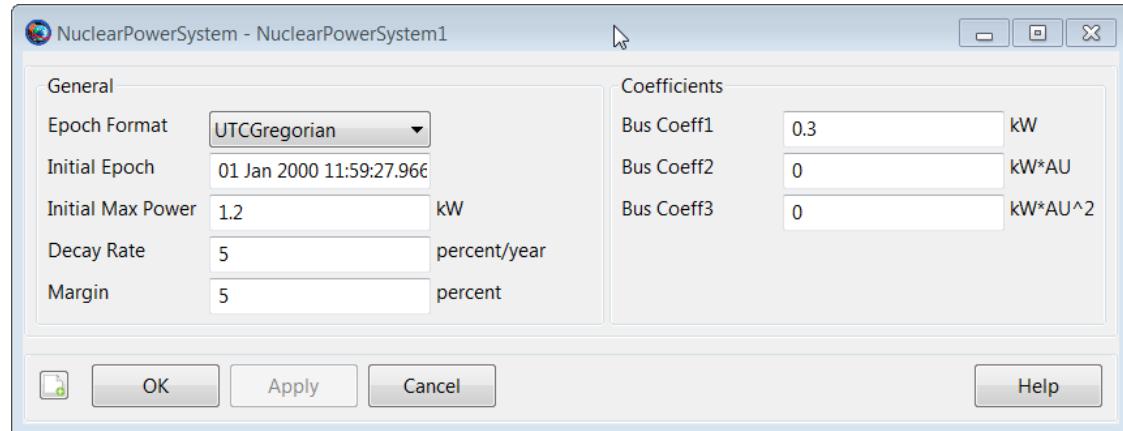
### Fields

Field	Description
<b>AnnualDecayRate</b>	<p>The annual decay rate of the power system.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> 0 &lt;=Real &lt;= 100  <b>Access</b> set  <b>Default Value</b> 5  <b>Units</b> Percent/Year  <b>Interfaces</b> GUI, script</p>
<b>BusCoeff1</b>	<p>Coefficient of power required by spacecraft bus.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0.3  <b>Units</b> kW  <b>Interfaces</b> GUI, script</p>
<b>BusCoeff2</b>	<p>Coefficient of power required by spacecraft bus.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> kW*AU  <b>Interfaces</b> GUI, script</p>
<b>BusCoeff3</b>	<p>Coefficient of power required by spacecraft bus.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> kw*AU<sup>2</sup>  <b>Interfaces</b> GUI, script</p>

Field	Description	
<b>EpochFormat</b>	The epoch format for the PowerInitialEpoch field.	
	<b>Data Type</b>	String
	<b>Allowed Values</b>	Valid Epoch format.
	<b>Access</b>	set
	<b>Default Value</b>	UTCGregorian
	<b>Units</b>	N/A
	<b>Interfaces</b>	GUI, script
<b>InitialEpoch</b>	The initial epoch of the system used to define power system elapsed lifetime.	
	<b>Data Type</b>	String
	<b>Allowed Values</b>	Valid GMAT Epoch consistent with PowerInitialEpochFormat
	<b>Access</b>	set
	<b>Default Value</b>	01 Jan 2000 11:59:27.966
	<b>Units</b>	N/A
	<b>Interfaces</b>	GUI, script
<b>InitialMaxPower</b>	The maximum power generated at the <b>PowerInitialEpoch</b> .	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real >= 0
	<b>Access</b>	set
	<b>Default Value</b>	1.2
	<b>Units</b>	kW
	<b>Interfaces</b>	GUI, script
<b>Margin</b>	The required margin between power left after power bus, and power used by the propulsion system.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	0 <= Real <= 100
	<b>Access</b>	set
	<b>Default Value</b>	5
	<b>Units</b>	Percent
	<b>Interfaces</b>	GUI, script

## GUI

The GUI for the **NuclearPowerSystem** is shown below.



## Remarks

### Computation of Base Power

The **NuclearPowerSystem** models power degradation as a function of time. You must provide a power system initial epoch, the power generated at that epoch, and an annual power decay rate. Additionally, the **AnnualDecayRate** field models the power degradation on a per year basis. The base power is computed using

$$P_{Base} = P_0(1 - \tau/100)^{\Delta t}$$

where "tau" is the power **AnnualDecayRate**,  $P_0$  is **InitialMaxPower**, and "delta t" is the elapsed time between the simulation epoch and **InitialEpoch**.

### Computation of Bus Power

The power required by the spacecraft bus for all subsystems other than the propulsion system is computed using

$$P_{Bus} = A_{Bus} + B_{Bus}(\frac{1}{r}) + C_{Bus}(\frac{1}{r^2})$$

where  $A_{Bus}$ ,  $B_{Bus}$ , and  $C_{Bus}$  are **BusCoeff1**, **BusCoeff2**, and **BusCoeff3** respectively and  $r$  is the distance from the Sun in AU.

### Computation of Power Available for Propulsion

Total power is compute using

$$P_{Tot} = P_{Base}$$

Thrust power available for electric propulsion is finaly computed using

$$P_{Thrust} = (1 - \frac{\delta M}{100})(P_{Tot} - P_{Bus})$$

Where "delta M" is power **Margin**.

## Examples

Create a **NuclearPowerSystem** and attach it to a **Spacecraft**.

```
Create Spacecraft DefaultSC
DefaultSC.PowerSystem = NuclearPowerSystem1

Create NuclearPowerSystem NuclearPowerSystem1

BeginMissionSequence
```

For a complete description of how to configure all Resources required for electric propulsion modeling, see the Tutorial named *Electric Propulsion*.

## PlanetographicRegion

Define an area on a celestial body's surface as a target for an observing **Spacecraft**

### Description



#### Note

**PlanetographicRegion** is closely tied to the **ContactLocator** resource. It effectively defines an area target that is then used as any other target in the **ContactLocator**.

A **PlanetographicRegion** is an area target on the surface of a celestial body used to find a sub-satellite point crossing of a **Spacecraft** into and out of the **PlanetographicRegion**. The **PlanetographicRegion** is defined by user-input latitude and longitude pairs of points. By default, **PlanetographicRegion** uses **ContactLocator** to generate a text event report listing the beginning and ending times of each crossing event, along with the duration. Contact location can be performed over the entire propagation interval or over a subinterval; unlike regular **ContactLocator**, light-time delay and stellar aberration are ignored. Another difference from standard contact location is that **PlanetographicRegion** uses the sub-satellite point, so the elevation angle is 90 degrees by design.

Contact location can be performed between one **Spacecraft (Observer)** and one **PlanetographicRegion** region (**Target**). More than one target-observer pair may be included in a run using multiple **ContactLocator** resources.

By default, the **PlanetographicRegion** searches the entire interval of propagation of the **Observer**; see [Remarks](#) for details. To search a custom interval, as with standard **ContactLocator**, set **UseEntireInterval** to `False` and set **InitialEpoch** and **FinalEpoch** accordingly. Note that if these epochs fall outside the propagation interval of the **Observer**, GMAT will display an error.

Unlike the standard **ContactLocator**, the **PlanetographicRegion** ignores both light-time delay and stellar aberration. The switches may be set either to `True` or `False`, though each combination will result in the same output intervals. (While irrelevant to **PlanetographicRegion**, GMAT will throw an error if the stellar aberration is `True` when the light-time correction is `False`.) This behavior was chosen to make the results consistent with using the sub-satellite point in the calculation of the crossing times.

The event search is performed at a fixed step through the interval. You can control the step size (in seconds) by setting the **StepSize** field. For crossing complicated regions (e.g. with densely packed latitude/longitude **PlanetographicRegion** definition points), or grazing "sharp" target areas, it may be useful to reduce the step size; otherwise, the algorithm may "step over" the feature, leading to a false positive or false negative entry/exit for the region. See [Remarks](#) for details.

GMAT uses the SPICE library for the fundamental event location algorithm. As such, all celestial body data is loaded from SPICE kernels for this subsystem, rather than GMAT's

own **CelestialBody** shape and orientation configuration. Currently **PlanetographicRegion** only supports Earth as a **CentralBody**; other choices will cause GMAT to throw an error.

Unless otherwise mentioned, **ContactLocator** fields cannot be set in the mission sequence.

See Also: [ContactLocator](#), [Spacecraft](#), [CelestialBody](#), [FindEvents](#)

## Fields

Field	Description												
<b>AreaFileName</b>	<p>Name and path of the definition file for the region. File can contain comments at the top, then has pairs of latitude and longitude points. See below for a sample. For a specific region, use this file to define the area OR the latitude/longitude arrays described below. Using both for the same region will cause GMAT to throw an error.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Valid file path</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>None</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Valid file path	<b>Access</b>	set	<b>Default Value</b>	None	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Valid file path												
<b>Access</b>	set												
<b>Default Value</b>	None												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>CentralBody</b>	<p>Body on which the region is defined. Currently only Earth is implemented.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Only "Earth"</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>"Earth"</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Only "Earth"	<b>Access</b>	set	<b>Default Value</b>	"Earth"	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Only "Earth"												
<b>Access</b>	set												
<b>Default Value</b>	"Earth"												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>Latitude</b>	<p>Array of latitude points defining the region. Must have a corresponding <b>Longitude</b> array with the same number of elements.</p> <table> <tr> <td><b>Data Type</b></td><td>Array of real values, separated by commas.</td></tr> <tr> <td><b>Allowed Values</b></td><td>-90 to 90</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>None</td></tr> <tr> <td><b>Units</b></td><td>Degrees</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Array of real values, separated by commas.	<b>Allowed Values</b>	-90 to 90	<b>Access</b>	set	<b>Default Value</b>	None	<b>Units</b>	Degrees	<b>Interfaces</b>	script
<b>Data Type</b>	Array of real values, separated by commas.												
<b>Allowed Values</b>	-90 to 90												
<b>Access</b>	set												
<b>Default Value</b>	None												
<b>Units</b>	Degrees												
<b>Interfaces</b>	script												

Field	Description	
<b>Longitude</b>	Array of longitude points defining the region. Must have a corresponding <b>Latitude</b> array with the same number of elements.	
	<b>Data Type</b>	Array of real values, separated by commas.
	<b>Allowed Values</b>	-180 to 180 OR 0 to 360 (cannot mix both in one array)
	<b>Access</b>	set
	<b>Default Value</b>	None
	<b>Units</b>	Degrees
	<b>Interfaces</b>	script

## Remarks

### Search interval

For a **PlanetographicRegion**, the **ContactLocator** search interval can be specified either as the entire ephemeris interval of the **Observers**, or as a user-defined interval. Each mode offers specific behavior related to handling of discontinuous intervals.

If **UseEntireInterval** is true, the search is performed over the entire ephemeris interval of the **Observers**, including any gaps or discontinuities. For **PlanetographicRegion** light-time delay is ignored.

If **UseEntireInterval** is false, the provided **InitialEpoch** and **FinalEpoch** are used to form the search interval directly. The user must ensure than the provided interval results in valid **Observers** ephemeris epochs.

### Run modes

For run modes, the **PlanetographicRegion** feature uses the **ContactLocator** function which works in conjunction with the **FindEvents** command: the **ContactLocator** resource defines the configuration of the event search, and the **FindEvents** command executes the search at a specific point in the mission sequence. The mode of interaction is defined by **ContactLocator.RunMode**, which has three options:

- Automatic: All **FindEvents** commands are executed as-is, plus an additional **FindEvents** is executed automatically at the end of the mission sequence.
- Manual: All **FindEvents** commands are executed as-is.
- Disabled: **FindEvents** commands are ignored.

### Search algorithm

The **PlanetographicRegion** algorithm makes a line segment from the sub-satellite point (at the specified time interval) to a point that's definitely outside of the celestial body. If it intersects an odd number of line segments (often one), then the point is considered to be *within* the polygon; likewise, if it encounters an even number (usually zero), then the sub-satellite point is considered to be *outside* of the region. When a change (inside-to-outside, or outside-to-inside) occurs, then GMAT will determine *when* the change occurred.

The line segments between points are drawn based upon the shortest path between the two points on the surface of the celestial body on which the points reside. This is often referred to as the great circle path between the points. This means the line segment between two points may appear to curve when drawn on a flat map. This curving effect increases the closer you get to the poles and the longer the line segment is. If a non great circle path is desired, add additional points that lie along the desired line segment. This will straighten out the line when drawn on a flat map.

It is important to note that if the beginning epoch has the sub-satellite point within the region, then it will list this as the entering of the region even if it isn't close to the boundary; likewise, if the epoch ends with the sub-satellite point within the region, it will list the epoch end-time as the final point of leaving the region.

It is also important to note that if the sub-satellite point crosses two or more times between checks (due to a long interval), it may either not register the crossing (in the case of an even number of crossings), or not find all of the crossings (in the case of odd numbers three and above). In these cases, the **StepSize** parameter can be reduced to catch the finer details. For an example of this, see "Reducing Step Size for a Region with sharp Vertices" below.

In contrast, unnecessarily detailed regions or excessively small time intervals may cause performance issues. So there can be a trade off, e.g. if no area target is complex, you can increase performance of the search by increasing **StepSize**.

## Examples

Set up a basic **PlanetographicRegion** with a LEO spacecraft:

Create Spacecraft Fermi

```
Fermi.DateFormat = UTCGregorian;
Fermi.Epoch = '16 Mar 2010 00:00:00.000';
Fermi.CoordinateSystem = EarthMJ2000Eq;
Fermi.DisplayStateType = Cartesian;
Fermi.X = 1861.715588;
Fermi.Y = -6097.672271;
Fermi.Z = -2687.893642;
Fermi.VX = 7.278672;
Fermi.VY = 1.600198;
Fermi.VZ = 1.424786;
Fermi.DryMass = 4357.33;
Fermi.Cd = 2.1;
Fermi.CdSigma = 0.21;
Fermi.AtmosDensityScaleFactor = 1.0;
Fermi.AtmosDensityScaleFactorSigma = 1.0;
Fermi.Cr = 0.75;
Fermi.CrSigma = 0.1;
Fermi.DragArea = 14.18;
Fermi.SRPArea = 14.18;
Fermi.Id = 'Fermi'
```

```

Create ForceModel FM

FM.CentralBody          = Earth
FM.PointMasses          = {Earth}
FM.RelativisticCorrection = Off
FM.SRP                  = Off
FM.ErrorControl         = None

Create Propagator Prop

Prop.FM     = FM
Prop.Type   = RungeKutta89

Create PlanetographicRegion SAA
SAA.CentralBody = Earth
SAA.Latitude   = [ 20, 20, -20, -20]
SAA.Longitude  = [ 20, -20, -20, 20]

Create ContactLocator CL
CL.Observers = {Fermi}
CL.Target    = SAA
CL.Filename  = 'Contacts_PlanetoRegion_Square.txt'

BeginMissionSequence

Propagate Prop(Fermi) {Fermi.ElapsedDays = 1.0}

```

Input a **PlanetographicRegion** via a file for a LEO spacecraft:

```

%
Create Spacecraft Fermi

Fermi.DateFormat           = UTCGregorian;
Fermi.Epoch                = '16 Mar 2010 00:00:00.000';
Fermi.CoordinateSystem     = EarthMJ2000Eq;
Fermi.DisplayStateType     = Cartesian;
Fermi.X                    = 1861.715588
Fermi.Y                    = -6097.672271
Fermi.Z                    = -2687.893642
Fermi.VX                   = 7.278672
Fermi.VY                   = 1.600198
Fermi.VZ                   = 1.424786
Fermi.DryMass              = 4357.33
Fermi.Cd                   = 2.1
Fermi.CdSigma              = 0.21
Fermi.AtmosDensityScaleFactor = 1.0;
Fermi.AtmosDensityScaleFactorSigma = 1.0;
Fermi.Cr                   = 0.75

```

```

Fermi.CrSigma          = 0.1
Fermi.DragArea         = 14.18
Fermi.SRPArea          = 14.18
Fermi.Id               = 'Fermi'

Create ForceModel FM

FM.CentralBody        = Earth
FM.PointMasses         = {Earth}
FM.RelativisticCorrection = Off
FM.SRP                 = Off
FM.ErrorControl        = None

Create Propagator Prop

Prop.FM    = FM
Prop.Type = RungeKutta89

Create PlanetographicRegion SAA
SAA.CentralBody = Earth
SAA.AreaFileName = (optional directory path\)\PlanetoRegion_Sample.AT

Create ContactLocator CL
CL.Observers = {Fermi}
CL.Target     = SAA
CL.Filename   = 'Contacts_PlanetoRegion_Sample_FileInput.txt'

BeginMissionSequence

Propagate Prop(Fermi) {Fermi.ElapsedDays = 1.0}

```

Sample **PlanetographicRegion** area input file (for above example):

```

PlanetographicRegion
% First line is required to be the above keyword
% comment lines indicated by the percent sign
% any number of comment lines allowed between header and data lines
% blank lines are allowed in the header
% Windows or Linux line endings are allowed
% this file implements the same simple square which is
% implemented in arrays in the above sample
% each row is a Lat/Long pair:
%   first column is Latitude, second is Longitude
% no intrinsic limit on the number of rows; has been tested to 1200
% last row does not have to repeat first row

20    20
20    -20
-20   -20

```

-20 20

Using Multiple **PlanetographicRegion** areas in a single run (input areas can be any combination of files and arrays):

```
Create Spacecraft Fermi
Fermi.DateFormat          = UTCGregorian;
Fermi.Epoch               = '16 Mar 2010 00:00:00.000';
Fermi.CoordinateSystem    = EarthMJ2000Eq;
Fermi.DisplayStateType    = Cartesian;
Fermi.X                   = 1861.715588
Fermi.Y                   = -6097.672271
Fermi.Z                   = -2687.893642
Fermi.VX                  = 7.278672
Fermi.VY                  = 1.600198
Fermi.VZ                  = 1.424786
Fermi.DryMass              = 4357.33
Fermi.Cd                  = 2.1
Fermi.CdSigma              = 0.21
Fermi.AtmosDensityScaleFactor = 1.0;
Fermi.AtmosDensityScaleFactorSigma = 1.0;
Fermi.Cr                  = 0.75
Fermi.CrSigma              = 0.1
Fermi.DragArea              = 14.18
Fermi.SRPArea              = 14.18
Fermi.Id                  = 'Fermi'

Create ForceModel FM
FM.CentralBody            = Earth
FM.PointMasses             = {Earth}
FM.RelativisticCorrection = Off
FM.SRP                     = Off
FM.ErrorControl             = None

Create Propagator Prop
Prop.FM      = FM
Prop.Type    = RungeKutta89

Create PlanetographicRegion LAT_SAA
Create PlanetographicRegion GBM_SAA

LAT_SAA.CentralBody = Earth
LAT_SAA.Latitude   = [ 20, 20, -20, -20]
LAT_SAA.Longitude  = [ 20, -20, -20, 20]

GBM_SAA.CentralBody = Earth
GBM_SAA.Latitude   = [9.515, 11.0, -7.0, -9.0]
GBM_SAA.Longitude  = [-170.0, 168.0, 178.0, -175.0]
```

```

Create ContactLocator CL1
CL1.Observers = {Fermi}
CL1.Target     = LAT_SAA
CL1.Filename   = 'Contacts_PlanetoRegion_FermiMultiArea_LAT.txt'

Create ContactLocator CL2
CL2.Observers = {Fermi}
CL2.Target     = GBM_SAA
CL2.Filename   = 'Contacts_PlanetoRegion_FermiMultiArea2_GBM.txt'

BeginMissionSequence

Propagate Prop(Fermi) {Fermi.ElapsedDays = 1.0}

```

Reducing Step Size for a Region with sharp Vertices:

```

% South Polar Region Area target with EOS-like sun-sync satellite
Create Spacecraft EOS
EOS.DateFormat          = UTCGregorian;
EOS.Epoch               = '16 Mar 2010 00:00:00.000';
EOS.CoordinateSystem    = EarthMJ2000Eq;
EOS.DisplayStateType    = Cartesian;
EOS.X                  = 257.38045993527360
EOS.Y                  = 948.52767071254202
EOS.Z                  = -6869.1766527867969
EOS.VX                 = 6.1343425407376108
EOS.VY                 = -4.4346302750983723
EOS.VZ                 = -0.38250721354048136
EOS.DryMass             = 4357.33
EOS.Cd                  = 2.1
EOS.CdSigma             = 0.21
EOS.AtmosDensityScaleFactor = 1.0;
EOS.AtmosDensityScaleFactorSigma = 1.0;
EOS.Cr                  = 0.75
EOS.CrSigma              = 0.1
EOS.DragArea             = 14.18
EOS.SRPArea              = 14.18
EOS.Id                  = 'EOS'

Create ForceModel FM
FM.CentralBody          = Earth
FM.PointMasses          = {Earth}
FM.RelativisticCorrection = Off
FM.SRP                  = Off
FM.ErrorControl          = None

Create Propagator Prop
Prop.FM      = FM
Prop.Type   = RungeKutta89

```

```

Create PlanetographicRegion SAA
SAA.CentralBody = Earth
SAA.Latitude  = [-70.0, -80.0, -85.0, -85.0, -70.0, -75.0]
SAA.Longitude = [20.0,   80.0,   0.0,   220.0, 320.0, 359.0]

Create ContactLocator CL
CL.StepSize = 1.0
CL.Observers = {EOS}
CL.Target    = SAA
CL.Filename  = 'Contacts_PlanetoRegion_EOSsouthPolarArea.txt'

BeginMissionSequence

Propagate Prop(EOS) {EOS.ElapsedDays = 1.0}

```

Generate report over only part of the **Observers** Orbit:

```

Create Spacecraft Fermi
Fermi.DateFormat          = UTCGregorian;
Fermi.Epoch                = '16 Mar 2010 00:00:00.000';
Fermi.CoordinateSystem     = EarthMJ2000Eq;
Fermi.DisplayStateType     = Cartesian;
Fermi.X                    = 1861.71558;
Fermi.Y                    = -6097.672271;
Fermi.Z                    = -2687.893642;
Fermi.VX                   = 7.278672;
Fermi.VY                   = 1.600198;
Fermi.VZ                   = 1.424786;
Fermi.DryMass              = 4357.33;
Fermi.Cd                    = 2.1;
Fermi.CdSigma              = 0.21;
Fermi.AtmosDensityScaleFactor = 1.0;
Fermi.AtmosDensityScaleFactorSigma = 1.0;
Fermi.Cr                    = 0.75;
Fermi.CrSigma              = 0.1;
Fermi.DragArea              = 14.18;
Fermi.SRPArea               = 14.18;
Fermi.Id                   = 'Fermi';

Create ForceModel FM
FM.CentralBody            = Earth
FM.PointMasses             = {Earth}
FM.RelativisticCorrection = Off
FM.SRP                     = Off
FM.ErrorControl            = None

Create Propagator Prop
Prop.FM      = FM

```

```
Prop.Type = RungeKutta89

Create PlanetographicRegion SAA
SAA.CentralBody = Earth
SAA.Latitude  = [ 20,  20, -20, -20]
SAA.Longitude = [ 20, -20, -20,  20]

Create ContactLocator CL
CL.Observers = {Fermi}
CL.Target     = SAA
CL.Filename   = 'Contacts_PlanetoRegion_DelayStartTime.txt'

CL.UseEntireInterval = false
CL.InputEpochFormat = UTCGregorian;
CL.InitialEpoch      = '16 Mar 2010 04:30:00.000';
CL.FinalEpoch        = '17 Mar 2010 00:00:00.000';

BeginMissionSequence

Propagate Prop(Fermi) {Fermi.ElapsedDays = 1.0}
```

## Plate

Used to specify the properties of a single spacecraft surface (body panel, solar array side, or other surface) for high-fidelity solar radiation pressure modeling, including specular, diffuse, and absorptive effects.

### Description

The **Plate** resource allows the user to construct a detailed spacecraft area model for higher-fidelity solar radiation pressure (SRP) modeling. A spacecraft will typically be modeled as a collection of plates; at a minimum six plates are required to represent the spacecraft as a rectangular prism or box. You may also specify plates to represent appendages such as solar arrays or a high-gain antenna. These plates can be modeled as having a dynamic attitude with respect to the spacecraft body, either by specifying them as Sun-facing (normal to the instantaneous spacecraft-Sun vector) or by providing an external file which gives the plate attitude as a function of time.

The collection of **Plate** resources that comprise the model are assigned on the Spacecraft object using the Spacecraft **AddPlates** field. Each Plate has an associated AreaCoefficient parameter which represents a correction factor that may be estimated in the orbit determination. You may estimate an individual correction for each Plate in the model, or choose to associate a single correction with a grouping of plates using the Spacecraft **NPlateSRPEquateAreaCoefficients** parameter.

See Also [Spacecraft Ballistic/Mass Properties](#)

### Fields

Field	Description
<b>Area</b>	The plate area surface area.  <b>Data Type</b> Real > 0 <b>Allowed Values</b> Any positive Real number <b>Access</b> Set <b>Default Value</b> 1 m^2 <b>Units</b> Meters^2 <b>Interfaces</b> Script
<b>AreaCoefficient</b>	A scale factor applied to the plate area, typically used for estimating errors in the plate model.  <b>Data Type</b> Real <b>Allowed Values</b> Real > 0 <b>Access</b> Set <b>Default Value</b> 1.0 <b>Units</b> None <b>Interfaces</b> Script

Field	Description
<b>AreaCoefficientSigma</b>	A-priori uncertainty of the <b>AreaCoefficient</b> . Only used for constraining estimation of the <b>AreaCoefficient</b> parameter.
	<b>Data Type</b> Real <b>Allowed Values</b> Real > 0 <b>Access</b> Set <b>Default Value</b> <b>1e70</b> <b>Units</b> None <b>Interfaces</b> Script
<b>DiffuseFraction</b>	Plate coefficient of diffuse reflectivity.
	<b>Data Type</b> Real number <b>Allowed Values</b> $0 \leq \text{DiffuseFraction} \leq 1$ <b>Access</b> Set <b>Default Value</b> <b>0</b> <b>Units</b> None <b>Interfaces</b> Script
<b>DiffuseFractionSigma</b>	A-priori uncertainty of the <b>DiffuseFraction</b> . Only used for constraining estimation of the <b>DiffuseFraction</b> parameter.
	<b>Data Type</b> Real <b>Allowed Values</b> Real > 0 <b>Access</b> Set <b>Default Value</b> <b>1e70</b> <b>Units</b> None <b>Interfaces</b> Script
<b>LitFraction</b>	A scale factor applied to the plate area to specify the fraction of the plate that is illuminated (not in shadow). This parameter can be used to model spacecraft self-shadowing, for example due to a solar array casting a shadow on a side of the spacecraft body.
	<b>Data Type</b> Real <b>Allowed Values</b> $0 < \text{LitFraction} \leq 1$ <b>Access</b> Set <b>Default Value</b> <b>1.0</b> <b>Units</b> None <b>Interfaces</b> Script

Field	Description
<b>PlateNormal</b>	<p>Plate surface normal vector. This specifies the orientation of the plate in the spacecraft body frame, when the <b>Plate.Type</b> is set to <b>FixedInBody</b>.</p>
	<p><b>Data Type</b> Vector  <b>Allowed Values</b> Non-null 3-D vector  <b>Access</b> Set  <b>Default Value</b> [1,0,0]  <b>Units</b> None  <b>Interfaces</b> Script</p>
<b>PlateNormalHistoryFile</b>	<p>Plate surface normal vector history file. This specifies the orientation of the plate when the <b>Plate.Type</b> is set to <b>File</b>.</p>
	<p><b>Data Type</b> String  <b>Allowed Values</b> Valid path and file name  <b>Access</b> set  <b>Default Value</b> None  <b>Units</b> Not applicable  <b>Interfaces</b> Script</p>
<b>PlateX</b>	<p>X-component of the plate's location expressed in the spacecraft's body coordinate system.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set, get  <b>Default Value</b> 0  <b>Units</b> Meters  <b>Interfaces</b> Script</p>
<b>PlateY</b>	<p>Y-component of the plate's location expressed in the spacecraft's body coordinate system.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set, get  <b>Default Value</b> 0  <b>Units</b> Meters  <b>Interfaces</b> Script</p>
<b>PlateZ</b>	<p>Z-component of the plate's location expressed in the spacecraft's body coordinate system.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set, get  <b>Default Value</b> 0  <b>Units</b> Meters  <b>Interfaces</b> Script</p>

Field	Description
<b>SolveFors</b>	List of estimated parameters for the plate.
	<b>Data Type</b>
	Enumeration
	<b>Allowed Values</b>
	AreaCoefficient, DiffuseFraction, Specular-
	Fraction
	<b>Access</b>
	Set
	<b>Default Value</b>
	Empty
	<b>Units</b>
	Not applicable
	<b>Interfaces</b>
	Script
<b>SpecularFraction</b>	Plate coefficient of specular reflectivity.
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	0 <= SpecularFraction <= 1
	<b>Access</b>
	Set
	<b>Default Value</b>
	1
	<b>Units</b>
	None
	<b>Interfaces</b>
<b>SpecularFractionSigma</b>	A-priori uncertainty of the <b>SpecularFraction</b> . Only used for constraining estimation of the <b>SpecularFraction</b> parameter.
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	Real > 0
	<b>Access</b>
	set
	<b>Default Value</b>
	1e70
	<b>Units</b>
	None
	<b>Interfaces</b>
<b>Type</b>	Specifies the method of describing the plate orientation. The orientation of a <b>FixedInBody</b> plate is specified by the <b>PlateNormal</b> vector. The orientation of a File plate is specified by the <b>PlateNormalHistoryFile</b> .
	The orientation of a SunFacing plate is taken to be perpendicular to the spacecraft-Sun vector. The attitude of a SunFacing plate is computed automatically by GMAT, and the <b>PlateNormal</b> and <b>PlateNormalHistoryFile</b> parameters are ignored if the plate is a SunFacing plate.
	<b>Data Type</b>
	Enumeration
	<b>Allowed Values</b>
	FixedInBody, SunFacing, File
	<b>Access</b>
	Set
	<b>Default Value</b>
	<b>FixedInBody</b>
	<b>Units</b>
	Not applicable
	<b>Interfaces</b>

## Remarks

Modeling of solar radiation pressure for each plate includes effects due to individual plate specular reflectivity, diffuse reflectivity, and absorption. The sum of each plate's specular, diffuse, and absorptive fractions must equal 1. In the Plate resource, the user specifies the specular and diffuse coefficients; the absorption fraction is the remainder from 1 of the sum of the specular and diffuse fractions.

### Plate normal history file format

If the Plate Type is set to **File**, the user must provide an external attitude history file, assigned on the **Plate.PlateNormalHistoryFile** parameter. The plate normal history file gives the plate normal vector as a function of time. The file contains a header as described below.

Keyword	Re- quired	Description and Supported Values
<b>Coordinate_System</b>	Y	Reference coordinate system of the included normal vectors. This may be any built-in or user defined inertial frame, or 'FixedInBody' to use the spacecraft body frame.
<b>Interpolation_Method</b>	N	Interpolation method to be used on the normal vectors. Linear interpolation is the only method currently supported.
<b>Start_Epoch</b>	Y	Base epoch for times in the table of normal vectors. Required format is UTCGregorian 'DD Mon YYYY HH:MM:SS.SSS'

Following the header are a series of records, one per line, giving a time in seconds from the Start\_Epoch, followed by the Cartesian components of the normal vector to the plate at the given time in seconds past the Start\_Epoch. A sample file is shown below.

```
Start_Epoch = '11 Jun 2019 00:00:00.000'
Coordinate_System = EarthMJ2000Eq
Interpolation_Method = Linear

    0.118      0.71134437  0.59768958  0.36980583
   60.118      0.70844298  0.64262126  0.29179866
  120.117      0.70342991  0.67911896  0.20972316
  180.118      0.69632195  0.70683245  0.12459387
  240.118      0.68720633  0.72550392  0.03730319
  300.118      0.67618273  0.73495324  -0.05119232
  360.118      0.6635059   0.73500373  -0.13974778
  420.118      0.64938672  0.72563809  -0.22747802
  480.117      0.63365791  0.70727707  -0.31342751
  540.118      0.6166704   0.67998056  -0.39666617
  600.118      0.59854485  0.64412315  -0.47628713
  660.118      0.57958926  0.60014396  -0.55127445
  720.118      0.55997495  0.54842962  -0.62100966
```

780.117	0.5399806	0.48973174	-0.68453179
840.117	0.51976556	0.42453172	-0.7413613
900.117	0.49951296	0.35366998	-0.79082511
960.117	0.47946796	0.27785984	-0.83240879
1020.118	0.45991923	0.19807528	-0.86558679
1080.118	0.44098414	0.11493292	-0.8901255
1140.118	0.42293817	0.02963382	-0.90567386
1200.117	0.40594474	-0.05701248	-0.91211756
1260.117	0.39029164	-0.14410621	-0.90934363
1320.117	0.37589181	-0.23056147	-0.89752257
1380.117	0.36306455	-0.31566225	-0.87666497
1440.118	0.35205587	-0.39829948	-0.84700306

## Examples

This example shows how to create a simple single-plate model. In this example, we model both the front and back of a single plate on the X-face of the spacecraft body.

```
Create Spacecraft SimSat;  
  
%  
% N-Plate models  
%  
  
Create Plate PlusX MinusX;  
  
PlusX.Type          = FixedInBody;  
PlusX.PlateNormal  = [1.0, 0.0, 0.0];  
PlusX.LitFraction   = 1.0;  
PlusX.AreaCoefficient = 1.0;  
PlusX.Area          = 12;  
PlusX.SpecularFraction = 1;  
PlusX.DiffuseFraction = 0;  
  
MinusX.Type          = FixedInBody;  
MinusX.PlateNormal  = [-1.0, 0.0, 0.0];  
MinusX.LitFraction   = 1.0;  
MinusX.AreaCoefficient = 1.0;  
MinusX.Area          = 12;  
MinusX.SpecularFraction = 0.5;  
MinusX.DiffuseFraction = 0.1;  
  
SimSat.AddPlates  = {PlusX, MinusX};
```

## Propagator

A propagator models spacecraft motion

### Overview of Propagator Components

A **Propagator** is the GMAT component used to model spacecraft motion. GMAT contains two types of propagators: a numerical integrator type, and an ephemeris type. When using a numerical integrator type **Propagator**, you can choose among a suite of numerical integrators implementing Runge-Kutta and predictor corrector methods. Numeric **Propagators** also require a **ForceModel**. Additionally, you can configure a **Propagator** to use SPICE kernels, and Code500, STK, and CCSDS ephemeris files for propagation. This resource cannot be modified in the Mission Sequence. However, you can set one **Propagator** equal to another **Propagator** in the mission,( i.e. `myPropagator = yourPropagator` ).

GMAT's documentation for **Propagator** components is broken down into these sections:

- For numerical **Propagator** documentation see [Numerical Propagator](#)
- For SPICE **Propagator** documentation see [SPK-Configured Propagator](#)
- For Code500 ephemeris **Propagator** documentation see [Code500 Ephemeris-Configured Propagator](#)
- For STK ephemeris **Propagator** documentation see [STK Ephemeris-Configured Propagator](#)
- For CCSDS OEM ephemeris **Propagator** documentation see [CCSDS OEM Ephemeris-Configured Propagator](#)
- For TLE **Propagator** documentation see [SPICESGP4 TLE Propagator](#)

See Also: [Spacecraft](#) and [Propagate](#). For special considerations regarding configuration of propagators for orbit determination, see [Configuration of Propagators for Orbit Determination](#).

## Numerical Propagator

### Overview

A **Propagator** object that uses a numerical integrator (as opposed to an ephemeris propagator) is one of a few objects in GMAT that is configured differently in the scripting and in the GUI. In the GUI, you configure the integrator and force model setting on the same dialog box. See the [Remarks](#) section below for detailed discussion of GMAT's numerical integrators as well as performance and accuracy comparisons, and usage recommendations. This resource cannot be modified in the Mission Sequence. However, you can do whole object assignment in the mission,( i.e. `myPropagator = yourPropagator` ).

When working in the script, you must create a **ForceModel** object separately from the **Propagator** and specify the force model using the “**FM**” field on the propagator object. See the [Examples](#) section later in this section for details.

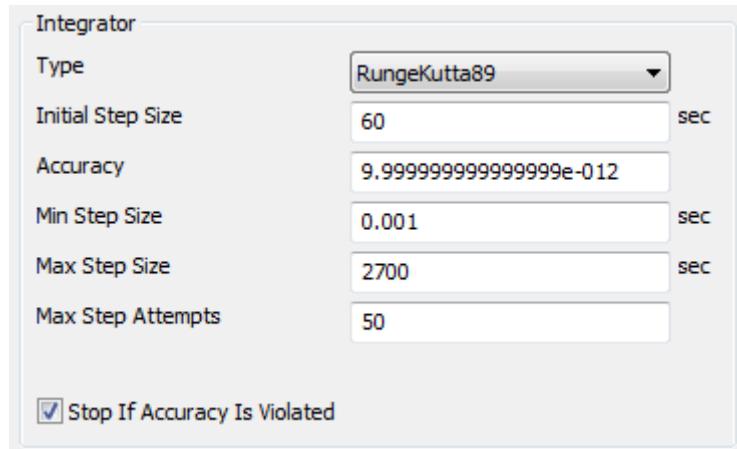
## Options

Option	Description
<b>Accuracy</b>	The desired accuracy for an integration step. GMAT uses the method selected in the <b>ErrorControl</b> field on the Force Model to determine a metric of the integration accuracy. For each step, the integrator ensures that the error in accuracy is smaller than the value defined by the <b>ErrorControl</b> metric.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Real &gt; 0 AND Real &lt; 1</p> <p><b>Default Value</b> 1e-11 except for ABM integrator which is 1e-10</p> <p><b>Interfaces</b> GUI, script</p> <p><b>Access</b> set</p> <p><b>Units</b> N/A</p>
<b>FM</b>	Identifies the force model used by an integrator. If no force model is provided, GMAT uses an Earth centered propagator with a 4x4 gravity model.
	<p><b>Data Type</b> Resource reference</p> <p><b>Allowed Values</b> <b>ForceModel</b></p> <p><b>Default Value</b> N/A</p> <p><b>Interfaces</b> GUI, script</p> <p><b>Access</b> set</p> <p><b>Units</b> N/A</p>
<b>InitialStepSize</b>	<p>The size of the first step attempted by the integrator.</p> <p>Warning: The order of assignment of propagator parameters affects the results. Specifically, the <b>Type</b> must be specified before <b>InitialStepSize</b>, or <b>InitialStepSize</b> will reset back to the default value.</p> <p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Real &gt; 0.0001</p> <p><b>Default Value</b> 60</p> <p><b>Interfaces</b> GUI, script</p> <p><b>Access</b> set</p> <p><b>Units</b> sec.</p>

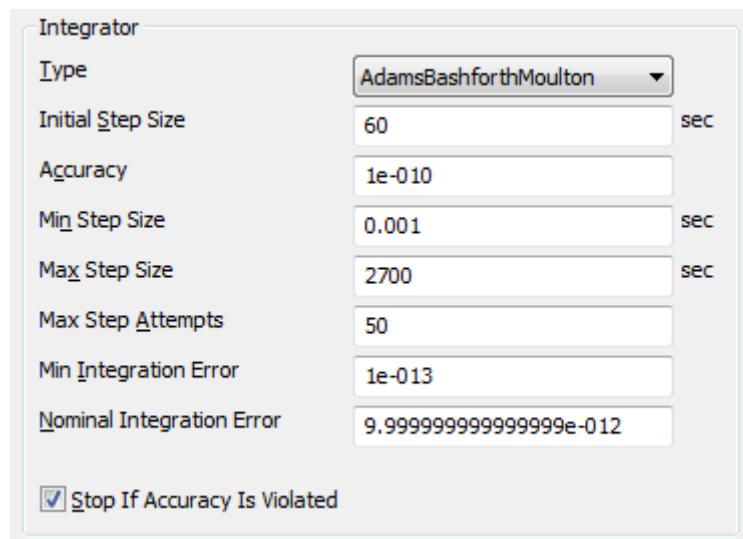
Option	Description
<b>LowerError</b>	<p>The lower bound on integration error, used to determine when to make the step size larger. Applies only to <b>AdamsBashforth-Moulton</b> integrator.</p>
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real > 0 AND 0 < LowerError < TargetError < Accuracy
<b>Default Value</b>	1e-13
<b>Interfaces</b>	GUI, script
<b>Access</b>	set
<b>Units</b>	N/A
<b>MaxStep</b>	<p>The maximum allowable step size.</p>
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real > 0 AND MinStep <= MaxStep
<b>Default Value</b>	2700
<b>Interfaces</b>	GUI, script
<b>Access</b>	set
<b>Units</b>	N/A
<b>MaxStepAttempts</b>	<p>The number of attempts the integrator takes to meet the tolerance defined by the <b>Accuracy</b> field.</p>
<b>Data Type</b>	Integer
<b>Allowed Values</b>	Integer >= 1
<b>Default Value</b>	50
<b>Interfaces</b>	GUI, script
<b>Access</b>	set
<b>Units</b>	N/A
<b>MinStep</b>	<p>The minimum allowable step size.</p>
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real > 0 AND MinStep <= MaxStep
<b>Default Value</b>	0.001
<b>Interfaces</b>	GUI, script
<b>Access</b>	set
<b>Units</b>	sec.
<b>StopIfAccuracyIsViolated</b>	<p>Flag to stop propagation if integration error value defined by <b>Accuracy</b> is not satisfied.</p>
<b>Data Type</b>	Boolean
<b>Allowed Values</b>	true, false
<b>Default Value</b>	true
<b>Interfaces</b>	GUI, script
<b>Access</b>	set
<b>Units</b>	N/A

Option	Description												
<b>TargetError</b>	<p>The nominal bound on integration error, used to set the target integration accuracy when adjusting step size. Applies only to <b>AdamsBashforthMoulton</b> integrator.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real &gt; 0 AND 0 &lt; <b>LowerError</b> &lt; <b>TargetError</b> &lt; <b>Accuracy</b></td></tr> <tr> <td><b>Default Value</b></td><td>1e-11</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real > 0 AND 0 < <b>LowerError</b> < <b>TargetError</b> < <b>Accuracy</b>	<b>Default Value</b>	1e-11	<b>Interfaces</b>	GUI, script	<b>Access</b>	set	<b>Units</b>	N/A
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real > 0 AND 0 < <b>LowerError</b> < <b>TargetError</b> < <b>Accuracy</b>												
<b>Default Value</b>	1e-11												
<b>Interfaces</b>	GUI, script												
<b>Access</b>	set												
<b>Units</b>	N/A												
<b>Type</b>	<p>Specifies the integrator or analytic propagator used to model the time evolution of spacecraft motion.</p> <p>Warning: The order of assignment of propagator parameters affects the results. Specifically, the <b>Type</b> must be specified before <b>InitialStepSize</b>, or <b>InitialStepSize</b> will reset back to the default value.</p> <table> <tr> <td><b>Data Type</b></td><td>Enumeration</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>PrinceDormand78</b>, <b>PrinceDormand853</b>, <b>PrinceDormand45</b>, <b>RungeKutta89</b>, <b>RungeKutta68</b>, <b>RungeKutta56</b>, <b>AdamsBashforthMoulton</b>, <b>SPK</b>, <b>CCSDS-OEM</b>, <b>Code500</b>, <b>STK</b></td></tr> <tr> <td><b>Default Value</b></td><td><b>RungeKutta89</b></td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> </table>	<b>Data Type</b>	Enumeration	<b>Allowed Values</b>	<b>PrinceDormand78</b> , <b>PrinceDormand853</b> , <b>PrinceDormand45</b> , <b>RungeKutta89</b> , <b>RungeKutta68</b> , <b>RungeKutta56</b> , <b>AdamsBashforthMoulton</b> , <b>SPK</b> , <b>CCSDS-OEM</b> , <b>Code500</b> , <b>STK</b>	<b>Default Value</b>	<b>RungeKutta89</b>	<b>Interfaces</b>	GUI, script	<b>Access</b>	set	<b>Units</b>	N/A
<b>Data Type</b>	Enumeration												
<b>Allowed Values</b>	<b>PrinceDormand78</b> , <b>PrinceDormand853</b> , <b>PrinceDormand45</b> , <b>RungeKutta89</b> , <b>RungeKutta68</b> , <b>RungeKutta56</b> , <b>AdamsBashforthMoulton</b> , <b>SPK</b> , <b>CCSDS-OEM</b> , <b>Code500</b> , <b>STK</b>												
<b>Default Value</b>	<b>RungeKutta89</b>												
<b>Interfaces</b>	GUI, script												
<b>Access</b>	set												
<b>Units</b>	N/A												

## GUI



Settings for the embedded Runge-Kutta integrators. Select the desired integrator from the **Type** menu.



The Adams-Bashforth-Moulton integrator has additional settings as shown.

## Remarks

### Best Practices for Using Numerical Integrators

The comparison data presented in a later section suggest that the **PrinceDormand78** integrator is the best all purpose integrator in GMAT. When in doubt, use the **Prince-Dormand78** integrator, and set **MinStep** to zero so that the integrator's adaptive step algorithm controls the minimum integration step size. Below are some important comments on GMAT's step size control algorithms and the dangers of using a non-zero value for the minimum integration step size. The **AdamsBashforthMoulton** integrator is a low order integrator and we only recommend its use for low precision analysis when a predictor-corrector algorithm is required. We recommend that you study the performance and accuracy analysis documented later in this section to select a numerical integrator for your application. You may need to perform further analysis and comparisons for your application.

### Caution



Caution: GMAT's default error computation mode is **RSSStep** and this is a more stringent error control method than **RSSState** that is often used as the default in other software such as STK. If you set Accuracy to a very small number, 1e-13 for example, and leave **ErrorControl** set to **RSSStep**, integrator performance will be poor, for little if any improvement in the accuracy of the orbit integration. To find the best balance between integration accuracy and performance, we recommend you experiment with the accuracy setting for your selected integrator for your application. You can start with a relatively high setting of **Accuracy**, say 1e-9, and lower the accuracy by an order of magnitude at a time and compare the final orbital states to determine where smaller values of **Accuracy** result in longer propagation times without providing more accurate orbital solutions.

**Caution**

Caution: GMAT allows you to set a minimum step on numerical integrators. It is possible that the requested **Accuracy** cannot be achieved given the **MinimumStep** setting. The **Propagator** flag **StopIfAccuracyIsViolated** determines the behavior if **Accuracy** cannot be satisfied. If **StopIfAccuracyIsViolated** is true, GMAT will throw an error and stop execution if integration accuracy is not satisfied. If **StopIfAccuracyIsViolated** is false, GMAT will only throw a warning that the integration accuracy was not satisfied but will continue to propagate the orbit.

## Numerical Integrators Overview

The table below describes each numerical integrator in detail.

Option	Description
<b>RungeKutta89</b>	An adaptive step, ninth order Runge-Kutta integrator with eighth order error control. The coefficients were derived by J. Verner. Verner developed several sets of coefficients for an 89 integrator and we have chosen the coefficients that are the most robust but not necessarily the most efficient.
<b>PrinceDormand78</b>	An adaptive step, eighth order Runge-Kutta integrator with seventh order error control. The coefficients were derived by Prince and Dormand.
<b>PrinceDormand853</b>	An adaptive step, eighth order Runge-Kutta integrator with 5th order error control that incorporates a 3rd order correction, as described in section II.10 of "Solving Ordinary Differential Equations I: Nonstiff Problems" by Hairer, Norsett and Warner. The coefficients were derived by Prince and Dormand. This integrator performs surprisingly well at loose Accuracy settings.
<b>PrinceDormand45</b>	An adaptive step, fifth order Runge-Kutta integrator with fourth order error control. The coefficients were derived by Prince and Dormand.
<b>RungeKutta68</b>	A second order Runge-Kutta-Nystrom type integrator with coefficients developed by by Dormand, El-Mikkawy and Prince. The integrator is a 9-stage Nystrom integrator, with error control on both the dependent variables and their derivatives. This second order implementation will correctly integrate forces that are non-conservative but it is not recommended for this use. See the integrator comparisons below for numerical comparisons. You cannot use this integrator to integrate mass during a finite maneuver because the mass flow rate is a first order differential equation not supported by this integrator.

Option	Description
<b>RungeKutta56</b>	An adaptive step, sixth order Runge-Kutta integrator with fifth order error control. The coefficients were derived by E. Fehlberg.
<b>AdamsBashforthMoulton</b>	A fourth-order Adams-Bashford predictor / Adams-Moulton corrector as described in Fundamentals of Astrodynamics by Bate, Mueller, and White. The predictor step extrapolates the next state of the variables using the derivative information at the current state and three previous states of the variables. The corrector uses derivative information evaluated for this state, along with the derivative information at the original state and two preceding states, to tune this state, giving the final, corrected state. The ABM integrator uses the RungeKutta89 integrator to start the integration process. The ABM is a low order integrator and should not be used for precise applications or for highly nonlinear applications such as celestial body flybys.

### Performance and Accuracy Comparison of Numerical Integrators

The tables below contain performance comparison data for GMAT's numerical integrators. The first table shows the orbit types, dynamics models, and propagation duration for each test case included in the comparison. Five orbit types were compared: low earth orbit, Molniya, Mars transfer (Type 2), Lunar transfer, and finite burn (case 1 is blow down, and case 2 is pressure regulated). For each test case, the orbit was propagated forward for a duration and then back-propagated to the intial epoch. The error values in the table are the RSS difference of the final position after forward and backward propagation to the initial position. The run time data for each orbit type is normalized on the integrator with the fastest run time for that orbit type. For all test cases the **ErrorControl** setting was set to **RSSStep**. **Accuracy** was set to 1e-12 for all integrators except for **AdamsBashfourthMoulton** which was set to 1e-11 because of poor performance when **Accuracy** was set to 1e-12.

Orbit	Dynamics Model	Duration
<b>LEO</b>	Earth 20x20, Sun, Moon, drag using 1 day MSISE90 density, SRP	
<b>Molniya</b>	Earth 20x20, Sun, Moon, drag using 3 days Jacchia Roberts density, SRP	
<b>Mars Transfer</b>	Near Earth: Earth 8x8, Sun, Moon, SRP 333 days  Deep Space: All planets as point mass perturbations  Near Mars: Mars 8x8 SRP	
<b>Lunar Transfer</b>	Earth central body with all planets as 5.8 days point mass perturbations	

Orbit	Dynamics Model	Duration
<b>Finite Burn (case 1 and 2)</b>	Point mass gravity	7200 sec.

Comparing the run time data for each integrator shown in the table below we see that the **PrinceDormand78** integrator was the fastest for 4 of the 6 cases and tied with the **RungeKutta89** integrator for LEO test case. For the Lunar flyby case, the **RungeKutta89** was the fastest integrator, however, in this case the **PrinceDormand78** integrator was at least 2 orders of magnitude more accurate given equivalent **Accuracy** settings. Notice that the **AdamsBashforthMoulton** integrator has km level errors for some orbits because it is a low-order integrator.

		RKV89	RKN68	RK56	PD45	PD78	ABM	PD853
<b>ISS</b>	Run Time	1.53	1.00	2.14	2.78	1.46	3.41	1.80
	Error (m)	0.003	64.060	0.022	0.002	0.006	0.012	0.013
<b>Molniya</b>	Run Time	1.32	1.47	1.99	3.08	1.00	3.35	1.92
	Error (m)	0.007	0.601	0.059	0.032	0.043	380.125	0.031
<b>Lunar Flyby</b>	Run Time	1.00	1.01	2.26	2.98	2.21	3.30	1.39
	Error (m)	0.063	0.017	0.002	0.023	0.000	0.236	0.080
<b>Mars Transfer</b>	Run Time	1.02	1.04	1.14	1.40	1.00	3.07	1.11
	Error (m)	0.030	0.001	0.043	0.194	0.009	25.231	0.030
<b>Finite burn 1</b>	Run Time	1.27	N/A	1.24	1.26	1.00	1.45	1.07
	Error (m)	0.002	N/A	0.006	0.002	0.002	0.000	0.002
<b>Finite burn 2</b>	Run Time	1.03	N/A	1.18	1.31	1.00	1.54	1.12
	Error (m)	0.002	N/A	0.000	0.000	0.001	0.003	0.002

## Fields Unique to the AdamsBashforthMoulton Integrator

The **AdamsBashforthMoulton** integrator has two additional fields named **TargetError** and **LowerError** that are only active when **Type** is set to **AdamsBashforthMoulton**. If you are using another integrator type, those fields must be removed from your script file to avoid parsing errors. When working in the GUI, this is performed automatically. See examples below for more details.

## Examples

Propagate an orbit using a general purpose Runge-Kutta integrator:

```
Create Spacecraft aSat
Create ForceModel aForceModel

Create Propagator aProp
aProp.FM          = aForceModel
aProp.Type        = PrinceDormand78
aProp.InitialStepSize = 60
aProp.Accuracy    = 1e-011
aProp.MinStep      = 0
aProp.MaxStep      = 86400
aProp.MaxStepAttempts = 50
aProp.StopIfAccuracyIsViolated = true
```

```
BeginMissionSequence
```

```
Propagate aProp(aSat) {aSat.ElapsedDays = .2}
```

Propagate using a fixed step configuration. Do this by setting **InitialStepSize** to the desired fixed step size and setting **ErrorControl** to **None**. This example propagates in constant steps of 30 seconds:

```
Create Spacecraft aSat
Create ForceModel aForceModel
aForceModel.ErrorControl = None

Create Propagator aProp
aProp.FM          = aForceModel
aProp.Type        = PrinceDormand78
aProp.InitialStepSize = 30
```

```
BeginMissionSequence
```

```
Propagate aProp(aSat) {aSat.ElapsedDays = .2}
```

Propagate an orbit using an Adams-Bashforth-Moulton predictor-corrector integrator:

```
Create Spacecraft aSat
Create ForceModel aForceModel
aForceModel.ErrorControl = RSSStep

Create Propagator aProp
aProp.FM          = aForceModel
aProp.Type        = AdamsBashforthMoulton
aProp.InitialStepSize = 60
aProp.MinStep     = 0
aProp.MaxStep     = 86400
aProp.MaxStepAttempts = 50
% Note the following fields must be set with decreasing values!
aProp.Accuracy    = 1e-010
aProp.TargetError  = 1e-011
aProp.LowerError   = 1e-013
aProp.StopIfAccuracyIsViolated = true
```

```
BeginMissionSequence
```

```
Propagate aProp(aSat) {aSat.ElapsedDays = .2}
```

## SPK-Configured Propagator

### Description

An SPK-configured **Propagator** propagates a spacecraft by interpolating user-provided SPICE kernels. You configure a **Propagator** to use an SPK kernel by setting the **Type**

field to **SPK**. SPK kernels and the **NAIFId** are defined on the **Spacecraft** Resource. You control propagation, including stopping conditions, using the **Propagate** command. This resource cannot be modified in the Mission Sequence. However, you can do whole object assignment in the mission,( i.e. `myPropagator = yourPropagator` ).

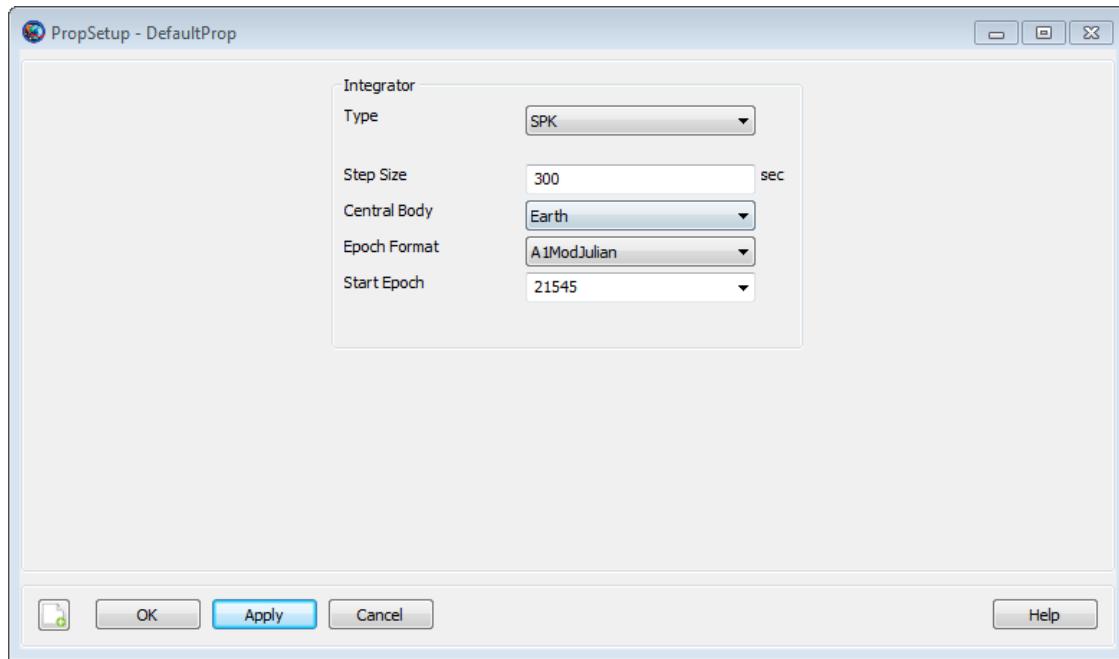
*See Also:* [Spacecraft](#), [Propagate](#)

## Fields

Field	Description	
<b>CentralBody</b>	The central body of propagation. This field has no effect for SPK, Code500, CCSDS-OEM, or STK propagators.	
	<b>Data Type</b>	Resource reference
	<b>Allowed Values</b>	Celestial body
	<b>Access</b>	set
	<b>Default Value</b>	<b>Earth</b>
	<b>Units</b>	N/A
	<b>Interfaces</b>	GUI, script
<b>EpochFormat</b>	Only used for an SPK, Code500, CCSDS-OEM, or STK propagator. The format of the epoch contained in the <b>StartEpoch</b> field.	
	<b>Data Type</b>	Enumeration
	<b>Allowed Values</b>	<b>A1ModJulian</b> , <b>TAIModJulian</b> , <b>UTC-ModJulian</b> , <b>TTModJulian</b> , <b>TDBModJulian</b> , <b>A1Gregorian</b> , <b>TAIGregorian</b> , <b>TTGregorian</b> , <b>UTCGregorian</b> , <b>TDB-Gregorian</b>
	<b>Access</b>	set
	<b>Default Value</b>	<b>A1ModJulian</b>
	<b>Units</b>	N/A unless Mod Julian and in that case Modified Julian Date
	<b>Interfaces</b>	GUI, script

Field	Description
<b>StartEpoch</b>	<p>Only used for an SPK, Code500, CCSDS-OEM, or STK propagator. The initial epoch of propagation. When an epoch is provided that epoch is used as the initial epoch. When the keyword "FromSpacecraft" is provided, the start epoch is inherited from the spacecraft. If this parameter is omitted or set to "EphemStart", propagation will begin at the start of the ephemeris file.</p>
	<b>Data Type</b> String
	<b>Allowed Values</b> "Gregorian: 04 Oct 1957 12:00:00.000 <= Epoch <= 28 Feb 2100 00:00:00.000 Modified Julian: 6116.0 <= Epoch <= 58127.5, "EphemStart", or "FromSpacecraft"
	<b>Access</b> set
	<b>Default Value</b> "EphemStart"
	<b>Units</b> N/A
	<b>Interfaces</b> GUI, script
<b>StepSize</b>	<p>The step size for an SPK, Code500, CCSDS-OEM, or STK Propagator.</p>
	<b>Data Type</b> Real
	<b>Allowed Values</b> Real > 0
	<b>Access</b> set
	<b>Default Value</b> 300
	<b>Units</b> N/A
	<b>Interfaces</b> GUI, script
<b>Type</b>	<p>Specifies the integrator or analytic propagator used to model time evolution of spacecraft motion. Specify <b>SPK</b> for an SPK file ephemeris propagator.</p>
	<b>Data Type</b> Enumeration
	<b>Allowed Values</b> PrinceDormand78, PrinceDormand45, RungeKutta89, RungeKutta68, RungeKutta56, BulirschStoer, AdamsBashforthMoulton, SPK, STK, CCSDS-OEM, Code500
	<b>Access</b> set
	<b>Default Value</b> RungeKutta89
	<b>Units</b> N/A
	<b>Interfaces</b> GUI, script

## GUI



To configure a **Propagator** to use SPK files, on the **Propagator** dialog box, select **SPK** in the **Type** menu. There are four fields you can configure for an SPK propagator including **StepSize**, **CentralBody**, **EpochFormat**, and **StartEpoch**. Note that changing the **EpochFormat** setting converts the input epoch to the selected format. You can also type **FromSpacecraft** into the **StartEpoch** field and the **Propagator** will use the epoch of the **Spacecraft** as the initial propagation epoch.

### Remarks

To use an SPK-configured **Propagator**, you must specify the SPK kernels and **NAIFId** on the **Spacecraft**, configure a **Propagator** to use SPK files as opposed to numerical methods, and configure the **Propagate** command to use the configured SPK propagator. The subsections and examples below discuss each of these items in detail.

### Configuring Spacecraft SPK Kernels

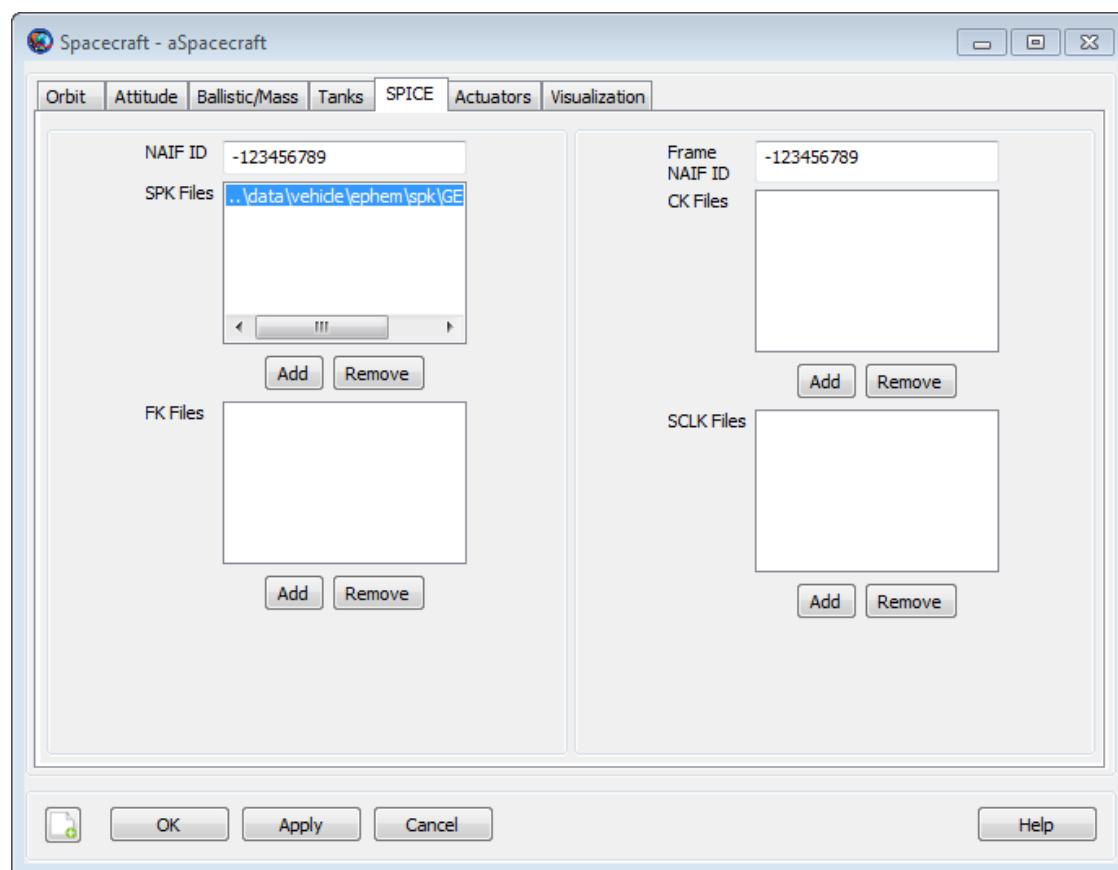
To use an SPK-configured **Propagator**, you must add the SPK kernels to the **Spacecraft** and define the spacecraft's **NAIFId**. SPK Kernels for selected spacecraft are available [here](#). Two sample vehicle spk kernels, (GEOSat.bsp and MoonTransfer.bsp) are distributed with GMAT for example purposes. An example of how to add spacecraft kernels via the script interface is shown below.

```
Create Spacecraft aSpacecraft
GMAT aSpacecraft.NAIFId = -123456789
GMAT aSpacecraft.OrbitSpiceKernelName = {...}
                                '..\data\vehicle\ephem\spk\GEOSat.bsp'}
```

To add **Spacecraft** SPK kernels via the GUI:

1. On the **Spacecraft** dialog box, click the **SPICE** tab.

2. Under the **SPK Files** list, click **Add**.
3. Browse to locate and select the desired SPK file
4. Repeat to add all necessary SPK kernels
5. In the **NAIF ID** field, enter the spacecraft integer NAIF id number. Note: For a given mission, each spacecraft should have a unique NAIF ID if the spacecraft are propagated with an SPK propagator.



You can add more than one kernel to a spacecraft as shown via scripting below, where the files GEOSat1.bsp and GEOSat2.bsp are dummy file names used for example purposes only and are not distributed with GMAT. In the script, you can use relative path or absolute path to define the location of an SPK file. Relative paths are defined with respect to the GMAT bin directory of your local installation.

```
Create Spacecraft aSpacecraft
aSpacecraft.OrbitSpiceKernelName ={ 'C:\MyDataFiles\GEOSat1.bsp', ...
                                'C:\MyDataFiles\GEOSat2.bsp'}
```

### Configuring an SPK Propagator

You can define the **StartEpoch** of propagation of an SPK-configured **Propagator** on either the **Propagator** Resource or inherit the **StartEpoch** from the **Spacecraft**. Below is a script snippet that shows how to inherit the **StartEpoch** from the **Spacecraft**. To inherit the **StartEpoch** from the **Spacecraft** using the GUI

1. Open the SPK propagator dialog box,
2. In the **StartEpoch** field., type **FromSpacecraft** or select **FromSpacecraft** from the drop-down menu

To explicitly define the **StartEpoch** on the **Propagator** Resource use the following syntax.

```
Create Propagator spkProp
spkProp.EpochFormat = 'UTCGregorian'
spkProp.StartEpoch = '22 Jul 2014 11:29:10.811'

Create Propagator spkProp2
spkProp2.EpochFormat = 'TAIModJulian'
spkProp2.StartEpoch = '23466.5'
```

If you omit **StartEpoch**, propagation will begin at the start time of the ephemeris file. To configure the step size, use the **StepSize** field.

```
Create Propagator spkProp
spkProp.Type = SPK
spkProp.StepSize = 300
```

### Interaction with the Propagate Command

An SPK-configured **Propagator** works with the **Propagate** command in the same way numerical propagators work with the **Propagate** command with the following exceptions:

- If a **Propagate** command uses an SPK propagator, then you can only propagate one spacecraft using that propagator. You can however, mix SPK propagators and numeric propagators in a single propagate command.
- SPK-configured **Propagators** will not propagate the STM or compute the orbit Jacobian (A matrix).

In the example below, we assume a **Spacecraft** named **aSpacecraft** and a **Propagator** named **spkProp** have been configured a-priori. An example command to propagate **aSpacecraft** to Earth Periapsis using **spkProp** is shown below.

```
Propagate spkProp(aSpacecraft) {aSpacecraft.Earth.Periapsis}
```

Below is a script snippet that demonstrates how to propagate backwards using an SPK propagator.

```
Propagate BackProp spkProp(aSpacecraft) {aSpacecraft.ElapsedDays = -1.5}
```

### Behavior Near Ephemeris Boundaries

In general, ephemeris interpolation is less accurate near the boundaries of ephemeris files and we recommend providing ephemeris for significant periods beyond the initial and final epochs of your application for this and other reasons. When propagating near

the beginning or end of ephemeris files, the use of the double precision arithmetic may affect results. For example, if an ephemeris file has an initial epoch TDBModJulian = 21545.00037249916, and you specify the StartEpoch in UTC Gregorian, round off error in time conversions and/or truncation of time using the Gregorian format (only accurate to millisecond) may cause the requested epoch to fall slightly outside of the range provided on the ephemeris file. The best solution is to provide extra ephemeris data to avoid time issues at the boundaries and the more subtle issue of poor interpolation.



## Warning

To locate requested stopping conditions, GMAT needs to bracket the root of the stopping condition function. Then, GMAT uses standard root finding techniques to locate the stopping condition to the requested accuracy. If the requested stopping condition lies at or near the beginning or end of the ephemeris data, then bracketing the stopping condition may not be possible without stepping off the ephemeris file which throw an error and execution will stop. In this case, you must provide more ephemeris data to locate the desired stopping condition.

## Examples

Propagate a GEO spacecraft using an SPK-configured **Propagator**. Define the **StartEpoch** from the spacecraft. Note: the SPK kernel GEOSat.bsp is distributed with GMAT.

```
Create Spacecraft aSpacecraft;
aSpacecraft.Epoch.UTCGregorian = '02 Jun 2004 12:00:00.000'
aSpacecraft.NAIFId = -123456789
aSpacecraft.OrbitSpiceKernelName = {'..\data\vehicle\ephem\spk\GEOSat.bsp'}

Create Propagator spkProp
spkProp.Type = SPK
spkProp.StepSize = 300
spkProp.CentralBody = Earth
spkProp.StartEpoch = FromSpacecraft

Create OrbitView EarthView
EarthView.Add = {aSpacecraft, Earth, Luna}
EarthView.ViewPointVector = [ 30000 -20000 10000 ]
EarthView.ViewScaleFactor = 2.5

BeginMissionSequence
Propagate spkProp(aSpacecraft) {aSpacecraft.TA = 90}
Propagate spkProp(aSpacecraft) {aSpacecraft.ElapsedDays = 2.4}
```

Simulate a lunar transfer using an SPK-configured **Propagator**. Define **StartEpoch** on the **Propagator**. Note: the SPK kernel MoonTransfer.bsp is distributed with GMAT.

```
Create Spacecraft aSpacecraft
```

```
aSpacecraft.NAIFId = -123456789
aSpacecraft.OrbitSpiceKernelName = {...'..\data\vehicle\ephem\spk\MoonTransfer.bsp'}

Create Propagator spkProp
spkProp.Type = SPK
spkProp.StepSize = 300
spkProp.CentralBody = Earth
spkProp.EpochFormat = 'UTCGregorian'
spkProp.StartEpoch = '22 Jul 2014 11:29:10.811'

Create OrbitView EarthView
EarthView.Add = {aSpacecraft, Earth, Luna}
EarthView.ViewPointVector = [ 30000 -20000 10000 ]
EarthView.ViewScaleFactor = 30

BeginMissionSequence
Propagate spkProp(aSpacecraft) {aSpacecraft.ElapsedDays = 12}
```

## Code500 Ephemeris-Configured Propagator

### Description

A Code500 ephemeris-configured **Propagator** propagates a spacecraft by interpolating or stepping along a user-provided Code500-format binary ephemeris file. You configure a **Propagator** to use a Code500 ephemeris by setting the **Type** field to **Code500**. The Code500 ephemeris file is specified on the **Spacecraft.EphemerisName** resource. The user controls propagation, including stopping conditions, using the **Propagate** command. This resource cannot be modified in the Mission Sequence. However, you can do whole object assignment in the mission sequence, (i.e. `myPropagator = yourPropagator` ).

The **Propagator CentralBody** option is not applicable to the Code500 propagator and should not be used with the Code500 propagator type. GMAT will automatically detect and use the central body of the ephemeris file. The **Propagate** command should be used to traverse the ephemeris file. GMAT will throw an error message and terminate when attempting to propagate outside the bounds of the ephemeris file.

Code500 ephemeris files are binary-format files. As discussed in the [EphemerisFile](#) help, GMAT can generate Code500 ephemeris files in both little-endian and big-endian binary format (via **EphemerisFile.OutputFormat**). The ephemeris propagator can read Code500 ephemeris files in either endian format. The endian format of the ephemeris file will be automatically detected by GMAT.

See Also: [Spacecraft](#), [Propagate](#), [EphemerisFile](#)

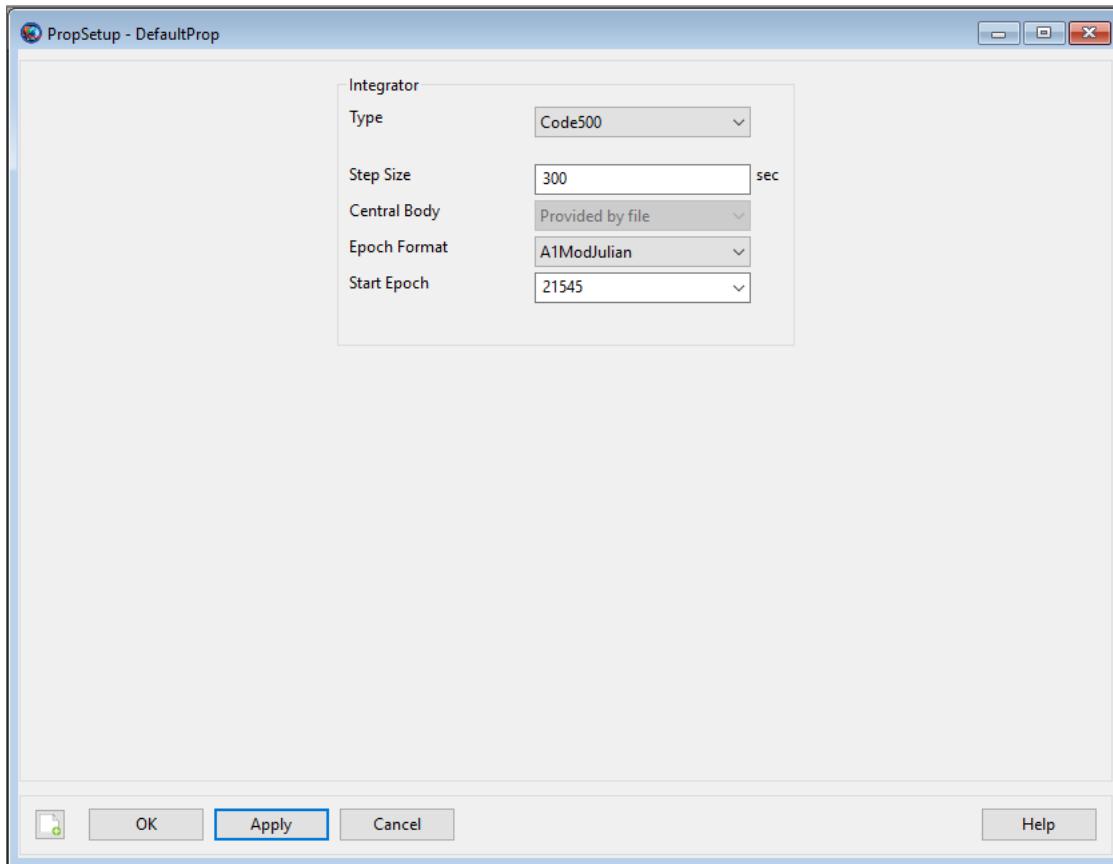
### Fields

The only **Propagator** fields applicable to the Code500 ephemeris propagator are **EpochFormat**, **StartEpoch**, **StepSize** and **Type**.

Field	Description
<b>EpochFormat</b>	<p>Only used for an SPK, Code500, CCSDS-OEM, or STK propagator. Specifies format of the epoch contained in the <b>StartEpoch</b> field.</p>
	<b>Data Type</b> Enumeration
	<b>Allowed Values</b> <b>A1ModJulian</b> , <b>TAIModJulian</b> , <b>UTC-ModJulian</b> , <b>TTModJulian</b> , <b>TDBMod-Julian</b> , <b>A1Gregorian</b> , <b>TAIGregorian</b> , <b>TTGregorian</b> , <b>UTCGregorian</b> , <b>TDB-Gregorian</b>
	<b>Access</b> set
	<b>Default Value</b> <b>A1ModJulian</b>
	<b>Units</b> N/A unless Mod Julian and in that case Modified Julian Date
	<b>Interfaces</b> GUI, script
<b>StartEpoch</b>	<p>Only used for an SPK, Code500, CCSDS-OEM, or STK propagator. Specifies initial epoch of propagation. When an epoch is provided that epoch is used as the initial epoch. When the keyword <b>FromSpacecraft</b> is provided, the start epoch is inherited from the spacecraft. If this parameter is omitted or set to "EphemStart", propagation will begin at the start of the ephemeris file.</p>
	<b>Data Type</b> String
	<b>Allowed Values</b> "Gregorian: 04 Oct 1957 12:00:00.000 <= Epoch <= 28 Feb 2100 00:00:00.000 Modified Julian: 6116.0 <= Epoch <= 58127.5, "EphemStart", or "FromSpacecraft"
	<b>Access</b> set
	<b>Default Value</b> "EphemStart"
	<b>Units</b> N/A
	<b>Interfaces</b> GUI, script
<b>StepSize</b>	<p>The step size for an Code500 Propagator. GMAT will use this step size when traversing the ephemeris file, regardless of the internal step size of the ephemeris. GMAT will perform interpolation between vectors on the file as needed.</p>
	<b>Data Type</b> Real
	<b>Allowed Values</b> Real > 0
	<b>Access</b> set
	<b>Default Value</b> 300
	<b>Units</b> Seconds
	<b>Interfaces</b> GUI, script

Field	Description	
<b>Type</b>	Specifies the integrator or analytic propagator used to model time evolution of spacecraft motion. Specify <b>Code500</b> for a Code500 ephemeris propagator.	
<b>Data Type</b>	Enumeration	
<b>Allowed Values</b>	<b>PrinceDormand78</b> , <b>PrinceDormand45</b> , <b>RungeKutta89</b> , <b>RungeKutta68</b> , <b>RungeKutta56</b> , <b>BulirschStoer</b> , <b>AdamsBashforthMoulton</b> , <b>SPK</b> , <b>CCSDS-OEM</b> , <b>Code500</b>	
<b>Access</b>	set	
<b>Default Value</b>	<b>RungeKutta89</b>	
<b>Units</b>	N/A	
<b>Interfaces</b>	GUI, script	

## GUI



To configure a **Propagator** from the GMAT GUI to use Code500 ephemeris files, select and open a **Propagator** from the Resources tree. In the **Integrator** category select **Code500** from the **Type** drop-down box. This will display the Code500 propagator options dialog. There are four fields displayed for a Code500 propagator - **StepSize**, **CentralBody**, **EpochFormat**, and **StartEpoch**. Note that changing the **EpochFormat**

setting converts the input epoch to the selected format. You can also type **FromSpacecraft** into the **StartEpoch** field and the **Propagator** will use the epoch of the **Spacecraft** as the initial propagation epoch. The **CentralBody** field is displayed to the user, but is unused when the integrator type is Code500.

### Remarks

There is currently no GUI option to assign the Code500 ephemeris file to the **Spacecraft** resource. You must specify the Code500 ephemeris file on the **Spacecraft.EphemerisName** parameter via script. The subsections below provide examples of how to do this.

## Configuring Spacecraft Ephemeris Files

A spacecraft may have only one Code500 ephemeris assigned. There is currently no GUI option to add a Code500 ephemeris file to a spacecraft. To use a Code500 ephemeris-configured **Propagator**, you must add the Code500 ephemeris file to the **Spacecraft** in your script using the **EphemerisName** parameter. A sample spacecraft Code500 ephemeris, (sat\_leo.ephem, in the data/vehicle/ephem/code500 directory) is distributed with GMAT. This sample file has a span of 4/20/2015 00:00:00 to 4/30/2015 00:00:00. An example of how to assign this ephemeris to a spacecraft is shown below. Relative paths are defined with respect to the GMAT bin directory of your local installation.

```
Create Spacecraft aSpacecraft  
aSpacecraft.EphemerisName = '../data/vehicle/ephem/code500/sat_leo.ephem'  
BeginMissionSequence
```

## Configuring a Code500 Ephemeris Propagator

If you have assigned the ephemeris file to your spacecraft, configuring the propagator only requires assigning the **Code500** type and the desired step size on a **Propagator** resource. The central body of propagation will be the central body of the the ephemeris file. If desired, you may also specify an **EpochFormat** and **StartEpoch** on the propagator to specify an initial epoch from which to start propagation. The same effect can be accomplished with an independent **Propagate** command (see [Propagate](#)) to the desired starting epoch.

```
Create Propagator Code500Prop  
Code500Prop.Type      = 'Code500'  
Code500Prop.StepSize = 60.  
  
BeginMissionSequence
```

The same remarks mentioned in the prior section on SPK propagators with regard to interaction with the **Propagate** command and behavior near ephemeris boundaries also apply to the Code500 ephemeris propagator.

## Examples

This example propagates a spacecraft using a Code500 ephemeris, defining the **StartEpoch** from the spacecraft. The ephemeris file used in this example is included in the GMAT distribution at the indicated location. The code below will run if you copy and paste it into a new GMAT script.

```
Create Spacecraft aSpacecraft

% Ephem file span is 4/20/2015 - 4/30/2015

aSpacecraft.EphemerisName = '../data/vehicle/ephem/code500/sat_leo.ephem'
aSpacecraft.DateFormat      = UTCGregorian
aSpacecraft.Epoch          = '22 Apr 2015 00:00:00.000'

Create Propagator Code500Prop

Code500Prop.Type          = 'Code500'
Code500Prop.StepSize       = 60.
Code500Prop.StartEpoch    = 'FromSpacecraft'

Create ReportFile PropReport

PropReport.Filename        = 'EphemPropagator_Code500_ForwardProp.txt'
PropReport.WriteHeaders     = True

BeginMissionSequence

While aSpacecraft.ElapsedDays <= 1

    Propagate Code500Prop(aSpacecraft)

    Report PropReport aSpacecraft.UTCGregorian aSpacecraft.TAIModJulian ...
        aSpacecraft.X aSpacecraft.Y aSpacecraft.Z ...
        aSpacecraft.VX aSpacecraft.VY aSpacecraft.VZ

EndWhile
```

An additional, more detailed, example of use of the Code500 ephemeris propagator is shown in the `Ex_Code500_EphemerisCompare.script` file provided in the `samples\Navigation` directory. This script generates a report showing the difference, in RIC coordinates, between the orbits in two different Earth-centered Code500 ephemeris files.

## STK Ephemeris-Configured Propagator

### Description

An STK ephemeris-configured **Propagator** propagates a spacecraft by interpolating or stepping along a user-provided STK-format ephemeris file. You configure a **Propagator** to use an STK ephemeris by setting the **Type** field to **STK**. The STK ephemeris file is specified on a Spacecraft resource using the **Spacecraft.EphemerisName** field. The user controls propagation, including stopping conditions, using the **Propagate** command. This resource cannot be modified in the Mission Sequence. However, you can do whole object assignment in the mission sequence, (i.e. `myPropagator = yourPropagator` ).

The **Propagator CentralBody** option is not applicable to the STK propagator and should not be used with the STK propagator type. GMAT will automatically detect and use the central body of the ephemeris file. The **Propagate** command should be used to traverse the ephemeris file. GMAT will throw an error message and terminate when attempting to propagate outside the bounds of the ephemeris file. The STK propagator includes code that steps the spacecraft to the ephem boundary before stepping out of the span of the file.

STK ephemeris files are ASCII files conforming to the Systems Tool Kit ephemeris Time-PoSVel specifications. As discussed in the [EphemerisFile](#) help, GMAT can generate STK ephemeris files using the **EphemerisFile.OutputFormat** field. The STK propagator works with STK formatted files, starting with STK 4.0, or GMAT STK ephemerides.

See Also: [Spacecraft](#), [Propagate](#), [EphemerisFile](#)

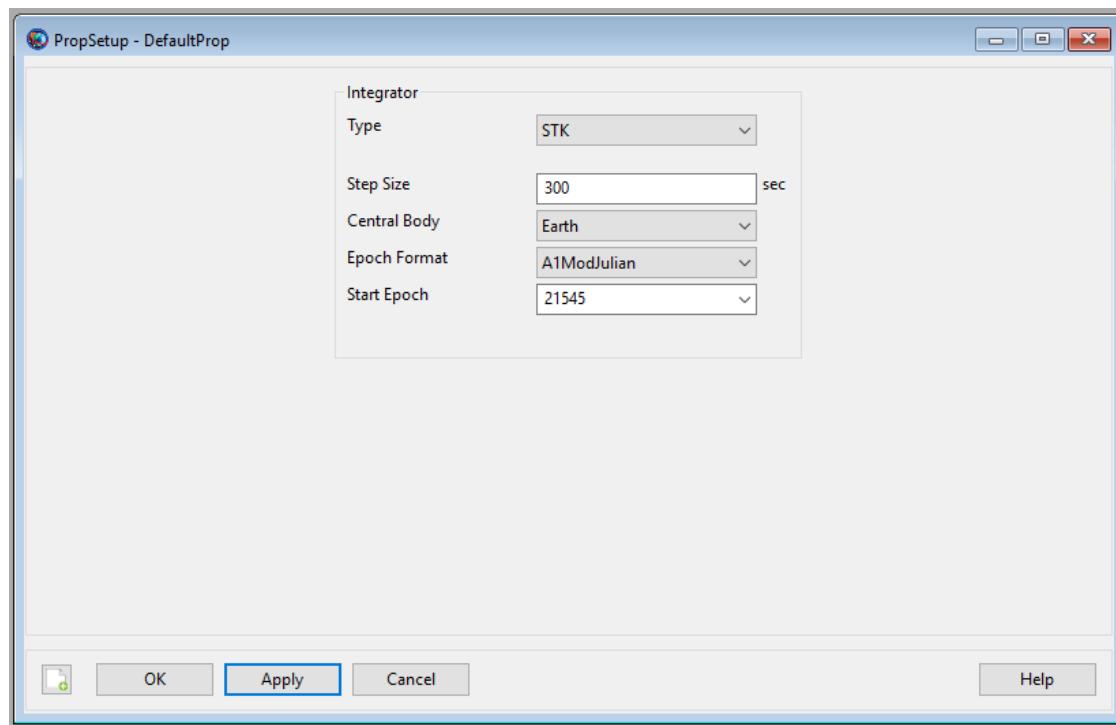
### Fields

The only **Propagator** fields applicable to the STK ephemeris propagator are **EpochFormat**, **StartEpoch**, **StepSize** and **Type**.

Field	Description		
<b>EpochFormat</b>	Only used for an SPK, Code500, CCSDS-OEM, or STK propagator. Specifies format of the epoch contained in the <b>StartEpoch</b> field.	<b>Data Type</b>	Enumeration
		<b>Allowed Values</b>	A1ModJulian, TAIModJulian, UTC-ModJulian, TTModJulian, TDBModJulian, A1Gregorian, TAIGregorian, TTGregorian, UTCGregorian, TDBGregorian
		<b>Access</b>	set
		<b>Default Value</b>	A1ModJulian
		<b>Units</b>	N/A unless Mod Julian and in that case Modified Julian Date
		<b>Interfaces</b>	GUI, script

Field	Description
<b>StartEpoch</b>	<p>Only used for an SPK, Code500, CCSDS-OEM, or STK propagator. Specifies initial epoch of propagation. When an epoch is provided that epoch is used as the initial epoch. When the keyword <b>FromSpacecraft</b> is provided, the start epoch is inherited from the spacecraft. If this parameter is omitted or set to "EphemStart", propagation will begin at the start of the ephemeris file.</p>
	<b>Data Type</b>
	String
	<b>Allowed Values</b>
	<p>"Gregorian: 04 Oct 1957 12:00:00.000      &lt;= Epoch &lt;= 28 Feb 2100      00:00:00.000 Modified Julian: 6116.0      &lt;= Epoch &lt;= 58127.5, "EphemStart",      or "FromSpacecraft"</p>
	<b>Access</b>
	set
	<b>Default Value</b>
	"EphemStart"
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	GUI, script
<b>StepSize</b>	<p>The step size for the Propagator. GMAT will use this step size when traversing the ephemeris file, regardless of the internal step size of the ephemeris. GMAT will perform interpolation between vectors on the file as needed.</p>
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	Real > 0
	<b>Access</b>
	set
	<b>Default Value</b>
	300
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	GUI, script
<b>Type</b>	<p>Specifies the integrator or analytic propagator used to model time evolution of spacecraft motion. Specify <b>STK</b> for an STK ephemeris propagator.</p>
	<b>Data Type</b>
	Enumeration
	<b>Allowed Values</b>
	<p><b>PrinceDormand78</b>, <b>PrinceDormand45</b>,  <b>RungeKutta89</b>, <b>RungeKutta68</b>,  <b>RungeKutta56</b>, <b>BulirschStoer</b>,  <b>AdamsBashforthMoulton</b>, <b>SPK</b>,  <b>CCSDS-OEM</b>, <b>Code500</b>, <b>STK</b></p>
	<b>Access</b>
	set
	<b>Default Value</b>
	<b>RungeKutta89</b>
	<b>Units</b>
	N/A
	<b>Interfaces</b>

## GUI



To configure a **Propagator** from the GMAT GUI to use STK ephemeris files, select and open a **Propagator** from the Resources tree. In the **Integrator** category select **STK** from the **Type** drop-down box. This will display the STK propagator options dialog. There are four fields displayed for an STK propagator that affect propagation - **StepSize**, **CentralBody**, **EpochFormat**, and **StartEpoch**. Note that changing the **EpochFormat** setting converts the input epoch to the selected format. You can also type **FromSpacecraft** into the **StartEpoch** field and the **Propagator** will use the epoch of the **Spacecraft** as the initial propagation epoch. The **CentralBody** field is displayed to the user, but is unused when the integrator type is STK.

### Implementation Notes

Position interpolation by default is performed using a 7th order Hermite-Newton divided difference interpolator using function value only data (i.e. position data for the position interpolation). Velocity interpolation uses the derivative of the position polynomial to produce interpolated values.

For segmented ephemerides, the interpolator restarts at segment boundaries. If an ephemeris segment has fewer than 8 points, the interpolator activates derivative information for the position interpolation by including the velocity data for the interpolation. The order of the interpolator changes to match the number of points in the segment (for  $n$  data points, order =  $2n - 1$  for position and  $n - 1$  for velocity). The first time this happens, a warning notice is posted to the message window indicating the order of the velocity interpolation. Subsequent changes are not reported, but the interpolation order will adapt to the number of points in subsequent segments.

Propagating with stopping conditions can show sub-millisecond related differences.

STK ephemeris files can set an ephemeris epoch that is very different from the data in the file by setting a distant in time Scenario Epoch, and compensating using the time offset for each ephemeris point in the file. This can lead to round-off issues in propagation, particularly when propagating to the end of an ephemeris (or back propagating to the start).

### Remarks

A spacecraft may have only one STK ephemeris assigned. There is currently no GUI option to assign the STK ephemeris file to the **Spacecraft** resource. You must specify the STK ephemeris file on the **Spacecraft.EphemerisName** parameter via script. The subsections below provide examples of how to do this.

GMAT supports reading a number of STK ephemeris reference frames, but there are some limitations to be aware of. The table below shows the status of GMAT support for reading STK ephemeris reference frames, and the mapping between STK reference frames and GMAT equivalent **CoordinateSystem Axes**. Any STK reference frame not specifically mentioned below is not supported for an STK ephemeris propagator.

STK Reference Frame	GMAT Axes	Status
J2000	J2000	Supported for all central bodies
J2000_Ecliptic	MJ2000Ec	Supported for Sun only
ICRF	ICRF	Supported for all central bodies
TrueOfDate	TODEq	Supported for Earth only
Fixed	BodyFixed	Supported for all central bodies. The Moon-fixed frame is interpreted as the Moon Principal Axis (PA) frame. The Moon-fixed Mean Earth/Polar Axis (ME) frame is not currently supported. See <a href="#">CelestialBody Remarks</a> for details on the interpretation of the body-fixed frame for Earth and other central bodies.

### Configuring Spacecraft Ephemeris Files

To use a STK ephemeris-configured **Propagator**, you must add the STK ephemeris file to the **Spacecraft**. A sample spacecraft STK ephemeris, (`SampleSTKEphem.e`, in the `data/vehicle/ephem/stk` directory) is distributed with GMAT. This sample file has a span of 1 Jan 2000 11:59:28.000 to 4 Jan 2000 11:59:28.000. An example of how to assign this ephemeris to a spacecraft is shown below. Relative paths are defined with respect to the GMAT bin directory of your local installation.

```
Create Spacecraft aSpacecraft;
aSpacecraft.EphemerisName = '../data/vehicle/ephem/stk/SampleSTKEphem.e';
BeginMissionSequence;
```

### Configuring an STK Ephemeris Propagator

If you have assigned the ephemeris file to your spacecraft, configuring the propagator only requires assigning the **STK** type and the desired step size on a **Propagator** re-

source. The central body of propagation will be the central body of the ephemeris file. If desired, you may also specify an **EpochFormat** and **StartEpoch** on the propagator to specify an initial epoch from which to start propagation. The same effect can be accomplished with an independent **Propagate** command (see [Propagate](#)) to advance the Spacecraft to the desired starting epoch.

```
Create Propagator STKProp;  
  
STKProp.Type      = 'STK';  
STKProp.StepSize = 60;  
  
BeginMissionSequence;
```

The same remarks mentioned in the section on SPK propagators with regard to interaction with the **Propagate** command and behavior near ephemeris boundaries also apply to the STK ephemeris propagator.

## Examples

This example propagates a spacecraft using an STK ephemeris, defining the **StartEpoch** from the spacecraft. The ephemeris file used in this example is included in the GMAT distribution at the indicated location. The code below will run if you copy and paste it into a new GMAT script.

```
%  
%   Spacecraft  
%  
Create Spacecraft STKSat;  
  
GMAT STKSat.DateFormat = UTCGregorian;  
GMAT STKSat.Epoch = '01 Jan 2000 12:00:00.000';  
GMAT STKSat.EphemerisName = '../data/vehicle/ephem/stk/SampleSTKEphem.e';  
  
%  
%   Propagator  
%  
  
Create Propagator STKProp;  
  
GMAT STKProp.Type = STK;  
GMAT STKProp.StepSize = 60;  
GMAT STKProp.CentralBody = Earth;  
GMAT STKProp.EpochFormat = 'A1ModJulian';  
GMAT STKProp.StartEpoch = 'FromSpacecraft';  
  
%  
%   Output  
%  
  
Create OrbitView OrbitView1;  
GMAT OrbitView1.SolverIterations = Current;  
GMAT OrbitView1.UpperLeft = [ 0 0 ];  
GMAT OrbitView1.Size = [ 0 0 ];  
GMAT OrbitView1.RelativeZOrder = 0;  
GMAT OrbitView1.Maximized = false;
```

```
GMAT OrbitView1.Add = {STKSat, Earth};

%-----  
%----- Arrays, Variables, Strings  
%-----  
  
Create Array initialState[6,1] finalState[6,1];  
  
%  
% Miscellaneous variables.  
%  
  
Create String initialEpoch finalEpoch;  
  
%  
% Mission Sequence  
%  
  
BeginMissionSequence;  
  
GMAT [initialEpoch, initialState, finalEpoch, finalState] = ...  
    GetEphemStates('STK', STKSat, 'UTCGregorian', EarthMJ2000Eq);  
  
GMAT STKSat.Epoch = initialEpoch;  
  
While STKSat.ElapsedDays <= 1  
    Propagate STKProp(STKSat);  
  
EndWhile;
```

This example is provided in the samples directory, in the Ex\_2017a\_STKEphemPropagation script.

## CCSDS OEM Ephemeris-Configured Propagator

### Description

A CCSDS-OEM ephemeris-configured **Propagator** propagates a spacecraft by interpolating or stepping along a user-provided CCSDS OEM-format ephemeris file. You configure a **Propagator** to use an OEM ephemeris by setting the **Type** field to **CCSDS-OEM**. The OEM ephemeris file is specified on a Spacecraft resource using the **Spacecraft.EphemerisName** field. The user controls propagation, including stopping conditions, using the **Propagate** command. This resource cannot be modified in the Mission Sequence. However, you can do whole object assignment in the mission sequence, (i.e. myPropagator = yourPropagator ).

The **Propagator CentralBody** option is not applicable to the OEM propagator and should not be used with the OEM propagator type. GMAT will automatically detect and use the central body of the ephemeris file. The **Propagate** command should be used to traverse the ephemeris file. GMAT will throw an error message and terminate when attempting to propagate outside the bounds of the ephemeris file. The OEM propagator includes code that steps the spacecraft to the ephemeris boundary before stepping out of the span of the file.

OEM ephemeris files are ASCII files conforming to the Consultative Committee for Space Data Systems Orbit Data Messages standard (CCSDS 502.0-B-2). As discussed in the [EphemerisFile](#) help, GMAT can generate OEM ephemeris files using the **EphemerisFile.OutputFormat** field. GMAT currently only supports Version 1.0 OEM ephemeris files.

See Also: [Spacecraft](#), [Propagate](#), [EphemerisFile](#)

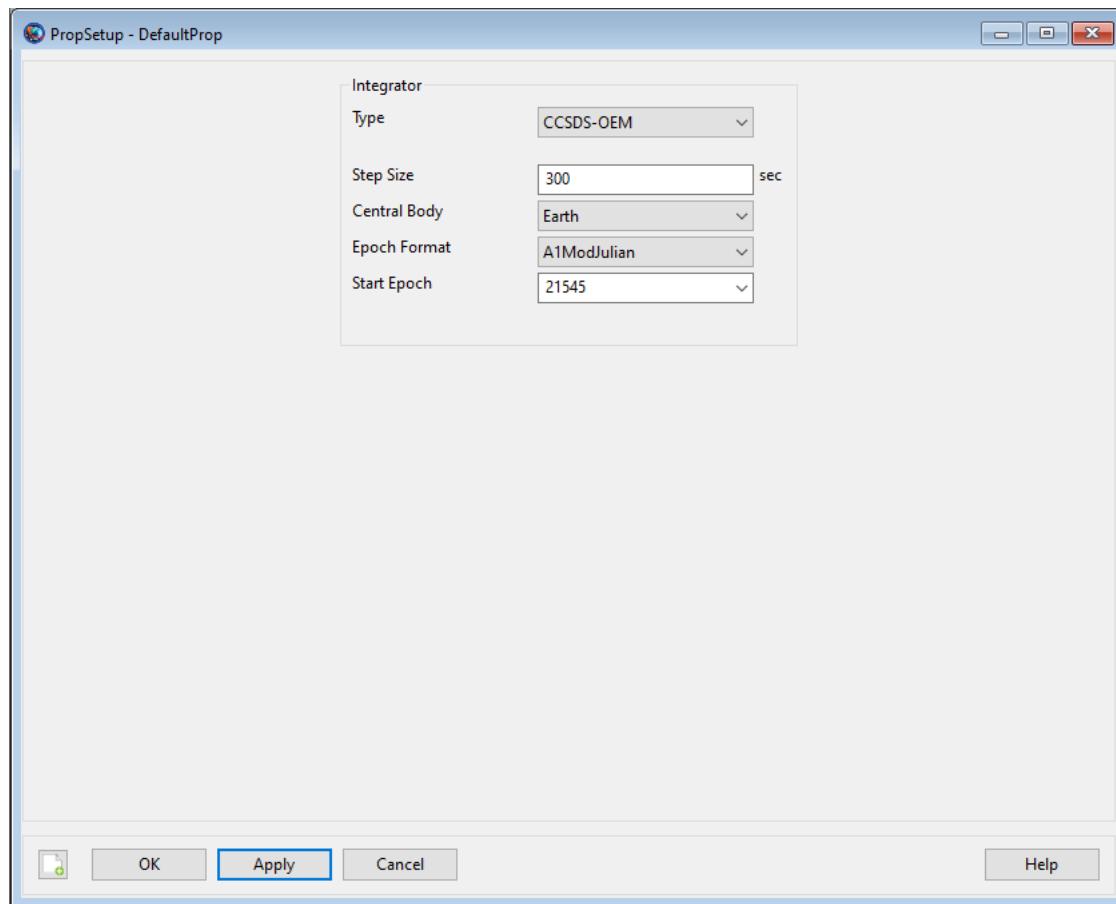
## Fields

The only **Propagator** fields applicable to the OEM ephemeris propagator are **EpochFormat**, **StartEpoch**, **StepSize** and **Type**.

Field	Description												
<b>EpochFormat</b>	<p>Only used for an SPK, Code500, CCSDS-OEM, or STK propagator. Specifies format of the epoch contained in the <b>StartEpoch</b> field.</p> <table> <tr> <td><b>Data Type</b></td><td>Enumeration</td></tr> <tr> <td><b>Allowed Values</b></td><td>A1ModJulian, TAIModJulian, UTC-ModJulian, TTModJulian, TDBModJulian, A1Gregorian, TAIGregorian, TTGregorian, UTCGregorian, TDBGregorian</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>A1ModJulian</b></td></tr> <tr> <td><b>Units</b></td><td>N/A unless Mod Julian and in that case Modified Julian Date</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Enumeration	<b>Allowed Values</b>	A1ModJulian, TAIModJulian, UTC-ModJulian, TTModJulian, TDBModJulian, A1Gregorian, TAIGregorian, TTGregorian, UTCGregorian, TDBGregorian	<b>Access</b>	set	<b>Default Value</b>	<b>A1ModJulian</b>	<b>Units</b>	N/A unless Mod Julian and in that case Modified Julian Date	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Enumeration												
<b>Allowed Values</b>	A1ModJulian, TAIModJulian, UTC-ModJulian, TTModJulian, TDBModJulian, A1Gregorian, TAIGregorian, TTGregorian, UTCGregorian, TDBGregorian												
<b>Access</b>	set												
<b>Default Value</b>	<b>A1ModJulian</b>												
<b>Units</b>	N/A unless Mod Julian and in that case Modified Julian Date												
<b>Interfaces</b>	GUI, script												
<b>StartEpoch</b>	<p>Only used for an SPK, Code500, CCSDS-OEM, or STK propagator. Specifies initial epoch of propagation. When an epoch is provided that epoch is used as the initial epoch. When the keyword <b>FromSpacecraft</b> is provided, the start epoch is inherited from the spacecraft. If this parameter is omitted or set to "EphemStart", propagation will begin at the start of the ephemeris file.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>"Gregorian: 04 Oct 1957 12:00:00.000 &lt;= Epoch &lt;= 28 Feb 2100 00:00:00.000 Modified Julian: 6116.0 &lt;= Epoch &lt;= 58127.5, "EphemStart", or "FromSpacecraft"</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>"EphemStart"</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	"Gregorian: 04 Oct 1957 12:00:00.000 <= Epoch <= 28 Feb 2100 00:00:00.000 Modified Julian: 6116.0 <= Epoch <= 58127.5, "EphemStart", or "FromSpacecraft"	<b>Access</b>	set	<b>Default Value</b>	"EphemStart"	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	"Gregorian: 04 Oct 1957 12:00:00.000 <= Epoch <= 28 Feb 2100 00:00:00.000 Modified Julian: 6116.0 <= Epoch <= 58127.5, "EphemStart", or "FromSpacecraft"												
<b>Access</b>	set												
<b>Default Value</b>	"EphemStart"												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

<b>Field</b>	<b>Description</b>												
<b>StepSize</b>	<p>The step size for the Propagator. GMAT will use this step size when traversing the ephemeris file, regardless of the internal step size of the ephemeris. GMAT will perform interpolation between vectors on the file as needed.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real &gt; 0</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>300</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real > 0	<b>Access</b>	set	<b>Default Value</b>	300	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real > 0												
<b>Access</b>	set												
<b>Default Value</b>	300												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>Type</b>	<p>Specifies the integrator or analytic propagator used to model time evolution of spacecraft motion. Specify <b>CCSDS-OEM</b> for an OEM ephemeris propagator.</p> <table> <tr> <td><b>Data Type</b></td><td>Enumeration</td></tr> <tr> <td><b>Allowed Values</b></td><td>PrinceDormand78, PrinceDormand45, RungeKutta89, RungeKutta68, RungeKutta56, BulirschStoer, AdamsBashforthMoulton, SPK, CCSDS-OEM, Code500, STK</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>RungeKutta89</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Enumeration	<b>Allowed Values</b>	PrinceDormand78, PrinceDormand45, RungeKutta89, RungeKutta68, RungeKutta56, BulirschStoer, AdamsBashforthMoulton, SPK, CCSDS-OEM, Code500, STK	<b>Access</b>	set	<b>Default Value</b>	RungeKutta89	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Enumeration												
<b>Allowed Values</b>	PrinceDormand78, PrinceDormand45, RungeKutta89, RungeKutta68, RungeKutta56, BulirschStoer, AdamsBashforthMoulton, SPK, CCSDS-OEM, Code500, STK												
<b>Access</b>	set												
<b>Default Value</b>	RungeKutta89												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

## GUI



To configure a **Propagator** from the GMAT GUI to use CCSDS OEM ephemeris files, select and open a **Propagator** from the Resources tree. In the **Integrator** category select **CCSDS-OEM** from the **Type** drop-down box. This will display the OEM propagator options dialog. There are four fields displayed for an OEM propagator that affect propagation - **StepSize**, **CentralBody**, **EpochFormat**, and **StartEpoch**. Note that changing the **EpochFormat** setting converts the input epoch to the selected format. You can also type **FromSpacecraft** into the **StartEpoch** field and the **Propagator** will use the epoch of the **Spacecraft** as the initial propagation epoch. The **CentralBody** field is displayed to the user, but is unused when the integrator type is CCSDS-OEM.

### Implementation Notes

Position interpolation by default is performed using a 7th order Hermite-Newton divided difference interpolator using function value only data (i.e. position data for the position interpolation). Velocity interpolation uses the derivative of the position polynomial to produce interpolated values.

For segmented ephemerides, the interpolator restarts at segment boundaries. If an ephemeris segment has fewer than 8 points, the interpolator activates derivative information for the position interpolation by including the velocity data for the interpolation. The order of the interpolator changes to match the number of points in the segment (for  $n$  data points, order =  $2n - 1$  for position and  $n - 1$  for velocity). The first time this

happens, a warning notice is posted to the message window indicating the order of the velocity interpolation. Subsequent changes are not reported, but the interpolation order will adapt to the number of points in subsequent segments.

Propagating with stopping conditions can show sub-millisecond related differences.

### Remarks

There is currently no GUI option to assign the OEM ephemeris file to the **Spacecraft** resource. You must assign the OEM ephemeris file on the **Spacecraft.EphemerisName** parameter via script. The subsections below provide examples of how to do this.

GMAT supports reading a number of OEM ephemeris reference frames. The table below shows the status of GMAT support for reading OEM ephemeris reference frames, and the mapping between OEM reference frames and GMAT equivalent **CoordinateSystem Axes**. Any OEM reference frame not specifically mentioned below is not supported for an OEM ephemeris propagator.

OEM Reference Frame	GMAT Axes	Status
EME2000	MJ2000Eq	Supported for all central bodies
TOD	TODEq	Supported for Earth only
GRC or TDR	BodyFixed	Supported for Earth only

## Configuring Spacecraft Ephemeris Files

A spacecraft may have only one OEM ephemeris assigned. To use an OEM ephemeris-configured **Propagator**, you must add the CCSDS OEM ephemeris file to the **Spacecraft** in your script using the **EphemerisName** parameter. A sample spacecraft CCSDS-OEM ephemeris, (`SampleOEMEphem.oem`, in the `data/vehicle/ephem/ccsds` directory) is distributed with GMAT. This sample file has a span of 1 Jan 2000 12:00:00.000 to 3 Jan 2000 12:00:00.000. An example of how to assign this ephemeris to a spacecraft is shown below. Relative paths are defined with respect to the GMAT bin directory of your local installation.

```
Create Spacecraft aSpacecraft;
aSpacecraft.EphemerisName = '../data/vehicle/ephem/ccsds/SampleOEMEphem.oem';
BeginMissionSequence;
```

## Configuring an OEM Ephemeris Propagator

If you have assigned the ephemeris file to your spacecraft, configuring the propagator only requires assigning the **CCSDS-OEM** type on a **Propagator** resource. The central body of propagation will be the central body of the ephemeris file. If desired, you may also specify an **EpochFormat** and **StartEpoch** on the propagator to specify an initial epoch from which to start propagation. The same effect can be accomplished with an independent **Propagate** command (see [Propagate](#)) to advance the Spacecraft to the desired starting epoch.

```
Create Propagator OEMProp;
```

```
OEMProp.Type      = 'CCSDS-OEM';
OEMProp.StepSize = 60;

BeginMissionSequence;
```

The same remarks mentioned in the section on SPK propagators with regard to interaction with the **Propagate** command and behavior near ephemeris boundaries also apply to the OEM ephemeris propagator.

## Examples

This example propagates a spacecraft using an OEM ephemeris, beginning from the start of the ephemeris file. The ephemeris file used in this example is included in the GMAT distribution at the indicated location. The code below will run if you copy and paste it into a new GMAT script.

```
%  
%   Spacecraft  
  
Create Spacecraft OEMSat;  
  
OEMSat.EphemerisName = '../data/vehicle/ephem/ccsds/SampleOEMEphem.oem';  
  
%  
%   Propagator  
  
Create Propagator OEMProp;  
  
OEMProp.Type = 'CCSDS-OEM';  
  
%  
%   Output  
  
Create OrbitView OrbitView1;  
  
OrbitView1.SolverIterations = Current;  
OrbitView1.UpperLeft      = [ 0 0 ];  
OrbitView1.Size           = [ 0 0 ];  
OrbitView1.RelativeZOrder = 0;  
OrbitView1.Maximized      = False;  
OrbitView1.Add             = {OEMSat, Earth};  
  
%  
%   Mission Sequence  
  
BeginMissionSequence;  
  
While OEMSat.ElapsedDays <= 1  
    Propagate OEMProp(OEMSat);  
EndWhile;
```

## SPICESGP4 TLE Propagator

### Description

A **SPICESGP4 Propagator** propagates a spacecraft by processing the data in a standard Two-Line element (TLE) using SPICE's implementation of the SGP4 algorithm. You configure a **Propagator** to use a TLE data file by setting the **Type** field to **SPICESGP4**. The TLE data is specified on a Spacecraft resource using the **Spacecraft.EphemerisName** field with the **Spacecraft.Id** field matching either the name of the spacecraft in the TLE or matching the satellite catalog number. The user controls propagation, including stopping conditions, using the **Propagate** command. This resource can be modified in the Mission Sequence, but an initial TLE must be provided before beginning the Mission Sequence. However, you can change the TLE value once the Mission Sequence has begun.

The **Propagator CentralBody** option is not applicable to the TLE propagator and should not be used with the TLE propagator type. The TLE format has by definition the Earth as the central body.

See Also: [Spacecraft](#), [Propagate](#)

### Fields

The only **Propagator** fields applicable to the SPICESGP4 ephemeris propagator are **StepSize** and **Type**.

Field	Description
<b>StepSize</b>	The step size for the Propagator. GMAT will use this step size when propagating the TLE.  Data Type            Real Allowed Values    Real > 0 Access              set Default Value     300 Units               N/A Interfaces          GUI, script

Field	Description		
<b>Type</b>	Specifies the integrator or analytic propagator used to model time evolution of spacecraft motion. Specify <b>CCSDS-OEM</b> for an OEM ephemeris propagator.		
	<b>Data Type</b>	Enumeration	
	<b>Allowed Values</b>	PrinceDormand78, PrinceDormand45, RungeKutta89, RungeKutta68, RungeKutta56, BulirschStoer, AdamsBashforthMoulton, SPK, CCSDS-OEM, Code500, STK, SPICESGP4	PrinceDormand45, RungeKutta89, RungeKutta68, BulirschStoer, AdamsBashforthMoulton, SPK, CCSDS-OEM, Code500, STK, SPICESGP4
	<b>Access</b>	set	
	<b>Default Value</b>	RungeKutta89	
	<b>Units</b>	N/A	
	<b>Interfaces</b>	GUI, script	

### Implementation Notes

The **SPICESGP4** propagator is powered by the SPICE implementation of the SGP4 algorithm. This approach is based on the algorithms published by Vallado et. al. in the 2006 paper *Revisiting Spacetrack Report #3*.

### Remarks

There is currently no GUI option to assign a TLE to the **Spacecraft** resource. You must assign the TLE file on the **Spacecraft.EphemerisName** parameter via script. The subsections below provide examples of how to do this. By default, the initial epoch of the Spacecraft will be set to the initial value of the TLE, but this may be changed by defining the **Spacecraft.Epoch** parameter.

### Configuring Spacecraft Ephemeris Files

A spacecraft may have only one TLE file assigned. To use the SPICESGP4 type **Propagator**, you must add a TLE file to the **Spacecraft** in your script using the **EphemerisName** parameter. A sample spacecraft TLE, (Ex\_R2022a\_TLEPropagationTLE.otxt, in the samples/SupportFiles directory) is distributed with GMAT. The name of the object in the TLE should be the same as the value set in the script using the **Spacecraft.Id** parameter. An example of how to assign this TLE to a spacecraft is shown below. Relative paths are defined with respect to the GMAT bin directory of your local installation.

```
Create Spacecraft aSpacecraft;
aSpacecraft.EphemerisName = '../samples/SupportFiles/Ex_R2022a_TLEPropagationTLE.txt';
aSpacecraft.Id = 'ExampleSat';

BeginMissionSequence;
```

## Configuring a SPICESPG4 Ephemeris Propagator

If you have assigned the ephemeris file to your spacecraft, configuring the propagator only requires assigning the **SPICESGP4** type on a **Propagator** resource. Below is a script example demonstrating creation of a **SPICESGP4** type **Propagator** with a 60 second step size.

```
Create Propagator SPICESGP4Propagator;  
  
SPICESGP4Propagator.Type      = 'SPICESGP4';  
SPICESGP4Propagator.StepSize = 60;  
  
BeginMissionSequence;
```

### Examples

This example propagates a spacecraft using a data from a TLE, and record the state information to a report file. The file used in this example is included in the GMAT distribution at the indicated location. The code below will run if you copy and paste it into a new GMAT script.

```
%  
% Spacecraft  
% %-----  
%----- Spacecraft  
%-----  
  
Create Spacecraft ExampleSat;  
ExampleSat.DateFormat = UTCGregorian;  
ExampleSat.EphemerisName = '../samples/SupportFiles/Ex_R2022a_TLEPropagationTLE.txt';  
ExampleSat.Id = 'ExampleSat';  
  
%-----  
%----- Propagators  
%-----  
  
Create Propagator TLEProp;  
TLEProp.Type = SPICESGP4;  
TLEProp.StepSize = 300;  
  
%-----  
%----- Subscribers  
%-----  
  
Create ReportFile rf;  
rf.Filename = BasicPropagation.txt  
rf.Add = {ExampleSat.UTCGregorian, ExampleSat.X, ExampleSat.Y, ExampleSat.Z, ExampleSat.VX, ExampleSat.VY,  
ExampleSat.VZ};  
  
%-----  
%----- Mission Sequence  
%-----  
  
BeginMissionSequence;  
  
Propagate TLEProp(ExampleSat) {ExampleSat.ElapsedDays = 1.0};
```

## SolarPowerSystem

A solar power system model

### Description

The **SolarPowerSystem** models a solar power system including power generated as function of time and distance from the sun, and includes shadow modeling by celestial bodies. The model allows you to configure the power generated by the solar arrays, and the power required by the spacecraft bus.

For a complete descriptor of how to configure all Resources required for electric propulsion modeling, see the Tutorial named [Electric Propulsion](#)

See Also [ElectricTank](#), [ElectricThruster](#), [NuclearPowerSystem](#)

### Fields

Field	Description
<b>AnnualDecayRate</b>	<p>The annual decay rate of the power system.</p> <p><b>Data Type</b> Real <b>Allowed Values</b> 0 &lt;=Real &lt;= 100 <b>Access</b> set <b>Default Value</b> 5 <b>Units</b> Percent/Year <b>Interfaces</b> GUI, script</p>
<b>BusCoeff1</b>	<p>Coefficient of power required by spacecraft bus.</p> <p><b>Data Type</b> Real <b>Allowed Values</b> Real <b>Access</b> set <b>Default Value</b> 0.3 <b>Units</b> kW <b>Interfaces</b> GUI, script</p>
<b>BusCoeff2</b>	<p>Coefficient of power required by spacecraft bus.</p> <p><b>Data Type</b> Real <b>Allowed Values</b> Real <b>Access</b> set <b>Default Value</b> 0 <b>Units</b> kW*AU <b>Interfaces</b> GUI, script</p>

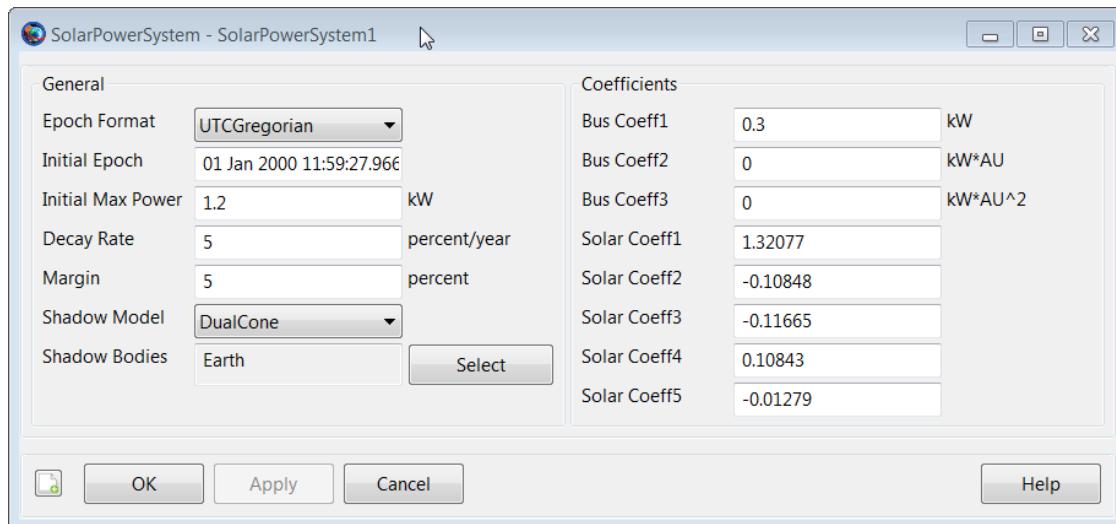
Field	Description
<b>BusCoeff3</b>	Coefficient of power required by spacecraft bus.
	<b>Data Type</b> Real <b>Allowed Values</b> Real <b>Access</b> set <b>Default Value</b> 0 <b>Units</b> kw*AU <sup>2</sup> <b>Interfaces</b> GUI, script
<b>EpochFormat</b>	The epoch format for the PowerInitialEpoch field.
	<b>Data Type</b> String <b>Allowed Values</b> Valid Epoch format. <b>Access</b> set <b>Default Value</b> UTCGregorian <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>InitialEpoch</b>	The initial epoch of the system used to define power system elapsed lifetime.
	<b>Data Type</b> String <b>Allowed Values</b> Valid GMAT Epoch consistent with PowerInitialEpochFormat <b>Access</b> set <b>Default Value</b> 01 Jan 2000 11:59:27.966 <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>InitialMaxPower</b>	The maximum power generated at the PowerInitialEpoch.
	<b>Data Type</b> Real <b>Allowed Values</b> Real >= 0 <b>Access</b> set <b>Default Value</b> 1.2 <b>Units</b> kW <b>Interfaces</b> GUI, script
<b>Margin</b>	The required margin between power left after power bus, and power used by the propulsion system.
	<b>Data Type</b> Real <b>Allowed Values</b> 0 <=Real <= 100 <b>Access</b> set <b>Default Value</b> 5 <b>Units</b> Percent <b>Interfaces</b> GUI, script

Field	Description												
<b>ShadowBodies</b>	<p>A list of celestial bodies for use in the shadow computation. A body cannot be added more than once.</p> <table> <tr> <td data-bbox="736 340 964 375"><b>Data Type</b></td><td data-bbox="1013 340 1144 375">String List</td></tr> <tr> <td data-bbox="736 382 964 418"><b>Allowed Values</b></td><td data-bbox="1013 382 1323 418">A list of celestial bodies.</td></tr> <tr> <td data-bbox="736 424 833 460"><b>Access</b></td><td data-bbox="1013 424 1046 460">set</td></tr> <tr> <td data-bbox="736 466 915 502"><b>Default Value</b></td><td data-bbox="1013 466 1078 502">Earth</td></tr> <tr> <td data-bbox="736 508 817 544"><b>Units</b></td><td data-bbox="1013 508 1062 544">N/A</td></tr> <tr> <td data-bbox="736 551 866 587"><b>Interfaces</b></td><td data-bbox="1013 551 1144 587">GUI, script</td></tr> </table>	<b>Data Type</b>	String List	<b>Allowed Values</b>	A list of celestial bodies.	<b>Access</b>	set	<b>Default Value</b>	Earth	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String List												
<b>Allowed Values</b>	A list of celestial bodies.												
<b>Access</b>	set												
<b>Default Value</b>	Earth												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>ShadowModel</b>	<p>The model used for shadow computation in the Solar System Power Model.</p> <table> <tr> <td data-bbox="736 677 882 713"><b>Data Type</b></td><td data-bbox="1013 677 1078 713">String</td></tr> <tr> <td data-bbox="736 720 948 756"><b>Allowed Values</b></td><td data-bbox="1013 720 1225 756">None, DualCone</td></tr> <tr> <td data-bbox="736 762 833 798"><b>Access</b></td><td data-bbox="1013 762 1046 798">set</td></tr> <tr> <td data-bbox="736 804 915 840"><b>Default Value</b></td><td data-bbox="1013 804 1127 840">DualCone</td></tr> <tr> <td data-bbox="736 846 817 882"><b>Units</b></td><td data-bbox="1013 846 1062 882">N/A</td></tr> <tr> <td data-bbox="736 889 866 925"><b>Interfaces</b></td><td data-bbox="1013 889 1144 925">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	None, DualCone	<b>Access</b>	set	<b>Default Value</b>	DualCone	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	None, DualCone												
<b>Access</b>	set												
<b>Default Value</b>	DualCone												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>SolarCoeff1</b>	<p>Coefficient of power created by solar power system.</p> <table> <tr> <td data-bbox="736 967 882 1003"><b>Data Type</b></td><td data-bbox="1013 967 1062 1003">Real</td></tr> <tr> <td data-bbox="736 1009 948 1045"><b>Allowed Values</b></td><td data-bbox="1013 1009 1062 1045">Real</td></tr> <tr> <td data-bbox="736 1058 833 1094"><b>Access</b></td><td data-bbox="1013 1058 1046 1094">set</td></tr> <tr> <td data-bbox="736 1100 915 1136"><b>Default Value</b></td><td data-bbox="1013 1100 1111 1136">1.32077</td></tr> <tr> <td data-bbox="736 1142 817 1178"><b>Units</b></td><td data-bbox="1013 1142 1176 1178">See Remarks</td></tr> <tr> <td data-bbox="736 1184 866 1220"><b>Interfaces</b></td><td data-bbox="1013 1184 1144 1220">GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real	<b>Access</b>	set	<b>Default Value</b>	1.32077	<b>Units</b>	See Remarks	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real												
<b>Access</b>	set												
<b>Default Value</b>	1.32077												
<b>Units</b>	See Remarks												
<b>Interfaces</b>	GUI, script												
<b>SolarCoeff2</b>	<p>Coefficient of power created by solar power system.</p> <table> <tr> <td data-bbox="736 1256 882 1292"><b>Data Type</b></td><td data-bbox="1013 1256 1062 1292">Real</td></tr> <tr> <td data-bbox="736 1298 948 1334"><b>Allowed Values</b></td><td data-bbox="1013 1298 1062 1334">Real</td></tr> <tr> <td data-bbox="736 1341 833 1377"><b>Access</b></td><td data-bbox="1013 1341 1046 1377">set</td></tr> <tr> <td data-bbox="736 1383 915 1419"><b>Default Value</b></td><td data-bbox="1013 1383 1111 1419">-0.10848</td></tr> <tr> <td data-bbox="736 1425 817 1461"><b>Units</b></td><td data-bbox="1013 1425 1176 1461">See Remarks</td></tr> <tr> <td data-bbox="736 1467 866 1503"><b>Interfaces</b></td><td data-bbox="1013 1467 1144 1503">GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real	<b>Access</b>	set	<b>Default Value</b>	-0.10848	<b>Units</b>	See Remarks	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real												
<b>Access</b>	set												
<b>Default Value</b>	-0.10848												
<b>Units</b>	See Remarks												
<b>Interfaces</b>	GUI, script												
<b>SolarCoeff3</b>	<p>Coefficient of power created by solar power system.</p> <table> <tr> <td data-bbox="736 1541 882 1577"><b>Data Type</b></td><td data-bbox="1013 1541 1062 1577">Real</td></tr> <tr> <td data-bbox="736 1584 948 1619"><b>Allowed Values</b></td><td data-bbox="1013 1584 1062 1619">Real</td></tr> <tr> <td data-bbox="736 1626 833 1662"><b>Access</b></td><td data-bbox="1013 1626 1046 1662">set</td></tr> <tr> <td data-bbox="736 1668 915 1704"><b>Default Value</b></td><td data-bbox="1013 1668 1111 1704">-0.11665</td></tr> <tr> <td data-bbox="736 1710 817 1746"><b>Units</b></td><td data-bbox="1013 1710 1176 1746">See Remarks</td></tr> <tr> <td data-bbox="736 1752 866 1788"><b>Interfaces</b></td><td data-bbox="1013 1752 1144 1788">GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real	<b>Access</b>	set	<b>Default Value</b>	-0.11665	<b>Units</b>	See Remarks	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real												
<b>Access</b>	set												
<b>Default Value</b>	-0.11665												
<b>Units</b>	See Remarks												
<b>Interfaces</b>	GUI, script												

Field	Description	
<b>SolarCoeff4</b>	Coefficient of power created by solar power system.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real
	<b>Access</b>	set
	<b>Default Value</b>	0.10843
	<b>Units</b>	See Remarks
	<b>Interfaces</b>	GUI, script
<b>SolarCoeff5</b>	Coefficient of power created by solar power system.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real
	<b>Access</b>	set
	<b>Default Value</b>	-0.01279
	<b>Units</b>	See Remarks
	<b>Interfaces</b>	GUI, script

## GUI

The GUI for the **SolarPowerSystem** is shown below.



## Remarks

### Computation of Base Power

The **SolarPowerSystem** models power degradation as a function of time. You must provide a power system initial epoch, the power generated at that epoch, and an annual power decay rate. Additionally, the **AnnualDecayRate** field models the power degradation on a per year basis. The base power is computed using

$$\overrightarrow{P}_{Base} = P_0(1 - \tau/100)^{\Delta t}$$

where "tau" is the power **AnnualDecayRate**, P\_0 is **InitialMaxPower**, and "delta t" is the elapsed time between the simulation epoch and **InitialEpoch**.

### Computation of Bus Power

The power required by the spacecraft bus for all subsystems other than the propulsion system is computed using

$$P_{Bus} = A_{Bus} + B_{Bus}\left(\frac{1}{r}\right) + C_{Bus}\left(\frac{1}{r^2}\right)$$

where A\_Bus, B\_Bus, and C\_Bus are **BusCoeff1**, **BusCoeff2**, and **BusCoeff3** respectively and r is the distance from the Sun in Au.

### Computation of Power Available for Propulsion

The solar power model scales the base power based on a polynomial function in terms of the solar distance. Total power is compute using

$$P_{Tot} = P_{sun} \frac{P_{Base}}{r^2} \left( \frac{C_1 + C_2/r + C_3/r^2}{1 + C_4r + C_5r^2} \right)$$

where P\_Sun is the percent sun ( full sun is 1.0, no sun is 0.0), r is the distance from the Sun in Au, and C\_1 is **SolarCoeff1** and so on. Thrust power available for electric propulsion is finaly computed using

$$P_{Thrust} = (1 - \frac{\delta M}{100})(P_{Tot} - P_{Bus})$$

Where "delta M" is power **Margin**.

### Shadow Modelling and Discontinuities

Note that when modeling shadows for a solar power system, discontinuities in the force model can occur when the power avialable for propulsion is less than a thruster's minimum useable power setting. As a spacecraft passes from penumbra to umbra, and power avialable for thusting goes to zero, thrust power causes thrust acceleration to discontinuously terminate, causing issues when using adaptive step integrators. In this case, there are a few options. You can configure any itegrator to use fixed step integration by setting the **ErrorControl** to **None**. Or you can configure the integrator to continue propagating if a bad step, in this case a small discontinuity, occurs. See the **Propagator** reference material for more information.

### Examples

Create a **SolarPowerSystem** and attach it to a **Spacecraft**.

```
% Create the Solar Power System
Create SolarPowerSystem SolarPowerSystem1

% Create a spacecraft an attach the Solar Power System
```

```
Create Spacecraft DefaultSC
DefaultSC.PowerSystem = SolarPowerSystem1

BeginMissionSequence
```

For a complete description of how to configure all Resources required for electric propulsion modeling, see the Tutorial named [\*Electric Propulsion\*](#).

## SolarSystem

High level solar system configuration options

### Description

The **SolarSystem** resource allows you to define global properties for the model of the solar system including the ephemeris source for built-in celestial bodies and selected settings to improve performance when medium fidelity modeling is acceptable for your application. This resource cannot be modified in the mission sequence.



#### Note

As of release R2015a, GMAT uses two separate solar system configurations for core parts of the system. For propagation, GMAT uses the source specified by **SolarSystem.EphemerisSource** and the **CelestialBody** properties configured on each resource. For event location with the new **ContactLocator** and **EclipseLocator** resources, GMAT always uses SPICE data for **SolarSystem** and **CelestialBody** properties. See [ContactLocator](#), [EclipseLocator](#), and [CelestialBody](#) for details.

See Also: [CelestialBody](#), [LibrationPoint](#), [Barycenter](#), [CoordinateSystem](#)

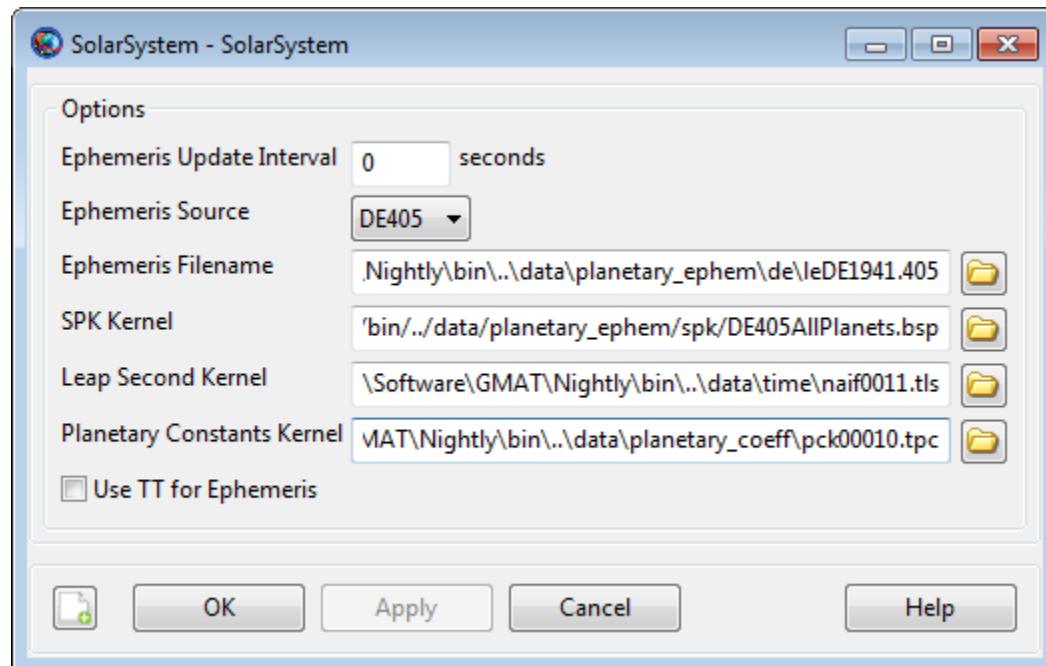
### Fields

Field	Description
<b>DEFilename</b>	The path and name of the DE file.  <b>Data Type</b> String <b>Allowed Values</b> Valid DE file <b>Access</b> set <b>Default Value</b> ../data/planetary_ephem/de/leDE1941.405 <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>EphemerisSource</b>	The ephemeris model for built-in celestial bodies.  <b>Data Type</b> String <b>Allowed Values</b> <b>DE405</b> , <b>DE421</b> , <b>DE424</b> , or <b>SPICE</b> <b>Access</b> set <b>Default Value</b> <b>DE405</b> <b>Units</b> N/A <b>Interfaces</b> GUI, script

Field	Description
<b>EphemerisUpdateInterval</b>	The time between time updates for celestial body ephemeris. For example, if <b>EphemerisUpdateInterval</b> = 60, if an ephemeris call is made at time t = 1200, and a subsequent call is made at time t = 1210, the same ephemeris will be returned for the second call. This option is for high speed, low fidelity modeling or for use when modeling orbits far from third body perturbation sources.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Real &gt;= 0</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 0</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>LSKFilename</b>	The path and name of the SPK leap second kernel.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> Valid SPK leapsecond kernel</p> <p><b>Access</b> set</p> <p><b>Default Value</b> ./data/time/naif0011.tls</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>PCKFilename</b>	The path and name of the PCK planetary constants kernel.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> Path to valid PCK planetary constants kernel (.tpc)</p> <p><b>Access</b> set</p> <p><b>Default Value</b> ./data/planetary_coeff/pck00010.tpc</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>SPKFilename</b>	The path and name of the SPK orbit ephemeris kernel.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> Valid SPK ephemeris kernel (.bsp)</p> <p><b>Access</b> set</p> <p><b>Default Value</b> ./data/planetary_ephem/spk/DE405AllPlanets.bsp</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>

Field	Description	
<b>UseTTForEphemeris</b>	Flag to use Terrestrial Time (TT) as input to the orbital ephemeris routines. When set to false, TDB is used.	
	<b>Data Type</b>	String
	<b>Allowed Values</b>	true,false
	<b>Access</b>	set
	<b>Default Value</b>	false
	<b>Units</b>	N/A
	<b>Interfaces</b>	GUI, script

## GUI



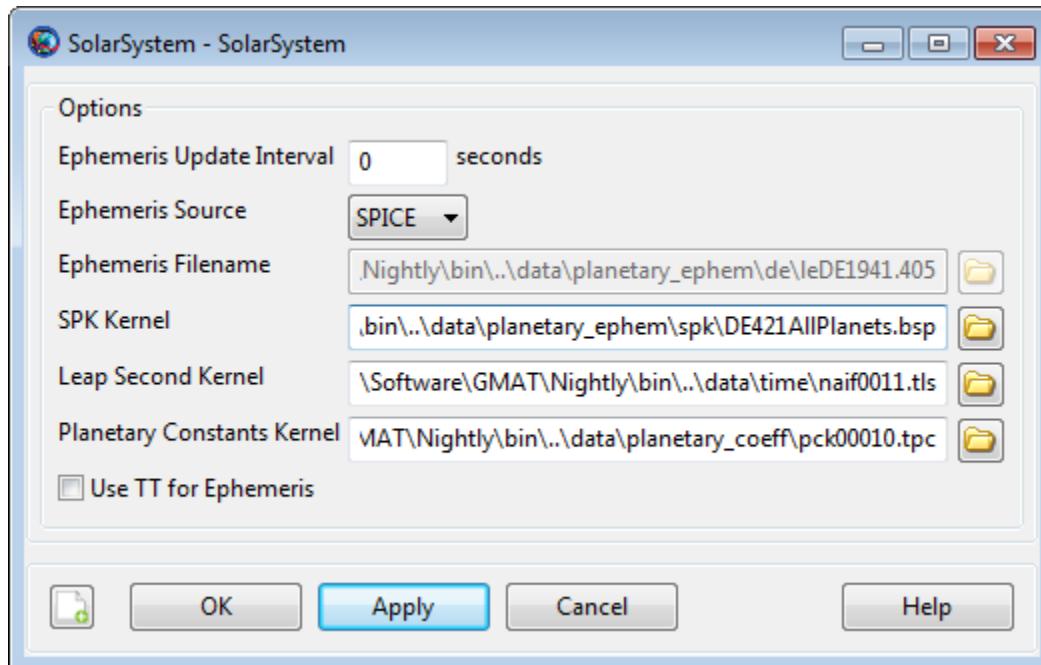
The **SolarSystem** dialog box allows you to configure global properties for solar system modeling. The default configuration is illustrated above. Use **Ephemeris Source** to choose the ephemeris model for built-in celestial bodies. If you select either **DE405**, **DE421**, or **DE424** the dialog box above illustrates available options.

**Warning**

GMAT allows you to provide user-created DE or SPK kernel files but we recommend using the files distributed with GMAT. The files provided with GMAT have been extensively tested for consistency and accuracy with the original data provided by JPL and other models in GMAT. Using inconsistent ephemeris files or user-generated files can result in instability or numerical issues if the files are not generated correctly.

Changing the ephemeris source for an application is equivalent to making a fundamental change to the model of the solar system. We recommend selecting the **EphemerisSource** early in the analysis process and using that model consistently. In the event that an ephemeris model change is necessary, we recommend that you change the model in the script file and not via the GUI. We allow you to change **EphemerisSource** via the GUI for convenience in early design phases when rigorous consistency in modeling is less important.

Additionally, when using DE as the **EphemerisSource**, modeling is with respect to planetary system barycenter except for Earth and Moon which are with respect to the body center. When using SPICE as the **EphemerisSource**, modeling is with respect to the NaifId defined on the body.



If you select **SPICE** for **Ephemeris Source**, the **SolarSystem** dialog box reconfigures to disable the **Ephemeris Filename** option, indicating that this is no longer used in this mission..

## Remarks

GMAT uses the ephemeris file selected in the **EphemerisSource** field for all built-in celestial bodies. For user-defined bodies, the ephemeris model is specified on the **CelestialBody** object.

- For more information on the DE files provided by JPL see [here](#).
- For general information on SPICE ephemeris files see the [JPL NAIF site](#).
- For information on the SPK kernel named DE???AllPlanets.bsp distributed with GMAT, see the Readme-DE???AllPlanets.txt files located in \data\planetary\_ephem\spk in the GMAT distribution.

Note: The **SolarSystem** and built-in **CelestialBody** resources require several hundred fields for full configuration. GMAT only saves non-default values for **SolarSystem** and **CelestialBody** to the script so that scripts are not populated with hundreds of default settings.

## GMAT Support for ICRF Solar System Ephemeris Files

JPL planetary ephemeris files from DE400 and later are referenced to the International Celestial Reference Frame (ICRF), which is not precisely equivalent to the J2000 reference frame. The distinction between ICRF and J2000 is not relevant for most orbits, most particularly those in the near-Earth region. However, users should be aware that GMAT currently treats ICRF solar system ephemeris states as J2000 and therefore users may encounter inconsistency between GMAT and other systems that perform ICRF to J2000 transformations of the solar system ephemeris.

## Modeling Additional Solar System Bodies

The planetary ephemeris files delivered with GMAT include most solar system planets, but do not include the natural satellites of planets. It is possible to model the moons of Jupiter, Saturn, and other planets in GMAT, but the user must obtain the ephemeris data for these bodies from external sources. The most convenient method for this is to obtain appropriate SPICE ephemeris files from the JPL NAIF website (look for "Generic Kernels"), and then use that SPICE file as the **OrbitSpiceKernelName** for a new instance of **CelestialBody**. An example of this process is shown for Saturn's moon Titan in the examples section for **CelestialBody**.

## Examples

Use **DE421** for ephemeris.

```
GMAT SolarSystem.EphemerisSource = 'DE421'

Create Spacecraft aSpacecraft
Create Propagator aPropagator
aPropagator.FM = aForceModel
Create ForceModel aForceModel
aForceModel.PointMasses = {Luna, Sun}
```

```
BeginMissionSequence
```

```
Propagate aPropagator(aSpacecraft) {aSpacecraft.ElapsedSecs = 12000.0}
```

Use **SPICE** for ephemeris.

```
GMAT SolarSystem.EphemerisSource = 'SPICE'
```

```
Create Spacecraft aSpacecraft
```

```
Create Propagator aPropagator
```

```
aPropagator.FM = aForceModel
```

```
Create ForceModel aForceModel
```

```
aForceModel.PointMasses = {Luna, Sun}
```

```
BeginMissionSequence
```

```
Propagate aPropagator(aSpacecraft) {aSpacecraft.ElapsedSecs = 12000.0}
```

## Spacecraft

A spacecraft model

### Description

A **Spacecraft** resource is GMAT's spacecraft model and includes data and models for the spacecraft's orbit, epoch, attitude, and physical parameters (such as mass and drag coefficient), as well as attached hardware, including tanks and thrusters. The **Spacecraft** model also contains the data that configures how the **Spacecraft** 3-D CAD model is used in an **OrbitView**. **Spacecraft** has certain fields that can be set in the Mission Sequence and some that cannot. See the field tables on the pages below for more information.

GMAT's documentation for **Spacecraft** is extensive and is broken down into the following sections:

- [Spacecraft Attitude](#)
- [Spacecraft Ballistic/Mass Properties](#)
- [Spacecraft Epoch](#)
- [Spacecraft Hardware](#)
- [Spacecraft Navigation](#)
- [Spacecraft Orbit State](#)
- [Spacecraft Visualization Properties](#)

## Spacecraft Attitude

The spacecraft attitude model

### Description

GMAT models the orientation and rate of rotation of a spacecraft using several different mathematical models. Currently, GMAT assumes that a **Spacecraft** is a rigid body. The currently supported attitude models are **Spinner**, **PrecessingSpinner**, **CoordinateSystemFixed**, **NadirPointing**, **CommandableNadirPointing**, **ThreeAxisKinematic**, **CCSDS-AEM** and **SpiceAttitude**. The **Spinner** model is a simple, inertially fixed spin axis model. The **PrecessingSpinner** model adds models for precession and nutation of the spin axis. The **CoordinateSystemFixed** model allows you to use any **CoordinateSystem** supported by GMAT as the attitude of a **Spacecraft**. The **NadirPointing** model constructs a coordinate system based on spacecraft position and velocity vectors. The **CommandableNadirPointing** attitude model is identical to the Nadir Pointing model, with the added ability to set the attitude using quaternions from the mission sequence. The **SpiceAttitude** model allows you to define the **Spacecraft** attitude based on SPICE attitude kernels. The **ThreeAxisKinematic** model propagates the attitude quaternion from angular velocity inputs; it was originally designed for an animation application where attitude was propagated every 25 msec.

See Also: [Spacecraft](#)

### Fields

Field	Description												
<b>AngularVelocityX</b>	The x-component of <b>Spacecraft</b> body angular velocity expressed in the inertial frame. <b>AngularVelocityX</b> is used for the following Attitude models: <b>Spinner</b> .												
	<table><tr><td><b>Data Type</b></td><td>Real</td></tr><tr><td><b>Allowed Values</b></td><td>-# &lt; Real &lt; #</td></tr><tr><td><b>Access</b></td><td>set,get</td></tr><tr><td><b>Default Value</b></td><td>0</td></tr><tr><td><b>Units</b></td><td>deg/sec</td></tr><tr><td><b>Interfaces</b></td><td>GUI, script</td></tr></table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-# < Real < #	<b>Access</b>	set,get	<b>Default Value</b>	0	<b>Units</b>	deg/sec	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-# < Real < #												
<b>Access</b>	set,get												
<b>Default Value</b>	0												
<b>Units</b>	deg/sec												
<b>Interfaces</b>	GUI, script												
<b>AngularVelocityY</b>	The y-component of <b>Spacecraft</b> body angular velocity expressed in the inertial frame. <b>AngularVelocityY</b> is used for the following Attitude models: <b>Spinner</b> .												
	<table><tr><td><b>Data Type</b></td><td>Real</td></tr><tr><td><b>Allowed Values</b></td><td>-# &lt; Real &lt; #</td></tr><tr><td><b>Access</b></td><td>set,get</td></tr><tr><td><b>Default Value</b></td><td>0</td></tr><tr><td><b>Units</b></td><td>deg/sec</td></tr><tr><td><b>Interfaces</b></td><td>GUI, script</td></tr></table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-# < Real < #	<b>Access</b>	set,get	<b>Default Value</b>	0	<b>Units</b>	deg/sec	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-# < Real < #												
<b>Access</b>	set,get												
<b>Default Value</b>	0												
<b>Units</b>	deg/sec												
<b>Interfaces</b>	GUI, script												

Field	Description												
<b>AngularVelocityZ</b>	<p>The z-component of <b>Spacecraft</b> body angular velocity expressed in the inertial frame. <b>AngularVelocityZ</b> is used for the following Attitude models: <b>Spinner</b>.</p> <table> <tr> <td data-bbox="747 382 979 418"><b>Data Type</b></td><td data-bbox="979 382 1478 418">Real</td></tr> <tr> <td data-bbox="747 418 979 454"><b>Allowed Values</b></td><td data-bbox="979 418 1478 454">-# &lt; Real &lt; #</td></tr> <tr> <td data-bbox="747 454 979 489"><b>Access</b></td><td data-bbox="979 454 1478 489">set, get</td></tr> <tr> <td data-bbox="747 489 979 525"><b>Default Value</b></td><td data-bbox="979 489 1478 525">0</td></tr> <tr> <td data-bbox="747 525 979 561"><b>Units</b></td><td data-bbox="979 525 1478 561">deg/sec</td></tr> <tr> <td data-bbox="747 561 979 593"><b>Interfaces</b></td><td data-bbox="979 561 1478 593">GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-# < Real < #	<b>Access</b>	set, get	<b>Default Value</b>	0	<b>Units</b>	deg/sec	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-# < Real < #												
<b>Access</b>	set, get												
<b>Default Value</b>	0												
<b>Units</b>	deg/sec												
<b>Interfaces</b>	GUI, script												
<b>Attitude</b>	<p>The attitude mode for the <b>Spacecraft</b>.</p> <table> <tr> <td data-bbox="747 656 979 692"><b>Data Type</b></td><td data-bbox="979 656 1478 692">String</td></tr> <tr> <td data-bbox="747 692 979 728"><b>Allowed Values</b></td><td data-bbox="979 692 1478 868">CoordinateSystemFixed, Spinner, SpiceAttitude, NadirPointing, CommandableNadirPointing, CCSDS-AEM, PrecessingSpinner, ThreeAxisKinematic</td></tr> <tr> <td data-bbox="747 868 979 903"><b>Access</b></td><td data-bbox="979 868 1478 903">set</td></tr> <tr> <td data-bbox="747 903 979 939"><b>Default Value</b></td><td data-bbox="979 903 1478 939"><b>CoordinateSystemFixed</b></td></tr> <tr> <td data-bbox="747 939 979 975"><b>Units</b></td><td data-bbox="979 939 1478 975">N/A</td></tr> <tr> <td data-bbox="747 975 979 1011"><b>Interfaces</b></td><td data-bbox="979 975 1478 1011">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	CoordinateSystemFixed, Spinner, SpiceAttitude, NadirPointing, CommandableNadirPointing, CCSDS-AEM, PrecessingSpinner, ThreeAxisKinematic	<b>Access</b>	set	<b>Default Value</b>	<b>CoordinateSystemFixed</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	CoordinateSystemFixed, Spinner, SpiceAttitude, NadirPointing, CommandableNadirPointing, CCSDS-AEM, PrecessingSpinner, ThreeAxisKinematic												
<b>Access</b>	set												
<b>Default Value</b>	<b>CoordinateSystemFixed</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>AttitudeConstraintType</b>	<p>The constraint type for resolving attitude ambiguity. The attitude is computed such that the angle between the <b>BodyConstraintVector</b> and the constraint defined by <b>AttitudeConstraintType</b> is minimized. A <b>Velocity</b> constraint uses the inertial velocity vector expressed with respect to the <b>AttitudeReferenceBody</b>. An <b>OrbitNormal</b> constraint uses the orbit normal vector expressed with respect to the <b>AttitudeReferenceBody</b>. <b>AttitudeConstraintType</b> is used for the following attitude models: <b>NadirPointing</b>, <b>CommandableNadirPointing</b>.</p> <table> <tr> <td data-bbox="747 1410 979 1446"><b>Data Type</b></td><td data-bbox="979 1410 1478 1446">Enumeration</td></tr> <tr> <td data-bbox="747 1446 979 1482"><b>Allowed Values</b></td><td data-bbox="979 1446 1478 1482"><b>Velocity</b>, <b>OrbitNormal</b></td></tr> <tr> <td data-bbox="747 1482 979 1518"><b>Access</b></td><td data-bbox="979 1482 1478 1518">set</td></tr> <tr> <td data-bbox="747 1518 979 1554"><b>Default Value</b></td><td data-bbox="979 1518 1478 1554">OrbitNormal</td></tr> <tr> <td data-bbox="747 1554 979 1590"><b>Units</b></td><td data-bbox="979 1554 1478 1590">N/A</td></tr> <tr> <td data-bbox="747 1590 979 1624"><b>Interfaces</b></td><td data-bbox="979 1590 1478 1624">GUI, script</td></tr> </table>	<b>Data Type</b>	Enumeration	<b>Allowed Values</b>	<b>Velocity</b> , <b>OrbitNormal</b>	<b>Access</b>	set	<b>Default Value</b>	OrbitNormal	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Enumeration												
<b>Allowed Values</b>	<b>Velocity</b> , <b>OrbitNormal</b>												
<b>Access</b>	set												
<b>Default Value</b>	OrbitNormal												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

Field	Description
<b>AttitudeCoordinateSystem</b>	<p>The <b>CoordinateSystem</b> used in attitude computations. The <b>AttitudeCoordinateSystem</b> field is only used for the following attitude models: <b>CoordinateSystemFixed</b>.</p>
	<p><b>Data Type</b> String  <b>Allowed Values</b> <b>CoordinateSystem</b> resource.  <b>Access</b> set  <b>Default Value</b> <b>EarthMJ2000Eq</b>  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>AttitudeFileName</b>	<p>Path (optional) and name of CCSDS attitude ephemeris message file. If a path is not provided, and GMAT does not find the file in the current directory, then an error occurs and execution is halted.</p>
	<p><b>Data Type</b> String  <b>Allowed Values</b> AEM File  <b>Access</b> set  <b>Default Value</b> N/A  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>AttitudeRate-DisplayStateType</b>	<p>The attitude rate representation to display in the GUI and script file. <b>AttitudeRateDisplayType</b> is used for the following attitude models: <b>Spinner</b>.</p>
	<p><b>Data Type</b> String  <b>Allowed Values</b> <b>AngularVelocity</b>, <b>EulerAngleRates</b>  <b>Access</b> set  <b>Default Value</b> <b>AngularVelocity</b>  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>AttitudeReferenceBody</b>	<p>The celestial body used to define nadir. <b>AttitudeReferenceBody</b> is used for the following attitude models: <b>NadirPointing</b>, <b>CommandableNadirPointing</b>.</p>
	<p><b>Data Type</b> Resource  <b>Allowed Values</b> Celestial Body  <b>Access</b> set  <b>Default Value</b> Earth  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>

Field	Description
<b>AttitudeSpiceKernel-Name</b>	SPK Kernels for <b>Spacecraft</b> attitude. SPK attitude kernels have extension ".BC". This field cannot be set in the Mission Sequence. An empty list unloads all kernels of this type on the <b>Spacecraft</b> .
<b>Data Type</b>	String array
<b>Allowed Values</b>	Array of attitude kernel files
<b>Access</b>	set
<b>Default Value</b>	empty array
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>BodyAlignmentVectorX</b>	The x-component of the alignment vector, expressed in the body frame, to align with the opposite of the radial vector. <b>BodyAlignmentVectorX</b> is used for the following attitude models: <b>NadirPointing</b> , <b>CommandableNadirPointing</b> .
<b>Data Type</b>	Real
<b>Allowed Values</b>	-# < Real < #
<b>Access</b>	set
<b>Default Value</b>	1
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>BodyAlignmentVectorY</b>	The y-component of the alignment vector, expressed in the body frame, to align with the opposite of the radial vector. <b>BodyAlignmentVectorY</b> is used for the following attitude models: <b>NadirPointing</b> , <b>CommandableNadirPointing</b> .
<b>Data Type</b>	Real
<b>Allowed Values</b>	-# < Real < #
<b>Access</b>	set
<b>Default Value</b>	0
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

Field	Description
<b>BodyAlignmentVectorZ</b>	The z-component of the alignment vector, expressed in the body frame, to align with the opposite of the radial vector. <b>BodyAlignmentVectorZ</b> is used for the following attitude models: <b>NadirPointing</b> , <b>CommandableNadirPointing</b> .
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>BodyConstraintVectorX</b>	The x-component of the constraint vector, expressed in the body frame. See <a href="#">NadirPointing</a> description for further details. <b>BodyConstraintVectorX</b> is used for the following attitude models: <b>NadirPointing</b> , <b>CommandableNadirPointing</b> .
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>BodyConstraintVectorY</b>	The y-component of the constraint vector, expressed in the body frame. See <a href="#">NadirPointing</a> description for further details. <b>BodyConstraintVectorY</b> is used for the following attitude models: <b>NadirPointing</b> , <b>CommandableNadirPointing</b> .
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>

Field	Description
<b>BodyConstraintVectorZ</b>	The z-component of the constraint vector, expressed in the body frame. See <a href="#">NadirPointing</a> description for further details. <b>BodyConstraintVectorZ</b> is used for the following attitude models: <b>NadirPointing</b> , <b>Commandable-NadirPointing</b> .
	<p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set  <b>Default Value</b> 1  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>BodySpinAxisX</b>	The x-component of the spin axis, expressed in the body frame. <b>BodySpinAxisX</b> is used for the following attitude models: <b>PrecessingSpinner</b> .
	<p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>BodySpinAxisY</b>	The y-component of the spin axis, expressed in the body frame. <b>BodySpinAxisY</b> is used for the following attitude models: <b>PrecessingSpinner</b> .
	<p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>BodySpinAxisZ</b>	The z-component of the spin axis, expressed in the body frame. <b>BodySpinAxisZ</b> is used for the following attitude models: <b>PrecessingSpinner</b> .
	<p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set  <b>Default Value</b> 1  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>

Field	Description												
<b>DCM11</b>	<p>Component (1,1) of the Direction Cosine Matrix. <b>DCM11</b> is used for the following Attitude models: <b>Spinner</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-1 &lt;= Real &lt;=1</td></tr> <tr> <td><b>Access</b></td><td>set,get</td></tr> <tr> <td><b>Default Value</b></td><td>1</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-1 <= Real <=1	<b>Access</b>	set,get	<b>Default Value</b>	1	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-1 <= Real <=1												
<b>Access</b>	set,get												
<b>Default Value</b>	1												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>DCM12</b>	<p>Component (1,2) of the Direction Cosine Matrix. <b>DCM12</b> is used for the following Attitude models: <b>Spinner</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-1 &lt;= Real &lt;=1</td></tr> <tr> <td><b>Access</b></td><td>set,get</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-1 <= Real <=1	<b>Access</b>	set,get	<b>Default Value</b>	0	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-1 <= Real <=1												
<b>Access</b>	set,get												
<b>Default Value</b>	0												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>DCM13</b>	<p>Component (1,3) of the Direction Cosine Matrix. <b>DCM13</b> is used for the following Attitude models: <b>Spinner</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-1 &lt;= Real &lt;=1</td></tr> <tr> <td><b>Access</b></td><td>set,get</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-1 <= Real <=1	<b>Access</b>	set,get	<b>Default Value</b>	0	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-1 <= Real <=1												
<b>Access</b>	set,get												
<b>Default Value</b>	0												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>DCM21</b>	<p>Component (2,1) of the Direction Cosine Matrix. <b>DCM21</b> is used for the following Attitude models: <b>Spinner</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-1 &lt;= Real &lt;=1</td></tr> <tr> <td><b>Access</b></td><td>set,get</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-1 <= Real <=1	<b>Access</b>	set,get	<b>Default Value</b>	0	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-1 <= Real <=1												
<b>Access</b>	set,get												
<b>Default Value</b>	0												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>DCM22</b>	<p>Component (2,2) of the Direction Cosine Matrix. <b>DCM22</b> is used for the following Attitude models: <b>Spinner</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-1 &lt;= Real &lt;=1</td></tr> <tr> <td><b>Access</b></td><td>set,get</td></tr> <tr> <td><b>Default Value</b></td><td>1</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-1 <= Real <=1	<b>Access</b>	set,get	<b>Default Value</b>	1	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-1 <= Real <=1												
<b>Access</b>	set,get												
<b>Default Value</b>	1												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

Field	Description
<b>DCM23</b>	Component (2,3) of the Direction Cosine Matrix. <b>DCM23</b> is used for the following Attitude models: <b>Spinner</b> .
	<b>Data Type</b> Real <b>Allowed Values</b> -1 <= Real <=1 <b>Access</b> set,get <b>Default Value</b> 0 <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>DCM31</b>	Component (3,1) of the Direction Cosine Matrix. <b>DCM31</b> is used for the following Attitude models: <b>Spinner</b> .
	<b>Data Type</b> Real <b>Allowed Values</b> -1 <= Real <=1 <b>Access</b> set,get <b>Default Value</b> 0 <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>DCM32</b>	Component (3,2) of the Direction Cosine Matrix. <b>DCM32</b> is used for the following Attitude models: <b>Spinner</b> .
	<b>Data Type</b> Real <b>Allowed Values</b> -1 <= Real <=1 <b>Access</b> set,get <b>Default Value</b> 1 <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>DCM33</b>	Component (3,3) of the Direction Cosine Matrix. <b>DCM33</b> is used for the following Attitude models: <b>Spinner</b> .
	<b>Data Type</b> Real <b>Allowed Values</b> -1 <= Real <=1 <b>Access</b> set,get <b>Default Value</b> 1 <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>EulerAngle1</b>	The value of the first Euler angle. <b>EulerAngle1</b> is used for the following Attitude models: <b>Spinner</b> .
	<b>Data Type</b> Real <b>Allowed Values</b> -# < Real < # <b>Access</b> set,get <b>Default Value</b> 0 <b>Units</b> deg. <b>Interfaces</b> GUI, script

Field	Description												
<b>EulerAngle2</b>	<p>The value of the second Euler angle. <b>EulerAngle2</b> is used for the following Attitude models: <b>Spinner</b>.</p> <table> <tr> <td data-bbox="638 340 817 371"><b>Data Type</b></td><td data-bbox="915 340 980 371">Real</td></tr> <tr> <td data-bbox="638 378 850 409"><b>Allowed Values</b></td><td data-bbox="915 378 1078 409">-# &lt; Real &lt; #</td></tr> <tr> <td data-bbox="638 416 736 447"><b>Access</b></td><td data-bbox="915 416 997 447">set,get</td></tr> <tr> <td data-bbox="638 454 817 483"><b>Default Value</b></td><td data-bbox="915 454 931 483">0</td></tr> <tr> <td data-bbox="638 489 703 521"><b>Units</b></td><td data-bbox="915 489 964 521">deg.</td></tr> <tr> <td data-bbox="638 528 768 559"><b>Interfaces</b></td><td data-bbox="915 528 1046 559">GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-# < Real < #	<b>Access</b>	set,get	<b>Default Value</b>	0	<b>Units</b>	deg.	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-# < Real < #												
<b>Access</b>	set,get												
<b>Default Value</b>	0												
<b>Units</b>	deg.												
<b>Interfaces</b>	GUI, script												
<b>EulerAngle3</b>	<p>The value of the third Euler angle. <b>EulerAngle3</b> is used for the following Attitude models: <b>Spinner</b>.</p> <table> <tr> <td data-bbox="638 673 817 705"><b>Data Type</b></td><td data-bbox="915 673 980 705">Real</td></tr> <tr> <td data-bbox="638 711 850 743"><b>Allowed Values</b></td><td data-bbox="915 711 1078 743">-# &lt; Real &lt; #</td></tr> <tr> <td data-bbox="638 749 736 779"><b>Access</b></td><td data-bbox="915 749 997 779">set,get</td></tr> <tr> <td data-bbox="638 785 817 815"><b>Default Value</b></td><td data-bbox="915 785 931 815">0</td></tr> <tr> <td data-bbox="638 821 703 853"><b>Units</b></td><td data-bbox="915 821 964 853">deg.</td></tr> <tr> <td data-bbox="638 859 768 891"><b>Interfaces</b></td><td data-bbox="915 859 1046 891">GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-# < Real < #	<b>Access</b>	set,get	<b>Default Value</b>	0	<b>Units</b>	deg.	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-# < Real < #												
<b>Access</b>	set,get												
<b>Default Value</b>	0												
<b>Units</b>	deg.												
<b>Interfaces</b>	GUI, script												
<b>EulerAngleRate1</b>	<p>The value of the first Euler angle rate. <b>EulerAngleRate1</b> is used for the following Attitude models: <b>Spinner</b>.</p> <table> <tr> <td data-bbox="638 1005 817 1036"><b>Data Type</b></td><td data-bbox="915 1005 980 1036">Real</td></tr> <tr> <td data-bbox="638 1043 850 1075"><b>Allowed Values</b></td><td data-bbox="915 1043 1078 1075">-# &lt; Real &lt; #</td></tr> <tr> <td data-bbox="638 1081 736 1110"><b>Access</b></td><td data-bbox="915 1081 997 1110">set,get</td></tr> <tr> <td data-bbox="638 1117 817 1146"><b>Default Value</b></td><td data-bbox="915 1117 931 1146">0</td></tr> <tr> <td data-bbox="638 1153 703 1184"><b>Units</b></td><td data-bbox="915 1153 997 1184">deg./sec.</td></tr> <tr> <td data-bbox="638 1191 768 1222"><b>Interfaces</b></td><td data-bbox="915 1191 1046 1222">GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-# < Real < #	<b>Access</b>	set,get	<b>Default Value</b>	0	<b>Units</b>	deg./sec.	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-# < Real < #												
<b>Access</b>	set,get												
<b>Default Value</b>	0												
<b>Units</b>	deg./sec.												
<b>Interfaces</b>	GUI, script												
<b>EulerAngleRate2</b>	<p>The value of the second Euler angle rate. <b>EulerAngleRate2</b> is used for the following Attitude models: <b>Spinner</b>.</p> <table> <tr> <td data-bbox="638 1336 817 1368"><b>Data Type</b></td><td data-bbox="915 1336 980 1368">Real</td></tr> <tr> <td data-bbox="638 1374 850 1406"><b>Allowed Values</b></td><td data-bbox="915 1374 1078 1406">-# &lt; Real &lt; #</td></tr> <tr> <td data-bbox="638 1412 736 1442"><b>Access</b></td><td data-bbox="915 1412 997 1442">set,get</td></tr> <tr> <td data-bbox="638 1448 817 1476"><b>Default Value</b></td><td data-bbox="915 1448 931 1476">1</td></tr> <tr> <td data-bbox="638 1482 703 1514"><b>Units</b></td><td data-bbox="915 1482 997 1514">deg./sec.</td></tr> <tr> <td data-bbox="638 1520 768 1552"><b>Interfaces</b></td><td data-bbox="915 1520 1046 1552">GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-# < Real < #	<b>Access</b>	set,get	<b>Default Value</b>	1	<b>Units</b>	deg./sec.	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-# < Real < #												
<b>Access</b>	set,get												
<b>Default Value</b>	1												
<b>Units</b>	deg./sec.												
<b>Interfaces</b>	GUI, script												
<b>EulerAngleRate3</b>	<p>The value of the third Euler angle rate. <b>EulerAngleRate3</b> is used for the following Attitude models: <b>Spinner</b>.</p> <table> <tr> <td data-bbox="638 1666 817 1698"><b>Data Type</b></td><td data-bbox="915 1666 980 1698">Real</td></tr> <tr> <td data-bbox="638 1704 850 1736"><b>Allowed Values</b></td><td data-bbox="915 1704 1078 1736">-# &lt; Real &lt; #</td></tr> <tr> <td data-bbox="638 1742 736 1771"><b>Access</b></td><td data-bbox="915 1742 997 1771">set,get</td></tr> <tr> <td data-bbox="638 1778 817 1805"><b>Default Value</b></td><td data-bbox="915 1778 931 1805">1</td></tr> <tr> <td data-bbox="638 1812 703 1843"><b>Units</b></td><td data-bbox="915 1812 997 1843">deg./sec.</td></tr> <tr> <td data-bbox="638 1850 768 1881"><b>Interfaces</b></td><td data-bbox="915 1850 1046 1881">GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-# < Real < #	<b>Access</b>	set,get	<b>Default Value</b>	1	<b>Units</b>	deg./sec.	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-# < Real < #												
<b>Access</b>	set,get												
<b>Default Value</b>	1												
<b>Units</b>	deg./sec.												
<b>Interfaces</b>	GUI, script												

Field	Description
<b>EulerAngleSequence</b>	<p>The Euler angle sequence used for Euler angle input and output..</p> <p><b>Data Type</b> String  <b>Allowed Values</b> 123,231,312,132,321,213,121,232,313,131,323,212  <b>Access</b> set  <b>Default Value</b> 321  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>FrameSpiceKernelName</b>	<p>SPK Kernels for <b>Spacecraft</b> body frame. SPK Frame kernels have extension ".TF". This field cannot be set in the Mission Sequence. An empty list unloads all kernels of this type on the <b>Spacecraft</b>.</p> <p><b>Data Type</b> String array  <b>Allowed Values</b> Array of .tf files.  <b>Access</b> set  <b>Default Value</b> empty array  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>InitialPrecessionAngle</b>	<p>The initial precession angle. <b>InitialPrecessionAngle</b> is used for the following attitude models: <b>PrecessingSpinner</b>.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> deg.  <b>Interfaces</b> GUI, script</p>
<b>InitialSpinAngle</b>	<p>The initial attitude spin angle. <b>InitialSpinAngle</b> is used for the following attitude models: <b>PrecessingSpinner</b>.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> deg.  <b>Interfaces</b> GUI, script</p>

Field	Description
<b>NAIFIdReferenceFrame</b>	The Id of the spacecraft body frame used in SPICE kernels.
	<p><b>Data Type</b> Integer</p> <p><b>Allowed Values</b> -# &lt; Integer &lt; #</p> <p><b>Access</b> set</p> <p><b>Default Value</b> -9000001</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>NutationAngle</b>	The attitude nutation angle. <b>NutationAngle</b> is used for the following attitude models: <b>PrecessingSpinner</b> .
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> -# &lt; Real &lt; #</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 15</p> <p><b>Units</b> deg.</p> <p><b>Interfaces</b> GUI, script</p>
<b>NutationReferenceVectorX</b>	The x-component of the nutation reference vector, expressed in the inertial frame. <b>NutationReferenceVectorX</b> is used for the following attitude models: <b>PrecessingSpinner</b> .
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> -# &lt; Real &lt; #</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 0</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>NutationReferenceVectorY</b>	The y-component of the nutation reference vector, expressed in the inertial frame. <b>NutationReferenceVectorY</b> is used for the following attitude models: <b>PrecessingSpinner</b> .
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> -# &lt; Real &lt; #</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 0</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>

Field	Description
<b>NutationReferenceVectorZ</b>	<p>The z-component of the nutation reference vector, expressed in the inertial frame. <b>NutationReferenceVectorZ</b> is used for the following attitude models: <b>PrecessingSpinner</b>.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set  <b>Default Value</b> 1  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>MRP1</b>	<p>The value of the first modified Rodrigues parameter. <b>MRP1</b> is used for the following Attitude models: <b>Spinner</b>.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set,get  <b>Default Value</b> 0  <b>Units</b> dimensionless  <b>Interfaces</b> GUI, script</p>
<b>MRP2</b>	<p>The value of the second modified Rodrigues parameter. <b>MRP2</b> is used for the following Attitude models: <b>Spinner</b>.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set,get  <b>Default Value</b> 0  <b>Units</b> dimensionless  <b>Interfaces</b> GUI, script</p>
<b>MRP3</b>	<p>The value of the third modified Rodrigues parameter. <b>MRP3</b> is used for the following Attitude models: <b>Spinner</b>.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set,get  <b>Default Value</b> 0  <b>Units</b> dimensionless  <b>Interfaces</b> GUI, script</p>

Field	Description
<b>PrecessionRate</b>	<p>The rate of attitude precession. <b>InitialPrecessionAngle</b> is used for the following attitude models: <b>PrecessingSpinner</b>.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> deg./s  <b>Interfaces</b> GUI, script</p>
<b>Q1</b>	<p>First component of quaternion. GMAT's quaternion representation includes the three "vector" components as the first three elements in the quaternion and the "rotation" component as the last element in the quaternion. <b>Q1</b> is used for the following Attitude models: <b>Spinner</b>.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set,get  <b>Default Value</b> 0  <b>Units</b> dimensionless  <b>Interfaces</b> GUI, script</p>
<b>Q2</b>	<p>Second component of quaternion. GMAT's quaternion representation includes the three "vector" components as the first three elements in the quaternion and the "rotation" component as the last element in the quaternion. <b>Q2</b> is used for the following Attitude models: <b>Spinner</b>.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set,get  <b>Default Value</b> 0  <b>Units</b> dimensionless  <b>Interfaces</b> GUI, script</p>
<b>Q3</b>	<p>Third component of quaternion. GMAT's quaternion representation includes the three "vector" components as the first three elements in the quaternion and the "rotation" component as the last element in the quaternion. <b>Q3</b> is used for the following Attitude models: <b>Spinner</b>.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set,get  <b>Default Value</b> 0  <b>Units</b> dimensionless  <b>Interfaces</b> GUI, script</p>

Field	Description
<b>Q4</b>	<p>Fourth component of quaternion. GMAT's quaternion representation includes the three "vector" components as the first three elements in the quaternion and the "rotation" component as the last element in the quaternion. <b>Q4</b> is used for the following Attitude models: <b>Spinner</b>.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set,get  <b>Default Value</b> 1  <b>Units</b> dimensionless  <b>Interfaces</b> GUI, script</p>
<b>Quaternion</b>	<p>The quaternion vector. GMAT's quaternion representation includes the three "vector" components as the first three elements in the quaternion and the "rotation" component as the last element in the quaternion. <b>Quaternion</b> is used for the following Attitude models: <b>Spinner</b>.</p>
	<p><b>Data Type</b> Real array  <b>Allowed Values</b> Real array (length four)  <b>Access</b> set,get  <b>Default Value</b> [0 0 0 1];  <b>Units</b> dimensionless  <b>Interfaces</b> GUI, script</p>
<b>SCClockSpiceKernel-Name</b>	<p>SPK Kernels for spacecraft clock. SPK clock kernels have extension ".TSC". This field cannot be set in the Mission Sequence. An empty list unloads all kernels of this type on the <b>Spacecraft</b>. An empty list unloads all kernels of this type on the <b>Spacecraft</b>.</p>
	<p><b>Data Type</b> String array  <b>Allowed Values</b> Array of .tsc file names  <b>Access</b> set,get  <b>Default Value</b> empty array  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>SpinRate</b>	<p>The attitude spin rate. <b>SpinRate</b> is used for the following attitude models: <b>PrecessingSpinner</b>.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> -# &lt; Real &lt; #  <b>Access</b> set  <b>Default Value</b> 10  <b>Units</b> deg./s  <b>Interfaces</b> GUI, script</p>

## Remarks

### Overview of Available Attitude Models

GMAT supports many attitude models including the following: **CoordinateSystem-Fixed**, **SpiceAttitude**, **NadirPointing**, **CommandableNadirPointing**, **CCSDS-AEM**, **PrecessingSpinner**, **ThreeAxisKinematic** and **Spinner** (we recommend using the new **PrecessingSpinner** model instead of **Spinner**). Different attitude models require different information to fully configure the model. For example, when you select the **CoordinateSystemFixed** model, the attitude and body rates are entirely determined by the **CoordinateSystem** model and defining Euler angles or angular velocity components are not required and have no effect. The reference tables above, and the detailed examples for each model type below, describe which fields are used for each model.



#### Note

GMAT attitude parameterizations such as the DCM rotate from inertial to body.

### Overview of State Representations

#### Quaternion

The quaternion is a four element, non-singular attitude representation. GMAT's quaternion representation includes the three "vector" components as the first three elements in the quaternion and the "rotation" component as the last element in the quaternion. In assignment mode, you can set the quaternions element by element like this

```
aSpacecraft.Q1 = 0.5  
aSpacecraft.Q2 = 0.5  
aSpacecraft.Q3 = 0.5  
aSpacecraft.Q4 = 0.5
```

or simultaneously set the entire quaternion like this

```
aSpacecraft.Quaternion = [0.5 0.5 0.5 0.5]
```

GMAT normalizes the quaternion before use. In command mode, you must enter the entire quaternion as a single vector to avoid scaling components of the quaternion before the entire quaternion is set.

#### DirectionCosineMatrix (DCM)

The Direction Cosine Matrix is a 3x3 array that contains cosines of the angles that rotate from the x, y, and z inertial axes to the x, y, and z body axes. The direction cosine matrix must be ortho-normal and you define the DCM element by element. Here is an example that shows how to define the attitude using the DCM.

```
aSpacecraft.DCM11 = 1  
aSpacecraft.DCM12 = 0
```

```
aSpacecraft.DCM13 = 0  
aSpacecraft.DCM21 = 0  
aSpacecraft.DCM22 = 1  
aSpacecraft.DCM23 = 0  
aSpacecraft.DCM31 = 0  
aSpacecraft.DCM32 = 0  
aSpacecraft.DCM33 = 1
```

## Euler Angles

Euler angles are a sequence of three rotations about coordinate axes to transform from one system to another system. GMAT supports all 12 Euler angle sequences. Here is an example setting attitude using a “321” sequence.

```
aSpacecraft.EulerAngleSequence = '321'  
aSpacecraft.EulerAngle1 = 45  
aSpacecraft.EulerAngle2 = 45  
aSpacecraft.EulerAngle3 = 90
```



### Warning

Caution: The Euler angles have singularities that can cause issues during modeling. We recommend using other representations for this reason.

## Modified Rodrigues parameters

The modified Rodrigues parameters are a modification of the Euler Axis/Angle representation. Specifically, the MRP vector is equal to  $n\hat{h} \tan(\text{Euler Angle}/4)$  where  $n\hat{h}$  is the unitized Euler Axis.

```
aSpacecraft.MRP1 = 0.2928932188134525  
aSpacecraft.MRP2 = 0.2928932188134524  
aSpacecraft.MRP3 = 1.149673585146546e-017
```

## Euler Angles Rates

The Euler angle rates are the first time derivative of the Euler angles and can be used to define the body rates. Euler angle rates use the same sequence as the EulerAngles. The example below shows how to define the Euler angle rates for a spacecraft.

```
aSpacecraft.EulerAngleSequence = '321'  
aSpacecraft.EulerAngleRate1 = -5  
aSpacecraft.EulerAngleRate2 = 20  
aSpacecraft.EulerAngleRate3 = 30
```

## Angular Velocity

The angular velocity is the angular velocity of the spacecraft body with respect to the inertial frame, expressed in the inertial frame. The example below shows how to define the angular velocity for a spacecraft.

```
aSpacecraft.AngularVelocityX = 5;  
aSpacecraft.AngularVelocityY = 10;  
aSpacecraft.AngularVelocityZ = 5;
```

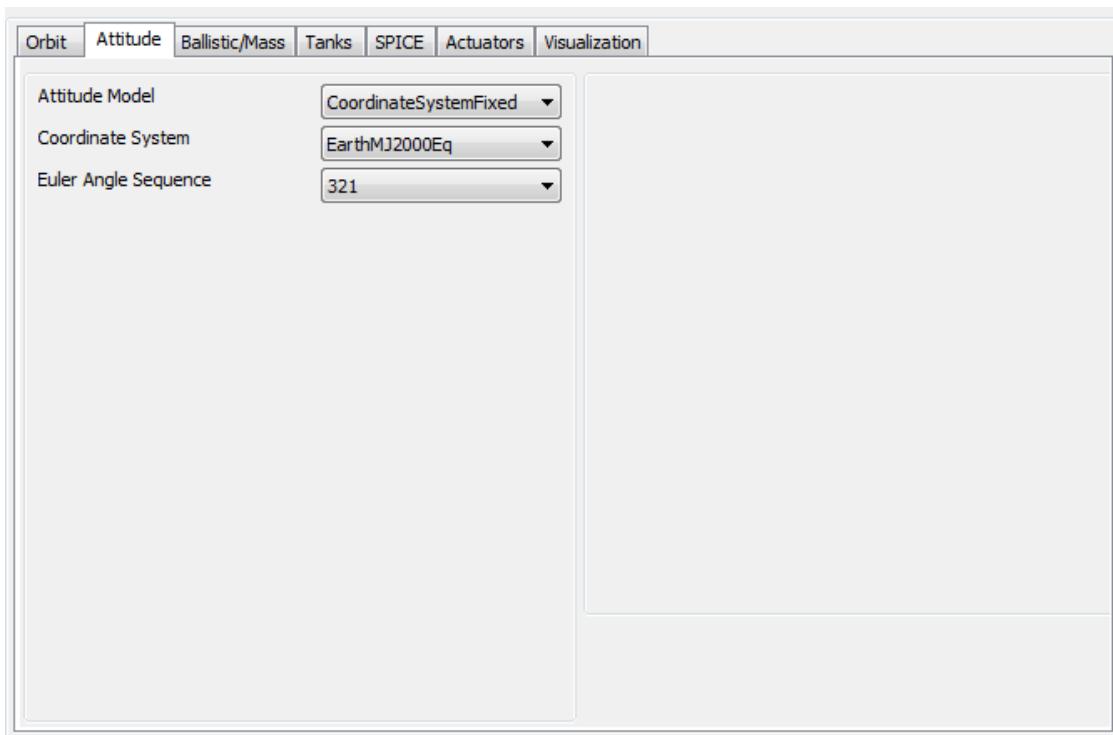
### Coordinate System Fixed Attitude Model

The **CoordinateSystemFixed** model allows you to use any existing **CoordinateSystem** to define the attitude of a **Spacecraft**. The attitude uses the axes defined on the **CoordinateSystem** to compute the body fixed to inertial matrix and attitude rate parameters such as the angular velocity. To configure this attitude mode, select **CoordinateSystemFixed**, for **Attitude**. You can define the **EulerAngleSequence** used when outputting **EulerAngles** and **EulerAngle rates**.



#### Warning

For the **CoordinateSystemFixed** attitude model, the attitude is completely described by the selected coordinate system. If you are working in the script, setting attitude parameters (Euler Angles, Quaternion etc.) or setting attitude rate parameters such as (Euler Angle Rates etc.) has no effect.



The script example below shows how to configure a **Spacecraft** to use a spacecraft VNB attitude system.

```
Create Spacecraft aSat  
aSat.Attitude          = CoordinateSystemFixed  
aSat.ModelRotationZ    = -90
```

```
aSat.AttitudeCoordinateSystem = 'attCoordSys'

Create ForceModel Propagator1_ForceModel
Create Propagator Propagator1
Propagator1.FM          = Propagator1_ForceModel
Propagator1.MaxStep    = 10

Create CoordinateSystem attCoordSys
attCoordSys.Origin     = Earth
attCoordSys.Axes       = ObjectReferenced
attCoordSys.XAxis      = V
attCoordSys.YAxis      = N
attCoordSys.Primary    = Earth
attCoordSys.Secondary = aSat

Create OrbitView OrbitView1;
OrbitView1.Add           = {aSat, Earth}
OrbitView1.ViewPointReference = Earth
OrbitView1.ViewPointVector   = [ 30000 0 0 ]

BeginMissionSequence

Propagate Propagator1(aSat) {aSat.ElapsedSecs = 12000.0}
```

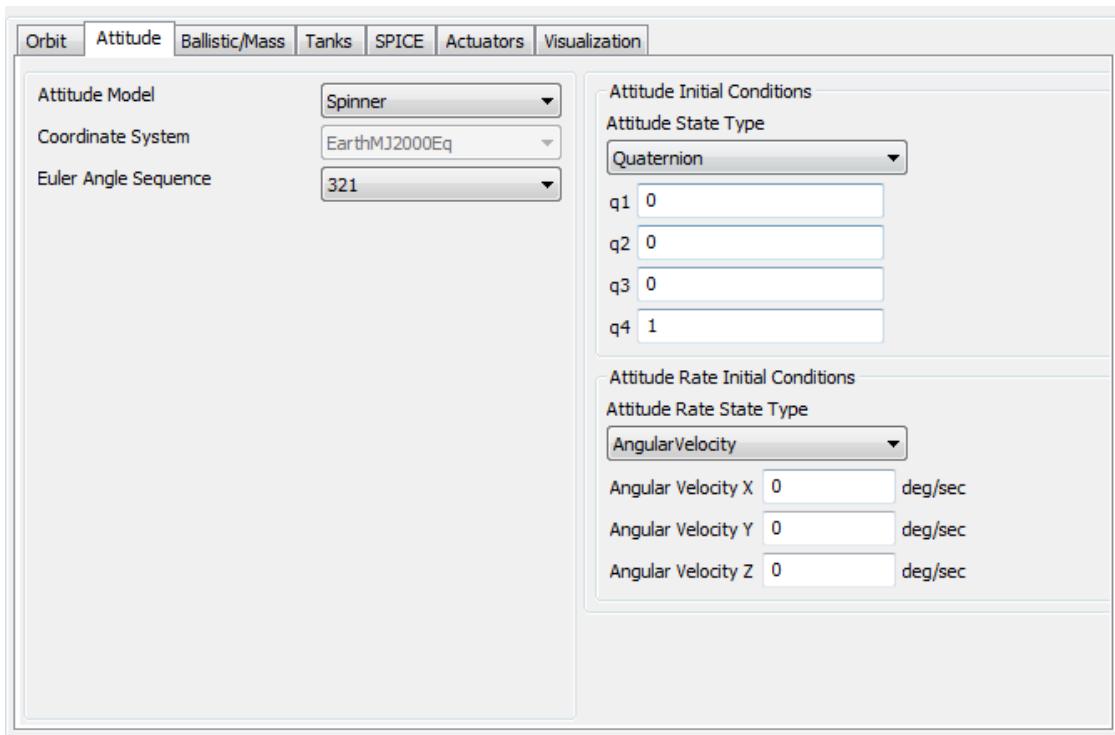
### Spinner Attitude Model

The **Spinner** attitude model propagates the attitude assuming the spin axis direction is fixed in inertial space. We recommend using the newer PrecessingSpinner model instead of Spinner, and this model is maintained primarily for backwards compatibility. You define the attitude by providing initial body orientation and rates. GMAT propagates the attitude by computing the angular velocity and then rotates the **Spacecraft** about that angular velocity vector at a constant rate defined by the magnitude of the angular velocity. You can define the initial attitude using quaternions, Euler angles, the DCM, or the modified Rodrigues parameters. You can define the attitude rates using Euler angles rates or angular velocity. When working with Euler angles, the rotation sequence is determined by the **EulerAngleSequence** field.



#### Warning

Caution: If you are working in the script, setting the **CoordinateSystem** for the Spinner attitude model has no effect.



The example below configures a spacecraft to spin about the inertial z axis.

```
Create Spacecraft aSat;
aSat.Attitude      = Spinner
aSat.ModelRotationZ = -90
aSat.AngularVelocityZ = 5

Create ForceModel Propagator1_ForceModel
Create Propagator Propagator1
GMAT Propagator1.FM      = Propagator1_ForceModel
GMAT Propagator1.MaxStep = 10

Create CoordinateSystem attCoordSys
attCoordSys.Origin      = Earth
attCoordSys.Axes        = ObjectReferenced
attCoordSys.XAxis       = V
attCoordSys.YAxis       = N
attCoordSys.Primary     = Earth
attCoordSys.Secondary   = aSat

Create OrbitView OrbitView1;
OrbitView1.Add           = {aSat, Earth}
OrbitView1.ViewPointReference = Earth
OrbitView1.ViewPointVector = [ 30000 0 0 ]

BeginMissionSequence
```

```
Propagate Propagator1(aSat) {aSat.ElapsedSecs = 12000.0}
```

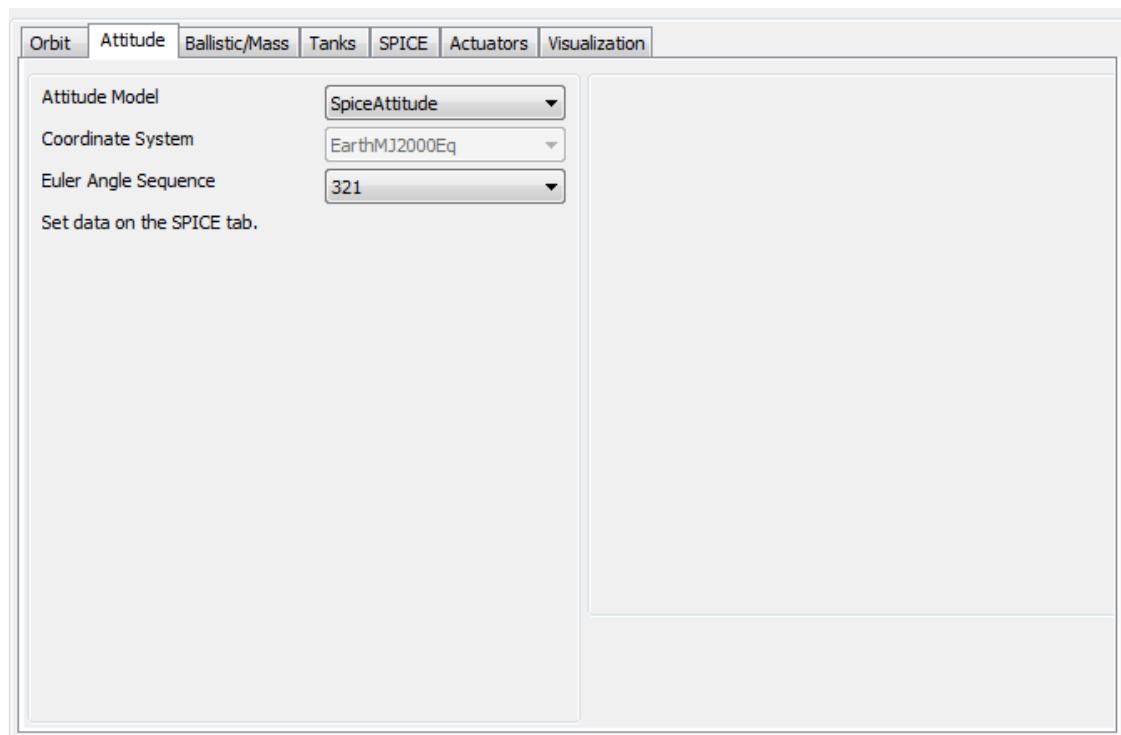
### SPK Attitude Model

The **SpiceAttitude** model propagates the attitude using attitude SPICE kernels. To configure a **Spacecraft** to use SPICE kernels select **SpiceAttitude** for the **Attitude** field as shown below.

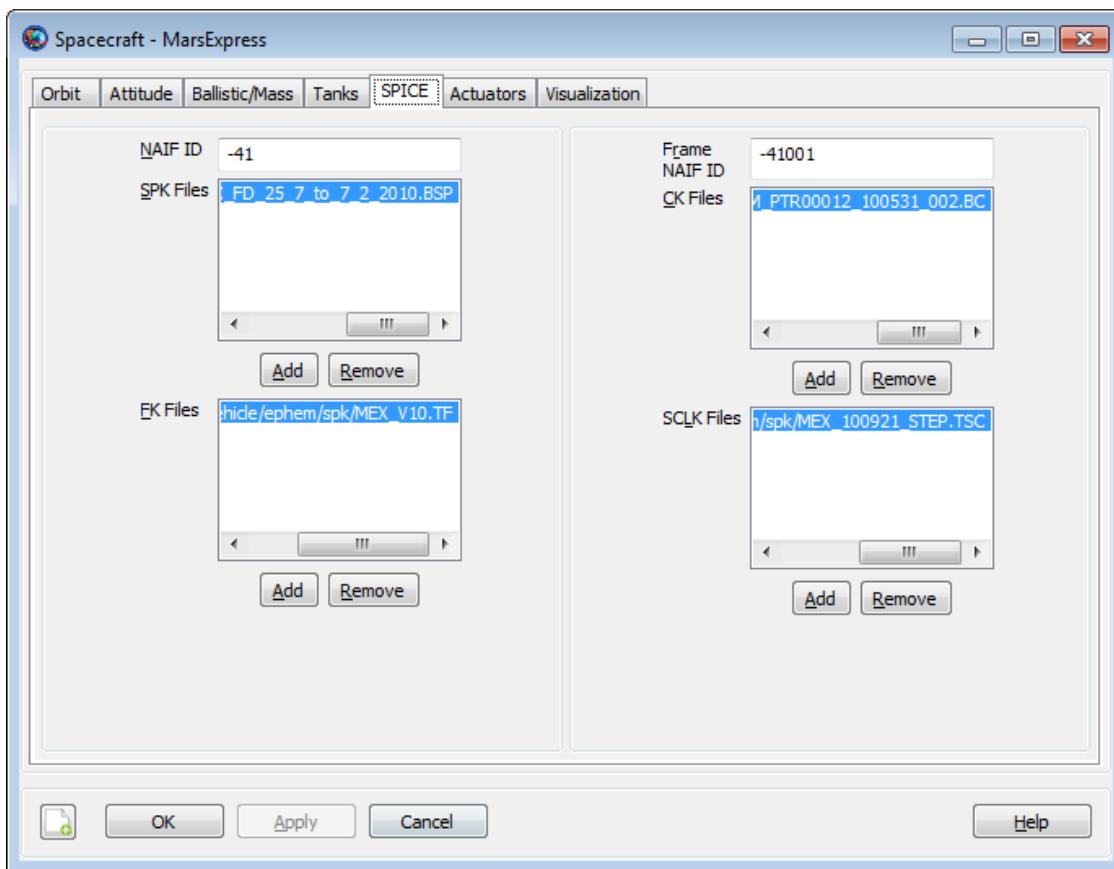


### Warning

Caution: For the **SpiceAttitude** model, the attitude is completely described by the spice kernels. When working in the script, setting the **CoordinateSystem**, attitude parameters (**EulerAngles**, **Quaternion** etc.) or attitude rate parameters such as (**EulerAngleRates** etc.) has no effect.



You must provide three SPICE kernel types for the **SpiceAttitude** model: the attitude kernel (.bc file), the frame kernel (.tf file) and the spacecraft clock kernel (.tsc file). These files are defined on the **Spacecraft** SPICE tab as shown below. In addition to the kernels, you must also provide the **Spacecraft NAIId** and the **NAIIdReferenceFrame**. Below is an illustration of the SPICE tab configured for MarsExpress script found later in this section.



The example below configures a **Spacecraft** to use SPK kernels to propagator the attitude for Mars Express. The SPK kernels are distributed with GMAT.

```
Create Spacecraft MarsExpress
MarsExpress.NAIFId = -41
MarsExpress.NAIFIdReferenceFrame = -41001
MarsExpress.Attitude = 'SpiceAttitude'
MarsExpress.OrbitSpiceKernelName = ...
{'../data/vehicle/ephem/spk/MarsExpress_Short.BSP'}
MarsExpress.AttitudeSpiceKernelName = ...
{'../data/vehicle/ephem/spk/MarsExpress_ATNM_PTR00012_100531_002.BC'}
MarsExpress.SCClockSpiceKernelName = ...
{'../data/vehicle/ephem/spk/MarsExpress_MEX_100921_STEP.TSC'}
MarsExpress.FrameSpiceKernelName = ...
{'../data/vehicle/ephem/spk/MarsExpress_MEX_V10.TF'}

Create Propagator spkProp
spkProp.Type = SPK
spkProp.StepSize = 60
spkProp.CentralBody = Mars
spkProp.EpochFormat = 'UTCGregorian'
spkProp.StartEpoch = '01 Jun 2010 16:59:09.815'
```

```
Create CoordinateSystem MarsMJ2000Eq
MarsMJ2000Eq.Origin = Mars
MarsMJ2000Eq.Axes = MJ2000Eq

Create OrbitView Enhanced3DView1
Enhanced3DView1.Add = {MarsExpress, Mars}
Enhanced3DView1.CoordinateSystem = MarsMJ2000Eq
Enhanced3DView1.ViewPointReference = Mars
Enhanced3DView1.ViewPointVector = [ 10000 10000 10000 ]
Enhanced3DView1.ViewDirection = Mars

BeginMissionSequence

Propagate spkProp(MarsExpress) {MarsExpress.ElapsedDays = 0.2}
```

### Nadir Pointing Model

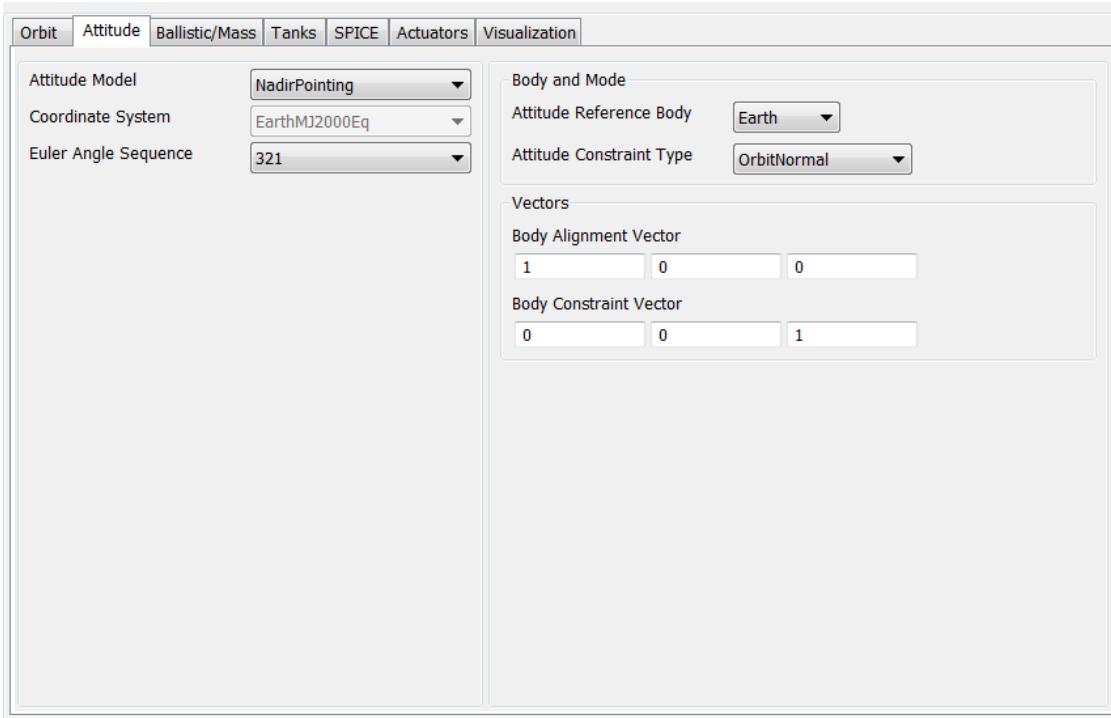
The **NadirPointing** attitude mode configures the attitude of a spacecraft to point a specified vector in the spacecraft body system in the nadir direction. The ambiguity in angle about the nadir vector is resolved by minimizing the angle between two constraint vectors. Note: the nadir pointing mode points the attitude in the negative radial direction (not opposite the planetodetic normal).

To configure which axis points to nadir, set the **AttitudeReferenceBody** field to the desired celestial body and define the body components of the alignment vector using the **BodyAlignmentVector** fields. To configure the constraint, set the **AttitudeConstraintType** field to the desired constraint type, and define the body components of the constraint using the **BodyConstraintVector** fields. GMAT supports two constraint types, **OrbitNormal** and **Velocity**, and in both cases the vectors are constructed using the inertial spacecraft state with respect to the **AttitudeReferenceBody**.



#### Warning

Attitude rates are not computed for the **NadirPointing** model. If you perform a computation that requires attitude rate information when using the **NadirPointing** mode, GMAT will throw an error message and execution will stop. Similarly, if the definitions of the **BodyAlignmentVector** and **BodyConstraintVector** fields result in an undefined attitude, an error message is thrown and execution will stop.



The script example below shows how to configure a **Spacecraft** to use an Earth **Nadir-Pointing** attitude system where the body y-axis points nadir and the angle between the body x-axis and the orbit normal vector is a minimum.

```
Create Spacecraft aSat;
GMAT aSat.Attitude          = NadirPointing;
GMAT aSat.AttitudeReferenceBody = Earth
GMAT aSat.AttitudeConstraintType = OrbitNormal
GMAT aSat.BodyAlignmentVectorX = 0
GMAT aSat.BodyAlignmentVectorY = 1
GMAT aSat.BodyAlignmentVectorZ = 0
GMAT aSat.BodyConstraintVectorX = 1
GMAT aSat.BodyConstraintVectorY = 0
GMAT aSat.BodyConstraintVectorZ = 0

Create ForceModel Propagator1_ForceModel
Create Propagator Propagator1
Propagator1.FM      = Propagator1_ForceModel
Propagator1.MaxStep = 10

Create OrbitView OrbitView1;
OrbitView1.Add          = {aSat, Earth}
OrbitView1.ViewPointReference = Earth
OrbitView1.ViewPointVector = [ 30000 0 0 ]

BeginMissionSequence
```

```
Propagate Propagator1(aSat) {aSat.ElapsedSecs = 12000.0}
```

### Commandable Nadir Pointing Model

The Commandable Nadir Pointing attitude mode is identical to the Nadir Pointing mode, with the added ability to set the attitude using quaternions from the mission sequence. As with the Nadir Pointing model, GMAT will not compute the angular velocity.

Implementing Commandable Nadir Pointing was motivated by a mission which needed to compute attitude maneuvers with respect to a nadir-pointing frame (such as a yaw flip), and to model angular momentum changes over the duration of the maneuver using GMAT's mass property and torque models. GMAT needed to use this attitude to compute the torques that needed to be integrated.

The solution is to propagate maneuvers in a script, set the attitude in GMAT, do any computations needed (torque and momentum computations in this case) using that attitude, then propagate the spacecraft for the next step, which resets the attitude to the nadir pointing mode.

The steps are listed in more detail below. The quaternions used are

- qRI - The rotation from inertial to the nadir pointing reference frame
- qBR - The rotation from the reference frame to the body frame
- qBI - The rotation from the inertial frame to the body frame

The quaternion functions referenced below are found in the user functions directory, and aSat refers to the Spacecraft object at hand.

1. Set qRI = aSat.Quaternion at the start. This must be done first, as the nadir-pointing frame is computed directly from position and velocity. Otherwise the default attitude is (erroneously) used.
2. Compute qBR in the script if in a slew using the PropagateQuaternion function. Skip this step if the angular velocity is zero with respect to nadir-pointing reference frame; qBR is constant in that case.
3. Compute qBI = qBR \* qRI using the ComposeQuaternions function
4. Set aSat.Quaternion to qBI
5. Make any needed GMAT computations
6. Call Propagate command to advance spacecraft state
7. Repeat as needed.

The script below illustrates the overwriting of the GMAT computed quaternion with a quaternion set via a script:

```
Create Spacecraft aSat;
GMAT aSat.DateFormat = UTCGregorian;
GMAT aSat.Epoch = '03 Jan 2021 09:00:01.000';
GMAT aSat.CoordinateSystem = EarthFixed;
GMAT aSat.DisplayStateType = Cartesian;
GMAT aSat.X = 10767.10941722319;
GMAT aSat.Y = -40769.63147707024;
GMAT aSat.Z = -71.30282941332682;
GMAT aSat.VX = -0.0003907864381020865;
```

```
GMAT aSat.VY = -0.0001003662189780208;
GMAT aSat.VZ = 0.003005535138648318;
GMAT aSat.Id = 'aSat';

GMAT aSat.Attitude = CommandableNadirPointing;
GMAT aSat.AttitudeDisplayStateType = 'Quaternion';
GMAT aSat.AttitudeConstraintType = 'OrbitNormal';
GMAT aSat.BodyAlignmentVectorX = 1;
GMAT aSat.BodyAlignmentVectorY = 0;
GMAT aSat.BodyAlignmentVectorZ = 0;
GMAT aSat.BodyConstraintVectorX = 0;
GMAT aSat.BodyConstraintVectorY = 0;
GMAT aSat.BodyConstraintVectorZ = 1;

Create Propagator aProp

Create ReportFile AttitudeReport;
GMAT AttitudeReport.Filename = 'SC_CNP.report';
GMAT AttitudeReport.WriteHeaders = false;

Create Array q[4];

----- Mission Sequence -----

BeginMissionSequence;
% report initial value of quaternion
Report AttitudeReport aSat.Quaternion
Report AttitudeReport aSat.DirectionCosineMatrix

% need to do first get to properly initialize
q = aSat.Quaternion
Report AttitudeReport aSat.Quaternion
Report AttitudeReport aSat.DirectionCosineMatrix

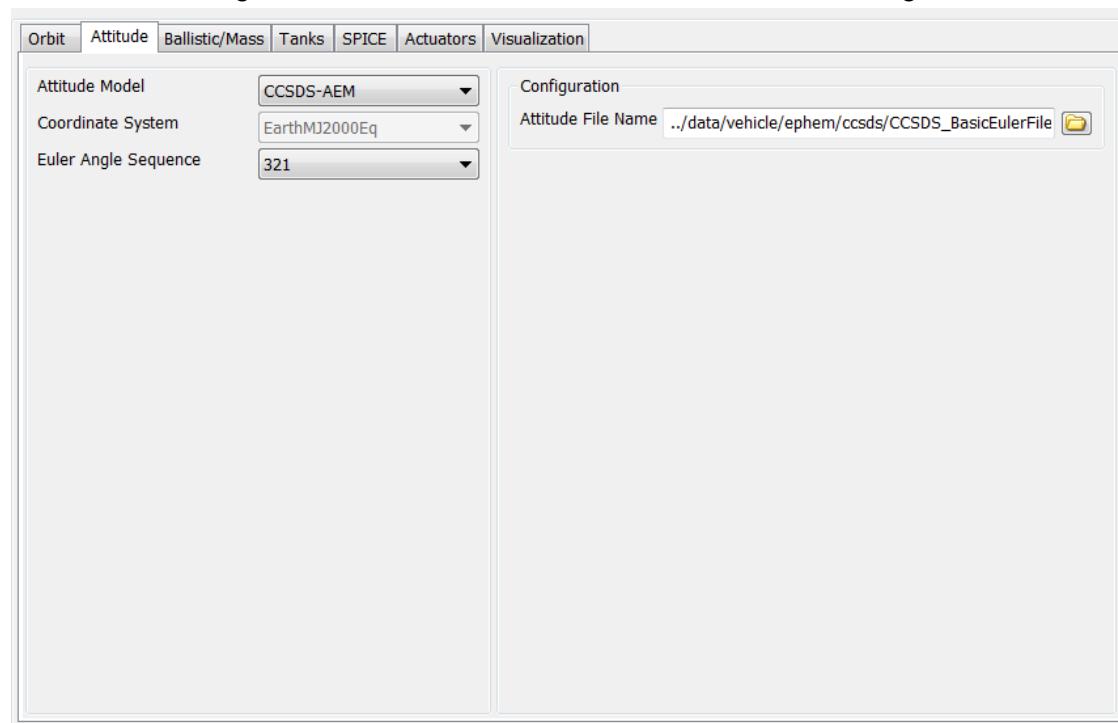
% now set should work OK
aSat.Quaternion = [1 2 3 4]
Report AttitudeReport aSat.Quaternion
Report AttitudeReport aSat.DirectionCosineMatrix

% now propagate; [1 2 3 4] values should be replaced
% with nadir-pointing attitude
Propagate aProp(aSat) {aSat.ElapsedSecs = 30.0}
Report AttitudeReport aSat.Quaternion
Report AttitudeReport aSat.DirectionCosineMatrix
```

### CCSDS Attitude Ephemeris Message

The CCSDS Attitude Ephemeris Message (AEM) is an ASCII standard for attitude ephemerides documented in "ATTITUDE DATA MESSAGES" RECOMMENDED

STANDARD CCSDS 504.0-B-1. GMAT supports some, but not all, of the attitude messages defined in the standard. According to the CCSDS AEM specification, “The set of attitude data messages described in this Recommended Standard is the baseline concept for attitude representation in data interchange applications that are cross-supported between Agencies of the CCSDS.” Additionally, the forward of the standard states “Derived Agency standards may implement only a subset of the optional features allowed by the Recommended Standard and may incorporate features not addressed by this Recommended Standard. See the details below for supported keyword types and details for creating AEM files that GMAT can use for attitude modeling.



An AEM file must have the format illustrated below described in Table 4-1 of the standard. The header section contains high level information on the version, originator, and date. The body of the file is composed of paired blocks of Metadata and data. The Metadata sections contain information on the data such as the first and last epoch of the block, the time system employed, the reference frames, the attitude type (quaternion, Euler Angle, etc.) and many other items documented in later sections. The data sections contain lines of epoch and attitude data.

Item			Obligatory?
Header			Yes
Body	Segment 1	Metadata 1	Yes
		Data 1	
	Segment 2	Metadata 2	No
		Data 2	
	.	.	No
	.	.	
	Segment n	Metadata n	No
		Data n	

An example CCSDS AEM file is shown below

```

CCSDS_AEM_VERS = 1.0
CREATION_DATE = 2002-11-04T17:22:31
ORIGINATOR = NASA/JPL

META_START
COMMENT This file was produced by M.R. Somebody, MSOO NAV/JPL, 2002 OCT 04.
COMMENT It is to be used for attitude reconstruction only.
COMMENT The relative accuracy of these attitudes is 0.1 degrees per axis.
OBJECT_NAME = MARS GLOBAL SURVEYOR
OBJECT_ID = 1996-062A
CENTER_NAME = mars barycenter
REF_FRAME_A = EME2000
REF_FRAME_B = SC_BODY_1
ATTITUDE_DIR = A2B
TIME_SYSTEM = UTC
START_TIME = 1996-11-28T21:29:07.2555
USEABLE_START_TIME = 1996-11-28T22:08:02.5555
USEABLE_STOP_TIME = 1996-11-30T01:18:02.5555
STOP_TIME = 1996-11-30T01:28:02.5555
ATTITUDE_TYPE = QUATERNION
QUATERNION_TYPE = LAST
INTERPOLATION_METHOD = hermite
INTERPOLATION_DEGREE = 7
META_STOP

DATA_START
1996-11-28T21:29:07.2555 0.56748 0.03146 0.45689 0.68427
1996-11-28T22:08:03.5555 0.42319 -0.45697 0.23784 0.74533
1996-11-28T22:08:04.5555 -0.84532 0.26974 -0.06532 0.45652
< intervening data records omitted here >
1996-11-30T01:28:02.5555 0.74563 -0.45375 0.36875 0.31964
DATA_STOP

META_START

```

```

COMMENT This block begins after trajectory correction maneuver TCM-3.
OBJECT_NAME = mars global surveyor
OBJECT_ID = 1996-062A
CENTER_NAME = MARS BARYCENTER
REF_FRAME_A = EME2000
REF_FRAME_B = SC_BODY_1
ATTITUDE_DIR = A2B
TIME_SYSTEM = UTC
START_TIME = 1996-12-18T12:05:00.5555
USEABLE_START_TIME = 1996-12-18T12:10:00.5555
USEABLE_STOP_TIME = 1996-12-28T21:23:00.5555
STOP_TIME = 1996-12-28T21:28:00.5555
ATTITUDE_TYPE = QUATERNION
QUATERNION_TYPE = LAST
META_STOP

DATA_START
1996-12-18T12:05:00.5555 -0.64585 0.018542 -0.23854 0.72501
1996-12-18T12:10:05.5555 0.87451 -0.43475 0.13458 -0.16767
1996-12-18T12:10:10.5555 0.03125 -0.65874 0.23458 -0.71418
< intervening records omitted here >
1996-12-28T21:28:00.5555 -0.25485 0.58745 -0.36845 0.67394
DATA_STOP

```

CCSDS files require many keywords and fields, some are required for all file types, others are Situationally Required (SR) depending upon the type of file (i.e. If ATTITUDE\_TYPE = QUATERNION, then QUATERNION\_TYPE must be included). The tables below describe GMAT's implementation starting with header keywords

<b>Keyword</b>	<b>Re- quired</b>	<b>Description and Supported Values</b>
<b>CCSDS_AEM_VERS</b>	Y	Format version in the form of 'x.y', where 'y' is incremented for corrections and minor changes, and 'x' is incremented for major changes. This particular line must be the first non-blank line in the file. In GMAT the version must be set to 1.0. If the version is not set to a supported version, then GMAT throws an exception.
		Example:  CCSDS_AEM_VERS =1.0
<b>COMMENT</b>	N	Comments (allowed after AEM version number and META_START and before a data block of ephemeris lines). Each comment line shall begin with this keyword. GMAT does not use this field.

<b>Keyword</b>	<b>Re- quired</b>	<b>Description and Supported Values</b>
<b>CREATION_DATE</b>	Y	File creation date/time in one of the following formats: YYYY-MM-DDThh:mm:ss[.d?d] or YYYY-DDDThh:mm:ss[.d?d] where 'YYYY' is the year, 'MM' is the two-digit month, 'DD' is the two-digit day, 'DDD' is the three-digit day of year, 'T' is constant, 'hh:mm:ss[.d?d]' is the UTC time in hours, minutes, seconds, and optional fractional seconds. As many 'd' characters to the right of the period as required may be used to obtain the required precision. All fields require leading zeros. GMAT does not use this field.
<b>ORIGINATOR</b>	Y	Creating agency (value should be specified in an ICD). GMAT does not use this field.

MetaData Keywords are described in the table below.

<b>Keyword</b>	<b>Re- quired</b>	<b>Description and Supported Values</b>
<b>META_START</b>	Y	The AEM message contains both metadata and attitude ephemeris data; this keyword is used to delineate the start of a metadata block within the message (metadata are provided in a block, surrounded by 'META_START' and 'META_STOP' markers to facilitate file parsing). This keyword must appear on a line by itself.
<b>COMMENT</b>	N	Comments allowed only at the beginning of the Metadata section. Each comment line shall begin with this keyword. GMAT does not use this.  Example:  COMMENT This is a comment

Keyword	Re- quired	Description and Supported Values	
<b>OBJECT_NAME</b>	Y	Spacecraft name of the object corresponding to the attitude data to be given. There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the SPACEWARN Bulletin, which include the Object name and international designator of the participant.	
Example:		OBJECT_NAME = EUTELSAT	
Note: GMAT does not use this field. In GMAT, you associate a file with a particular spacecraft by configuring a particular spacecraft to use the file as shown below.		<pre>Create Spacecraft aSat aSat.Attitude = CCSDS-AEM aSat.AttitudeFileName = myFile.aem</pre>	
<b>OBJECT_ID</b>	Y	Spacecraft identifier of the object corresponding to the attitude data to be given. See the AEM specification for recommendations for spacecraft IDs. GMAT does not use this field.	
<b>CENTER_NAME</b>	N	Origin of reference frame, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this the value for 'CENTER_NAME' is subject to the same rules as for 'OBJECT_NAME'). There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the NASA/JPL Solar System Dynamics Group . GMAT does not use this field.	
<b>REF_FRAME_A</b>	Y	The name of the reference frame specifying one frame of the transformation, whose direction is specified using the keyword ATTITUDE_DIR. The full set of values is enumerated in annex A of the AEM standard, with an excerpt provided in the 'Values / Examples' column.	
In GMAT, REF_FRAME_A can be any of the following and must be different than REF_FRAME_B: EME2000, SC_BODY_1		Example:	
REF_FRAME_A = EME2000		REF_FRAME_A = SC_Body_1	

Keyword	Re- quired	Description and Supported Values
<b>REF_FRAME_B</b>	Y	<p>The name of the reference frame specifying one frame of the transformation, whose direction is specified using the keyword ATTITUDE_DIR. The full set of values is enumerated in annex A of the AEM standard, with an excerpt provided in the 'Values / Examples' column.</p> <p>In GMAT, REF_FRAME_B can be any of the following and must be different than REF_FRAME_A: EME2000, SC_BODY_1</p> <p>Example:</p> <pre>REF_FRAME_A = EME2000 REF_FRAME_A = SC_Body_1</pre>
<b>ATTITUDE_DIR</b>	Y	<p>Rotation direction of the attitude specifying from which frame the transformation is to: A2B specifies a transformation from the REF_FRAME_A to the REF_FRAME_B; B2A specifies a transformation from the REF_FRAME_B to the REF_FRAME_A.</p> <p>Examples:</p> <pre>ATTITUDE_DIR = A2B ATTITUDE_DIR = B2A</pre>
<b>TIME_SYSTEM</b>	Y	<p>Time system used for both attitude ephemeris data and metadata. GMAT supports the following options: UTC</p> <p>Example:</p> <pre>TIME_SYSTEM = UTC</pre>
<b>START_TIME</b>	Y	<p>Start of TOTAL time span covered by attitude ephemeris data immediately following this metadata block. The START_TIME time tag at a new block of attitude ephemeris data must be equal to or greater than the STOP_TIME time tag of the previous block. See the CREATION_DATE specification for detailed information on time formats. Note: precision in the seconds place is only preserved to a few microseconds.</p> <p>Example:</p> <pre>START_TIME = 1996-12-18T14:28:15.117</pre>

Keyword	Re- quired	Description and Supported Values
<b>USEABLE_ START_TIME, USE- ABLE_STOP_TIME</b>	N	Optional start and end of USEABLE time span covered by attitude ephemeris data immediately following this metadata block. To allow for proper interpolation near the ends of the attitude ephemeris data block, it may be necessary, depending upon the interpolation method to be used, to utilize these keywords with values within the time span covered by the attitude ephemeris data records as denoted by the START/STOP_TIME time tags. If this is provided, GMAT only uses data in the USEABLE timespan for interpolation. If it is not provided, GMAT uses the data in the START_TIME/STOP_TIME segment for interpolation. See the CREATION_DATE specification for detailed information on time formats.
		Example:
		USEABLE_START_TIME = 1996-12-18T14:28:15.117
		USEABLE_STOP_TIME = 1996-12-18T14:28:15.117
<b>STOP_TIME</b>	Y	End of TOTAL time span covered by the attitude ephemeris data immediately following this metadata block. The STOP_TIME time tag for the block of attitude ephemeris data must be equal to or less than the START_TIME time tag of the next block. See the CREATION_DATE specification for detailed information on time formats. Note: precision in the seconds place is only preserved to a few microseconds.
		Example:
		STOP_TIME = 1996-12-18T14:28:15.117
<b>ATTITUDE_TYPE</b>	Y	The format of the data lines in the message. GMAT supports the following types
		ATTITUDE_TYPE = QUATERNION
		ATTITUDE_TYPE = EULER_ANGLE

Keyword	Re- quired	Description and Supported Values
<b>QUATERNION_TYPE</b>	S	The placement of the scalar portion of the quaternion (QC) in the attitude data. This keyword is only used if ATTITUDE_TYPE denotes quaternion and in that case the field is required.
		Example:  QUATERNION_TYPE = FIRST  QUATERNION_TYPE = LAST
<b>EULER_ROT_SEQ</b>	SR	The rotation sequence of the Euler angles that rotate from REF_FRAME_A to REF_FRAME_B, or vice versa, as specified using the ATTITUDE_DIR keyword. This keyword is only used if ATTITUDE_TYPE denotes EulerAngles and in that case the field is required.
		Example:  EULER_ROT_SEQ = 321
<b>RATE_FRAME</b>	N	GMAT does not use this field.
<b>INTERPOLATION_METHOD</b>	N	Recommended interpolation method for attitude ephemeris data in the block immediately following this metadata block. Note. GMAT uses spherical linear interpolation when ATTITUDE_TYPE = QUATERNION. GMAT uses lagrange interpolation for ATTITUDE_TYPE = EULER_ANGLE.
		Examples:  INTERPOLATION_METHOD = LINEAR  INTERPOLATION_METHOD = LAGRANGE
<b>INTERPOLATION_DEGREE</b>	SR	Recommended interpolation degree for attitude ephemeris data in the block immediately following this metadata block. It must be an integer value. This keyword must be used if the 'INTERPOLATION_METHOD' keyword is used. The field is only used for Lagrange Interpolation and in that case the value must be between 0 and 9. In the case order is zero for Lagrange interpolation, no interpolation is performed, and the attitude returned is the value immediately before the requested epoch.
		Example:  INTERPOLATION_DEGREE = 7

Keyword	Re- quired	Description and Supported Values
<b>META_STOP</b>	Y	The end of a metadata block within the message. The AEM message contains both metadata and attitude ephemeris data; this keyword is used to delineate the end of a metadata block within the message (metadata are provided in a block, surrounded by 'META_START' and 'META_STOP' markers to facilitate file parsing). This keyword must appear on a line by itself.

Data Keywords are described in the table below.

Keyword	Re- quired	Description and Supported Values
<b>DATA_START</b>	Y	The start of an attitude data block within the message. The AEM message contains both metadata and attitude ephemeris data; this keyword is used to delineate the start of a data block within the message (data are provided in a block, surrounded by 'DATA_START' and 'DATA_STOP' markers to facilitate file parsing). This keyword must appear on a line by itself.
<b>DATA_STOP</b>	Y	The end of an attitude data block within the message. The AEM message contains both metadata and attitude ephemeris data; this keyword is used to delineate the end of a data block within the message (data are provided in a block, surrounded by 'DATA_START' and 'DATA_STOP' markers to facilitate file parsing). This keyword must appear on a line by itself.
<b>QUATERNION</b>	SR	Required when ATTITUDE_TYPE = QUATERNION. The general format of a quaternion data line is: Epoch, QC, Q1, Q2, Q3 or Epoch, Q1, Q2, Q3, QC  Example:  2000-01-01T11:59:28.000      0.195286      -0.079460 0.3188764 0.92404936
<b>EULER ANGLE</b>	SR	Required when ATTITUDE_TYPE = EULER_ANGLE. The general format of an Euler angle data line is: Epoch, X_Angle, Y_Angle, Z_Angle.  Example:  2000-001T11:59:28.000 35.45409 -15.74726 18.803877

Propagate a spacecraft's attitude using a CCSDS AEM file

Create Spacecraft aSat ;

```
GMAT aSat.Attitude = CCSDS-AEM;
GMAT aSat.AttitudeFileName = ...
    '../data/vehicle/ephem/ccsds/CCSDS_BasicEulerFile.aem'

Create Propagator aProp;

Create OrbitView a3DView
a3DView.Add = {aSat,Earth}

BeginMissionSequence;

Propagate aProp(aSat) {aSat.ElapsedSecs = 3600};
```

### Precessing Spinner Model

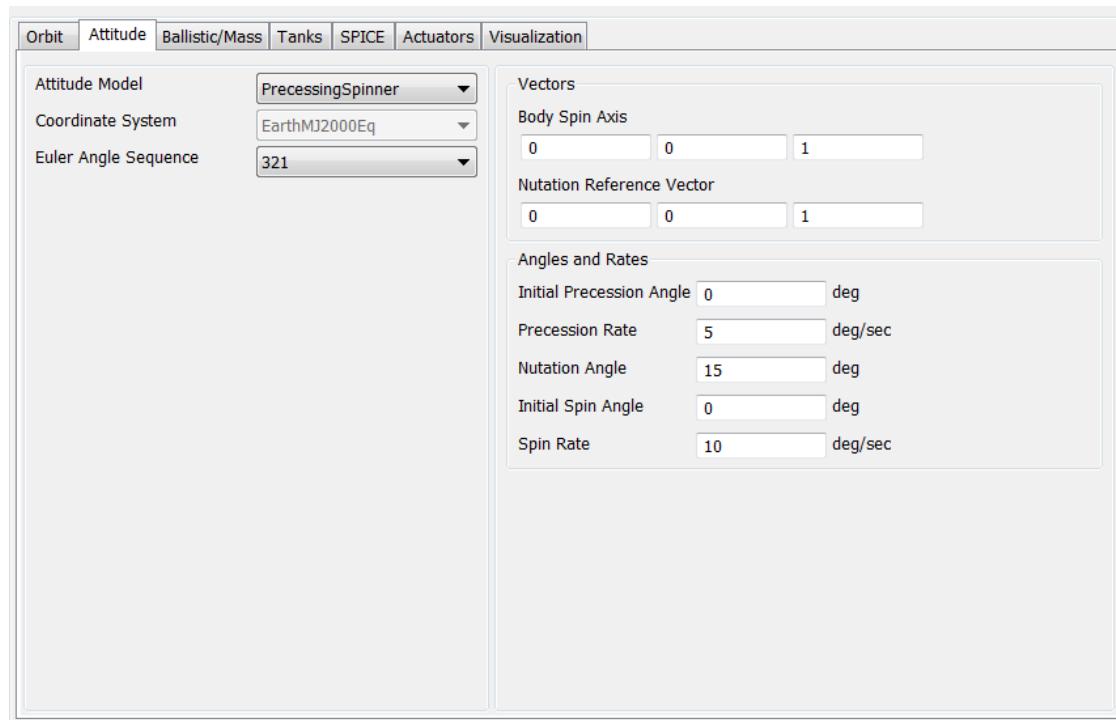
The **PrecessingSpinner** attitude mode configures the attitude of a spacecraft to have steady-state precession motion with respect to a specified vector defined in the inertial frame. The spin axis must be provided in the spacecraft body frame.

To configure the spin axis of the spacecraft body, set the **BodySpinAxis**, which is expressed in the body frame, and define the reference vector of the steady-state precession motion using the **NutationReferenceVector**, which is expressed in the inertial frame. To configure the initial attitude of the spacecraft, set **InitialPrecessionAngle** to define the initial angle of the precession, set **InitialSpinAngle** to define the initial angle of the spin, and set **NutationAngle** to define the nutation angle which is constant. To configure the rate of precession and spin rate, set **PrecessingRate** and **SpinRate** which are constant.



#### Note

The **PrecessingSpinner** model uses the cross product of the **BodySpinAxis** axis and the inertial x-axis as a reference for the initial attitude. To avoid an undefined attitude when the spin axis is aligned, or nearly aligned, with the inertial x-axis, a different reference vector is used in that case. In the event that the cross product of **BodySpinAxis** and the inertial x-axis is less than 1e-5, the inertial y-axis is used as the reference vector. For further details see the engineering/mathematical specifications.



The script example below shows how to configure a Spacecraft to have **PrecessingSpinner** attitude mode where the body z-axis spins with respect to the inertial z-axis. **PrecessionRate** is set to 1 deg./sec., **InitialPrecessionAngle** is set to 0 deg./sec., **SpinRate** is set to 2 deg./sec., **InitialSpinAngle** is set to 0 deg./sec., and **NutationAngle** is set to 30 deg.

```

Create Spacecraft aSat;
GMAT aSat.Attitude = PrecessingSpinner;
GMAT aSat.NutationReferenceVectorX = 0;
GMAT aSat.NutationReferenceVectorY = 0;
GMAT aSat.NutationReferenceVectorZ = 1;
GMAT aSat.BodySpinAxisX = 0;
GMAT aSat.BodySpinAxisY = 0;
GMAT aSat.BodySpinAxisZ = 1;
GMAT aSat.InitialPrecessionAngle = 0;
GMAT aSat.PrecessionRate = 1;
GMAT aSat.NutationAngle = 30;
GMAT aSat.InitialSpinAngle = 0;
GMAT aSat.SpinRate = 2;

Create OrbitView OrbitView1;
OrbitView1.Add = {aSat, Earth}
OrbitView1.ViewPointReference = Earth
OrbitView1.ViewPointVector = [ 30000 0 0 ]

Create Propagator aProp
aProp.MaxStep = 10

```

```
BeginMissionSequence  
Propagate aProp(aSat) {aSat.ElapsedSecs = 12000.0}
```

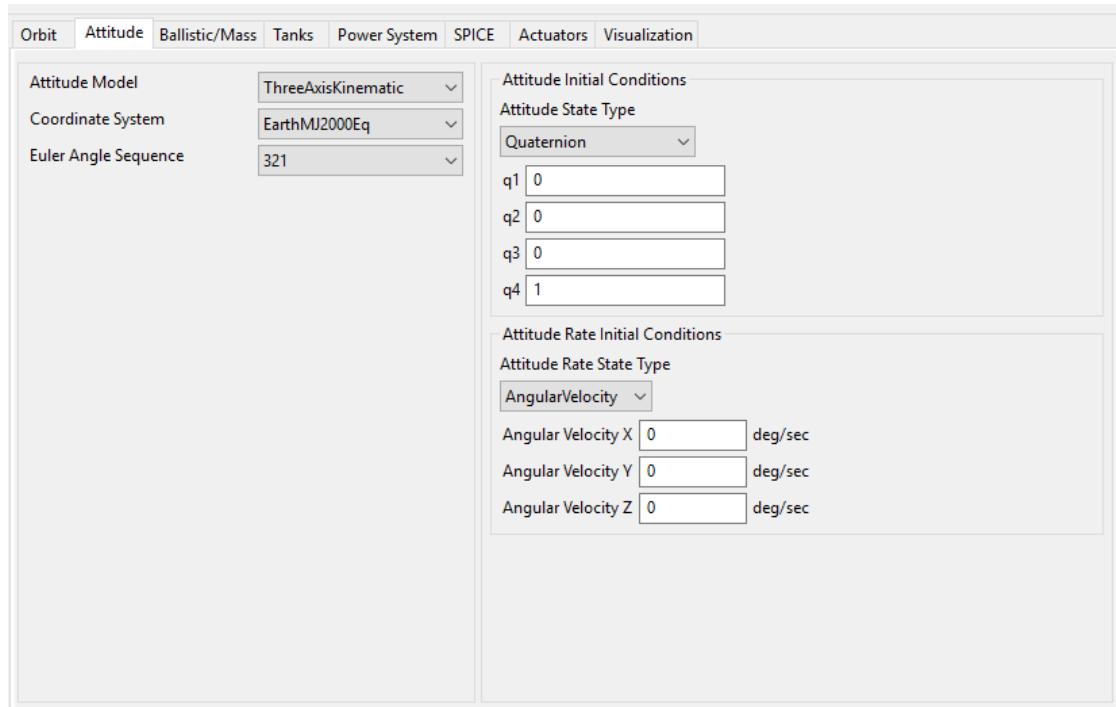
### Three Axis Kinematic Model

The **ThreeAxisKinematic** attitude model propagates the attitude state using a function of the attitude quaternion and the angular velocity. It does not include any modeling of torques. The quaternion kinematic algorithm was used for onboard attitude computations before rad hard processors were powerful enough to support numeric integration. Mathematically it produces the same result as the **Spinner** model; operationally there is no assumption that the spin axis is fixed – its first use was for a Lunar Catalyst project in which a new angular velocity would be read from telemetry every second. The initial attitude can be specified with any of DCM, quaternion, Euler angles, or Modified Rodrigues parameters; the initial rates can be specified with either angular velocity or Euler rates. When working with Euler rates, the rotation sequence is determined by the **EulerAngleSequence** field.



### Warning

Caution: If you are working in the script, setting the **CoordinateSystem** for the **ThreeAxisKinematic** attitude model has no effect.



The example below configures a spacecraft to roll at 3 degrees/second.

```
Create Spacecraft aSat;
```

```
aSat.Attitude = ThreeAxisKinematic;

Create ForceModel Propagator1_ForceModel;
Create Propagator Propagator1;
Propagator1.FM = Propagator1_ForceModel;

aSat.Q1 = 0.0
aSat.Q2 = 0.0
aSat.Q3 = 0.0
aSat.Q4 = 1.0;
GMAT DefaultSC.AngularVelocityX = 3; % deg/sec
GMAT DefaultSC.AngularVelocityY = 0
GMAT DefaultSC.AngularVelocityZ = 0;

BeginMissionSequence

Propagate Propagator1(aSat) {aSat.ElapsedSecs = 12000.0}
```

## Spacecraft Ballistic/Mass Properties

The physical properties of the spacecraft

### Description

The **Spacecraft** ballistic and mass properties include the drag and SRP areas and coefficients as well as the spacecraft dry mass. These quantities are used primarily in orbital dynamics modeling. GMAT supports spherical SRP and drag models, and a higher fidelity drag and area model called SPAD.

GMAT also supports an extended set of mass properties that are used in modeling torques and changes in angular momentum. The **Spacecraft** extended mass properties are the spacecraft dry center of mass and dry moment of inertia.

Both the standard and extended mass property models collaborate with **FuelTank** models to compute the aggregation of the dry spacecraft mass properties and the mass properties of the tank contents. The details of how this is done are discussed in the Remarks.

See Also: [Propagate](#), [Propagator](#), [Spacecraft](#), [ChemicalTank](#),

### Fields

Field	Description												
<b>AddPlates</b>	For use with the NPlate area model. Selection of <b>Plate</b> objects that comprise the spacecraft area model. See also <a href="#">Plate</a>  <table><tr><td><b>Data Type</b></td><td>Resource array</td></tr><tr><td><b>Allowed Values</b></td><td>Instances of the <b>Plate</b> resource</td></tr><tr><td><b>Access</b></td><td>Set</td></tr><tr><td><b>Default Value</b></td><td>Empty</td></tr><tr><td><b>Units</b></td><td>Not applicable</td></tr><tr><td><b>Interfaces</b></td><td>Script</td></tr></table>	<b>Data Type</b>	Resource array	<b>Allowed Values</b>	Instances of the <b>Plate</b> resource	<b>Access</b>	Set	<b>Default Value</b>	Empty	<b>Units</b>	Not applicable	<b>Interfaces</b>	Script
<b>Data Type</b>	Resource array												
<b>Allowed Values</b>	Instances of the <b>Plate</b> resource												
<b>Access</b>	Set												
<b>Default Value</b>	Empty												
<b>Units</b>	Not applicable												
<b>Interfaces</b>	Script												
<b>AtmosDensityScaleFactor</b>	A multiplicative scale factor applied to the nominal atmospheric density computed by the chosen density model.  <table><tr><td><b>Data Type</b></td><td>Real</td></tr><tr><td><b>Allowed Values</b></td><td>Real &gt; 0</td></tr><tr><td><b>Access</b></td><td>Set</td></tr><tr><td><b>Default Value</b></td><td>1.0</td></tr><tr><td><b>Units</b></td><td>dimensionless</td></tr><tr><td><b>Interfaces</b></td><td>Script</td></tr></table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real > 0	<b>Access</b>	Set	<b>Default Value</b>	1.0	<b>Units</b>	dimensionless	<b>Interfaces</b>	Script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real > 0												
<b>Access</b>	Set												
<b>Default Value</b>	1.0												
<b>Units</b>	dimensionless												
<b>Interfaces</b>	Script												

Field	Description												
<b>Cd</b>	<p>The coefficient of drag used to compute the acceleration due to drag for the spherical drag area model. This parameter is ignored when using SPAD drag modeling.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real &gt;= 0</td></tr> <tr> <td><b>Access</b></td><td>Set, get</td></tr> <tr> <td><b>Default Value</b></td><td>2.2</td></tr> <tr> <td><b>Units</b></td><td>dimensionless</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real >= 0	<b>Access</b>	Set, get	<b>Default Value</b>	2.2	<b>Units</b>	dimensionless	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real >= 0												
<b>Access</b>	Set, get												
<b>Default Value</b>	2.2												
<b>Units</b>	dimensionless												
<b>Interfaces</b>	GUI, script												
<b>CenterOfMassOffsetX</b>	<p>X component of offset to center of mass. This offset is only used with the "Lookup" model, allowing for deviations caused by factors not accounted for in pre-tabulated data.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any Real number</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>m</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Any Real number	<b>Access</b>	set	<b>Default Value</b>	0	<b>Units</b>	m	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Any Real number												
<b>Access</b>	set												
<b>Default Value</b>	0												
<b>Units</b>	m												
<b>Interfaces</b>	script												
<b>CenterOfMassOffsetY</b>	<p>Y component of offset to center of mass. This offset is only used with the "Lookup" model, allowing for deviations caused by factors not accounted for in pre-tabulated data.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any Real number</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>m</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Any Real number	<b>Access</b>	set	<b>Default Value</b>	0	<b>Units</b>	m	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Any Real number												
<b>Access</b>	set												
<b>Default Value</b>	0												
<b>Units</b>	m												
<b>Interfaces</b>	script												
<b>CenterOfMassOffsetZ</b>	<p>Z component of offset to center of mass. This offset is only used with the "Lookup" model, allowing for deviations caused by factors not accounted for in pre-tabulated data.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any Real number</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>m</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Any Real number	<b>Access</b>	set	<b>Default Value</b>	0	<b>Units</b>	m	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Any Real number												
<b>Access</b>	set												
<b>Default Value</b>	0												
<b>Units</b>	m												
<b>Interfaces</b>	script												

<b>Field</b>	<b>Description</b>												
<b>CenterOf-MassTableFileName</b>	<p>Name of file containing center of mass interpolation data for various values of total spacecraft mass. The total mass includes both the dry mass of the spacecraft and the mass of the contents of fuel tanks.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Valid file name for the center of mass table lookup file</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>N/A</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Valid file name for the center of mass table lookup file	<b>Access</b>	set	<b>Default Value</b>	N/A	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Valid file name for the center of mass table lookup file												
<b>Access</b>	set												
<b>Default Value</b>	N/A												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>Cr</b>	<p>The coefficient of reflectivity used to compute the acceleration due to SRP for the spherical area model. A value of zero means the spacecraft is translucent to incoming radiation. A value of 1.0 indicates all radiation is absorbed and all the force is transmitted to the spacecraft. A value of 2.0 indicates all radiation is reflected and twice the force is transmitted to the spacecraft. This parameter is ignored when using SPAD SRP modeling.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real <math>\geq 0</math></td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>1.8</td></tr> <tr> <td><b>Units</b></td><td>dimensionless</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real $\geq 0$	<b>Access</b>	set, get	<b>Default Value</b>	1.8	<b>Units</b>	dimensionless	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real $\geq 0$												
<b>Access</b>	set, get												
<b>Default Value</b>	1.8												
<b>Units</b>	dimensionless												
<b>Interfaces</b>	GUI, script												
<b>Drag Area</b>	<p>The area used to compute acceleration due to atmospheric drag for the spherical drag area model. This parameter is ignored when using SPAD drag modeling.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real <math>&gt;= 0</math></td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>15</td></tr> <tr> <td><b>Units</b></td><td><math>m^2</math></td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real $>= 0$	<b>Access</b>	set, get	<b>Default Value</b>	15	<b>Units</b>	$m^2$	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real $>= 0$												
<b>Access</b>	set, get												
<b>Default Value</b>	15												
<b>Units</b>	$m^2$												
<b>Interfaces</b>	GUI, script												
<b>DryCenterOfMassX</b>	<p>The X component of dry spacecraft center of mass in BCS (m)</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any Real number</td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>0.0</td></tr> <tr> <td><b>Units</b></td><td>m</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Any Real number	<b>Access</b>	set, get	<b>Default Value</b>	0.0	<b>Units</b>	m	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Any Real number												
<b>Access</b>	set, get												
<b>Default Value</b>	0.0												
<b>Units</b>	m												
<b>Interfaces</b>	script												

Field	Description
<b>DryCenterOfMassY</b>	The Y component of dry spacecraft center of mass in BCS (m)
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Any Real number</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 0.0</p> <p><b>Units</b> m</p> <p><b>Interfaces</b> script</p>
<b>DryCenterOfMassZ</b>	The Z component of dry spacecraft center of mass in BCS (m)
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Any Real number</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 0.0</p> <p><b>Units</b> m</p> <p><b>Interfaces</b> script</p>
<b>DryMass</b>	The dry mass of the <b>Spacecraft</b> (does not include fuel mass).
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Real <math>\geq 0</math></p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 850</p> <p><b>Units</b> kg</p> <p><b>Interfaces</b> GUI, script</p>
<b>DryMomentOfInertiaXX</b>	The XX component of the dry spacecraft moment of inertia
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Real <math>\geq 0</math></p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 999</p> <p><b>Units</b> Kg-m<sup>2</sup></p> <p><b>Interfaces</b> script</p>
<b>DryMomentOfInertiaXY</b>	The XY component of the dry spacecraft moment of inertia
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Any Real number</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 0</p> <p><b>Units</b> Kg-m<sup>2</sup></p> <p><b>Interfaces</b> script</p>

Field	Description
<b>DryMomentOfIner-</b> <b>tiaXZ</b>	The XZ component of the dry spacecraft moment of inertia <b>Data Type</b> Real <b>Allowed Values</b> Any Real number <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> Kg-m^2 <b>Interfaces</b> script
<b>DryMomentOfIner-</b> <b>tiaYY</b>	The YY component of the dry spacecraft moment of inertia <b>Data Type</b> Real <b>Allowed Values</b> Real >= 0 <b>Access</b> set, get <b>Default Value</b> 999 <b>Units</b> Kg-m^2 <b>Interfaces</b> script
<b>DryMomentOfIner-</b> <b>tiaYZ</b>	The YZ component of the dry spacecraft moment of inertia <b>Data Type</b> Real <b>Allowed Values</b> Any Real number <b>Access</b> set, get <b>Default Value</b> 0 <b>Units</b> Kg-m^2 <b>Interfaces</b> script
<b>DryMomentOfIner-</b> <b>tiaZZ</b>	The ZZ component of the dry spacecraft moment of inertia <b>Data Type</b> Real <b>Allowed Values</b> Real >= 0 <b>Access</b> set, get <b>Default Value</b> 999 <b>Units</b> Kg-m^2 <b>Interfaces</b> script
<b>Extended-</b> <b>MassProperties-</b> <b>Model</b>	Selection of whether to model center of mass, moment of inertia, both, or neither. <b>Data Type</b> String <b>Allowed Values</b> <b>None</b> , <b>CenterOfMass</b> , <b>MomentOfInertia</b> , <b>CenterOfMassAndMomentOfInertia</b> <b>Access</b> set <b>Default Value</b> <b>None</b> <b>Units</b> N/A <b>Interfaces</b> script

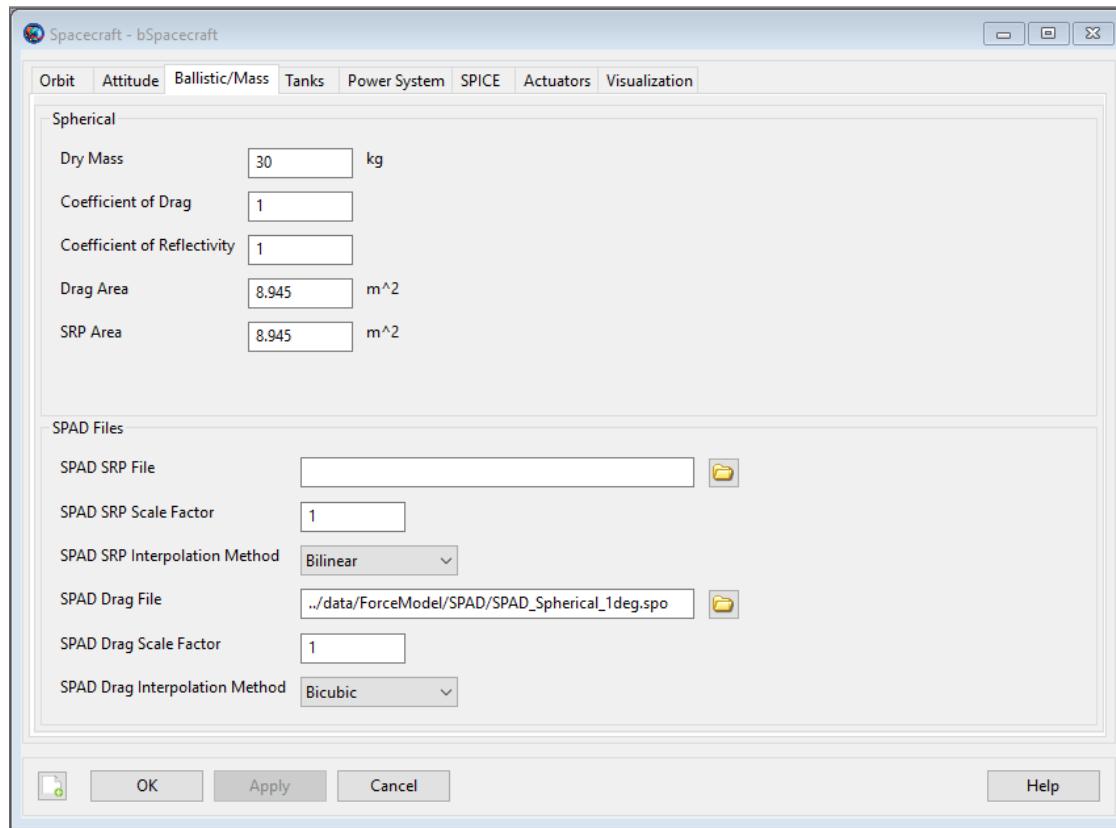
Field	Description
<b>Extended-MassProperties-ModelType</b>	Selection of models used to compute center of mass and moment of inertia. The available models are to interpolate mass property files ("Lookup") or to compute the system mass properties based on the dry spacecraft mass properties and the mass properties of the contents of each FuelTank ("Analytic").
	<b>Data Type</b>
	String
	<b>Allowed Values</b>
	Lookup, Analytic
	set
	<b>Default Value</b>
	Analytic
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	script
<b>MassPropertiesTableFilePath</b>	Path to files used to interpolate center of mass or moment of inertia data.
	<b>Data Type</b>
	String
	Valid path to directory containing interpolation table text file(s) for center of mass or moment of inertia
	set
	""
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	script
<b>MomentOfInertiaOffsetXX</b>	XX component of offset to moment of inertia. This offset is only used with the "Lookup" model, allowing for deviations caused by factors not accounted for in pre-tabulated data.
	<b>Data Type</b>
	Real
	Any Real number
	set
	0
	kg-m^2
	<b>Interfaces</b>
	script
<b>MomentOfInertiaOffsetXY</b>	XY component of offset to moment of inertia. This offset is only used with the "Lookup" model, allowing for deviations caused by factors not accounted for in pre-tabulated data.
	<b>Data Type</b>
	Real
	Any Real number
	set
	0
	kg-m^2
	<b>Interfaces</b>
	script

Field	Description
<b>MomentOfInertiaOffsetXZ</b>	<p>XZ component of offset to moment of inertia. This offset is only used with the "Lookup" model, allowing for deviations caused by factors not accounted for in pre-tabulated data.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Any Real number  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> kg-m<sup>2</sup>  <b>Interfaces</b> script</p>
<b>MomentOfInertiaOffsetYY</b>	<p>YY component of offset to moment of inertia. This offset is only used with the "Lookup" model, allowing for deviations caused by factors not accounted for in pre-tabulated data.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Any Real number  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> kg-m<sup>2</sup>  <b>Interfaces</b> script</p>
<b>MomentOfInertiaOffsetYZ</b>	<p>YZ component of offset to moment of inertia. This offset is only used with the "Lookup" model, allowing for deviations caused by factors not accounted for in pre-tabulated data.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Any Real number  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> kg-m<sup>2</sup>  <b>Interfaces</b> script</p>
<b>MomentOfInertiaOffsetZZ</b>	<p>ZZ component of offset to moment of inertia. This offset is only used with the "Lookup" model, allowing for deviations caused by factors not accounted for in pre-tabulated data.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Any Real number  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> kg-m<sup>2</sup>  <b>Interfaces</b> script</p>

Field	Description
<b>MomentOfInertiaTableFileName</b>	<p>Name of file containing moment of inertia interpolation data for various values of total spacecraft mass. The total mass includes both the dry mass of the spacecraft and the mass of the contents of fuel tanks.</p>
	<p><b>Data Type</b> String  <b>Allowed Values</b> Valid file name for the moment of inertia table lookup file  <b>Access</b> set  <b>Default Value</b> N/A  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>NPlateSRPEqualAreaCoefficients</b>	<p>Equate or link NPlate model SRP area coefficients for estimation. When estimating the AreaCoefficient for one or more plates, any plates specified in this list will be forced to have the same value of AreaCoefficient during the estimation process. Only applicable when the NPlate area model is in use and solving for AreaCoefficient.</p>
	<p><b>Data Type</b> Resource array  <b>Allowed Values</b> Instances of the <b>Plate</b> resource  <b>Access</b> Set  <b>Default Value</b> Empty  <b>Units</b> Not applicable  <b>Interfaces</b> Script</p>
<b>SPADDragFile</b>	<p>Name (and optionally path information) of SPAD drag model file.</p>
	<p><b>Data Type</b> String  <b>Allowed Values</b> valid path and SPAD file  <b>Access</b> set  <b>Default Value</b> N/A  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>SPADDragInterpolationMethod</b>	<p>Interpolation method for SPAD drag vectors.</p>
	<p><b>Data Type</b> String  <b>Allowed Values</b> 'Bicubic' or 'Bilinear'  <b>Access</b> set  <b>Default Value</b> Bilinear  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>

Field	Description
<b>SPADDragScale-Factor</b>	Scale factor applied to the drag force when using a SPAD drag area model.
	<b>Data Type</b> Real <b>Allowed Values</b> Any Real number <b>Access</b> set <b>Default Value</b> 1.0 <b>Units</b> dimensionless <b>Interfaces</b> GUI, script
<b>SPADSRPFile</b>	Name (and optionally path information) of SPAD SRP model file.
	<b>Data Type</b> String <b>Allowed Values</b> valid path and SPAD file <b>Access</b> set <b>Default Value</b> N/A <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>SPADSRPInterpolationMethod</b>	Interpolation method for SPAD SRP model vectors.
	<b>Data Type</b> String <b>Allowed Values</b> 'Bicubic' or 'Bilinear' <b>Access</b> set <b>Default Value</b> Bilinear <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>SPADSRPScale-Factor</b>	Scale factor applied to SRP force when using a SPAD SRP area model.
	<b>Data Type</b> Real <b>Allowed Values</b> Any Real number <b>Access</b> set <b>Default Value</b> 1.0 <b>Units</b> dimensionless <b>Interfaces</b> GUI, script
<b>SRPArea</b>	The area used to compute acceleration due to solar radiation pressure for the spherical SRP area model. This parameter is ignored when using SPAD SRP modeling.
	<b>Data Type</b> Real <b>Allowed Values</b> Real > 0 <b>Access</b> set, get <b>Default Value</b> 1 <b>Units</b> m^2 <b>Interfaces</b> GUI, script

## GUI



The GUI interface for ballistic and mass properties is contained on the **Ballistic/Mass** tab of the **Spacecraft** resource. You can enter physical properties such as the drag and SRP areas and coefficients and the **Spacecraft** dry mass which are used in orbital dynamics modeling. GMAT supports a spherical SRP model and a SPAD (Solar Pressure and Aerodynamic Drag) file.

## Remarks

### Configuring Area Properties for the Spherical Area Model

GMAT supports a spherical (sometimes called a "cannonball") area model for drag and SRP modeling. In the spherical model, the area is assumed to be independent of the spacecraft's orientation with respect to the local velocity vector and the sun vector. The spherical area model is selected by setting the configured **ForceModel SRP.SRPModel** and **Drag.DragModel** to **Spherical**. For more details on the computation and configuration of drag and SRP models see the [ForceModel](#) documentation.

### Configuring Area Properties for the NPlate Area Model

GMAT supports a multi-plate area model for SRP modeling. In the NPlate model, the area is built up from a collection of **Plate** resources, each specifying a separate area, orientation, and reflectivity properties. The NPlate area model is selected by setting the configured **ForceModel SRP.SRPModel** to **NPlate**. The NPlate model is not currently available for drag modeling. For more details on the configuration of the NPlate model, see the [Plate](#) documentation.

## Configuring Area Properties for the SPAD Area Model

SPAD stands for Solar Pressure and Aerodynamic Drag. A SPAD file can be used for high fidelity SRP and drag modeling taking into account the physical properties of the spacecraft (shape and reflectivity) and the spacecraft attitude. SPAD files contain tabulated data representing the spacecraft area scaled by physical properties like Cr including specular, diffuse, and reflective properties. Area data in the SPAD file is tabulated as a function of azimuth and elevation in the spacecraft body frame. In the case of SRP modeling, the azimuth and elevation tabulated on the file should be the azimuth and elevation of the vector from the Spacecraft to the Sun, expressed in the body frame. For drag modeling, the azimuth and elevation denote the direction of the spacecraft velocity vector relative to the rotating atmosphere. The SPAD area model is selected by setting the configured **ForceModel SRP.SRPModel** and **Drag.DragModel** to **SPADFile**.

To compute the SRP or drag acceleration at each integration point, GMAT determines the sun or relative velocity vector's azimuth and elevation in the spacecraft body frame at the integration time, and then interpolates the SPAD data using bi-linear or bi-cubic interpolation. Since the SRP or drag vector is taken in the spacecraft body frame, this formulation results in an attitude dependent acceleration. For more details on the computation and configuration of drag and SRP models see the [ForceModel](#) documentation.

### Caution



When using a SPAD file, GMAT uses the attitude defined on the **Spacecraft** resource to compute the Sun's or relative velocity vector in the body frame. If the attitude uses a coordinate system with **Axes** set to **ObjectReferenced**, and those axes refer back to the **Spacecraft** orbit state (i.e. VNB or LVLH systems), GMAT holds the attitude constant over a given integration step. In those cases, we recommend carefully choosing a maximum step size small enough to ensure the resulting approximation is acceptable for your application.

A valid SPAD file header, and the first three lines of data are shown below for illustrative purposes. Note, GMAT does not use all values provide on the file and GMAT's usage of SPAD files is described in detail in the table below the example.

```
Version      : 4.21
System       : sphericalSat
Analysis Type : Area
Pixel Size   : 5
Spacecraft Size : 436.2
Pressure     : 1
Center of Mass : (50.9, 184.9, -49)
Current time  : May  7, 2009 15:53:38.00

Motion      : 1
Name        : Azimuth
Method      : Step
Minimum    : -180
Maximum    : 180
```

```

Step      : 5
Motion    : 2
Name      : Elevation
Method    : Step
Minimum   : -90
Maximum   : 90
Step      : 5
: END

Record count       : 2701

AzimuthElevatio Force(X)  Force(Y)  Force(Z)
degrees degrees      m^2        m^2        m^2
-----
-180.00   -90.00 -0.00000000000000 -0.00000000000000 -8.94500000000000
-180.00   -85.00 -0.77960811887780 -0.00000000000000 -8.91096157443066
-180.00   -80.00 -1.55328294923069 -0.00000000000000 -8.80910535069420

```

A SPAD file contains three sections as illustrated below. Data specifications for items in each section are described in the tables below. A SPAD file header may contain many fields but only a few are used by GMAT as described below. Other fields are ignored.

Keyword	Re- quired	Description and Supported Values
<b>Analysis Type</b>	Y	The SPAD software can creates files with Analysis Types of Solar Pressure, Area, and Drag. GMAT only supports the Area option.
Example:		
<b>Pressure</b>	N	SPAD supports the ability to apply a scale factor for SRP and drag. GMAT does not read this value, and its purpose in the SPAD file is to inform the user that the properties on the file have been scaled by the Pressure factor. The value is usually "1". However, when not 1, it is possible to apply a scale factor twice, once from the value applied on the data in the SPAD file, and once from the <b>SPADSRPScaleFactor</b> or <b>SPADDragScaleFactor</b> . Care should be taken to ensure that if the desired scale factor was applied during file creation that it is not reapplied in GMAT.

The SPAD file Motion Data section describes the data contained in the body of the file. The Motion Data fields used by GMAT are described below. Others are ignored.

Keyword	Re- quired	Description and Supported Values
<b>Motion</b>	Y	<p>Together, the Motion and Name fields specify the type of data in the first two columns of the body of the file. GMAT currently supports Azimuth and Elevation Motion only (no articulating appendages) and requires that the first Motion is Azimuth and the second Motion is Elevation as shown below.</p>
		<p>Examples:</p>
		<pre>Motion : 1 Name : Azimuth</pre>
		<p>and</p>
		<pre>Motion : 2 Name : Elevation</pre>
<b>Name</b>	Y	<p>Together, the Motion and Name fields specify the type of data in the first two columns of the body of the file. GMAT currently supports Azimuth and Elevation Motion only (no articulating appendages) and requires that the first Motion is Azimuth and the second Motion is Elevation as shown below.</p>
		<p>Examples:</p>
		<pre>Motion : 1 Name : Azimuth</pre>
		<p>and</p>
		<pre>Motion : 2 Name : Elevation</pre>
<b>Method</b>	Y	<p>The step size in the independent variable. The only supported value is Step.</p>
		<p>Example:</p>
		<pre>Motion : 1 Method : Step</pre>

Keyword	Re- quired	Description and Supported Values
<b>Maximum</b>	Y	The maximum value for an independent variable (Motion Type). For Azimuth, Maximum must be 180, and for Elevation Maximum must be 90.
		Example:
		<pre>Motion : 1 Name : Azimuth Maximum : 180  Motion : 2 Name : Elevation Maximum : 90</pre>
<b>Minimum</b>	Y	The minimum value for an independent variable. (Motion Type). For Azimuth, minimum must be -180, and for Elevation minimum must be -90.
		Example:
		<pre>Motion : 1 Name : Azimuth Minimum : -180  Motion : 2 Name : Elevation Minimum : -90</pre>
<b>Step</b>	Y	The step size for the independent variable (Motion Type). If Step does not divide evenly into the variable range, then errors may occur because the maximum and/or minimum values may not be on the file.
		Example:
		Motion : 1
		Step : 15
<b>Record count</b>	Y	Record count is the number of rows of data in the data segment. Record count = $(360 / (\text{Azimuth Step}) + 1) * (180 / (\text{Elevation Step}) + 1)$ .
		Example:
		Record count : 325

The SPAD file data block contains tabulated force modeling data as described below.

Keyword	Re- quired	Description and Supported Values
<b>Azimuth</b>	Y	<p>Azimuth data column. Must be first column in the data. Units must be degrees. Azimuth is the azimuth of the vector from spacecraft to Sun (for SRP, atan2(ySun,xSun)), or the relative velocity vector (for drag) expressed in the body frame.</p> <p>Example:</p> <pre>AzimuthElevatio degrees degrees ----- -180.00 -90.00 -180.00 -75.00 -180.00 -60.00</pre>
<b>Elevation</b>	N	<p>Elevation data column. Must be second column in the data. Units must be degrees. Elevation is the elevation of the vector from spacecraft to Sun (for SRP, atan2(zSun,sqrt(xSun^2 + ySun^2))), or the relative velocity vector (for drag) expressed in the body frame.</p> <p>Example:</p> <pre>AzimuthElevatio degrees degrees ----- -180.00 -90.00 -180.00 -75.00 -180.00 -60.00</pre>
<b>Force(*)</b>	N	<p>Area vector columns. Must be columns 3-5 in the data. Quantities must be in base units of m^2,mm^2,cm^2,in^2, or ft^2. If another unit is provided in the header lines, an exception is thrown. The area vector is the direction of the resulting SRP force in the spacecraft body frame, scaled by area and reflectivity properties.</p> <p>Example: See code listing above.</p>

## Total Mass Computation

The **TotalMass** property of a **Spacecraft** is a read-only property that is the sum of the **DryMass** value and the sum of the fuel mass in all attached fuel tanks. GMAT's propagators will not allow the total mass of a spacecraft to be negative. However, GMAT will allow the mass of a **ChemicalTank** to be negative. See the [ChemicalTank](#) documentation for details.

## Extended Mass Properties: Overview

In addition to computing the **TotalMass** property of a **Spacecraft**, GMAT can compute the **SystemCenterOfMass** and **SystemMomentOfInertia** properties. Like **TotalMass** these properties are read-only and they are computed from the corresponding properties of the dry **Spacecraft**. The resulting **SystemCenterOfMass** is expressed in the **Spacecraft**'s body coordinate system (BCS), and the resulting **SystemMomentOfInertia** is with respect to the **SystemCenterOfMass**.

There are two models for computing the extended mass properties

- the **Lookup** option which interpolates lookup tables where mass is the independent variable and either center of mass or moment of inertia is the dependent variable, and
- the **Analytic** option, which computes the system properties from the dry properties and the fuel properties.

At this writing the **Lookup** model is fully implemented and the **Analytic** model is under development.

The selection of models is controlled by two input parameters. The first, **ExtendedMassPropertiesModelType**, controls whether the **Lookup** or **Analytic** model is to be used. The second, **ExtendedMassPropertiesModeled**, controls which properties are to be computed. The **TotalMass** is always computed, if neither center of mass nor moment of inertia are needed, the value of **ExtendedMassPropertiesModeled** is set to **None**. This is the default. The default value of **ExtendedMassPropertiesModelType** is **Analytic**; this was chosen so that no lookup files would need to be specified in the default case. Until the analytic model for extended mass properties is completed choosing the **Analytic** model is *only* valid if **ExtendedMassPropertiesModel** is set to **None**. Put another way, the default is to not model the extended mass properties, and only compute **TotalMass**. The other options are **CenterOfMass**, **MomentOfInertia**, and **CenterOfMassAndMomentOfInertia**, and should be self-explanatory.

### Extended Mass Properties: Lookup Model

There are three elements to using the **Lookup** model: specifying the filenames to be used, understanding the formats of the lookup table files, and the offsets from interpolated data. The center of mass and moment of inertia lookup data are stored in separate files and interpolated independently. It is up to the user to get a consistent set of data for a given spacecraft; the **Lookup** model is more often used in mission operations for spacecraft whose properties are well understood. It is expected that the two files will be stored in the same folder; the parameter **MassPropertiesTableFilePath** is used to set a path to that folder. The file names are provided by the parameters **CenterOfMassTableName** and **MomentOfInertiaTableName**.

Both files are text files containing spacecraft masses as the first parameter in each row, and the corresponding center of mass or moment of inertia values completing the row.

The center of mass data is tabulated in a text file indexed by this value. A sample file is shown below. The header data in this file is informational only in the current implemen-

tation. The data shown there is not used in the current GMAT code, but may be used in a later implementation.

```
% Center of Mass Datafile

Spacecraft: SampleSat
Index: TotalMass
CoordinateSystem: BCS
Units: Meters

% Data order:
% RefMass, COMx COMy COMz

BeginData
2200    0.0220    0.0500    0.3000
2100    0.0215    0.0366    0.2888
2000    0.0211    0.0233    0.2777
1900    0.0206    0.0100    0.2666
1800    0.0202   -0.0033    0.2555
1700    0.0197   -0.0166    0.2444
1600    0.0193   -0.0300    0.2333
1500    0.0188   -0.0433    0.2222
1400    0.0184   -0.0566    0.2111
1300    0.0180   -0.0700    0.2000
EndData
```

The data tabulated between the BeginData and EndData lines are used in GMAT to interpolate the location of the center of mass, using GMAT's Lagrange interpolator. The first column of the data is spacecraft's total mass, providing the index into the table. This index column must be monotonic, but can be either increasing or, as shown here, decreasing. The location of the center of mass is tabulated in Cartesian body fixed coordinates. Each row specifies the center of mass location corresponding to the total mass value in the first column. The data are in X-Y-Z order. The center of mass location is specified in meters. If the **TotalMass** used to interpolate is outside of the range given by the upper and lower bounds of the tabulated masses in the first column, GMAT throws an exception indicating that the spacecraft center of mass cannot be interpolated.

The moment of inertia tensor is tabulated similarly. A sample file is shown below. As in the case of center of mass, the header information in the moment of inertial table file is not currently used, but may be in a later implementation.

```
% Moment of Inertia Datafile

Spacecraft: SampleSat
Index: TotalMass
Origin: Spacecraft Center of Mass
Units: kg-m^2
```

```
% Data order:
% RefMass, MOIxx MOIyy MOIzz MOIxy MOIxz MOIyz

BeginData
1300    12.755    17.423    14.111    0.187    -0.622    0.455
1400    12.655    17.001    14.116    0.186    -0.622    0.445
1500    12.455    16.722    14.120    0.185    -0.622    0.435
1600    12.155    16.432    14.123    0.184    -0.622    0.425
1700    12.055    16.395    14.124    0.183    -0.622    0.415
1800    12.155    16.388    14.124    0.182    -0.622    0.405
1900    12.455    16.376    14.124    0.181    -0.622    0.395
2000    12.555    16.368    14.123    0.180    -0.622    0.385
2100    12.755    16.365    14.119    0.179    -0.622    0.375
2200    12.955    16.365    14.107    0.178    -0.622    0.365
EndData
```

The data tabulated between the BeginData and EndData lines are used in GMAT to interpolate the moments and products of inertia relative to the spacecraft's center of mass, using GMAT's Lagrange interpolator. The first column of the data is spacecraft's total mass, providing the index into the table. This index column must be monotonic, but can be either increasing, as shown here, or decreasing. Each tensor element is tabulated in the Cartesian system. Each row specifies the inertia tensor component relative to the spacecraft center of mass that corresponds to the total mass value in the first column. The data are in XX-YY-ZZ-XY-XZ-YZ order. The moments and products of inertia are specified in kilogram-meters squared. If the **TotalMass** used to interpolate is outside of the range given by the upper and lower bounds of the tabulated masses in the first column, GMAT throws an exception indicating that the spacecraft center of mass cannot be interpolated.

The spacecraft center of mass as tabulated above is specified as a nominal location for the center of mass. That location may shift based on factors in the spacecraft configuration that were not accounted for in the tabulated data at the start of a project. GMAT scripting accommodates these factors through a set of offset values on the spacecraft. Center of mass has 3 offset parameters representing an offset in the X, Y and Z directions. Moment of inertia has 6 offsets, representing the XX, YY, ZZ, XY, XZ, and YZ. In both cases the offsets default to zero. Of the two, the center of mass offset is more likely to be used in practice; the moment of inertia offsets are there for completeness and the unanticipated.

### Extended Mass Properties: Analytic Model

As this model is not yet completed, this section will outline the computations and not emphasize the different user options, which will be documented here upon complete implementation. We will assume that both center of mass and moment of inertia have been selected.

The analytic model divides the responsibility for computing the extended mass properties between the **Spacecraft** and **FuelTank** classes. The **FuelTank** will be capable of computing its own center of mass in BCS and moment of inertia about the system center of mass. The **Spacecraft** is responsible for adding up all the fuel mass properties

and the dry spacecraft mass properties to get the system mass properties. For moment of inertia, since all the components are computing their moments of inertia around the system center of mass the system moment of inertia is the sum of all the component moments of inertia. The computational steps are:

- For each **FuelTank**, compute center of mass and moment of inertia of its contents -- this is the part of the model that has not yet been completed.
- For each **FuelTank**, compute the center of mass in BCS. This is a function of the tank's center of mass in tank coordinates, the position of the tank coordinate system's origin in BCS and the orientation of the tank coordinate system to the BCS.
- In the **Spacecraft** object, compute the system center of mass. This is the weighted average of the individual centers of mass of fuel and the dry spacecraft, weighted by the mass of each.
- For each **FuelTank**, compute the moment of inertia about the system center of mass using the Parallel Axis Theorem. Note that this computation uses the system center of mass computed in the previous step.
- In the **Spacecraft** object, compute system moment of inertia. This is simply the sum of each of the individual moments of inertia, as they are all computed about the system center of mass.

The code for the last 4 steps is implemented and integrated into both classes. When the last piece is implemented the code raising an exception if analytic modeling of extended mass properties is selected will be removed.

## Examples

Configure physical properties for a spherical SRP model.

```
Create Spacecraft aSpacecraft
aSpacecraft.Cd      = 2.2
aSpacecraft.Cr      = 1.8
aSpacecraft.DragArea = 40
aSpacecraft.SRPArea = 35
aSpacecraft.DryMass  = 2000
Create Propagator aPropagator

BeginMissionSequence

Propagate aPropagator(aSpacecraft, {aSpacecraft.ElapsedSecs = 600})
```

Configure a SPAD SRP model.

```
Create Spacecraft aSpacecraft;
aSpacecraft.DryMass = 2000
aSpacecraft.SPADSRPFile = '../data/vehicle/spad/SphericalModel.spo'
aSpacecraft.SPADSRPScaleFactor = 1
aSpacecraft.SPADDragInterpolationMethod = Bicubic

Create ForceModel aFM;
aFM.SRP          = On;
```

```
aFM.SRP.SRPMODEL = SPADFILE

Create Propagator aProp;
aProp.FM = aFM;

BeginMissionSequence

Propagate aProp(aSpacecraft) {aSpacecraft.ElapsedDays = 0.2}
```

Computing center of mass and moment of inertia changes.

```
%----- Spacecraft -----
Create Spacecraft JSL;
JSL.Tanks = {TankA}
JSL.Thrusters = {ThrusterA}

%% Added Mass Properties' lookup table files
JSL.DryMass = 2440;
JSL.MassPropertiesTableFilePath = '../include'
JSL.ExtendedMassPropertiesModelType = 'Lookup'
JSL.ExtendedMassPropertiesModel = 'CenterOfMassAndMomentOfInertia'
JSL.CenterOfMassTableName = 'FakeLinearCM.table'
JSL.MomentOfInertiaTableName = 'FakeLinearMOI.table'

Create ChemicalTank TankA
TankA.Volume = 2.0
TankA.FuelMass = 1500
Create Thruster ThrusterA
ThrusterA.Tank = {TankA}
Create FiniteBurn fb1;
fb1.Thrusters = {ThrusterA};
ThrusterA.DecrementMass = true;

%----- Propagator -----
Create Propagator EarthProp;
Create ForceModel TorqueForces;
EarthProp.FM = TorqueForces

%----- Reports -----
Create ReportFile CM;
CM.Filename = 'CM.report'
Create ReportFile MOI;
MOI = 'MOI.report'

%----- Mission Sequence -----
BeginMissionSequence;

BeginFiniteBurn fb1(JSL);
```

```
For loop = 1:14
    Report CM JSL.TotalMass JSL.SystemCenterOfMassX JSL.SystemCenterOfMas
    Report MOI JSL.SystemMomentOfInertiaXX JSL.SystemMomentOfInertiaXY JSL.
        JSL.SystemMomentOfInertiaYY JSL.SystemMomentOfInertiaYZ JSL.
    nextFuelMass = JSL.TankA.FuelMass - 100
    Propagate EarthProp(JSL) {JSL.TankA.FuelMass = nextFuelMass}
EndFor
Report CM JSL.TotalMass JSL.SystemCenterOfMassX JSL.SystemCenterOfMassY
Report MOI JSL.SystemMomentOfInertiaXX JSL.SystemMomentOfInertiaXY JSL.Sy
    JSL.SystemMomentOfInertiaYY JSL.SystemMomentOfInertiaYZ JSL.Sy

EndFiniteBurn fb1(JSL);code>
```

## Spacecraft Epoch

The spacecraft epoch

### Description

The epoch of a **Spacecraft** is the time and date corresponding to the specified orbit state. See the [Spacecraft Orbit State](#) section for interactions between the epoch, coordinate system, and spacecraft state fields.

See Also: [Spacecraft](#)

### Caution



GMAT's Modified Julian Date (MJD) format differs from that of other software. The Modified Julian format is a constant offset from the full Julian date (JD):  
$$\text{MJD} = \text{JD} - \text{offset}$$

GMAT uses a non-standard offset, as shown in the following table.

Epoch Type	GMAT					common
reference epoch	05	Jan	1941	17	Nov	1858
	12:00:00.000				00:00:00.000	

---

Modified Julian offset	2430000.0	2400000.5
------------------------	-----------	-----------

### Fields

Field	Description		
<b>DateFormat</b>	The time system and format of the <b>Epoch</b> field. In the GUI, this field is called <b>EpochFormat</b> .		
	<b>Data Type</b>	Enumeration	
	<b>Allowed Values</b>	A1ModJulian, UTCModJulian, TDBModJulian, TAIGregorian, TTGregorian, UTC-Gregorian, TDBGregorian	TAIModJulian, TTModJulian, A1Gregorian, TAIGregorian, TTGregorian, UTC-Gregorian, TDBGregorian
	<b>Access</b>	set only	
	<b>Default Value</b>	TAIModJulian	
	<b>Interfaces</b>	GUI, script	

Field	Description	
<b>Epoch</b>	The time and date corresponding to the specified orbit state.	
	<b>Data Type</b>	Time
	<b>Allowed Values</b>	Gregorian: 04 Oct 1957 12:00:00.000 <= <b>Epoch</b> <= 28 Feb 2100 00:00:00.000
	<b>Access</b>	Modified Julian: <b>6116.0 &lt;= Epoch &lt;= 58127.5</b>
	<b>Default Value</b>	set only
	<b>Interfaces</b>	21545
		GUI, script
<b>A1ModJulian</b>	The <b>Spacecraft</b> orbit epoch in the A.1 system and the Modified Julian format.	
	<b>Data Type</b>	String
	<b>Allowed Values</b>	See <b>Epoch</b>
	<b>Access</b>	set, get (mission sequence only)
	<b>Default Value</b>	21545.00000039794
	<b>Units</b>	Days
	<b>Interfaces</b>	script
<b>Epoch.A1ModJulian</b>	The spacecraft orbit epoch in the A.1 system and the Modified Julian format.	
	<b>Data Type</b>	String
	<b>Allowed Values</b>	See <b>Epoch</b>
	<b>Access</b>	set, get
	<b>Default Value</b>	21545.00000039794
	<b>Units</b>	Days
	<b>Interfaces</b>	none
<b>CurrA1MJD</b>	<i>This field has been deprecated and should no longer be used.</i>	
	The current epoch in the <b>A1ModJulian</b> format. This field can only be used within the mission sequence.	
	<b>Data Type</b>	Time
	<b>Allowed Values</b>	<b>6116.0 &lt;= CurrA1MJD &lt;= 58127.5</b>
	<b>Access</b>	get, set (mission sequence only)
	<b>Default Value</b>	converted equivalent of 21545 Modified Julian (TAI)
	<b>Interfaces</b>	script only

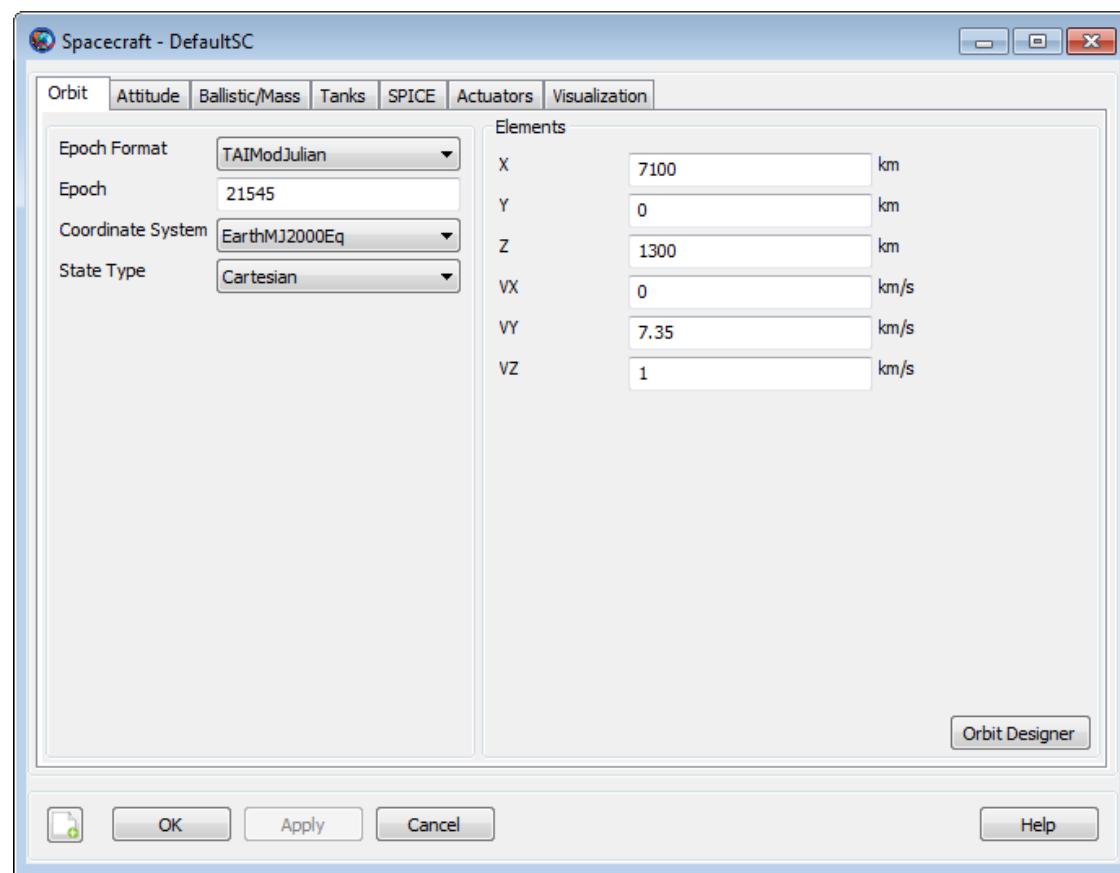
Field	Description
<b>A1Gregorian</b>	<p>The <b>Spacecraft</b> orbit epoch in the A.1 system and the Gregorian format.</p> <p><b>Data Type</b> String  <b>Allowed Values</b> See <a href="#">Epoch</a>  <b>Access</b> set, get (mission sequence only)  <b>Default Value</b> 01 Jan 2000 12:00:00.034  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>TAIGregorian</b>	<p>The <b>Spacecraft</b> orbit epoch in the TAI system and the Gregorian format.</p> <p><b>Data Type</b> String  <b>Allowed Values</b> See <a href="#">Epoch</a>  <b>Access</b> set, get (mission sequence only)  <b>Default Value</b> 01 Jan 2000 12:00:00.000  <b>Units</b> Gregorian date  <b>Interfaces</b> GUI, script</p>
<b>TAIModJulian</b>	<p>The <b>Spacecraft</b> orbit epoch in the TAI system and the Modified Julian format.</p> <p><b>Data Type</b> String  <b>Allowed Values</b> See <a href="#">Epoch</a>  <b>Access</b> set, get (mission sequence only)  <b>Default Value</b> 21545  <b>Units</b> See <a href="#">A1ModJulian</a>  <b>Interfaces</b> GUI, script</p>
<b>TDBGregorian</b>	<p>The <b>Spacecraft</b> orbit epoch in the TDB system and the Gregorian format.</p> <p><b>Data Type</b> String  <b>Allowed Values</b> See <a href="#">Epoch</a>  <b>Access</b> set, get (mission sequence only)  <b>Default Value</b> 01 Jan 2000 12:00:32.184  <b>Units</b> See <a href="#">A1Gregorian</a>  <b>Interfaces</b> GUI, script</p>
<b>TDBModJulian</b>	<p>The <b>Spacecraft</b> orbit epoch in the TDB system and the Modified Julian format.</p> <p><b>Data Type</b> String  <b>Allowed Values</b> See <a href="#">Epoch</a>  <b>Access</b> set, get (mission sequence only)  <b>Default Value</b> 21545.00037249916  <b>Units</b> See <a href="#">A1ModJulian</a>  <b>Interfaces</b> GUI, script</p>

Field	Description												
<b>TTGregorian</b>	<p>The <b>Spacecraft</b> orbit epoch in the TT system and the Gregorian format.</p> <table> <tr> <td data-bbox="641 344 796 375"><b>Data Type</b></td><td data-bbox="918 344 1000 375">String</td></tr> <tr> <td data-bbox="641 382 869 413"><b>Allowed Values</b></td><td data-bbox="918 382 1073 413">See <a href="#">Epoch</a></td></tr> <tr> <td data-bbox="641 420 747 451"><b>Access</b></td><td data-bbox="918 420 1269 451">set, get (mission sequence only)</td></tr> <tr> <td data-bbox="641 458 837 489"><b>Default Value</b></td><td data-bbox="918 458 1261 489">01 Jan 2000 12:00:32.184</td></tr> <tr> <td data-bbox="641 496 722 528"><b>Units</b></td><td data-bbox="918 496 1147 528">See A1Gregorian</td></tr> <tr> <td data-bbox="641 534 788 566"><b>Interfaces</b></td><td data-bbox="918 534 1065 566">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	See <a href="#">Epoch</a>	<b>Access</b>	set, get (mission sequence only)	<b>Default Value</b>	01 Jan 2000 12:00:32.184	<b>Units</b>	See A1Gregorian	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	See <a href="#">Epoch</a>												
<b>Access</b>	set, get (mission sequence only)												
<b>Default Value</b>	01 Jan 2000 12:00:32.184												
<b>Units</b>	See A1Gregorian												
<b>Interfaces</b>	GUI, script												
<b>TTModJulian</b>	<p>The <b>Spacecraft</b> orbit epoch in the TT system and the Modified Julian format.</p> <table> <tr> <td data-bbox="641 682 796 713"><b>Data Type</b></td><td data-bbox="918 682 1000 713">String</td></tr> <tr> <td data-bbox="641 720 869 751"><b>Allowed Values</b></td><td data-bbox="918 720 1073 751">See <a href="#">Epoch</a></td></tr> <tr> <td data-bbox="641 758 747 789"><b>Access</b></td><td data-bbox="918 758 1269 789">set, get (mission sequence only)</td></tr> <tr> <td data-bbox="641 796 837 827"><b>Default Value</b></td><td data-bbox="918 796 1122 827">21545.0003725</td></tr> <tr> <td data-bbox="641 834 722 865"><b>Units</b></td><td data-bbox="918 834 1147 865">See A1ModJulian</td></tr> <tr> <td data-bbox="641 872 788 903"><b>Interfaces</b></td><td data-bbox="918 872 1065 903">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	See <a href="#">Epoch</a>	<b>Access</b>	set, get (mission sequence only)	<b>Default Value</b>	21545.0003725	<b>Units</b>	See A1ModJulian	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	See <a href="#">Epoch</a>												
<b>Access</b>	set, get (mission sequence only)												
<b>Default Value</b>	21545.0003725												
<b>Units</b>	See A1ModJulian												
<b>Interfaces</b>	GUI, script												
<b>UTCGregorian</b>	<p>The <b>Spacecraft</b> orbit epoch in the UTC system and the Gregorian format.</p> <table> <tr> <td data-bbox="641 1020 796 1051"><b>Data Type</b></td><td data-bbox="918 1020 1000 1051">String</td></tr> <tr> <td data-bbox="641 1058 869 1089"><b>Allowed Values</b></td><td data-bbox="918 1058 1073 1089">See <a href="#">Epoch</a></td></tr> <tr> <td data-bbox="641 1096 747 1127"><b>Access</b></td><td data-bbox="918 1096 1269 1127">set, get (mission sequence only)</td></tr> <tr> <td data-bbox="641 1134 837 1165"><b>Default Value</b></td><td data-bbox="918 1134 1261 1165">01 Jan 2000 11:59:28.000</td></tr> <tr> <td data-bbox="641 1172 722 1203"><b>Units</b></td><td data-bbox="918 1172 1147 1203">See A1Gregorian</td></tr> <tr> <td data-bbox="641 1210 788 1241"><b>Interfaces</b></td><td data-bbox="918 1210 1065 1241">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	See <a href="#">Epoch</a>	<b>Access</b>	set, get (mission sequence only)	<b>Default Value</b>	01 Jan 2000 11:59:28.000	<b>Units</b>	See A1Gregorian	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	See <a href="#">Epoch</a>												
<b>Access</b>	set, get (mission sequence only)												
<b>Default Value</b>	01 Jan 2000 11:59:28.000												
<b>Units</b>	See A1Gregorian												
<b>Interfaces</b>	GUI, script												
<b>UTCModJulian</b>	<p>The <b>Spacecraft</b> orbit epoch in the UTC system and the Modified Julian format.</p> <table> <tr> <td data-bbox="641 1358 796 1389"><b>Data Type</b></td><td data-bbox="918 1358 1000 1389">String</td></tr> <tr> <td data-bbox="641 1396 869 1427"><b>Allowed Values</b></td><td data-bbox="918 1396 1073 1427">See <a href="#">Epoch</a></td></tr> <tr> <td data-bbox="641 1434 747 1465"><b>Access</b></td><td data-bbox="918 1434 1269 1465">set, get (mission sequence only)</td></tr> <tr> <td data-bbox="641 1472 837 1503"><b>Default Value</b></td><td data-bbox="918 1472 1196 1503">21544.99962962963</td></tr> <tr> <td data-bbox="641 1510 722 1541"><b>Units</b></td><td data-bbox="918 1510 1147 1541">See A1ModJulian</td></tr> <tr> <td data-bbox="641 1548 788 1579"><b>Interfaces</b></td><td data-bbox="918 1548 1065 1579">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	See <a href="#">Epoch</a>	<b>Access</b>	set, get (mission sequence only)	<b>Default Value</b>	21544.99962962963	<b>Units</b>	See A1ModJulian	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	See <a href="#">Epoch</a>												
<b>Access</b>	set, get (mission sequence only)												
<b>Default Value</b>	21544.99962962963												
<b>Units</b>	See A1ModJulian												
<b>Interfaces</b>	GUI, script												
<b>Epoch.A1Gregorian</b>	<p>The <b>Spacecraft</b> orbit epoch in the A.1 system and the Gregorian format.</p> <table> <tr> <td data-bbox="641 1695 796 1727"><b>Data Type</b></td><td data-bbox="918 1695 1000 1727">String</td></tr> <tr> <td data-bbox="641 1733 869 1765"><b>Allowed Values</b></td><td data-bbox="918 1733 1073 1765">See <a href="#">Epoch</a></td></tr> <tr> <td data-bbox="641 1771 747 1803"><b>Access</b></td><td data-bbox="918 1771 1016 1803">set, get</td></tr> <tr> <td data-bbox="641 1809 837 1841"><b>Default Value</b></td><td data-bbox="918 1809 1261 1841">01 Jan 2000 12:00:00.034</td></tr> <tr> <td data-bbox="641 1848 722 1879"><b>Units</b></td><td data-bbox="918 1848 967 1879">N/A</td></tr> <tr> <td data-bbox="641 1886 788 1917"><b>Interfaces</b></td><td data-bbox="918 1886 1065 1917">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	See <a href="#">Epoch</a>	<b>Access</b>	set, get	<b>Default Value</b>	01 Jan 2000 12:00:00.034	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	See <a href="#">Epoch</a>												
<b>Access</b>	set, get												
<b>Default Value</b>	01 Jan 2000 12:00:00.034												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

Field	Description												
<b>Epoch.TAIGregorian</b>	<p>The <b>Spacecraft</b> orbit epoch in the TAI system and the Gregorian format.</p> <table> <tr> <td data-bbox="736 346 964 384"><b>Data Type</b></td><td data-bbox="1024 346 1095 384">String</td></tr> <tr> <td data-bbox="736 388 964 426"><b>Allowed Values</b></td><td data-bbox="1024 388 1171 426">See <b>Epoch</b></td></tr> <tr> <td data-bbox="736 430 964 468"><b>Access</b></td><td data-bbox="1024 430 1122 468">set, get</td></tr> <tr> <td data-bbox="736 473 964 511"><b>Default Value</b></td><td data-bbox="1024 473 1188 511">DefaultValue</td></tr> <tr> <td data-bbox="736 515 964 553"><b>Units</b></td><td data-bbox="1024 515 1356 553">01 Jan 2000 12:00:00.000</td></tr> <tr> <td data-bbox="736 557 964 595"><b>Interfaces</b></td><td data-bbox="1024 557 1160 595">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	See <b>Epoch</b>	<b>Access</b>	set, get	<b>Default Value</b>	DefaultValue	<b>Units</b>	01 Jan 2000 12:00:00.000	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	See <b>Epoch</b>												
<b>Access</b>	set, get												
<b>Default Value</b>	DefaultValue												
<b>Units</b>	01 Jan 2000 12:00:00.000												
<b>Interfaces</b>	GUI, script												
<b>Epoch.TAIModJulian</b>	<p>The <b>Spacecraft</b> orbit epoch in the TAI system and the Modified Julian format.</p> <table> <tr> <td data-bbox="736 667 964 705"><b>Data Type</b></td><td data-bbox="1024 667 1095 705">String</td></tr> <tr> <td data-bbox="736 709 964 747"><b>Allowed Values</b></td><td data-bbox="1024 709 1356 747">See <b>Epoch.A1ModJulian</b></td></tr> <tr> <td data-bbox="736 751 964 789"><b>Access</b></td><td data-bbox="1024 751 1122 789">set, get</td></tr> <tr> <td data-bbox="736 794 964 832"><b>Default Value</b></td><td data-bbox="1024 794 1106 832">21545</td></tr> <tr> <td data-bbox="736 836 964 874"><b>Units</b></td><td data-bbox="1024 836 1339 874">See <b>Epoch.A1ModJulian</b></td></tr> <tr> <td data-bbox="736 878 964 916"><b>Interfaces</b></td><td data-bbox="1024 878 1160 916">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	See <b>Epoch.A1ModJulian</b>	<b>Access</b>	set, get	<b>Default Value</b>	21545	<b>Units</b>	See <b>Epoch.A1ModJulian</b>	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	See <b>Epoch.A1ModJulian</b>												
<b>Access</b>	set, get												
<b>Default Value</b>	21545												
<b>Units</b>	See <b>Epoch.A1ModJulian</b>												
<b>Interfaces</b>	GUI, script												
<b>Epoch.TDBGregorian</b>	<p>The <b>Spacecraft</b> orbit epoch in the TDB system and the Gregorian format.</p> <table> <tr> <td data-bbox="736 988 964 1026"><b>Data Type</b></td><td data-bbox="1024 988 1095 1026">String</td></tr> <tr> <td data-bbox="736 1030 964 1068"><b>Allowed Values</b></td><td data-bbox="1024 1030 1171 1068">See <b>Epoch</b></td></tr> <tr> <td data-bbox="736 1072 964 1110"><b>Access</b></td><td data-bbox="1024 1072 1122 1110">set, get</td></tr> <tr> <td data-bbox="736 1115 964 1153"><b>Default Value</b></td><td data-bbox="1024 1115 1356 1153">01 Jan 2000 12:00:32.184</td></tr> <tr> <td data-bbox="736 1157 964 1195"><b>Units</b></td><td data-bbox="1024 1157 1339 1195">See <b>Epoch.A1Gregorian</b></td></tr> <tr> <td data-bbox="736 1199 964 1237"><b>Interfaces</b></td><td data-bbox="1024 1199 1160 1237">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	See <b>Epoch</b>	<b>Access</b>	set, get	<b>Default Value</b>	01 Jan 2000 12:00:32.184	<b>Units</b>	See <b>Epoch.A1Gregorian</b>	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	See <b>Epoch</b>												
<b>Access</b>	set, get												
<b>Default Value</b>	01 Jan 2000 12:00:32.184												
<b>Units</b>	See <b>Epoch.A1Gregorian</b>												
<b>Interfaces</b>	GUI, script												
<b>Epoch.TDBModJulian</b>	<p>The <b>Spacecraft</b> orbit epoch in the TDB system and the Modified Julian format.</p> <table> <tr> <td data-bbox="736 1326 964 1364"><b>Data Type</b></td><td data-bbox="1024 1326 1095 1364">String</td></tr> <tr> <td data-bbox="736 1368 964 1406"><b>Allowed Values</b></td><td data-bbox="1024 1368 1171 1406">See <b>Epoch</b></td></tr> <tr> <td data-bbox="736 1410 964 1448"><b>Access</b></td><td data-bbox="1024 1410 1122 1448">set, get</td></tr> <tr> <td data-bbox="736 1453 964 1491"><b>Default Value</b></td><td data-bbox="1024 1453 1286 1491">21545.00037249916</td></tr> <tr> <td data-bbox="736 1495 964 1533"><b>Units</b></td><td data-bbox="1024 1495 1339 1533">See <b>Epoch.A1ModJulian</b></td></tr> <tr> <td data-bbox="736 1537 964 1575"><b>Interfaces</b></td><td data-bbox="1024 1537 1160 1575">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	See <b>Epoch</b>	<b>Access</b>	set, get	<b>Default Value</b>	21545.00037249916	<b>Units</b>	See <b>Epoch.A1ModJulian</b>	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	See <b>Epoch</b>												
<b>Access</b>	set, get												
<b>Default Value</b>	21545.00037249916												
<b>Units</b>	See <b>Epoch.A1ModJulian</b>												
<b>Interfaces</b>	GUI, script												
<b>Epoch.TTGregorian</b>	<p>The <b>Spacecraft</b> orbit epoch in the TT system and the Gregorian format.</p> <table> <tr> <td data-bbox="736 1643 964 1681"><b>Data Type</b></td><td data-bbox="1024 1643 1095 1681">String</td></tr> <tr> <td data-bbox="736 1685 964 1723"><b>Allowed Values</b></td><td data-bbox="1024 1685 1171 1723">See <b>Epoch</b></td></tr> <tr> <td data-bbox="736 1727 964 1765"><b>Access</b></td><td data-bbox="1024 1727 1122 1765">set, get</td></tr> <tr> <td data-bbox="736 1769 964 1807"><b>Default Value</b></td><td data-bbox="1024 1769 1356 1807">01 Jan 2000 12:00:32.184</td></tr> <tr> <td data-bbox="736 1812 964 1850"><b>Units</b></td><td data-bbox="1024 1812 1339 1850">See <b>Epoch.A1Gregorian</b></td></tr> <tr> <td data-bbox="736 1854 964 1892"><b>Interfaces</b></td><td data-bbox="1024 1854 1160 1892">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	See <b>Epoch</b>	<b>Access</b>	set, get	<b>Default Value</b>	01 Jan 2000 12:00:32.184	<b>Units</b>	See <b>Epoch.A1Gregorian</b>	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	See <b>Epoch</b>												
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<b>Default Value</b>	01 Jan 2000 12:00:32.184												
<b>Units</b>	See <b>Epoch.A1Gregorian</b>												
<b>Interfaces</b>	GUI, script												

Field	Description
<b>Epoch.TTModJulian</b>	The <b>Spacecraft</b> orbit epoch in the TT system and the Modified Julian format.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> See <a href="#">Epoch</a></p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 21545.0003725</p> <p><b>Units</b> See <a href="#">Epoch.A1ModJulian</a></p> <p><b>Interfaces</b> GUI, script</p>
<b>Epoch.UTCGregorian</b>	The <b>Spacecraft</b> orbit epoch in the UTC system and the Gregorian format.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> See <a href="#">Epoch</a></p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 01 Jan 2000 11:59:28.000</p> <p><b>Units</b> See <a href="#">Epoch.A1Gregorian</a></p> <p><b>Interfaces</b> GUI, script</p>
<b>Epoch.UTCModJulian</b>	The <b>Spacecraft</b> orbit epoch in the UTC system and the Modified Julian format.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> Range</p> <p><b>Access</b> See <a href="#">Epoch</a></p> <p><b>Default Value</b> 21544.99962962963</p> <p><b>Units</b> See <a href="#">Epoch.A1ModJulian</a></p> <p><b>Interfaces</b> GUI, script</p>

## GUI



A change in **EpochFormat** causes an immediate update to **Epoch** to reflect the chosen time system and format.

### Remarks

GMAT supports five time systems or scales and two formats:

A.1	USNO atomic time; GMAT's internal time system
TAI	International Atomic Time
TDB	Barycentric Dynamical Time
TT	Terrestrial Time
UTC	Coordinated Universal Time

Gregorian	Text with the following format: dd mmm yyyy HH:MM:SS.FFF  dd two-digit day of month mmm first three letters of month yyyy four-digit year HH two-digit hour MM two-digit minute SS two-digit second FFF three-digit fraction of second
Modified Julian	Floating-point number of days from a reference epoch. In GMAT, the reference epoch is 05 Jan 1941 12:00:00.000 (JD 2430000.0).

The epoch can be set in multiple ways. The default method is to set the **DateFormat** field to the desired time system and format, then set the **Epoch** field to the desired epoch. This method cannot be used to get the epoch value, such as on the right-hand side of an assignment statement.

```
aSat.DateFormat = UTCGregorian
aSat.Epoch = '18 May 2012 12:00:00.000'
```

An alternate method is to specify the **DateFormat** in the parameter name. This method works in both “get” and “set” modes.

```
aSat.Epoch.UTCGregorian = '18 May 2012 12:00:00.000'
Report aReport aSat.Epoch.UTCGregorian
```

A third method can be used in “get” mode everywhere, but in “set” mode only in the mission sequence (i.e. after the **BeginMissionSequence** command).

```
aSat.UTCGregorian = '18 May 2012 12:00:00.000'
Report aReport aSat.UTCGregorian
```

GMAT uses the A.1 time system in the Modified Julian format for its internal calculations. The system converts all other systems and formats on input and again at output.

### Leap Seconds

When converting to and from the UTC time system, GMAT includes leap seconds as appropriate, according to the `tai-utc.dat` data file from the IERS. This file contains the conversion between TAI and UTC, including all leap seconds that have been added or announced.

GMAT applies the leap second as the last second before the date listed in the `tai-utc.dat` file, which historically has been either January 1 or July 1. In the Gregorian date format, the leap second appears as a “60<sup>th</sup> second”: for example, “31 Dec 2008 23:59:60.000”. From the International Astronomical Union’s Standards of Fundamental Astronomy “SOFA Time Scale and Calendar Tools” documentation: “Note that UTC

*has to be expressed as hours, minutes and seconds (or at least in seconds in a given day) if leap seconds are to be taken into account in the correct manner.* In particular, it is inappropriate to express UTC as a Julian Date, because there will be an ambiguity during a leap second so that for example 1994 June 30 23:59:60:0 and 1994 July 1 00:00:00:0 would both come out as MJD 49534.00000 and because subtracting two such JDs would not yield the correct interval in cases that contain leap seconds." For this reason, we discourage use of the UTC modified Julian system, and recommend using UTC Gregorian when a UTC time system is required.

For epochs prior to the first entry in the leap-second file, the UTC and TAI time systems are considered identical (i.e. zero leap seconds are added). For epochs after the last entry, the leap second count from the last entry is used.

The tai-utc.dat file is periodically updated by the IERS when new leap seconds are announced. The latest version of this file can always be found at <http://maia.usno.navy.mil/ser7/tai-utc.dat>. To replace it, download the latest version and replace GMAT's file in the location <GMAT>/data/time/tai-utc.dat, where <GMAT> is the install directory of GMAT on your system.

## Examples

Setting the epoch for propagation

```
Create Spacecraft aSat
aSat.DateFormat = TAIModJulian
aSat.Epoch = 25562.5

Create ForceModel aFM
Create Propagator aProp
aProp.FM = aFM

BeginMissionSequence
Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

Plotting and reporting the epoch (syntax #1)

```
Create Spacecraft aSat
aSat.DateFormat = A1Gregorian
aSat.Epoch = '12 Jul 2015 08:21:45.921'

Create XYPlot aPlot
aPlot.XVariable = aSat.UTCModJulian
aPlot.YVariables = aSat.Earth.Altitude

Create Report aReport
aReport.Add = {aSat.UTCGregorian, aSat.EarthMJ2000Eq.ECC}
```

Plotting and reporting the epoch (syntax #2)

```
Create Spacecraft aSat
```

```
aSat.DateFormat = TTGregorian  
aSat.Epoch = '01 Dec 1978 00:00:00.000'  
  
Create XYPlot aPlot  
aPlot.XVariable = aSat.Epoch.TTModJulian  
aPlot.YVariables = aSat.Earth.RMAG  
  
Create Report aReport  
aReport.Add = {aSat.Epoch.A1Gregorian, aSat.Earth.RMAG}
```

## Spacecraft Hardware

Add hardware to a spacecraft

### Description

The hardware fields allow you to attach pre-configured hardware models to a spacecraft. Current models include **ChemicalTank**, **ChemicalThruster**, **ElectricTank**, and **ElectricThruster**. Before you attach a hardware model to a **Spacecraft**, you must first create the model.

See Also: [ChemicalTank](#), [ChemicalThruster](#), [ElectricTank](#), [ElectricThruster](#)

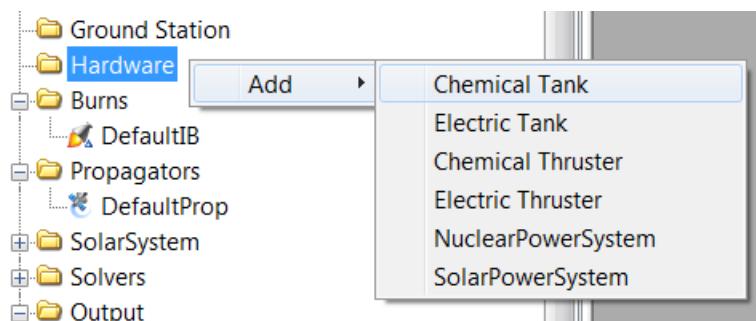
### Fields

Field	Description
<b>Tanks</b>	This field is used to attach <b>FuelTank(s)</b> to a <b>Spacecraft</b> . In a script command, an empty list, e.g., DefaultSC.Tanks={}, is allowed and is used to indicate that no <b>FuelTank(s)</b> is attached to the spacecraft.  <b>Data Type</b> Reference Array <b>Allowed Values</b> A list of <b>ChemicalTanks</b> and <b>Chemical Thrusters</b> . <b>Access</b> set <b>Default Value</b> N/A <b>Units</b> N/A <b>Interfaces</b> GUI, script.
<b>Thrusters</b>	This field is used to attach <b>Thruster(s)</b> to a <b>Spacecraft</b> . In a script command, an empty list, e.g., DefaultSC.Thrusters={}, is allowed and is used to indicate that no <b>Thrusters</b> are attached to the spacecraft.  <b>Data Type</b> Reference Array <b>Allowed Values</b> A list of <b>ChemicalThrusters</b> and <b>ElectricThrusters</b> . <b>Access</b> set <b>Default Value</b> N/A <b>Units</b> N/A <b>Interfaces</b> GUI, script

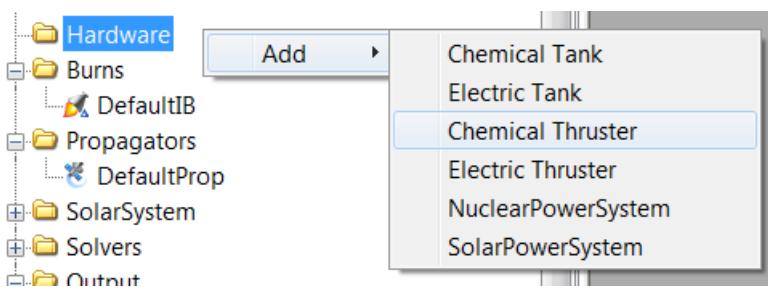
### GUI

There are two spacecraft hardware items, the **FuelTank** and the **Thruster**, that can be attached to a Spacecraft. Here, we describe the method used to create and then attach these items to a **Spacecraft**. For details on how to configure the **FuelTank** and **Thruster** resources, see the help for the individual hardware item. Note the discussion below uses a chemical system as an example but applies equally to electric systems.

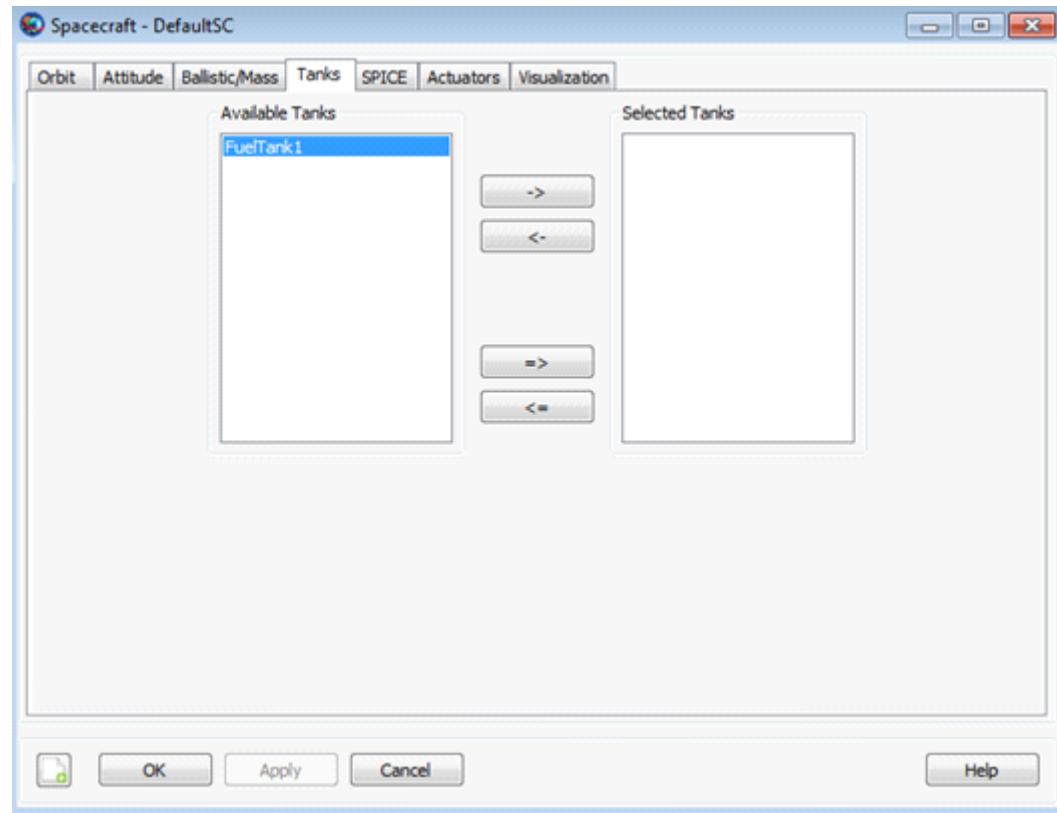
As shown below, to add a **ChemicalTank** to your script, highlight the **Hardware** resource and then right click to add a **ChemicalTank**.



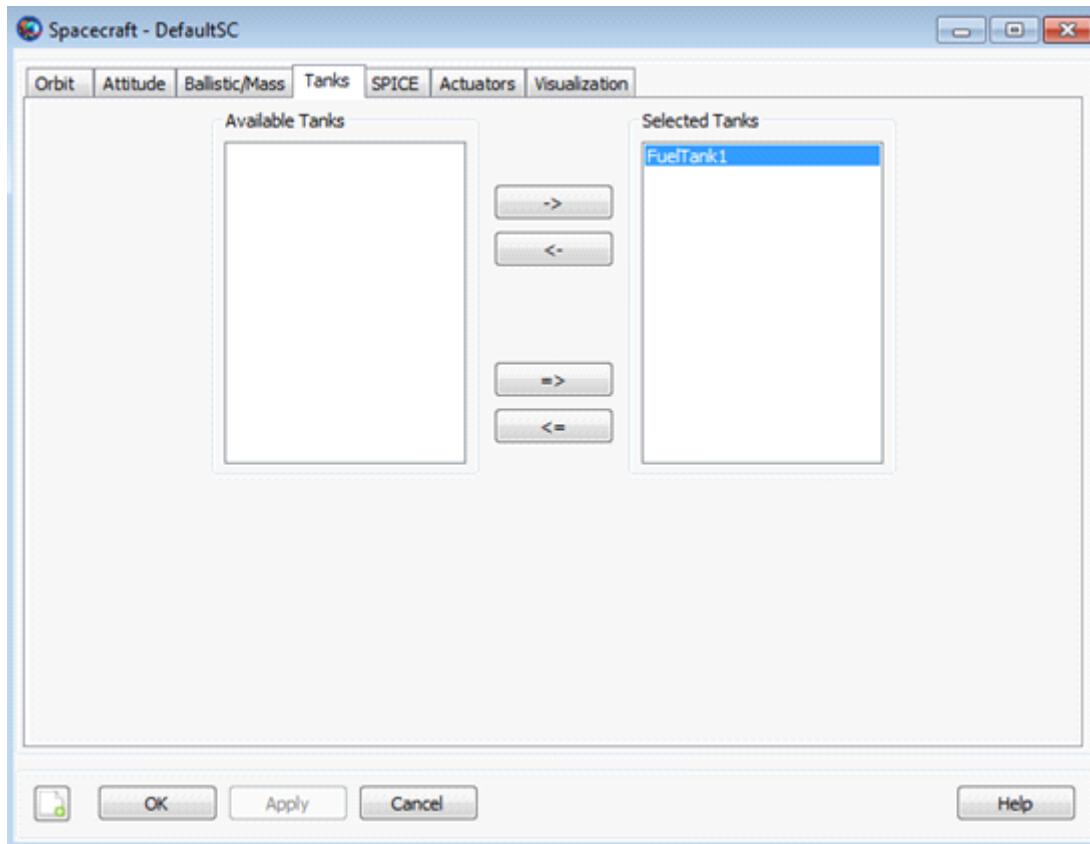
To add a **Thruster** to your script, highlight the **Hardware** resource and then right click to add a **Thruster**.



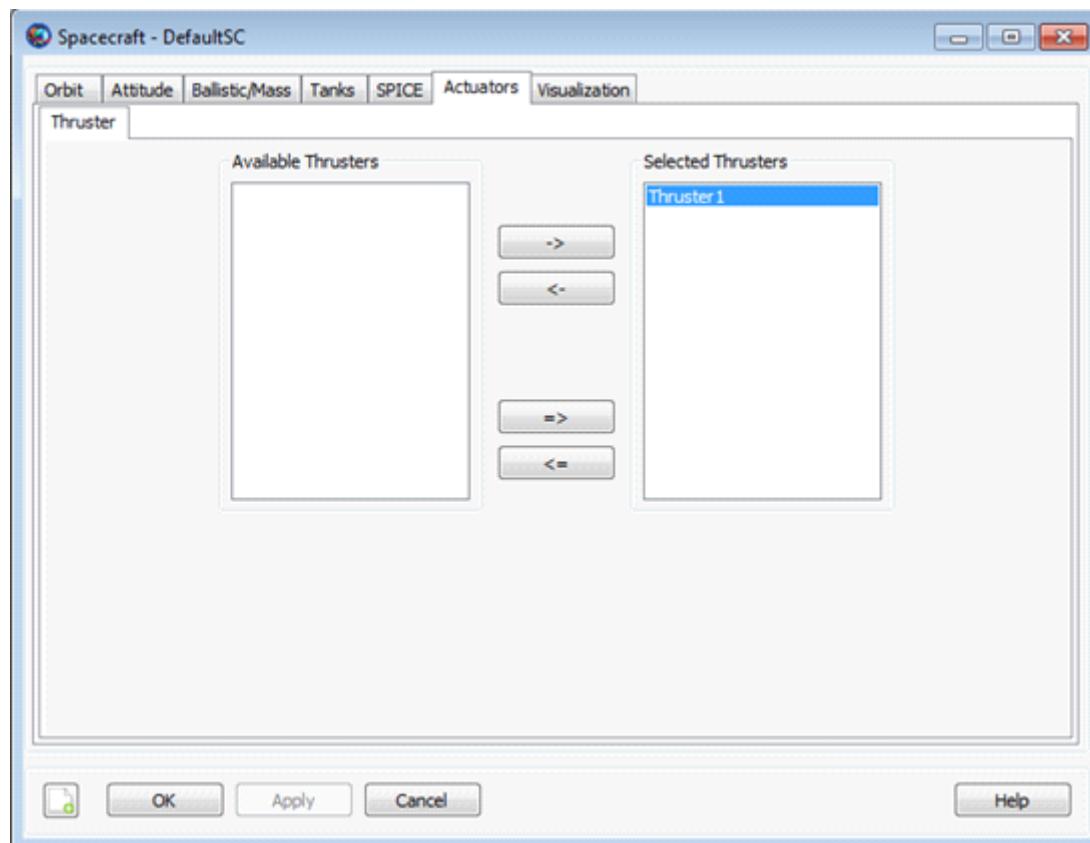
Thus far, we have created both a **ChemicalTank** and a **ChemicalThruster**. Next, we attach both the **ChemicalTank** and the **ChemicalThruster** to a particular **Spacecraft**. To do this, double click on the desired **Spacecraft** under the **Spacecraft** resource to bring up the associated GUI panel. Then click on the **Tanks** tab to bring up the following GUI display.



Next, select the desired **ChemicalTank** and use the right arrow button to attach the **ChemicalTank** to the **Spacecraft** as shown below. Then click the **Apply** button.



Similarly, to attach a **ChemicalThruster** to a **Spacecraft**, double click on the desired **Spacecraft** under the **Spacecraft** resource and then select the **Actuators** tab. Then select the desired **ChemicalThruster** and use the right arrow to attach the **ChemicalThruster** to the **Spacecraft** as shown below. Finally, click the **Apply** button.



## Remarks

To use a **Thruster** to apply a finite burn to a **Spacecraft**, additional steps are required. For example, when you create the **ChemicalThruster** resource, you have to associate a **ChemicalTank** with the **ChemicalThruster**. For details on this and related matters, see the help for the **ChemicalTank**, **ChemicalThruster**, and **FiniteBurn** resources.

## Examples

Create a default **Spacecraft**. Create **ChemicalTank** and **ChemicalThruster** resources and attach them to the **Spacecraft**.

```
% Create default Spacecraft, ChemicalTank, and Thruster Resources
Create Spacecraft DefaultSC
Create ChemicalTank FuelTank1
Create ChemicalThruster Thruster1

% Attach ChemicalTank and Thruster to the spacecraft
DefaultSC.Thrusters = {Thruster1}
DefaultSC.Tanks = {FuelTank1}

BeginMissionSequence
```

## Spacecraft Orbit State

The orbital initial conditions

### Description

GMAT supports a suite of state types for defining the orbital state, including **Cartesian** and **Keplerian**, among others. In addition, you can define the orbital state in different coordinate systems, for example **EarthMJ2000Eq** and **EarthFixed**. GMAT provides three general state types that can be used with any coordinate system: **Cartesian**, **SphericalAZFPA**, and **SphericalRADEC**. There are three additional state types that can be used with coordinate systems centered at a celestial body: **Keplerian**, **ModifiedKeplerian**, and **Equinoctial**.

In [the section called “Remarks”](#) below, we describe each state type in detail including state-type definitions, singularities, and how the state fields interact with the **CoordinateSystem** and **Epoch** fields. There are some limitations when setting the orbital state during initialization, which are discussed in [the section called “Remarks”](#). We also include examples for setting each state type in commonly used coordinate systems.

See Also: [Spacecraft](#), [Propagator](#), and [Spacecraft Epoch](#)

### Fields

Field	Description												
<b>AltEquinoctialP</b>	A measure of the orientation of the orbit. AltEquinoctialP and AltEquinoctialQ together govern how an orbit is oriented. <b>AltEquinoctialP</b> = $\sin(\text{INC}/2) * \sin(\text{RAAN})$ . <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-1 # <b>AltEquinoctialP</b> # 1</td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>0.08982062789020774</td></tr> <tr> <td><b>Units</b></td><td>(None)</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-1 # <b>AltEquinoctialP</b> # 1	<b>Access</b>	set, get	<b>Default Value</b>	0.08982062789020774	<b>Units</b>	(None)	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-1 # <b>AltEquinoctialP</b> # 1												
<b>Access</b>	set, get												
<b>Default Value</b>	0.08982062789020774												
<b>Units</b>	(None)												
<b>Interfaces</b>	GUI, script												
<b>AltEquinoctialQ</b>	A measure of the orientation of the orbit. AltEquinoctialP and AltEquinoctialQ together govern how an orbit is oriented. <b>AltEquinoctialQ</b> = $\sin(\text{INC}/2) * \cos(\text{RAAN})$ . <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-1 # <b>AltEquinoctialQ</b> # 1</td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>0.06674269576352432</td></tr> <tr> <td><b>Units</b></td><td>(None)</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-1 # <b>AltEquinoctialQ</b> # 1	<b>Access</b>	set, get	<b>Default Value</b>	0.06674269576352432	<b>Units</b>	(None)	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-1 # <b>AltEquinoctialQ</b> # 1												
<b>Access</b>	set, get												
<b>Default Value</b>	0.06674269576352432												
<b>Units</b>	(None)												
<b>Interfaces</b>	GUI, script												

Field	Description	
<b>AOP</b>	The orbital argument of periapsis expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	-# < AOP < #
	<b>Access</b>	set, get
	<b>Default Value</b>	314.1905515359921
	<b>Units</b>	deg.
	<b>Interfaces</b>	GUI, script
<b>AZI</b>	The orbital velocity azimuth expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	-# < AZI < #
	<b>Access</b>	set, get
	<b>Default Value</b>	82.37742168155043
	<b>Units</b>	deg.
	<b>Interfaces</b>	GUI, script
<b>BrouwerLongAOP</b>	Brouwer-Lyddane long-term averaged (short-term averaged) mean argument of periapsis.	
<b>BrouwerShortAOP</b>	<b>Data Type</b> Real <b>Allowed Values</b> -# < BrouwerLongAOP/BrouwerShortAOP < # <b>Access</b> set, get <b>Default Value</b> Conversion from default Cartesian state <b>Units</b> deg <b>Interfaces</b> GUI, script	
<b>BrouwerLongECC</b>	Brouwer-Lyddane long-term averaged (short-term averaged) mean eccentricity.	
<b>BrouwerShortECC</b>	<b>Data Type</b> Real <b>Allowed Values</b> 0 # BrouwerLongECC/BrouwerShort-ECC # 0.99 <b>Access</b> set, get <b>Default Value</b> Conversion from default Cartesian state <b>Units</b> N/A <b>Interfaces</b> GUI, script	

Field	Description		
<b>BrouwerLongINC</b>	Brouwer-Lyddane long-term averaged (short-term averaged) mean inclination.		
<b>BrouwerShortINC</b>	<b>Data Type</b>	Real	
	<b>Allowed Values</b>	0 # <b>BrouwerLongINC/BrouwerShortINC</b> # 180	
	<b>Access</b>	set, get	
	<b>Default Value</b>	Conversion from default Cartesian state	
	<b>Units</b>	deg	
	<b>Interfaces</b>	GUI, script	
<b>BrouwerLongMA</b>	Brouwer-Lyddane long-term averaged (short-term averaged) mean MA (mean anomaly).		
<b>BrouwerShortMA</b>	<b>Data Type</b>	Real	
	<b>Allowed Values</b>	-# < <b>BrouwerLongMA/BrouwerShortMA</b> < #	
	<b>Access</b>	set, get	
	<b>Default Value</b>	Conversion from default Cartesian state	
	<b>Units</b>	deg	
	<b>Interfaces</b>	GUI, script	
<b>BrouwerLongRAAN</b>	Brouwer-Lyddane long-term averaged (short-term averaged) mean RAAN (right ascension of the ascending node).		
<b>BrouwerShortRAAN</b>	<b>Data Type</b>	Real	
	<b>Allowed Values</b>	-# < <b>BrouwerLongRAAN/BrouwerShortRAAN</b> < #	
	<b>Access</b>	set, get	
	<b>Default Value</b>	Conversion from default Cartesian state	
	<b>Units</b>	deg	
	<b>Interfaces</b>	GUI, script	
<b>BrouwerLongSMA</b>	Long-term averaged (short-term averaged) mean semi-major axis.		
<b>BrouwerShortSMA</b>	<b>Data Type</b>	Real	
	<b>Allowed Values</b>	<b>Brouwer*SMA</b> > 3000/(1-Brouwer*ECC)	
	<b>Access</b>	set, get	
	<b>Default Value</b>	Conversion from default Cartesian state	
	<b>Units</b>	km	
	<b>Interfaces</b>	GUI, script	

Field	Description
<b>CoordinateSystem</b>	The coordinate system with respect to which the orbital state is defined. The <b>CoordinateSystem</b> field is dependent upon the <b>DisplayStateType</b> field. If the coordinate system chosen by the user does not have a gravitational body at the origin, then the state types <b>Keplerian</b> , <b>ModifiedKeplerian</b> , and <b>Equinoctial</b> are not permitted.
	<b>Data Type</b> String <b>Allowed Values</b> <b>CoordinateSystem</b> resource <b>Access</b> set <b>Default Value</b> <b>EarthMJ2000Eq</b> <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>DEC</b>	The declination of the orbital position expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.
	<b>Data Type</b> Real <b>Allowed Values</b> -90 # <b>DEC</b> # 90 <b>Access</b> set, get <b>Default Value</b> 10.37584492005105 <b>Units</b> deg <b>Interfaces</b> GUI, script
<b>DECV</b>	The declination of orbital velocity expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.
	<b>Data Type</b> Real <b>Allowed Values</b> -90 # <b>DECV</b> # 90 <b>Access</b> set, get <b>Default Value</b> 7.747772036108118 <b>Units</b> deg <b>Interfaces</b> GUI, script
<b>Delaunayg</b>	Delaunay "g" element, identical to <b>AOP</b> , expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.
	<b>Data Type</b> Real <b>Allowed Values</b> -# < <b>Delaunayg</b> < # <b>Access</b> set, get <b>Default Value</b> 314.1905515359921 <b>Units</b> deg <b>Interfaces</b> GUI, script

Field	Description
<b>DelaunayG</b>	Delaunay "G" element, the magnitude of the orbital angular momentum, expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> 0 # <b>DelaunayG</b> &lt; #</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 53525.52895581695</p> <p><b>Units</b> km<sup>2</sup>/s</p> <p><b>Interfaces</b> GUI, script</p>
<b>Delaunayh</b>	Delaunay "h" element, identical to <b>RAAN</b> , expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> -# &lt; <b>Delaunayh</b> &lt; #</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 306.6148021947984</p> <p><b>Units</b> deg</p> <p><b>Interfaces</b> GUI, script</p>
<b>DelaunayH</b>	Delaunay "H" element, the z-component of the orbital angular momentum vector, expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> -# &lt; <b>Delaunayl</b> &lt; #</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 52184.99999999999</p> <p><b>Units</b> km<sup>2</sup>/s</p> <p><b>Interfaces</b> GUI, script</p>
<b>Delaunayl</b>	Delaunay "#" element, identical to the mean anomaly, expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> -# &lt; <b>Delaunayl</b> &lt; #</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 97.10782663991999</p> <p><b>Units</b> deg</p> <p><b>Interfaces</b> GUI, script</p>

Field	Description
<b>DelaunayL</b>	<p>Delaunay "L" element, related to the two-body orbital energy, expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.</p>
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	0 # <b>DelaunayL</b> < #
	<b>Access</b>
	set, get
	<b>Default Value</b>
	53541.66590560955
	<b>Units</b>
	km <sup>2</sup> /s
	<b>Interfaces</b>
	GUI, script
<b>DisplayStateType</b>	<p>The orbital state type displayed in the GUI. Allowed state types are dependent upon the selection of <b>CoordinateSystem</b>. For example, if the coordinate system does not have a celestial body at the origin, <b>Keplerian</b>, <b>ModifiedKeplerian</b>, and <b>Equinoctial</b> are not allowed options for <b>DisplayStateType</b>.</p>
	<b>Data Type</b>
	String
	<b>Allowed Values</b>
	Cartesian, Keplerian, ModifiedKeplerian, SphericalAZFPA, SphericalRADEC, or Equinoctial
	<b>Access</b>
	set
	<b>Default Value</b>
	Cartesian
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	GUI, script
<b>ECC</b>	<p>The orbital eccentricity expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.</p>
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	<b>ECC</b> < 0.9999999 or <b>ECC</b> > 1.0000001. If <b>ECC</b> > 1, <b>SMA</b> must be < 0
	<b>Access</b>
	set, get
	<b>Default Value</b>
	0.02454974900598137
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	GUI, script

Field	Description												
<b>EphemerisName</b>	<p>Path to an ephemeris file to be used for the spacecraft. The parameter may specify a file in STK, CCSDS-OEM, or Code500 format. This file may be used with an ephemeris propagator to provide the spacecraft trajectory. SPICE BSP/SPK files are set on the <b>OrbitSpiceKernelName</b> parameter. See the <a href="#">Propagator</a> resource for details on using an ephemeris file propagator.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>A valid file path to an STK, CCSDS-OEM, or Code500 ephemeris file</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>Unset</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	A valid file path to an STK, CCSDS-OEM, or Code500 ephemeris file	<b>Access</b>	set	<b>Default Value</b>	Unset	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	A valid file path to an STK, CCSDS-OEM, or Code500 ephemeris file												
<b>Access</b>	set												
<b>Default Value</b>	Unset												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>EquinoctialH</b>	<p>A measure of the orbital eccentricity and argument of periapsis. <b>EquinoctialH</b> and <b>EquinoctialK</b> together govern how elliptic an orbit is and where the periapsis is located. <b>EquinoctialH = ECC * sin(AOP + RAAN)</b> .</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-0.99999 &lt; <b>EquinoctialH</b> &lt; 0.99999, AND sqrt(<b>EquinoctialH^2 + EquinoctialK^2</b>) &lt; 0.99999</td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>-0.02423431419337062</td></tr> <tr> <td><b>Units</b></td><td>dimless</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-0.99999 < <b>EquinoctialH</b> < 0.99999, AND sqrt( <b>EquinoctialH^2 + EquinoctialK^2</b> ) < 0.99999	<b>Access</b>	set, get	<b>Default Value</b>	-0.02423431419337062	<b>Units</b>	dimless	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-0.99999 < <b>EquinoctialH</b> < 0.99999, AND sqrt( <b>EquinoctialH^2 + EquinoctialK^2</b> ) < 0.99999												
<b>Access</b>	set, get												
<b>Default Value</b>	-0.02423431419337062												
<b>Units</b>	dimless												
<b>Interfaces</b>	GUI, script												
<b>EquinoctialK</b>	<p>A measure of the orbital eccentricity and argument of periapsis. <b>EquinoctialH</b> and <b>EquinoctialK</b> together govern how elliptic an orbit is and where the periapsis is located. <b>EquinoctialK = ECC * cos(AOP + RAAN)</b> .</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>-0.99999 &lt; <b>EquinoctialK</b> &lt; 0.99999, AND sqrt(<b>EquinoctialH^2 + EquinoctialK^2</b>) &lt; 0.99999</td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>-0.003922778585859663</td></tr> <tr> <td><b>Units</b></td><td>dimless</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	-0.99999 < <b>EquinoctialK</b> < 0.99999, AND sqrt( <b>EquinoctialH^2 + EquinoctialK^2</b> ) < 0.99999	<b>Access</b>	set, get	<b>Default Value</b>	-0.003922778585859663	<b>Units</b>	dimless	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	-0.99999 < <b>EquinoctialK</b> < 0.99999, AND sqrt( <b>EquinoctialH^2 + EquinoctialK^2</b> ) < 0.99999												
<b>Access</b>	set, get												
<b>Default Value</b>	-0.003922778585859663												
<b>Units</b>	dimless												
<b>Interfaces</b>	GUI, script												

Field	Description
<b>EquinoctialP</b>	A measure of the orientation of the orbit. <b>EquinoctialP</b> and <b>EquinoctialQ</b> together govern how an orbit is oriented. <b>EquinoctialP</b> = $\tan(\text{INC}/2) * \sin(\text{RAAN})$ .
	<b>Data Type</b> Real <b>Allowed Values</b> $-\# < \text{EquinoctialP} < \#$ <b>Access</b> set, get <b>Default Value</b> -0.09038834725719359 <b>Units</b> dimless <b>Interfaces</b> GUI, script
<b>EquinoctialQ</b>	A measure of the orientation of the orbit. <b>EquinoctialP</b> and <b>EquinoctialQ</b> together govern how an orbit is oriented. <b>EquinoctialQ</b> = $\tan(\text{INC}/2) * \cos(\text{RAAN})$ .
	<b>Data Type</b> Real <b>Allowed Values</b> $-\# < \text{EquinoctialQ} < \#$ <b>Access</b> set, get <b>Default Value</b> 0.06716454898232072 <b>Units</b> None <b>Interfaces</b> GUI, script
<b>FPA</b>	The orbital flight path angle expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.
	<b>Data Type</b> Real <b>Allowed Values</b> $0 \# \text{FPA} \# 180$ <b>Access</b> set, get <b>Default Value</b> 88.60870365370448 <b>Units</b> Deg. <b>Interfaces</b> GUI, script
<b>INC</b>	The orbital inclination expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.
	<b>Data Type</b> Real <b>Allowed Values</b> $0 \# \text{INC} \# 180$ <b>Access</b> set, get <b>Default Value</b> 12.85008005658097 <b>Units</b> deg <b>Interfaces</b> GUI, script

Field	Description
<b>IncomingBVAZI</b>	<b>IncomingBVAZI/OutgoingBVAZI</b> is the B-vector azimuth at infinity of the incoming/outgoing asymptote measured counter-clockwise from south. If <b>C3Energy</b> < 0 the apsides vector is substituted for the outgoing/incoming asymptote.
<b>OutgoingBVAZI</b>	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> -# &lt; <b>IncomingBVAZI/OutgoingBVAZI</b> &lt; #</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> Conversion from default Cartesian state</p> <p><b>Units</b> deg</p> <p><b>Interfaces</b> GUI, script</p>
<b>IncomingC3Energy</b>	C3 energy. <b>C3Energy</b> = -mu/SMA. <b>IncomingC3Energy/OutgoingC3Energy</b> differ only in that they are associated with
<b>OutgoingC3Energy</b>	the <b>IncomingAsymptote</b> and <b>OutgoingAsymptote</b> state representations, respectively.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> <b>IncomingC3Energy</b> # -1e-7 or <b>IncomingC3Energy</b> # 1e-7</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> Conversion from default Cartesian state</p> <p><b>Units</b> km<sup>2</sup>/s<sup>2</sup></p> <p><b>Interfaces</b> GUI, script</p>
<b>IncomingDHA</b>	<b>IncomingDHA/OutgoingDHA</b> is the declination of the incoming/outgoing asymptote. If <b>C3Energy</b> < 0 the apsides vector is substituted for the incoming/outgoing asymptote..
<b>OutgoingDHA</b>	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> -90° # <b>IncomingDHA/OutgoingDHA</b> &lt; 90°</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> Conversion from default Cartesian state</p> <p><b>Units</b> deg</p> <p><b>Interfaces</b> GUI, script</p>

Field	Description
<b>IncomingRadPer</b>	The orbital radius of periapsis. The radius of periapsis is the minimum distance (osculating) between the spacecraft and celestial body at the origin of coordinate system. <b>IncomingRadPer/OutgoingRadPer</b> differ from <b>RadPer</b> only in that they are associated with the <b>IncomingAsymptote</b> and <b>OutgoingAsymptote</b> state representations, respectively.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> <math>\text{abs}(\text{IncomingRadPer}) \# 1 \text{ meter}</math>.</p>
	<p><b>Access</b> set, get</p> <p><b>Default Value</b> Conversion from default Cartesian state</p> <p><b>Units</b> km</p> <p><b>Interfaces</b> GUI, script</p>
<b>IncomingRHA</b>	<b>IncomingRHA/OutgoingRHA</b> is the right ascension of the incoming/outgoing asymptote. If <b>C3Energy</b> < 0 the apsides vector is substituted for the incoming/outgoing asymptote.
<b>OutgoingRHA</b>	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> <math>-\# &lt; \text{IncomingRHA/OutgoingRHA} &lt; \#</math></p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> Conversion from default Cartesian state</p> <p><b>Units</b> deg</p> <p><b>Interfaces</b> GUI, script</p>
<b>MLONG</b>	A measure of the location of the spacecraft in it's orbit. <b>MLONG</b> = <b>AOP + RAAN + MA</b> .
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> <math>-360 \# \text{MLONG} \# 360</math></p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 357.9131803707105</p> <p><b>Units</b> deg.</p> <p><b>Interfaces</b> GUI, script</p>
<b>ModEquinoctialF</b>	Components of the eccentricity vector (with <b>ModEquinoctialG</b> ). The eccentricity vector has a magnitude equal to the eccentricity and it points from the central body to perigee. <b>ModEquinoctialF</b> = <b>ECC * cos(AOP+RAAN)</b>
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> <math>-\# &lt; \text{ModEquinoctialF} &lt; \#</math></p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> -0.003922778585859663</p> <p><b>Units</b> (None)</p> <p><b>Interfaces</b> GUI, script</p>

Field	Description
<b>ModEquinoctialG</b>	Components of eccentricity vector (with <b>ModEquinoctialF</b> ). <b>ModEquinoctialG = ECC * sin(AOP+RAAN)</b>
	<b>Data Type</b> Real <b>Allowed Values</b> -# < <b>ModEquinoctialG</b> < # <b>Access</b> set, get <b>Default Value</b> -0.02423431419337062 <b>Units</b> (None) <b>Interfaces</b> GUI, script
<b>ModEquinoctialH</b>	Identical to <b>EquinoctialQ</b> .
	<b>Data Type</b> Real <b>Allowed Values</b> -# < <b>ModEquinoctialH</b> < # <b>Access</b> set, get <b>Default Value</b> 0.06716454898232072 <b>Units</b> (None) <b>Interfaces</b> GUI, script
<b>ModEquinoctialK</b>	Identical to <b>EquinoctialP</b> .
	<b>Data Type</b> Real <b>Allowed Values</b> -# < <b>ModEquinoctialK</b> < # <b>Access</b> set, get <b>Default Value</b> -0.09038834725719359 <b>Units</b> (None) <b>Interfaces</b> GUI, script
<b>NAIFId</b>	The spacecraft Id used in SPICE kernels.
	<b>Data Type</b> String <b>Allowed Values</b> String <b>Access</b> set <b>Default Value</b> -123456789 <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>OrbitSpiceKernel-Name</b>	SPK Kernels for spacecraft orbit. SPK orbit kernels have extension ".BSP". This field cannot be set in the Mission Sequence.
	<b>Data Type</b> String array <b>Allowed Values</b> List of path and filenames. <b>Access</b> set <b>Default Value</b> No Default. The field is empty. <b>Units</b> N/A <b>Interfaces</b> GUI, script

Field	Description
<b>PlanetodeticAZI</b>	The orbital velocity azimuth expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field. Unlike the <b>AZI</b> field, <b>PlanetodeticAZI</b> is associated with the <b>Planetodetic</b> state representation, which is only valid for coordinate systems with <b>BodyFixed</b> axes.
<b>Data Type</b>	Real
<b>Allowed Values</b>	-# < <b>PlanetodeticAZI</b> < #
<b>Access</b>	set, get
<b>Default Value</b>	81.80908019114962
<b>Units</b>	deg
<b>Interfaces</b>	GUI, script
<b>PlanetodeticHFP</b>	The orbital horizontal flight path angle expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field. <b>PlanetodeticHFP</b> is only valid for coordinate systems with <b>BodyFixed</b> axes.
<b>Data Type</b>	Real
<b>Allowed Values</b>	-90 # <b>PlanetodeticHFP</b> # 90
<b>Access</b>	set, get
<b>Default Value</b>	1.494615814842774
<b>Units</b>	deg
<b>Interfaces</b>	GUI, script
<b>PlanetodeticLAT</b>	The planetodetic latitude expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field. This field is only valid for coordinate systems with <b>BodyFixed</b> axes.
<b>Data Type</b>	Real
<b>Allowed Values</b>	-90 # <b>PlanetodeticLAT</b> # 90
<b>Access</b>	set, get
<b>Default Value</b>	10.43478253114861
<b>Units</b>	deg
<b>Interfaces</b>	GUI, script
<b>PlanetodeticLON</b>	The planetodetic longitude expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field. This field is only valid for coordinate systems with <b>BodyFixed</b> axes.
<b>Data Type</b>	Real
<b>Allowed Values</b>	-# < <b>PlanetodeticLON</b> < #
<b>Access</b>	set, get
<b>Default Value</b>	79.67188405807977
<b>Units</b>	deg
<b>Interfaces</b>	GUI, script

Field	Description
<b>PlanetodeticRMAG</b>	The magnitude of the orbital position vector expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field. Unlike the <b>RMAG</b> field, <b>PlanetodeticRMAG</b> is associated with the <b>Planetodetic</b> state representation, which is only valid for coordinate systems with <b>BodyFixed</b> axes.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> <b>PlanetodeticRMAG</b> # 1e-10</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 7218.032973047435</p> <p><b>Units</b> km</p> <p><b>Interfaces</b> GUI, script</p>
<b>PlanetodeticVMAG</b>	The magnitude of the orbital velocity vector expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field. Unlike the <b>VMAG</b> field, <b>PlanetodeticVMAG</b> is associated with the <b>Planetodetic</b> state representation, which is only valid for coordinate systems with <b>BodyFixed</b> axes.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> <b>PlanetodeticVMAG</b> # 1e-10</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 6.905049647173787</p> <p><b>Units</b> km/s</p> <p><b>Interfaces</b> GUI, script</p>
<b>RA</b>	The right ascension of the orbital position expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> -# &lt; <b>RA</b> &lt; #</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 0</p> <p><b>Units</b> deg</p> <p><b>Interfaces</b> GUI, script</p>
<b>RAAN</b>	The orbital right ascension of the ascending node expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> -# &lt; <b>RAAN</b> &lt; #</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 306.6148021947984</p> <p><b>Units</b> deg</p> <p><b>Interfaces</b> GUI, script</p>

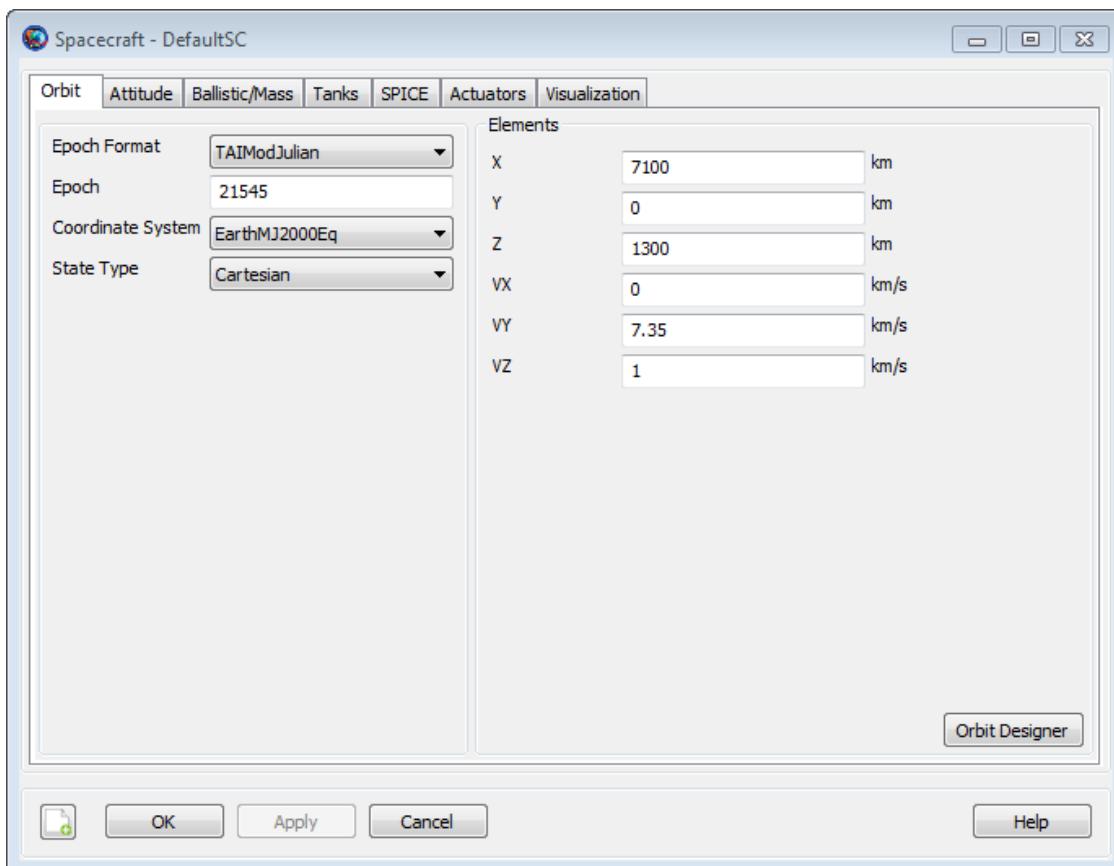
Field	Description												
<b>RadApo</b>	<p>The orbital radius of apoapsis expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field. The radius of apoapsis is the maximum distance (osculating) between the <b>Spacecraft</b> and celestial body at the origin of <b>CoordinateSystem</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td><math>\text{abs}(\text{RadApo}) \# 1</math> meter.</td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>7368.49911046818</td></tr> <tr> <td><b>Units</b></td><td>km</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	$\text{abs}(\text{RadApo}) \# 1$ meter.	<b>Access</b>	set, get	<b>Default Value</b>	7368.49911046818	<b>Units</b>	km	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	$\text{abs}(\text{RadApo}) \# 1$ meter.												
<b>Access</b>	set, get												
<b>Default Value</b>	7368.49911046818												
<b>Units</b>	km												
<b>Interfaces</b>	GUI, script												
<b>RadPer</b>	<p>The orbital radius of periapsis expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field. The radius of periapsis is the minimum distance (osculating) between the <b>Spacecraft</b> and celestial body at the origin of <b>CoordinateSystem</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td><math>\text{abs}(\text{RadPer}) \# 1</math> meter.</td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>7015.378524789846</td></tr> <tr> <td><b>Units</b></td><td>km</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	$\text{abs}(\text{RadPer}) \# 1$ meter.	<b>Access</b>	set, get	<b>Default Value</b>	7015.378524789846	<b>Units</b>	km	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	$\text{abs}(\text{RadPer}) \# 1$ meter.												
<b>Access</b>	set, get												
<b>Default Value</b>	7015.378524789846												
<b>Units</b>	km												
<b>Interfaces</b>	GUI, script												
<b>RAV</b>	<p>The right ascension of orbital velocity expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td><math>-\# &lt; \text{RAV} &lt; \#</math></td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>90</td></tr> <tr> <td><b>Units</b></td><td>deg</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	$-\# < \text{RAV} < \#$	<b>Access</b>	set, get	<b>Default Value</b>	90	<b>Units</b>	deg	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	$-\# < \text{RAV} < \#$												
<b>Access</b>	set, get												
<b>Default Value</b>	90												
<b>Units</b>	deg												
<b>Interfaces</b>	GUI, script												
<b>RMAG</b>	<p>The magnitude of the orbital position vector expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td><math>\text{RMAG} \# 1\text{e-}10</math></td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>7218.032973047435</td></tr> <tr> <td><b>Units</b></td><td>km</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	$\text{RMAG} \# 1\text{e-}10$	<b>Access</b>	set, get	<b>Default Value</b>	7218.032973047435	<b>Units</b>	km	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	$\text{RMAG} \# 1\text{e-}10$												
<b>Access</b>	set, get												
<b>Default Value</b>	7218.032973047435												
<b>Units</b>	km												
<b>Interfaces</b>	GUI, script												

Field	Description
<b>SemilatusRectum</b>	Magnitude of the position vector when at true anomaly of 90 deg.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> <b>SemilatusRectum</b> &gt; 1e-7</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 7187.60430675539</p> <p><b>Units</b> km</p> <p><b>Interfaces</b> GUI, script</p>
<b>SMA</b>	The orbital semi-major axis expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> SMA &lt; -0.001 km or SMA &gt; 0.001 km. If SMA &lt; 0, then <b>ECC</b> must be &gt; 1</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 7191.938817629013</p> <p><b>Units</b> km</p> <p><b>Interfaces</b> GUI, script</p>
<b>TA</b>	The orbital true anomaly expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> -# &lt; TA &lt; #</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 99.8877493320488</p> <p><b>Units</b> deg.</p> <p><b>Interfaces</b> GUI, script</p>
<b>TLONG</b>	True longitude of the osculating orbit. <b>TLONG</b> = <b>RAAN</b> + <b>AOP</b> + <b>TA</b>
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> -# &lt; TLONG &lt; #</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 0.6931030628392251</p> <p><b>Units</b> deg</p> <p><b>Interfaces</b> GUI, script</p>
<b>VMAG</b>	The magnitude of the orbital velocity vector expressed in the coordinate system chosen in the <b>CoordinateSystem</b> field.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> VMAG # 1e-10</p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 7.417715281675348</p> <p><b>Units</b> km/s</p> <p><b>Interfaces</b> GUI, script</p>

Field	Description
VX	<p>The x-component of the <b>Spacecraft</b> velocity with respect to the coordinate system chosen in the spacecraft's <b>CoordinateSystem</b> field.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> <math>-\# &lt; \text{VX} &lt; \#</math>  <b>Access</b> set, get  <b>Default Value</b> 0  <b>Units</b> km/s  <b>Interfaces</b> GUI, script</p>
VY	<p>The y-component of the <b>Spacecraft</b> velocity with respect to the coordinate system chosen in the spacecraft's <b>CoordinateSystem</b> field.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> <math>-\# &lt; \text{VY} &lt; \#</math>  <b>Access</b> set, get  <b>Default Value</b> 7.35  <b>Units</b> km/s  <b>Interfaces</b> GUI, script</p>
VZ	<p>The z-component of the <b>Spacecraft</b> velocity with respect to the coordinate system chosen in the spacecraft's <b>CoordinateSystem</b> field.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> <math>-\# &lt; \text{VZ} &lt; \#</math>  <b>Access</b> set, get  <b>Default Value</b> 1  <b>Units</b> km/s  <b>Interfaces</b> GUI, script</p>
X	<p>The x-component of the <b>Spacecraft</b> position with respect to the coordinate system chosen in the spacecraft's <b>CoordinateSystem</b> field.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> <math>-\# &lt; \text{X} &lt; \#</math>  <b>Access</b> set, get  <b>Default Value</b> 7100  <b>Units</b> km  <b>Interfaces</b> GUI, script</p>

Field	Description												
Y	<p>The y-component of the <b>Spacecraft</b> position with respect to the coordinate system chosen in the spacecraft's <b>CoordinateSystem</b> field.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td><math>-\# &lt; Y &lt; \#</math></td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>0</td></tr> <tr> <td><b>Units</b></td><td>km</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	$-\# < Y < \#$	<b>Access</b>	set, get	<b>Default Value</b>	0	<b>Units</b>	km	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	$-\# < Y < \#$												
<b>Access</b>	set, get												
<b>Default Value</b>	0												
<b>Units</b>	km												
<b>Interfaces</b>	GUI, script												
Z	<p>The z-component of the <b>Spacecraft</b> position with respect to the coordinate system chosen in the spacecraft's <b>CoordinateSystem</b> field.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td><math>-\# &lt; Z &lt; \#</math></td></tr> <tr> <td><b>Access</b></td><td>set, get</td></tr> <tr> <td><b>Default Value</b></td><td>1300</td></tr> <tr> <td><b>Units</b></td><td>km</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	$-\# < Z < \#$	<b>Access</b>	set, get	<b>Default Value</b>	1300	<b>Units</b>	km	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	$-\# < Z < \#$												
<b>Access</b>	set, get												
<b>Default Value</b>	1300												
<b>Units</b>	km												
<b>Interfaces</b>	GUI, script												

## GUI



The **Spacecraft** orbit state dialog box allows you to set the epoch, coordinate system, and state type values for the **Spacecraft** orbital state. When you specify an orbital state, you define the state in the representation selected in the **StateType** menu, with respect to the coordinate system specified in the **CoordinateSystem** menu, at the epoch defined in the **Epoch** menu. If the selected **CoordinateSystem** is time varying, the epoch of the coordinate system is defined by the **Epoch** field, and changing the epoch changes the inertial representation of the orbital state.

A change in **Epoch Format** causes an immediate update to **Epoch** to reflect the chosen time system and format.

The **Keplerian**, **ModifiedKeplerian**, and **Equinoctial** state types cannot be computed if the **CoordinateSystem** does not have a central body at the origin, or if the **CoordinateSystem** references the current spacecraft (resulting in a circular reference). For example, if you have selected the **Keplerian** state type, coordinate systems for which the Keplerian elements cannot be computed do not appear in the **CoordinateSystem** menu. Similarly, if you have selected a **CoordinateSystem** that does not have a celestial body at the origin, Keplerian-based state types will not appear as options in the **StateType** menu. The **Planetodetic** state type cannot be selected until the **CoordinateSystem** has **BodyFixed** axes.

## Remarks

### Cartesian State

The **Cartesian** state is composed of the position and velocity components expressed with respect to the selected **CoordinateSystem**.

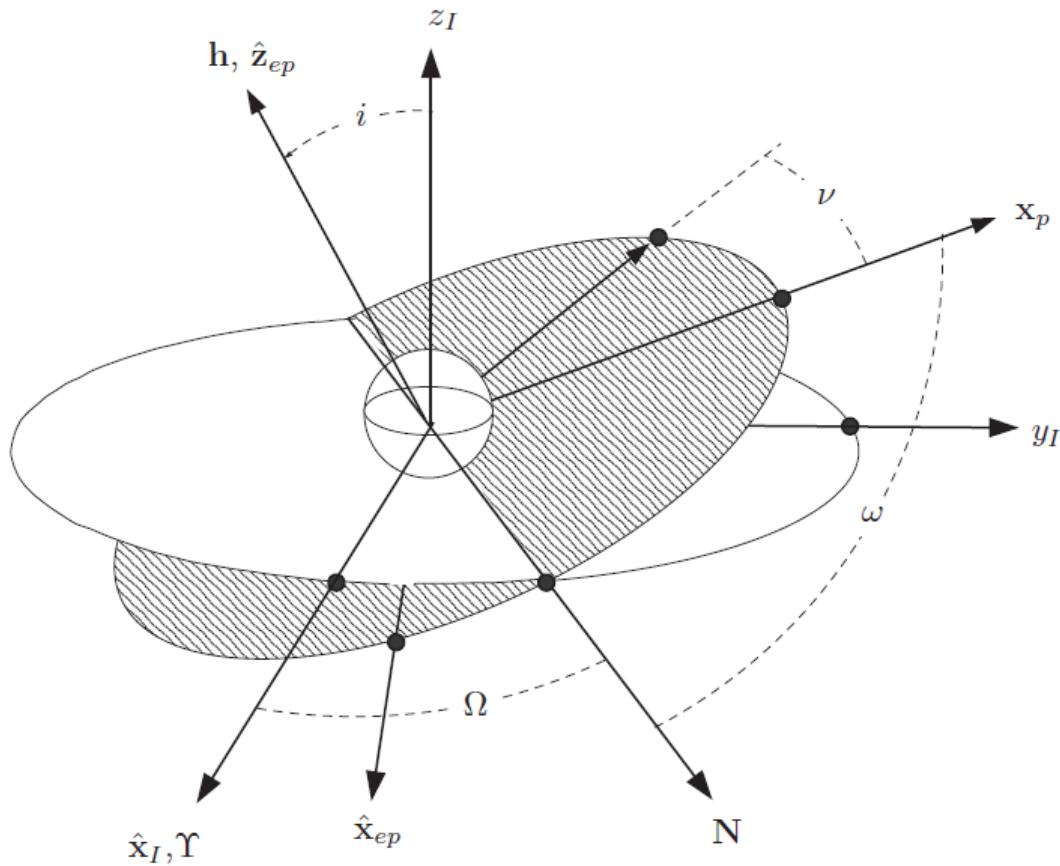
### Keplerian and Modified Keplerian State Types

The **Keplerian** and **ModifiedKeplerian** state types use the osculating Keplerian orbital elements with respect to the selected **CoordinateSystem**. To use either the **Keplerian** or **ModifiedKeplerian** state type, the **Spacecraft**'s coordinate system must have a central body at the origin. The two representations differ in how the orbit size and shape are defined. The **Keplerian** state type is composed of the following elements: **SMA**, **ECC**, **INC**, **RAAN**, **AOP**, and **TA**. The **ModifiedKeplerian** state type is composed of the following elements: **RadApo**, **RadPer**, **INC**, **RAAN**, **AOP**, and **TA**. The tables and figures below describe each **Keplerian** state element in detail including singularities.

### Geometry of the Keplerian Elements

Name	Description
<b>SMA</b>	<b>SMA</b> contains information on the type and size of an orbit. If <b>SMA</b> > 0 the orbit is elliptic. If <b>SMA</b> < 0 the orbit is hyperbolic. <b>SMA</b> is infinite for parabolic orbits.
<b>ECC</b>	<b>ECC</b> contains information on the shape of an orbit. If <b>ECC</b> = 0, then the orbit is circular. If $0 < \text{ECC} < 1$ , the orbit is elliptical. If $\text{ECC} = 1$ the orbit is parabolic. If $\text{ECC} > 1$ then the orbit is hyperbolic.

Name	Description
<b>INC</b>	<b>INC</b> is the angle between the orbit angular momentum vector and the z-axis. If <b>INC</b> < 90 deg., then the orbit is prograde. If <b>INC</b> > 90 deg, then the orbit is retrograde
<b>RAAN</b>	<b>RAAN</b> is defined as the angle between x-axis and the node vector measured counterclockwise. The node vector is defined as the cross product of the z-axis and orbit angular momentum vector. <b>RAAN</b> is undefined for equatorial orbits.
<b>AOP</b>	<b>AOP</b> is the angle between a vector pointing at periapsis and a vector pointing in the direction of the line of nodes. <b>AOP</b> is undefined for circular orbits.
<b>TA</b>	<b>TA</b> is defined as the angle between a vector pointing at periapsis and a vector pointing at the spacecraft. <b>TA</b> is undefined for circular orbits.



The **Keplerian** and **ModifiedKeplerian** state types have several singularities. The table below describes the different singularities and how each is handled in the state conversion algorithms.

Singularity	Comments and Behavior
<b>ECC = 1</b>	<b>SMA</b> is infinite and cannot be used to define the size of the orbit. GMAT requires <b>ECC</b> < 0.9999999 or <b>ECC</b> > 1.0000001 when setting <b>ECC</b> or when performing conversions. For transformations performed near these limits, loss of precision may occur.
<b>ECC = 0</b>	<b>AOP</b> is undefined. If <b>ECC</b> <= 1e-11, GMAT sets <b>AOP</b> to zero in the conversion from <b>Cartesian</b> to <b>Keplerian/ModKeplerian</b> and includes all orbital-plane angular displacement in the true anomaly.
<b>SMA = 0</b>	Results in a singular conic section. GMAT requires   <b>SMA</b>   > 1 meter when inputting <b>SMA</b> .
<b>SMA = INF</b>	<b>SMA</b> is infinite and another parameter is required to capture the size of the orbit. <b>Keplerian</b> elements are not supported.
<b>INC = 0</b>	<b>RAAN</b> is undefined. If <b>INC</b> < 6e-10, GMAT sets <b>RAAN</b> to 0 in the conversion from <b>Cartesian</b> to <b>Keplerian/ModKeplerian</b> . Then, if <b>ECC</b> < 1e-11, <b>AOP</b> is set to 0 and GMAT includes all angular displacement between the x-axis and the spacecraft in the true anomaly. If <b>ECC</b> # 1e-11, then <b>AOP</b> is computed as the angle between the eccentricity vector and the x-axis.
<b>INC = 180</b>	<b>RAAN</b> is undefined. If <b>INC</b> > (180 - 6e-10), GMAT sets <b>RAAN</b> to 0 in the conversion from <b>Cartesian</b> to <b>Keplerian/ModKeplerian</b> . Then, if <b>ECC</b> < 1e-11, <b>AOP</b> is set to 0 and GMAT includes all angular displacement between the x-axis and the spacecraft in the true anomaly. If <b>ECC</b> # 1e-11, then <b>AOP</b> is computed as the angle between the eccentricity vector and the x-axis.
<b>RadPer = 0</b>	Singular conic section. GMAT requires <b>RadPer</b> > 1 meter in state conversions.
<b>RadApo = 0</b>	Singular conic section. GMAT requires abs( <b>RadApo</b> ) > 1 meter in state conversions.

### Delaunay State Type

The conversion between **Delaunay** and **Cartesian** is performed passing through classical **Keplerian** state. Therefore, **Delaunay** state cannot represent parabolic orbits. Also, the **Delaunay** state cannot represent hyperbolic orbits because of the definition of **DelaunayL**, which is not a real value when **SMA** is negative. The table below describes the elements of the **Delaunay** state.

Element	Description
<b>Delaunayl</b>	The mean anomaly. It is related to uniform angular motion on a circle of radius <b>SMA</b> .
<b>Delaunayg</b>	See “Keplerian State” section, <b>AOP</b>
<b>Delaunayh</b>	See “Keplerian State” section, <b>RAAN</b>
<b>DelaunayL</b>	Related to the two-body orbital energy. <b>DelaunayL</b> = sqrt(mu * <b>SMA</b> )

Element	Description
<b>DelaunayG</b>	Magnitude of the orbital angular momentum vector. <b>DelaunayG</b> = <b>DelaunayL</b> *sqrt(1-ECC^2)
<b>DelaunayH</b>	The K component of the orbital angular momentum. <b>DelaunayH</b> = <b>DelaunayG</b> * cos(INC)

### Singularities in the Delaunay Elements

Singularities in the **Delaunay** elements is the same as the **Keplerian** elements, because it uses the **Keplerian** elements during conversion. See “Keplerian State” section. The table below shows the additional singularities regarding the **Delaunay** state type.

Element	Description
<b>ECC &gt; 1</b>	<b>DelaunayL</b> is not real for hyperbolic orbits by its definition.

### Brouwer-Lyddane Mean State Type

The **BrouwerMeanShort** state represents short-term averaged mean motion under low-order zonal harmonics (i.e. J2-J5). Likewise, **BrouwerMeanLong** state represents long-term averaged mean motion under low-order zonal harmonics (i.e. J2-J5). GMAT uses JGM-2 zonal coefficients in Brouwer Mean states algorithms. Both are singular for near parabolic or hyperbolic orbits. To use **BrouwerMeanShort/BrouwerMeanLong** state type in GMAT, the central body must be the Earth. If the central body is the Earth, GMAT can calculate **BrouwerMeanShort/BrouwerMeanLong** state from the osculating state (**Cartesian**, **Keplerian**, etc.) and vice-versa.

Element	Description
<b>BrouwerLongAOP</b>	Brouwer-Lyddane long-term averaged (short-term averaged) mean argument of periapsis.
<b>BrouwerShortAOP</b>	
<b>BrouwerLongMA</b>	Brouwer-Lyddane long-term averaged (short-term averaged) mean MA (mean anomaly).
<b>BrouwerShortMA</b>	
<b>BrouwerLongECC</b>	Brouwer-Lyddane long-term averaged (short-term averaged) mean eccentricity.
<b>BrouwerShortECC</b>	
<b>BrouwerLongINC</b>	Brouwer-Lyddane long-term averaged (short-term averaged) mean inclination.
<b>BrouwerShortINC</b>	
<b>BrouwerLongRAAN</b>	Brouwer-Lyddane long-term averaged (short-term averaged) mean RAAN (right ascension of the ascending node).
<b>BrouwerShortRAAN</b>	
<b>BrouwerLongSMA</b>	Long-term averaged (short-term averaged) mean semi-major axis.
<b>BrouwerShortSMA</b>	

## Singularities in the Brouwer-Lyddane Mean Elements

The table below shows the characteristics of singularities regarding **BrouwerMeanShort/BrouwerMeanLong** state and the implemented method to handle the singularities in GMAT state conversion algorithms. Note that because Brouwer-Lyddane mean elements involve an iterative solution, loss of precision may occur near singularities.

Element	Description
<b>BrouwerSMA &lt; 3000/(1-BrouwerECC)</b>	Because Brouwer's formulation based on Earth's zonal harmonics, <b>BrouwerMeanShort</b> and <b>BrouwerMeanLong</b> cannot address orbits with mean perigee distance is smaller than Earth's radius, 3000 km because of numerical instability.
<b>BrouwerLongINC= 63, BrouwerLongINC = 117</b>	If given <b>BrouwerLongINC</b> (long-term averaged INC only) is close to $i_c = 63$ deg. or $117$ deg., the algorithm is unstable because of singular terms (non-zero imaginary components). Thus, GMAT cannot calculate osculating elements.
<b>BrouwerLongECC = 0, BrouwerLongECC # 1</b>	If <b>BrouwerECC</b> is larger than 0.9, or <b>BrouwerECC</b> is smaller than $1E-7$ , it has been reported that Cartesian to <b>BrouwerMeanLong</b> state does not converge statistically. For these cases, GMAT gives a warning message with the current conversion error.

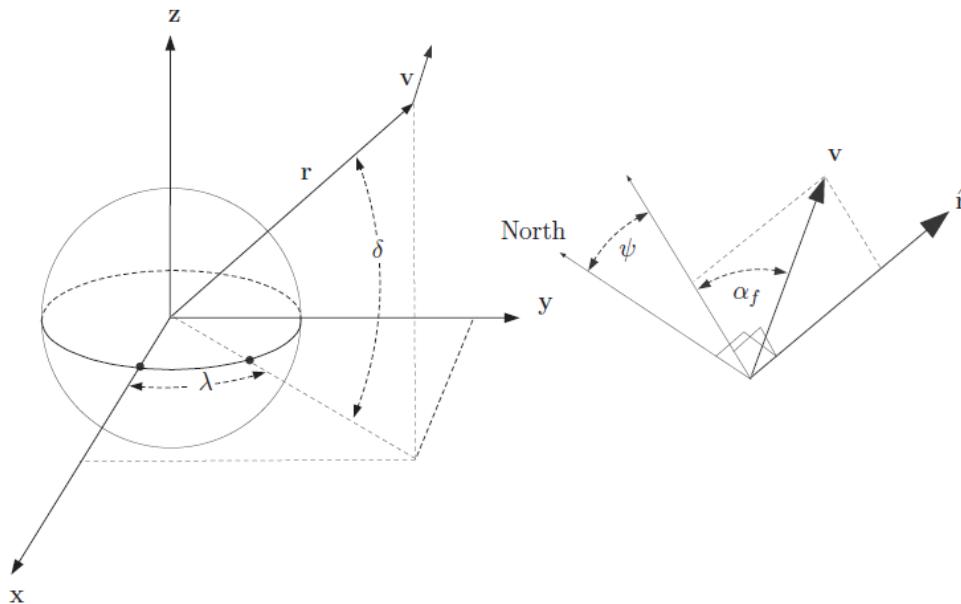
## Spherical State Types

The **SphericalAZFPA** and **SphericalRADEC** state types are composed of the polar coordinates of the spacecraft state expressed with respect to the selected **CoordinateSystem**. The two spherical representations differ in how the velocity is defined. The **SphericalRADEC** state type is composed of the following elements: **RMAG**, **RA**, **DEC**, **VMAG**, **RAV**, and **DECV**. The **SphericalAZFPA** state type is composed of the following elements: **RMAG**, **RA**, **DEC**, **VMAG**, **AZI** and **FPA**. The tables and figures below describe each spherical state element in detail including singularities.

### Geometry of the Spherical Elements

Name	Description
<b>RMAG</b>	The magnitude of the position vector.
<b>RA</b>	The right ascension which is the angle between the projection of the position vector into the xy-plane and the x-axis measured counterclockwise.
<b>DEC</b>	The declination which is the angle between the position vector and the xy-plane.
<b>VMAG</b>	The magnitude of the velocity vector.
<b>FPA</b>	The vertical flight path angle. The angle measured from a plane normal to the position vector to the velocity vector, measured in the plane formed by position vector and velocity vector.

Name	Description
<b>AZI</b>	The flight path azimuth. The angle measured from the vector perpendicular to the position vector and pointing north, to the projection of the velocity vector, into a plane normal to the position vector.
<b>RAV</b>	The right ascension of velocity. The angle between the projection of the velocity vector into the xy-plane and the x-axis measured counterclockwise.
<b>DECV</b>	The flight path azimuth. The angle between the velocity vector and the xy-plane.



## Singularities in the Spherical Elements

Singularity	Comments and Behavior
<b>RMAG = 0</b>	Results in a singular conic section: declination and flight path angle are undefined. GMAT will not allow transformations if <b>RMAG</b> < 1e-10. For <b>RMAG</b> values greater than, but near 1e-10, loss of precision may occur in transformations.
<b>VMAG = 0</b>	Results in a singular conic section: velocity declination and flight path angle are undefined. GMAT will not allow transformations if <b>VMAG</b> < 1e-10. For <b>VMAG</b> values greater than, but near 1e-10, loss of precision may occur in transformations.

## Planetodetic State Type

The **Planetodetic** state type is useful for specifying states relative to the surface of a central body. It is very similar to the spherical state types, but uses the central body's flattening in its definition. To use the **Planetodetic** state type, the spacecraft's coordinate system must have a celestial body at the origin, and must have **BodyFixed** axes.

Element	Description
<b>PlanetodeticRMAG</b>	Magnitude of the orbital radius vector.
<b>PlanetodeticLON</b>	Planetodetic longitude.
<b>PlanetodeticLAT</b>	Planetodetic latitude, using the <b>Flattening</b> of the central body.
<b>PlanetodeticVMAG</b>	Magnitude of the orbital velocity vector in the fixed frame.
<b>PlanetodeticAZI</b>	Orbital velocity azimuth in the fixed frame.
<b>PlanetodeticHFPA</b>	Horizontal flight path angle. <b>HFPA</b> = 90 - <b>VFPA</b>

### Singularities in the Planetodetic Elements

Singularity	Comments and Behavior
<b>PlanetodeticRMAG</b> = 0	Results in a singular conic section: declination and flight path angle are undefined. GMAT will not allow transformations if <b>PlanetodeticRMAG</b> < 1e-10. For <b>PlanetodeticRMAG</b> values greater than, but near 1e-10, loss of precision may occur in transformations.
<b>PlanetodeticVMAG</b> = 0	Results in a singular conic section: velocity declination and flight path angle are undefined. GMAT will not allow transformations if <b>PlanetodeticVMAG</b> < 1e-10. For <b>PlanetodeticVMAG</b> values greater than, but near 1e-10, loss of precision may occur in transformations.

### Equinoctial State Type

GMAT supports the **Equinoctial** state representation which is non-singular for elliptic orbits with inclinations less than 180 degrees. To use the **Equinoctial** state type, the spacecraft's coordinate system must have a central body at the origin.

Element	Description
<b>SMA</b>	See Keplerian section.
<b>EquinoctialH</b>	A measure of the orbital eccentricity and argument of periapsis. <b>EquinoctialH</b> and <b>EquinoctialK</b> together govern how elliptical an orbit is and where the periapsis is located. $\text{EquinoctialH} = \text{ECC} * \sin(\text{AOP})$
<b>EquinoctialK</b>	A measure of the orbital eccentricity and argument of periapsis. <b>EquinoctialH</b> and <b>EquinoctialK</b> together govern how elliptical an orbit is and where the periapsis is located. $\text{EquinoctialK} = \text{ECC} * \cos(\text{AOP})$
<b>EquinoctialP</b>	A measure of the orientation of the orbit. <b>EquinoctialP</b> and <b>EquinoctialQ</b> together govern how an orbit is oriented. $\text{EquinoctialP} = \tan(\text{INC}/2) * \sin(\text{RAAN})$
<b>EquinoctialQ</b>	A measure of the orientation of the orbit. <b>EquinoctialP</b> and <b>EquinoctialQ</b> together govern how an orbit is oriented. $\text{EquinoctialQ} = \tan(\text{INC}/2) * \cos(\text{RAAN})$

Element	Description
<b>MLONG</b>	A measure of the mean location of the spacecraft in its orbit. <b>MLONG = AOP + RAAN + MA</b> .

### Singularities in the Equinoctial Elements

Element	Description
<b>INC = 180</b>	<b>RAAN</b> is undefined. If <b>INC &gt; 180 - 1.0e-11</b> , GMAT sets <b>RAAN</b> to 0 degrees. GMAT does not support <b>Equinoctial</b> elements for true retrograde orbits.
<b>ECC &gt; 0.9999999</b>	<b>Equinoctial</b> elements are not defined for parabolic or hyperbolic orbits.

### Alternate Equinoctial State Type

The **AlternateEquinoctial** state type is a slight variation on the **Equinoctial** elements that uses  $\sin(\text{INC}/2)$  instead of  $\tan(\text{INC}/2)$  in the "P" and "Q" elements. Both representations have the same singularities.

Element	Description
<b>SMA</b>	See Keplerian section.
<b>EquinoctialH</b>	See Equinoctial section.
<b>EquinoctialK</b>	See Equinoctial section.
<b>AltEquinoctialP</b>	A measure of the orientation of the orbit. <b>AltEquinoctialP</b> and <b>AltEquinoctialQ</b> together govern how an orbit is oriented. <b>AltEquinoctialP = sin(INC/2)*sin(RAAN)</b> .
<b>AltEquinoctialQ</b>	A measure of the orientation of the orbit. <b>AltEquinoctialP</b> and <b>AltEquinoctialQ</b> together govern how an orbit is oriented. <b>AltEquinoctialP = sin(INC/2)*cos(RAAN)</b> .
<b>MLONG</b>	See Equinoctial section.

### Modified Equinoctial State Type

The **ModifiedEquinoctial** state representation is non-singular for circular, elliptic, parabolic, and hyperbolic orbits. The only singularity is for retrograde equatorial orbits, because, like **Equinoctial** and **ModifiedEquinoctial**, GMAT does not support the retrograde factor.

Element	Description
<b>SemilatusRectum</b>	Magnitude of the position vector when at true anomaly of 90 deg <b>SemilatusRectum = SMA*(1-ECC^2)</b>
<b>ModEquinoctialF</b>	Components of eccentricity vector (with <b>ModEquinoctialG</b> ). Projection of eccentricity vector onto x. <b>ModEquinoctialF = ECC * cos (AOP+RAAN)</b>

Element	Description
<b>ModEquinoctialG</b>	Components of eccentricity vector (with <b>ModEquinoctialF</b> ). Projection of eccentricity vector onto y. <b>ModEquinoctialG</b> = $ECC * \sin(AOP+RAAN)$
<b>ModEquinoctialH</b>	Identical to <b>EquinoctialQ</b> .
<b>ModEquinoctialK</b>	Identical to <b>EquinoctialP</b> .
<b>TLONG</b>	A measure of the true location of the spacecraft in its orbit. <b>TLONG</b> = $AOP + RAAN + TA$ .

### Singularities in the Modified Equinoctial Elements

Element	Description
<b>INC = 180</b>	Similar to <b>Equinoctial</b> elements, there is singularity at <b>INC</b> = 180 deg. GMAT does not support <b>ModifiedEquinoctial</b> elements for retrograde equatorial orbits.

### Hyperbolic Asymptote State Type

GMAT supports two related hyperbolic asymptote state types: **IncomingAsymptote** for defining the incoming hyperbolic asymptote, and **OutgoingAsymptote**, for defining the outgoing hyperbolic asymptote. Both representations are useful for defining flybys.

Element	Description
<b>IncomingRadPer</b>	The orbital radius of periapsis. The radius of periapsis is the minimum distance (osculating) between the spacecraft and celestial body at the origin of coordinate system.
<b>OutgoingRadPer</b>	<b>IncomingRadPer/OutgoingRadPer</b> differ from <b>RadPer</b> only in that they are associated with the <b>IncomingAsymptote</b> and <b>OutgoingAsymptote</b> state representations, respectively.
<b>IncomingC3Energy</b>	C3 energy. <b>C3Energy</b> = $-\mu/SMA$ . <b>IncomingC3Energy/OutgoingC3Energy</b> differ only in that they are associated with the <b>IncomingAsymptote</b> and <b>OutgoingAsymptote</b> state representations, respectively.
<b>OutgoingC3Energy</b>	
<b>IncomingRHA</b>	<b>IncomingRHA/OutgoingRHA</b> is the right ascension of the incoming/outgoing asymptote. If <b>C3Energy</b> < 0 the apsidal vector is substituted for the incoming/outgoing asymptote.
<b>OutgoingRHA</b>	
<b>IncomingDHA</b>	<b>IncomingDHA/OutgoingDHA</b> is the declination of the incoming/outgoing asymptote. If <b>C3Energy</b> < 0 the apsidal vector is substituted for the incoming/outgoing asymptote..
<b>OutgoingDHA</b>	

Element	Description
<b>IncomingBVAZI</b>	<b>IncomingBVAZI/OutgoingBVAZI</b> is the B-vector azimuth at infinity of the incoming/outgoing asymptote measured counter-clockwise from south. If <b>C3Energy</b> < 0 the apsides vector is substituted for the outgoing/incoming asymptote.
<b>OutgoingBVAZI</b>	
<b>TA</b>	See <b>Keplerian</b> .

### Singularities in the Hyperbolic Asymptote Elements

Element	Description
<b>IncomingC3Energy/OutgoingC3Energy = 0</b>	If <b>IncomingC3Energy/OutgoingC3Energy</b> = 0 the spacecraft has a parabolic orbit. Hyperbolic asymptote states do not support parabolic orbits. It must be avoided that -1E-7 # <b>IncomingC3Energy/OutgoingC3Energy</b> # 1E-7 by choosing a proper set of elements.
<b>ECC = 0</b>	For the case of circular orbits, <b>TA</b> is undefined. It must be avoided that <b>ECC</b> # 1E-7 by choosing a proper set of elements. GMAT does not support hyperbolic asymptote representation for true circular orbits.
<b>Asymptote vector parallel to z-axis</b>	If the asymptote vector is parallel or antiparallel to coordinate system's z-direction, then the B-plane is undefined. It must be avoided by choosing either a proper coordinate system or set of elements.

### State Component Interactions with the Spacecraft Coordinate System Field

When you define **Spacecraft** state elements such as **SMA**, **X**, or **DEC** for example, these values are set in coordinates defined by the **Spacecraft's CoordinateSystem** field. For example, the following lines result in the X-component of the **Cartesian** state of **MySat** to be 1000, in the **EarthFixed** system.

```
aSpacecraft.CoordinateSystem = EarthFixed
aSpacecraft.X = 1000
```

When the script lines above are executed in a script, GMAT converts the state to the specified coordinate system, in this case **EarthFixed**, sets the **X** component to 1000, and then converts the state back to the internal inertial representation.

The following example sets **SMA** to 8000 in the **EarthMJ2000Eq** system, then sets **X** to 6000 in the Earth fixed system. (Note this is NOT allowed in initialization mode; see later remarks for more information).

```
aSpacecraft.CoordinateSystem = EarthMJ2000Eq
aSpacecraft.SMA = 8000
aSpacecraft.CoordinateSystem = EarthFixed
```

```
aSpacecraft.X = 6000
```

### State Component Interactions with the Spacecraft Epoch Field

When you specify the **Spacecraft**'s epoch, you define the initial epoch of the spacecraft in the specified coordinate system. If your choice for the **Spacecraft**'s coordinate system is a time varying system such as the **EarthFixed** system, then you define the state in the **EarthFixed** system at that epoch. For example, the following lines would result in the cartesian state of **MySat** to be set to [7000 0 1300 0 7.35 1] in the **EarthFixed** system at 01 Dec 2000 12:00:00.000 UTC.

```
Create Spacecraft MySat
MySat.Epoch.UTCGregorian = '01 Dec 2000 12:00:00.000'
MySat.CoordinateSystem = EarthFixed
MySat.X = 7000
MySat.Y = 0
MySat.Z = 1300
MySat.VX = 0
MySat.VY = 7.35
MySat.VZ = 1
```

The corresponding **EarthMJ2000Eq** representation is

```
X = -2320.30266
Y = -6604.25075
Z = 1300.02599
VX = 7.41609
VY = -2.60562
VZ = 0.99953
```

You can change the epoch of a **Spacecraft** in the mission sequence using a script line like this:

```
MySat.Epoch.TAIGregorian = '02 Dec 2000 12:00:00.000'
```

When the above line is executed in the mission sequence, GMAT converts the state to the specified coordinate system and then to the specified state type — in this case **EarthFixed** and **Cartesian** respectively — sets the epoch to the value of 02 Dec 2000 12:00:00.000, and then converts the state back to the internal representation. This behavior is identical to that of the spacecraft orbit dialog box in the GUI. Because the coordinate system in this case is time varying, changing the spacecraft epoch has resulted in a change in the spacecraft's inertial state representation. After the epoch is changed to 02 Dec 2000 12:00:00.000, the **EarthMJ2000Eq** state representation is now:

```
X = -2206.35771
Y = -6643.18687
Z = 1300.02073
VX = 7.45981
VY = -2.47767
VZ = 0.99953
```

## Scripting Limitations during Initialization

When setting the **Spacecraft** orbit state in a script, there are a few limitations to be aware of. In the initialization portion of the script (before the **BeginMissionSequence** command), you should set the epoch and coordinate system only once; multiple definitions of these parameters will result in either errors or warning messages and may lead to unexpected results.

Also when setting a state during initialization, you must set the orbit state in a set of fields corresponding to a single state type. For example, set the orbit state using the **X**, **Y**, **Z**, **VX**, **VY**, **VZ** fields (for the **Cartesian** state type) or the **SMA**, **ECC**, **INC**, **RAAN**, **AOP**, **TA** fields (for the **Keplerian** state type), but not a mixture of the two. If you need to mix state types, coordinate systems, or epochs to define the state of a spacecraft, you must set the state using scripting in the mission sequence (after the **BeginMissionSequence** command).

## Shared State Components

Some state components, such as **SMA**, are shared among multiple state representations. In the mission sequence, GMAT does not require you to specify the state representation that you are setting; rather, you may specify a combination of elements from different representations.

For these shared components, GMAT defines a default representation for each, and uses that representation when setting or retrieving the value for the shared component. This is normally transparent, though it can have side effects if the default representation has singularities or numerical precision losses caused by the value being set or retrieved. The following table lists each shared state component and its default representation.

Field	Shared Between	Default Representation
AOP	Keplerian, ModifiedKeplerian	Keplerian
DEC	SphericalAZFPA, RADEC	Spherical- SphericalAZFPA
EquinoctialH	AlternateEquinoctial, Equinoctial	Equinoctial
EquinoctialK	AlternateEquinoctial, Equinoctial	Equinoctial
INC	Keplerian, ModifiedKeplerian	Keplerian
RA	SphericalAZFPA, RADEC	Spherical- SphericalAZFPA
RAAN	Keplerian, ModifiedKeplerian	Keplerian
RMAG	SphericalAZFPA, RADEC	Spherical- SphericalAZFPA
SMA	AlternateEquinoctial, Equinoctial, Keplerian	Keplerian
TA	IncomingAsymptote, OutgoingAsymptote, Keplerian, ModifiedKeplerian	Keplerian

Field	Shared Between	Default Representation
VMAG	SphericalAZFPA, RADEC	Spherical- SphericalAZFPA

As an example, consider the following mission sequence. Because GMAT executes each command sequentially, it uses the assigned state representation to calculate each component. For shared components, it uses the default representation for reach.

```
BeginMissionSequence
aSpacecraft.SMA = 20000          % conversion goes through Keplerian
aSpacecraft.RA = 30               % conversion goes through SphericalAZFPA
aSpacecraft.OutgoingDHA = 90      % conversion goes through OutgoingAsymptote
aSpacecraft.TA = 45               % conversion goes through Keplerian
```



### Warning

When setting state parameters (especially in Keplerian-based representations) using non-default dependencies, be careful of the loss of precision caused by large translations in the intermediate orbit.

## Examples

Define a **Spacecraft**'s Earth MJ2000Eq coordinates in the **Keplerian** representation:

```
Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = EarthMJ2000Eq
aSpacecraft.SMA   = 7100
aSpacecraft.ECC   = 0.01
aSpacecraft.INC   = 30
aSpacecraft.RAAN  = 45
aSpacecraft.AOP   = 90
aSpacecraft.TA    = 270
```

Define a **Spacecraft**'s Earth fixed coordinates in the **Cartesian** representation:

```
Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = EarthFixed
aSpacecraft.X = 7100
aSpacecraft.Y = 0
aSpacecraft.Z = 1300
aSpacecraft.VX = 0
aSpacecraft.VY = 7.35
aSpacecraft.VZ = 1
```

Define a **Spacecraft**'s Moon centered coordinates in **ModifiedKeplerian** representation.

```
Create CoordinateSystem MoonInertial
MoonInertial.Origin = Luna
```

```

MoonInertial.Axes = BodyInertial

Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = MoonInertial
aSpacecraft.RadPer = 2100
aSpacecraft.RadApo = 2200
aSpacecraft.INC = 90
aSpacecraft.RAAN = 45
aSpacecraft.AOP = 45
aSpacecraft.TA = 180

```

Define a **Spacecraft**'s Rotating Libration Point coordinates in the **SphericalAZFPA** representation:

```

Create LibrationPoint ESL1
ESL1.Primary = Sun
ESL1.Secondary = Earth
ESL1.Point = L1

Create CoordinateSystem EarthSunL1CS
EarthSunL1CS.Origin = ESL1
EarthSunL1CS.Axes = ObjectReferenced
EarthSunL1CS.XAxis = R
EarthSunL1CS.ZAxis = N
EarthSunL1CS.Primary = Sun
EarthSunL1CS.Secondary = Earth

Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = EarthSunL1CS
aSpacecraft.DateFormat = UTCGregorian
aSpacecraft.Epoch = '09 Dec 2005 13:00:00.000'
aSpacecraft.RMAG = 1520834.130720907
aSpacecraft.RA = -111.7450242065574
aSpacecraft.DEC = -20.23326432189756
aSpacecraft.VMAG = 0.2519453702907011
aSpacecraft.AZI = 85.22478175803107
aSpacecraft.FPA = 97.97050698644287

```

Define a **Spacecraft**'s Earth-fixed coordinates in the **Planetodetic** representation:

```

Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = EarthFixed
aSpacecraft.PlanetodeticRMAG = 7218.032973047435
aSpacecraft.PlanetodeticLON = 79.67188405817301
aSpacecraft.PlanetodeticLAT = 10.43478253417053
aSpacecraft.PlanetodeticVMAG = 6.905049647178043
aSpacecraft.PlanetodeticAZI = 81.80908019170981
aSpacecraft.PlanetodeticHFPA = 1.494615714741736

```

Set a **Spacecraft**'s Earth MJ2000 ecliptic coordinates in the **Equinoctial** representation:

```
Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = EarthMJ2000Ec
aSpacecraft.SMA = 9100
aSpacecraft.EquinoctialH = 0.00905
aSpacecraft.EquinoctialK = 0.00424
aSpacecraft.EquinoctialP = -0.1059
aSpacecraft.EquinoctialQ = 0.14949
aSpacecraft.MLONG = 247.4528
```

## Spacecraft Visualization Properties

The visual properties of the spacecraft

### Description

The **Spacecraft Visualization Properties** lets you define a spacecraft model, translate the spacecraft in X, Y, Z directions or apply a fixed rotation to the attitude orientation of the model. You can also adjust the scale factor of the spacecraft model size. GMAT lets you set orbit colors via the spacecraft visualization properties as well. You can set colors to spacecraft orbital trajectories and any perturbing trajectories that are drawn during iterative processes. See [Color](#) documentation for discussion and examples on how to set orbital colors using **Spacecraft** object's **OrbitColor** and **TargetColor** fields. Also see the [Fields](#) section below to read more about these two fields. The Spacecraft visualization properties can be configured either through GMAT's GUI or the script interface.

See Also: [OrbitView](#), [Color](#)

### Fields

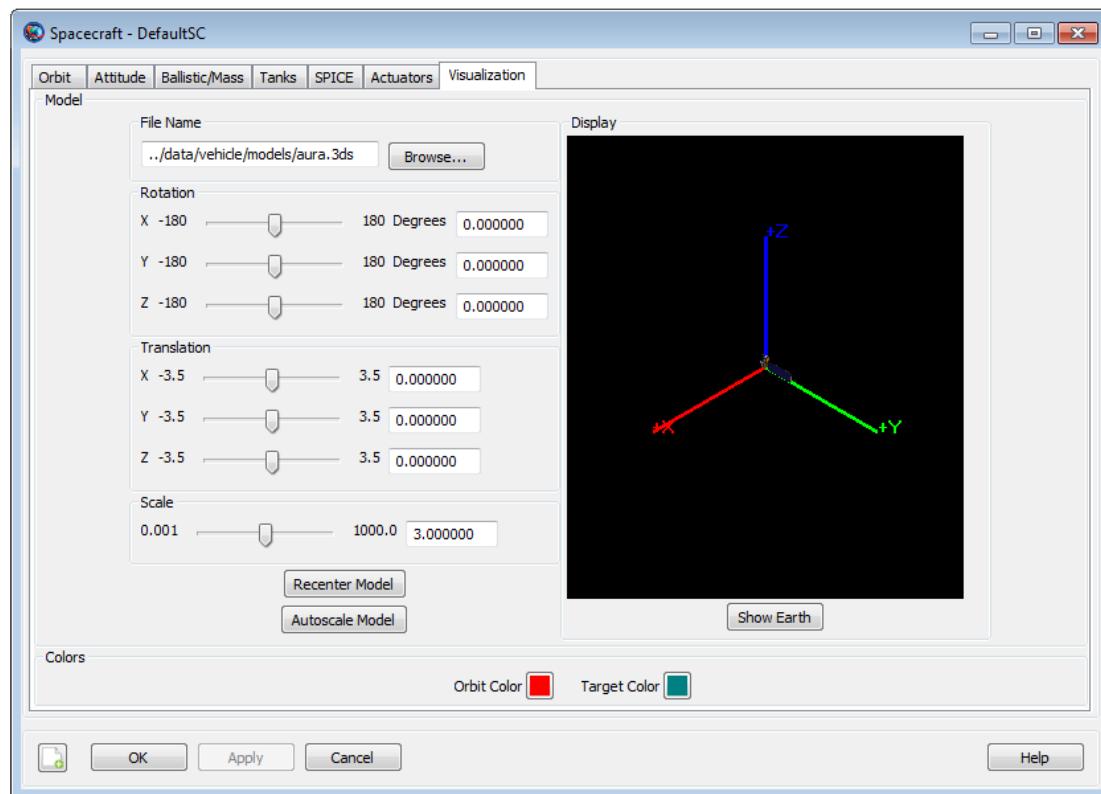
Field	Description	
<b>ModelOffsetX</b>	This field lets you translate a spacecraft in +X or -X axis of central body's coordinate system.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	-3.5 <= Real <= 3.5
	<b>Access</b>	set
	<b>Default Value</b>	0.000000
	<b>Units</b>	N/A
	<b>Interfaces</b>	GUI, script
<b>ModelOffsetY</b>	Allows you to translate a spacecraft in +Y or -Y axis of central body's coordinate system.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	-3.5 <= Real <= 3.5
	<b>Access</b>	set
	<b>Default Value</b>	0.000000
	<b>Units</b>	N/A
	<b>Interfaces</b>	GUI, script
<b>ModelOffsetZ</b>	Allows you to translate a spacecraft in +Z or -Z axis of central body's coordinate system.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	-3.5 <= Real <= 3.5
	<b>Access</b>	set
	<b>Default Value</b>	0.000000
	<b>Units</b>	N/A
	<b>Interfaces</b>	GUI, script

<b>Field</b>	<b>Description</b>
<b>ModelRotationX</b>	<p>Allows you to perform a fixed rotation of spacecraft's attitude w.r.t X-axis of central body's coordinate system.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> -180 &lt;= Real &lt;= 180  <b>Access</b> set  <b>Default Value</b> 0.000000  <b>Units</b> Deg.  <b>Interfaces</b> GUI, script</p>
<b>ModelRotationY</b>	<p>Allows you to perform a fixed rotation of spacecraft's attitude w.r.t Y-axis of central body's coordinate system.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> -180 &lt;= Real &lt;= 180  <b>Access</b> set  <b>Default Value</b> 0.000000  <b>Units</b> Deg.  <b>Interfaces</b> GUI, script</p>
<b>ModelRotationZ</b>	<p>Allows you to perform a fixed rotation of spacecraft's attitude w.r.t Z-axis of central body's coordinate system.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> -180 &lt;= Real &lt;= 180  <b>Access</b> set  <b>Default Value</b> 0.000000  <b>Units</b> Deg.  <b>Interfaces</b> GUI, script</p>
<b>ModelScale</b>	<p>Allows you to apply a scale factor to the spacecraft model's size.</p> <p><b>Data Type</b> Real  <b>Allowed Values</b> 0.001 &lt;= Real &lt;= 1000  <b>Access</b> set  <b>Default Value</b> 3.000000  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>ModelFile</b>	<p>Allows you to load spacecraft models that are in .3ds model formats.</p> <p><b>Data Type</b> String  <b>Allowed Values</b> . 3ds spacecraft model formats only  <b>Access</b> set  <b>Default Value</b> ../data/vehicle/models/aura.3ds  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>

Field	Description
<b>OrbitColor</b>	Allows you to set available colors on spacecraft orbits. The spacecraft orbits are drawn using the <b>OrbitView</b> graphics displays. The colors can be identified through a string or an integer array. For example: Setting spacecraft's orbit color to red can be done in following two ways: DefaultSC.OrbitColor = Red or DefaultSC.OrbitColor = [255 0 0]. This field can be modified in the Mission Sequence as well.
<b>Data Type</b>	Integer Array or String
<b>Allowed Values</b>	Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255.
<b>Access</b>	set
<b>Default Value</b>	Red
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>TargetColor</b>	Allows you to set available colors on a spacecraft's perturbing trajectories during iterative processes such as Differential Correction or Optimization. The perturbing trajectories are drawn through the <b>OrbitView</b> resource. The target color can be identified through a string or an integer array. For example: Setting spacecraft's perturbing trajectories to yellow color can be done in following two ways: DefaultSC.TargetColor = Yellow or DefaultSC.TargetColor = [255 255 0] . This field can be modified in the Mission Sequence as well.
<b>Data Type</b>	Integer Array or String
<b>Allowed Values</b>	Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255.
<b>Access</b>	set
<b>Default Value</b>	Teal
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

## GUI

The figure below shows the default settings for the **Spacecraft Visualization Properties** resource:



The GUI interface for **Spacecraft Visualization Properties** is contained on the Visualization tab of the **Spacecraft** resource. You can configure visualization properties of the spacecraft and visualize the changes in the **Display** window.

Within the **Display** window, you can **Left** click and drag your mouse to change camera orientation. Camera orientation can be changed in **Up/Down/Left/Right** directions. You can also **Right** click and drag your mouse to zoom in and out of the **Display** window. **Right** click and moving the cursor in **Up** direction helps to zoom out and moving the cursor in **Down** direction helps to zoom in.

## Remarks

### Configuring Spacecraft Visualization Properties

GMAT lets you define any spacecraft model but currently GMAT supports only .3ds model format. Several .3ds spacecraft model formats are available [here](#). You can also download more .3ds models by clicking [here](#). Most of these models are in .3ds format, which can be read by most 3D programs.

GMAT lets you apply fixed rotation to the attitude orientation of the spacecraft model or translate the model in any of the X, Y and Z directions. You can also apply a scale factor to the selected spacecraft model to adjust the size of the model. Any changes that are made to the spacecraft model, attitude orientation, translation or scale size factor will also be displayed in **OrbitView** resource's graphics window. The configured spacecraft visualization properties will only show up in OrbitView graphics window after you have

run the mission. See **OrbitView** resource's user-specification document to learn more about **OrbitView** graphics window.

## Examples

This example shows you how to configure **Spacecraft Visualization Properties** resource. All values are non-default values.

```
Create Spacecraft aSat
aSat.ModelFile = '../data/vehicle/models/aura.3ds'
aSat.ModelOffsetX = 1.5
aSat.ModelOffsetY = -2
aSat.ModelOffsetZ = 3
aSat.ModelRotationX = 180
aSat.ModelRotationY = 180
aSat.ModelRotationZ = 90
aSat.ModelScale = 15

Create Propagator aProp

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth}

BeginMissionSequence
Propagate aProp(aSat) {aSat.ElapsedSecs = 9000}
```

## ThrustHistoryFile

A time history of input thrust/acceleration vectors and mass flow rate

### Description

A **ThrustHistoryFile** resource is used to read in a time history of thrust or acceleration vectors that will be applied to a specified spacecraft. The user can optionally choose to read in a time history of mass flow rate that applies to a specified fuel resource.

See Also: [ThrustSegment](#), [BeginFileThrust](#), [EndFileThrust](#)

### Fields

Field	Description												
<b>AddThrustSegment</b>	<p>Method to specify one or more thrust segments contained in a given thrust/acceleration and mass flow rate history file.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any user-defined <b>ThrustSegment</b> resource</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>N/A</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Any user-defined <b>ThrustSegment</b> resource	<b>Access</b>	set	<b>Default Value</b>	N/A	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Any user-defined <b>ThrustSegment</b> resource												
<b>Access</b>	set												
<b>Default Value</b>	N/A												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>FileName</b>	<p>File name of the associated thrust/acceleration and mass flow rate history file. Details on the format of this user created file is described in the Remarks.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any user-defined file name</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>N/A</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Any user-defined file name	<b>Access</b>	set	<b>Default Value</b>	N/A	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Any user-defined file name												
<b>Access</b>	set												
<b>Default Value</b>	N/A												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												

### Remarks

#### Format of a thrust history file

The thrust history file contains blocks of data. Each block of data starts with a BeginThrust keyword and ends with an EndThrust keyword. More specifically, the start of a block of data is indicated by the keyword "BeginThrust {**ThrustSegment** object name}" and ends with the keyword "EndThrust {**ThrustSegment** object name}." The specified **ThrustSegment** resource defines how the data in a given block is to be used.

We assume that the user has created a script where a **ThrustSegment** resource, **Segment1**, has been created. Below, we show a sample thrust history file that references **Segment1**.

```

BeginThrust {Segment1}
Start_Epoch = 29 Jan 2019 16:35:00.000
Thrust_Vector_Coordinate_System = EarthMJ2000Eq
Thrust_Vector_Interpolation_Method = None
Mass_Flow_Rate_Interpolation_Method = None
ModelAccelOnly
0.0      0.003 0.011 0.002
1.0      0.003 0.011 0.002
EndThrust {Segment1}

```

The Start\_Epoch parameter value in this history file specifies that the thrust/acceleration data in the file should be applied starting at 29 Jan 2019 16:35:00.000 UTCG. The Thrust\_Vector\_Coordinate\_System parameter value specifies that the thrust/acceleration data in this file uses the EarthMJ2000Eq coordinate system. The Thrust\_Vector\_Interpolation\_Method parameter value specifies that the thrust/acceleration data in this file should not be interpolated. The Mass\_Flow\_Rate\_Interpolation\_Method parameter value specifies that mass flow rate data, if any, in this file, should not be interpolated. ModelAccelOnly in the file above is a header describing the data that follows. It tells GMAT what type of acceleration/thrust and mass flow rate modeling to perform. In this case, the ModelAccelOnly tells GMAT we are modeling acceleration only.

Next, the thrust history file contains two rows of acceleration data. The first entry in each row is elapsed seconds from the Start\_Epoch value. The next three entries in each row is an acceleration vector in  $m/s^2$ . The 0.0 value in the first row indicates that the acceleration should occur 0 elapsed seconds from Start\_Epoch, at 29 Jan 2019 16:35:00.000 UTCG. The acceleration vector, at this time, will have a value of (0.003 0.011 0.002)  $m/s^2$  applied in the EarthMJ2000Eq coordinate system. The 1.0 value in the second row indicates that the applied acceleration should end at 29 Jan 2019 16:35:01.000 UTCG. The acceleration vector, at this time, will have a value of (0.003 0.011 0.002)  $m/s^2$  applied in the EarthMJ2000Eq coordinate system. Note that if the interpolation method is None as shown here, the acceleration is applied in piecewise constant fashion and only the time from the last acceleration record is needed; the acceleration values are ignored. The Linear and CubicSpline interpolation methods will use the acceleration values in the last record as interpolation nodes.

The table below provides more information on the four parameters defined within a block of data, enclosed within BeginThrust/EndThrust pair keywords, in a thrust history file.

File Parameter	Description		
<b>Start_Epoch</b>	Reference epoch, in UTC Gregorian format, for the thrust/acceleration and mass flow rate data.	<b>Data Type</b>	String
		<b>Allowed Values</b>	Any valid Epoch in UTCG format
		<b>Units</b>	N/A

File Parameter	Description		
<b>Thrust_Vector_Coordinate_System</b>	Coordinate system used to specify the thrust/acceleration vector data.		
	<b>Data Type</b>	String	
	<b>Allowed Values</b>	Any valid built-in or user-defined <b>CoordinateSystem</b> resource. If a user-defined spacecraft body-fixed frame is chosen, the user must also define the spacecraft attitude separately.	
	<b>Units</b>	N/A	
<b>Thrust_Vector_Interpolation_Method</b>	Interpolation method used for the thrust/acceleration vector components.		
	<b>Data Type</b>	String	
	<b>Allowed Values</b>	Linear, CubicSpline, or None.	
	<b>Units</b>	N/A	
<b>Mass_Flow_Rate_Interpolation_Method</b>	Interpolation method used for the mass flow rate		
	<b>Data Type</b>	String	
	<b>Allowed Values</b>	Linear, CubicSpline, or None	
	<b>Units</b>	N/A	

The table below lists the four valid header values that describe how the data enclosed within BeginThrust/EndThrust pair keywords, in a thrust history file, is to be used.

Header	Description
<b>ModelThrustAnd- MassRate</b>	Each row of data contains five elements. The first element is the elapsed seconds (non-negative) from the Start_Epoch parameter value. The next three elements are the three components of thrust in Newtons (N). The final (fifth) element is the mass flow rate in kg/s. A positive value for this fifth element corresponds to a mass decrease to simulate fuel mass being consumed.
<b>ModelThrustOnly</b>	Each row of data contains four elements. The first element is the elapsed seconds (non-negative) from the Start_Epoch parameter value. The next three elements are the three components of thrust in Newtons (N).

Header	Description
<b>ModelAccelAndMassRate</b>	Each row of data contains five elements. The first element is the elapsed seconds (non-negative) from the Start_Epoch parameter value. The next three elements are the three components of acceleration in m/s^2. The final (fifth) element is the mass flow rate in kg/s. A positive value for this fifth element corresponds to a mass decrease to simulate fuel mass being consumed.
<b>ModelAccelOnly</b>	Each row of data contains four elements. The first element is the elapsed seconds (non-negative) from the Start_Epoch parameter value. The next three elements are the three components of acceleration in m/s^2.

### Equations of Motion (EOM) as a function of Header type and ThrustSegment.ApplyThrustScaleToMassFlow parameter value

The choice of header value as listed in the previous table will affect the GMAT EOM. In addition, the choice of value for the associated **ThrustSegment ApplyThrustScale-ToMassFlow** flag, either True or False, can also affect the EOM. The table below shows how the GMAT EOM change as a function of header type and value of the **ThrustSegment. ApplyThrustScaleToMassFlow** parameter.

Header	ApplyThrustScaleToMassFlow	Total Acceleration	Total Mass Flow Rate
ModelAccelOnly	True or False	$a_{Total} = a + s a_{File}$	$\dot{m}_{Total} = \dot{m}$
ModelThrustOnly	True or False	$a_{Total} = a + \frac{s T_{File}}{\dot{m}_{Total}}$	$\dot{m}_{Total} = \dot{m}$
ModelAccelAndMassRate	True	$a_{Total} = a + s a_{File}$	$\dot{m}_{Total} = \dot{m} - s s_m \dot{m}_{File}$
ModelAccelAndMassRate	False	$a_{Total} = a + s a_{File}$	$\dot{m}_{Total} = \dot{m} - s_m \dot{m}_{File}$
ModelThrustAndMassRate	True	$a_{Total} = a + \frac{s T_{File}}{\dot{m}_{Total}}$	$\dot{m}_{Total} = \dot{m} - s s_m \dot{m}_{File}$
ModelThrustAndMassRate	False	$a_{Total} = a + \frac{s T_{File}}{\dot{m}_{Total}}$	$\dot{m}_{Total} = \dot{m} - s_m \dot{m}_{File}$

Notation:

- $a_{Total}$  = Total acceleration
- $a$  = Acceleration due to all sources other than that given in the input thrust history file
- $a_{File}$  = Acceleration given in the input thrust history file
- $m_{Total}$  = Total mass
- $\dot{m}_{Total}$  = Total mass flow rate
- $\dot{m}$  = mass flow rate due to all sources other than that given in the input file
- $\dot{m}_{File}$  = mass flow rate given in the input file
- $T_{File}$  = Thrust given in the input file
- $s = ThrustSegment.ThrustScaleFactor$ . User can optionally solve for s as part of the estimation process.
- $s_m = ThrustSegment.MassFlowScaleFactor$ .

## Examples

Create a **ThrustHistoryFile** that utilizes two **ThrustSegments**.

```
Create ThrustHistoryFile aThrustHistoryFile
aThrustHistoryFile.AddThrustSegment = {Segment1, Segment2}
aThrustHistoryFile.FileName = '../data/myThrustFile.thrust'

Create ThrustSegment Segment1 Segment2

BeginMissionSequence;
```

The script above will pass a syntax check but in order for it to run without error, you would have to create a thrust file, `myThrustFile.thrust`, and place it in the GMAT 'data' folder. For a complete example of how the **ThrustHistoryFile** and **ThrustSegment** resources are used to apply a thrust/acceleration and mass flow rate profile to a spacecraft, see the first example in the [BeginFileThrust](#) Help.

## ThrustSegment

One or more **ThrustSegments** define how data in a thrust history file are used.

### Description

A **ThrustSegment** resource is used to define how a portion of data, encapsulated between the "BeginThrust {**ThrustSegment** object name}" and "EndThrust {**ThrustSegment** object name}" keywords, in a thrust history file is used.

*See Also:* [ThrustSegment](#), [BeginFileThrust](#), [EndFileThrust](#)

### Fields

Field	Description												
<b>ApplyThrustScaleToMass-Flow</b>	<p>Flag specifying if the thrust/acceleration <b>ThrustScaleFactor</b> should also be applied to the mass flow rate.</p> <table> <tr> <td><b>Data Type</b></td><td>Boolean</td></tr> <tr> <td><b>Allowed Values</b></td><td>True, False</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>False</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Boolean	<b>Allowed Values</b>	True, False	<b>Access</b>	set	<b>Default Value</b>	<b>False</b>	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Boolean												
<b>Allowed Values</b>	True, False												
<b>Access</b>	set												
<b>Default Value</b>	<b>False</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>MassFlowScaleFactor</b>	<p>Multiplicative scale factor applied to mass flow rate data in the thrust history file. Only used if mass flow rate is being modeled in the thrust history file.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any Real number</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>1.0</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Any Real number	<b>Access</b>	set	<b>Default Value</b>	<b>1.0</b>	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Any Real number												
<b>Access</b>	set												
<b>Default Value</b>	<b>1.0</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>MassSource</b>	<p>Fuel tank holding the propellant used when modeling the finite burn described in the thrust segment. GMAT will decrement the fuel mass contained in this tank according to the user-selected mass flow modeling options. If more than one tank is specified, only the first one is used.</p> <table> <tr> <td><b>Data Type</b></td><td>ChemicalTank</td></tr> <tr> <td><b>Allowed Values</b></td><td>{ } or any user defined <b>ChemicalTank</b> resource</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>{ }</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	ChemicalTank	<b>Allowed Values</b>	{ } or any user defined <b>ChemicalTank</b> resource	<b>Access</b>	set	<b>Default Value</b>	{ }	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	ChemicalTank												
<b>Allowed Values</b>	{ } or any user defined <b>ChemicalTank</b> resource												
<b>Access</b>	set												
<b>Default Value</b>	{ }												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												

Field	Description
<b>SolveFors</b>	<p>List of parameters to estimate.</p> <p><b>Data Type</b> String  <b>Allowed Values</b> {} or any combination of ThrustScaleFactor, ThrustAngle1, and/or ThrustAngle2  <b>Access</b> set  <b>Default Value</b> {}  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>ThrustAngle1</b>	<p>Coefficients for the first angle correction to the thrust or acceleration vector. See Remarks below for more details.</p> <p><b>Data Type</b> Real array  <b>Allowed Values</b> Any Real number(s)  <b>Access</b> set  <b>Default Value</b> [ 0.0 ]  <b>Units</b> deg, deg/sec, deg/sec^2 , ...  <b>Interfaces</b> script</p>
<b>ThrustAngle1Sigma</b>	<p>Standard deviation(s) of <b>ThrustAngle1</b>. Only used if <b>ThrustAngle1</b> is defined as a solve-for (using the <b>SolveFors</b> parameter defined above). See Remarks below for more details.</p> <p><b>Data Type</b> Real array  <b>Allowed Values</b> Positive real number(s)  <b>Access</b> set  <b>Default Value</b> [ 1e70 ]  <b>Units</b> deg, deg/sec, deg/sec^2 , ...  <b>Interfaces</b> script</p>
<b>ThrustAngle2</b>	<p>Coefficients for the second angle correction to the thrust or acceleration vector. See Remarks below for more details.</p> <p><b>Data Type</b> Real array  <b>Allowed Values</b> Any Real number(s)  <b>Access</b> set  <b>Default Value</b> [ 0.0 ]  <b>Units</b> deg, deg/sec, deg/sec^2 , ...  <b>Interfaces</b> script</p>

Field	Description
<b>ThrustAngle2Sigma</b>	<p>Standard deviation(s) of <b>ThrustAngle2</b>. Only used if <b>ThrustAngle2</b> is defined as a solve-for (using the <b>SolveFor</b>s parameter defined above). See Remarks below for more details.</p>
	<b>Data Type</b>
	Real array
	<b>Allowed Values</b>
	Positive real number(s)
	<b>Access</b>
	set
	<b>Default Value</b>
	[ 1e70 ]
	<b>Units</b>
	deg, deg/sec, deg/sec^2 , ...
	(See Remarks section)
	<b>Interfaces</b>
	script
<b>ThrustAngleConstraintVector</b>	<p>Vector which is used along with a vector in the direction of the thrust from the THF to define the coordinate system for the thrust angle rotations. See Remarks below for more details.</p>
	<b>Data Type</b>
	Real array
	<b>Allowed Values</b>
	Real array (length three)
	<b>Access</b>
	set
	<b>Default Value</b>
	[ 0 0 1 ]
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	script
<b>ThrustScaleFactor</b>	<p>Multiplicative scale factor applied to thrust/acceleration data in the thrust history file</p>
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	Any Real number
	<b>Access</b>
	set
	<b>Default Value</b>
	1.0
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	script
<b>ThrustScaleFactorSigma</b>	<p>Standard deviation of <b>ThrustScaleFactor</b>. Only used if <b>ThrustScaleFactor</b> is defined as a solve-for (using the <b>SolveFor</b>s parameter defined above)</p>
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	Positive real number
	<b>Access</b>
	set
	<b>Default Value</b>
	1e70
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	script

## Remarks

### Overview of Thrust Angle Corrections

The ThrustSegment supports small angle corrections to account for a misalignment in the thrust or acceleration vector defined in the thrust history file. The correction is applied by a two angle rotation about a coordinate system. Each angle is defined by a time varying polynomial:  $\theta = a_0 + a_1t + a_2t^2 + \dots + a_nt^n$ , with coefficients provided by the user via the fields **ThrustAngle1**, and **ThrustAngle2**, and time is measured as the seconds after the initial epoch of the **ThrustSegment**. The order of the polynomial is determined by the length of the arrays **ThrustAngle1**, and **ThrustAngle2**, and the user has a free choice in the length of this array.

The angle corrections are applied as two subsequent rotations to the thrust or acceleration vector about two orthogonal axes. All vectors are defined in the coordinate system specified in the **ThrustSegment** in the thrust history file. The first rotation is applied about the axis formed by the cross product of the vector aligned with the thrust or acceleration vector and the vector specified by **ThrustAngleConstraintVector**. The second rotation axis is aligned with the vector defined by the cross product of the first rotation axis vector and the direction the thrust vector points after the first angle rotation. For example, if the thrust history file specifies a thrust along the +X axis in the spacecraft body frame, choosing a constraint vector of [ 0 0 1 ] (also taken to be in body coordinates) will map **ThrustAngle1** to a rotation about the body -Y axis (equivalent to a pitch angle), and **ThrustAngle2** will map to a rotation about the body +Z axis (equivalent to a yaw angle).

### Solving for Thrust Angles

When solving for a thrust angle, GMAT will solve for each polynomial coefficient specified in **ThrustAngle1** or **ThrustAngle2**, provided they are listed in the **SolveFor**s field. The **ThrustAngle1Sigma** and **ThrustAngle2Sigma** fields contain the arrays of the a priori standard deviations for each coefficient in the corresponding angles field. When using the **BatchEstimator**, the user must also set the **BatchEstimator UseInitialCovariance** parameter to **True** for the thrust angle sigmas to be applied. The user can confirm the sigmas are applied by looking at the Estimation Initial Conditions report in the batch estimator output report file. The specified thrust angle sigmas are always automatically used by the **ExtendedKalmanFilter**.



## Note

The partial derivatives with respect to the angle coefficients are highly non-linear. When solving for thrust angles, care needs to be taken with respect to the order of the polynomials, the thrust angle uncertainties, and a priori values chosen. Convergence can become difficult if too high a polynomial order is used, if there are an insufficient number of observations during the thrust segment, or if the a priori angles are too far from the true misalignment angles. Using too large a value for the thrust angle sigmas can give too much freedom to the estimator to converge on for the coefficient values. Constraining the estimation by using the ThrustAngle sigmas (and setting **BatchEstimator UseInitialCovariance** to **True**) can aid convergence by restricting the freedom of the estimator, but this generally requires that the user have a good a priori knowledge of the thrust angles and their coefficients. These effects are additionally compounded by the periodic nature of angles such that an angle of 360 degrees is equivalent to an angle of 0 degrees.

## Units for Thrust Angles and Thrust Angle Sigmas

Because the values for **ThrustAngle1**, **ThrustAngle2**, **ThrustAngle1Sigma**, and **ThrustAngle2Sigma** are coefficients for a polynomial, the units depend on what element they are in the array. The first element in each array has units of degrees, and the next element has units of degrees/seconds. Each additional element has an additional "seconds" in the denominator.

## Examples

Create a **ThrustSegment** where the thrust scale factor, with a value of 2.0, will also be applied to the mass flow rate.

```
Create Spacecraft aSat
Create ChemicalTank aTank
aSat.Tanks = {aTank}

Create ThrustSegment aThrustSegment;
aThrustSegment.ThrustScaleFactor = 2.0;
aThrustSegment.ApplyThrustScaleToMassFlow = True;
aThrustSegment.MassFlowScaleFactor = 1.5;
aThrustSegment.MassSource={aTank};

BeginMissionSequence
```

If you use the script snippet above to create a full script, you will need to create a thrust/acceleration and mass flow rate input file. Suppose the mass flow rate for a given instant of time is set to 1 kg/s in the file, what is the actual mass flow rate applied to the spacecraft? We need to take into account the values of **ThrustScaleFactor**, **MassFlowScaleFactor**, and **ApplyThrustScaleToMassFlow** before we can answer this question. In all cases, **MassFlowScaleFactor** is applied to the mass flow rate value given in the file. In this example, since **ApplyThrustScaleToMassFlow** is set to **True**, the **ThrustS-**

caleFactor will also be applied to the mass flow rate value given in the file. Thus, to answer our question, in this example, the actual mass flow rate applied to the space-craft is MassFlowScaleFactor\*ThrustScaleFactor\*1 kg/s equals 3 kg/s. In the example above, the actual thrust/acceleration profile actually applied to the spacecraft is (ThrustScaleFactor = 2.0) times the thrust/acceleration given in the input file.

For a complete example of how the **ThrustHistoryFile** and **ThrustSegment** resources are used to apply a thrust/acceleration and mass flow rate profile to a spacecraft, see the first example in the [BeginFileThrust](#) Help.

## Commands

## BeginFileThrust

Apply a piece-wise continuous thrust/acceleration and mass flow rate profile

### Script Syntax

```
BeginFileThrust aThrustHistoryFile(aSpacecraft)
```

```
EndFileThrust aThrustHistoryFile(aSpacecraft)
```

### Description

When you apply a **BeginFileThrust** command, you turn on the thrust/acceleration and mass flow rate profile given in the specified **ThrustHistoryFile** as applied to the specified **Spacecraft**. Similarly when you apply an **EndFileThrust** command, you turn off the thrust/acceleration and mass flow rate profile given in the specified **ThrustHistoryFile** as applied to the specified **Spacecraft**. In order to actually apply the thrust/acceleration and mass flow rate profile, there must be a **Propagate** command between the **BeginFileThrust** and **EndFileThrust** commands.

To apply the **BeginFileThrust** and **EndFileThrust** commands, a **ThrustHistoryFile** object must be configured. This **ThrustHistoryFile** object, in turn, requires the configuration of one or more **ThrustSegment** objects. See the Remarks section and the examples below for a more detailed explanation.

See Also: [Spacecraft](#), [ThrustHistoryFile](#), [ThrustSegment](#), [ChemicalTank](#)

### Options

Option	Description												
<b>BeginFileThrust - ThrustHistoryFile</b>	<p>Specifies the <b>ThrustHistoryFile</b> object activated by the <b>BeginFileThrust</b> command.</p> <table> <tr> <td><b>Accepted Data Types</b></td><td><b>ThrustHistoryFile</b></td></tr> <tr> <td><b>Allowed Values</b></td><td><b>ThrustHistoryFile</b> object</td></tr> <tr> <td><b>Default Value</b></td><td>N/A</td></tr> <tr> <td><b>Required</b></td><td>yes</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Accepted Data Types</b>	<b>ThrustHistoryFile</b>	<b>Allowed Values</b>	<b>ThrustHistoryFile</b> object	<b>Default Value</b>	N/A	<b>Required</b>	yes	<b>Interfaces</b>	script		
<b>Accepted Data Types</b>	<b>ThrustHistoryFile</b>												
<b>Allowed Values</b>	<b>ThrustHistoryFile</b> object												
<b>Default Value</b>	N/A												
<b>Required</b>	yes												
<b>Interfaces</b>	script												
<b>BeginFileThrust - Spacecraft</b>	<p>Specifies the <b>Spacecraft</b> acted upon by the <b>BeginFileThrust</b> command. The mass/acceleration and mass flow rate profile specified by the <b>ThrustHistoryFile</b> and applied to the <b>Spacecraft</b> will be activated.</p> <table> <tr> <td><b>Accepted Data Types</b></td><td><b>Spacecraft</b></td></tr> <tr> <td><b>Allowed Values</b></td><td><b>Spacecraft Object</b></td></tr> <tr> <td><b>Default Value</b></td><td>N/A</td></tr> <tr> <td><b>Required</b></td><td>yes</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Accepted Data Types</b>	<b>Spacecraft</b>	<b>Allowed Values</b>	<b>Spacecraft Object</b>	<b>Default Value</b>	N/A	<b>Required</b>	yes	<b>Interfaces</b>	script		
<b>Accepted Data Types</b>	<b>Spacecraft</b>												
<b>Allowed Values</b>	<b>Spacecraft Object</b>												
<b>Default Value</b>	N/A												
<b>Required</b>	yes												
<b>Interfaces</b>	script												

Option	Description		
<b>EndFileThrust - ThrustHistory-File</b>	Specifies the <b>ThrustHistoryFile</b> object de-activated by the <b>EndFileThrust</b> command.		
	<b>Accepted Data Types</b>	<b>ThrustHistoryFile</b>	
	<b>Allowed Values</b>	<b>ThrustHistoryFile</b> object	
	<b>Default Value</b>	<b>N/A</b>	
	<b>Required</b>	yes	
	<b>Interfaces</b>	script	
<b>EndFileThrust - Spacecraft</b>	Specifies the <b>Spacecraft</b> acted upon by the <b>EndFileThrust</b> command. The mass/acceleration and mass flow rate profile specified by the <b>ThrustFile-History</b> and applied to the <b>Spacecraft</b> will be deactivated.		
	<b>Accepted Data Types</b>	<b>Spacecraft</b>	
	<b>Allowed Values</b>	<b>Spacecraft</b> object	
	<b>Default Value</b>	<b>N/A</b>	
	<b>Required</b>	yes	
	<b>Interfaces</b>	script	

## Remarks

### Using BeginFileThrust and EndFileThrust commands

To use the **BeginFileThrust** and **EndFileThrust** commands in your mission sequence, you must configure a **ThrustHistoryFile** object along with one or more **ThrustSegment** objects. In addition, if you wish to apply a mass flow rate profile, you must also create a **ChemicalTank** object. Additional details are provided in the steps below.

1. Create a **Spacecraft** object whose thrust/acceleration and/or mass flow rate profile you wish to modify.
2. If you wish to apply a mass flow rate profile, create and configure a **ChemicalTank** model. Add this **ChemicalTank** to the **Spacecraft** created in Step 1. The mass of the **ChemicalTank** will be changed according to the profile specified by the **ThrustHistoryFile** and **ThrustSegment** objects that we will create.
3. Create one or more **ThrustSegment** objects. A thrust segment is a block of data inside the file specified by the **ThrustHistoryFile** object, encapsulated between "BeginThrust {**ThrustSegment** object name}" and "EndThrust {**ThrustSegment** object name}" keywords. A given thrust history file can contain one or more thrust segments. As described in the **ThrustSegment** help, the **ThrustSegment** object describes how the segment data will be used. The following steps should be taken.
  - a. Set the parameters (scale factor related parameters, solve-for related parameters, etc) for the **ThrustSegment**.
  - b. (If modeling mass flow), configure the **ThrustSegment** to use the **ChemicalTank** created in Step 2.
4. Create a **ThrustHistoryFile** Object.

- a. Use the **ThrustHistoryFile.AddThrustSegment** parameter to specify which **ThrustSegments**, created in Step 3, our new **ThrustHistoryFile** object will use.
  - b. Specify the actual thrust history file name.
5. Create the thrust history file specified in part b of Step 4. Refer to the [ThrustHistoryFile Help](#), which contains a description of the file format, as needed.

When using the **Toggle** command in conjunction with modeling finite burns in an ephemeris file, a certain order of operations must be observed. The ephemeris Toggle commands must be placed inside the Begin and EndFileThrust commands as shown in the example below. This order of operations must be observed when propagating, as well as when running estimators like the **BatchEstimator**, **ExtendedKalmanFilter**, or **Smoother**.

```
BeginFileThrust ThrustHistory(Sat);
Toggle Ephem On;
Propagate Prop(Sat) {Sat.ElapsedDays = 1};
Toggle Ephem Off;
EndFileThrust ThrustHistory(Sat);
```

### BeginFileThrust and EndFileThrust commands are NOT branch commands

The **BeginFileThrust** and **EndFileThrust** commands are NOT branch commands, meaning, a **BeginFileThrust** command can exist without an **EndFileThrust** command.

Similarly, since the **BeginFileThrust** and **EndFileThrust** commands are used to turn on or off the thrust/mass and mass flow rate profiles, applying the same command multiple times in a script without its inverse is the same as applying it once. In other words, if you do this:

```
BeginFileThrust aThrustHistoryFile(aSat);
BeginFileThrust aThrustHistoryFile(aSat);
BeginFileThrust aThrustHistoryFile(aSat);
```

The effect is the same as only applying the **BeginFileThrust** command one time. The same holds true for the **EndFileThrust** command.

## Examples

### Apply a thrust and mass flow rate profile to a Spacecraft

We will create a sample script to apply a thrust and mass flow rate profile to a **Spacecraft** object. In our script, we will create a **Spacecraft** object, **aSat**, with an initial epoch of '01 Jan 2010 00:00:00.000.'. We decide that we want to apply a 3 Newton force in the Earth Centered Inertial (ECI) X direction for a duration of 100 seconds starting at '01 Jan 2010 00:01:00.000.' During the same time duration, we also want to apply a mass flow rate profile that uses fuel at a rate of 0.01 kg/s. Before we run our script, we will need to create a thrust history file, with the contents listed below. The user should name this file 'SampleThrustFile.thrust' and place it in the GMAT 'data' directory.

```
BeginThrust {aThrustSegment}
Start_Epoch = 01 Jan 2010 00:00:00.000
```

```
Thrust_Vector_Coordinate_System = EarthMJ2000Eq
Thrust_Vector_Interpolation_Method = None
Mass_Flow_Rate_Interpolation_Method = None
ModelThrustAndMassRate
60.0      3.0 0.0 0.0  0.01
160.0     3.0 0.0 0.0  0.01
EndThrust {aThrustSegment}
```

Below, we create a script that will

- Create and configure our needed **Spacecraft**, **ChemicalTank**, **Propagator**, **ThrustSegment**, and **ThrustHistoryFile** objects.
- Use the **BeginFileThrust** and **EndFileThrust** commands to apply our desired thrust and mass flow rate profile to our **Spacecraft** object, **aSat**.
- Create and configure a **ReportFile** object so that we can determine the fuel mass in our created **ChemicalTank** object both before and after the desired thrust and mass flow rate profile has been applied.

```
% Create and configure objects
Create Spacecraft aSat
aSat.DateFormat = UTCGregorian;
aSat.Epoch = '01 Jan 2010 00:00:00.000';

Create ChemicalTank aTank
aSat.Tanks = {aTank};

Create Propagator aPropagator

Create ThrustSegment aThrustSegment
aThrustSegment.ThrustScaleFactor = 1.2;
aThrustSegment.ApplyThrustScaleToMassFlow = false;
aThrustSegment.MassFlowScaleFactor = 2.0;
aThrustSegment.MassSource = {'aTank'};

Create ThrustHistoryFile aThrustHistoryFile

aThrustHistoryFile.AddThrustSegment = {'aThrustSegment'};
aThrustHistoryFile.FileName = '../data/SampleThrustFile.thrust';

Create ReportFile aReportFile

BeginMissionSequence

Report aReportFile aSat.aTank.FuelMass

BeginFileThrust aThrustHistoryFile(aSat);
    Propagate aPropagator(aSat) {aSat.ElapsedSecs = 180.0};
EndFileThrust aThrustHistoryFile(aSat);
```

```
Report aReportFile aSat.aTank.FuelMass
```

After running the script above, take a look at the before and after values of **aTank**'s fuel mass to note that the mass has decreased by 2 kg. This is the expected result. Recall that we apply a mass flow rate profile of 0.01 kg/s for 100 seconds starting at '01 Jan 2010 00:01:00.000' and ending at '01 Jan 2010 00:02:40.000'. 100 seconds multiplied by 0.01 kg/s corresponds to a mass drop of 1 kg but we need to remember that **aThrustSegment.MassFlowScaleFactor=2.0**. Thus, the mass flow rate specified in the file is doubled to obtain an expected mass drop of 2 kg.

## Navigation Applications

In the example above, we focused on applying a thrust and mass flow rate profile to a spacecraft in a mission design trajectory propagation context. We did this by sandwiching in a **Propagate** command in between a **BeginFileThrust** and **EndFileThrust** command. One can also use **BeginFileThrust** and **EndFileThrust** commands in the context of orbit determination. This is done by sandwiching in a **RunSimulator** or a **RunEstimator** command in between a **BeginFileThrust** and **EndFileThrust** command.

See the sample/Navigation folder for a script, **Simulate\_Continuous\_thrust\_SolveFor\_ScaleFactor.script**, that uses the **BeginFileThrust** and **EndFileThrust** commands in an orbit determination context. In this script,

- We configure two **Spacecraft**, **SimSat**, and **EstSat**, in Low Earth Orbit to use Range measurements from three **GroundStations** to obtain a navigation solution.
- The **SimSat** spacecraft is used to generate simulated Range measurements over a 12 hour period. During the entire period, a thrust history profile, 20 N in the velocity direction, is applied. When we apply this thrust, we use a **ThrustScaleFactor** of 1.0. For this simplified case, we do not apply a mass flow rate profile.
- The **EstSat** spacecraft reads in the simulated Range measurements generated by the **SimSat** spacecraft. During the entire 12 hour period, a thrust history profile, 20 N in the velocity direction, is applied, albeit with a different starting value for the **ThrustScaleFactor**. We wish to solve-for the **EstSat ThrustScaleFactor**. We start with an a priori guess, **ThrustScaleFactor = 0.75**, which results in large initial residuals. We run the estimation process to show that we both converge to a good orbit solution with low measurement residuals and that we solve for a **ThrustScaleFactor** close to the true 1.0 value.

## BeginFiniteBurn

Model finite thrust maneuvers

### Script Syntax

```
BeginFiniteBurn aFiniteBurn(aSpacecraft)
```

```
EndFiniteBurn aFiniteBurn(aSpacecraft)
```

### Description

When you apply a **BeginFiniteBurn** command, you turn on the thruster configuration given in the specified **FiniteBurn** model. Similarly, when you apply an **EndFiniteBurn** command, you turn off the thruster configuration in the specified **FiniteBurn** model. After GMAT executes a **BeginFiniteBurn** command, all propagation for the spacecraft affected by the **FiniteBurn** object will include the configured finite thrust in the dynamics until an **EndFiniteBurn** line is executed for that configuration. In order to apply a non-zero finite burn, there must be a **Propagate** command between the **BeginFiniteBurn** and **EndFiniteBurn** commands.

To apply the **BeginFiniteBurn** and **EndFiniteBurn** commands, a **FiniteBurn** object must be configured. This object requires the configuration of **ChemicalTank** and **ChemicalThruster** models. See the Remarks section and the examples below for a more detailed explanation.

See Also: [Spacecraft](#), [ChemicalThruster](#), [ChemicalTank](#), [FiniteBurn](#)

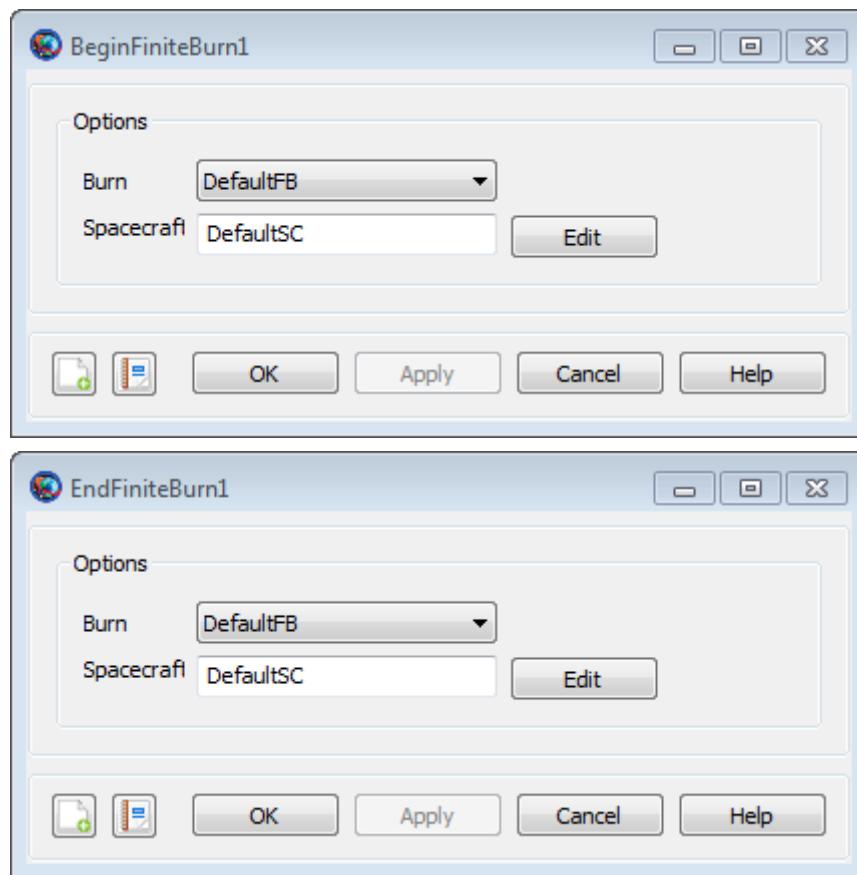
### Options

Option	Description		
<b>BeginFiniteBurn - Burn</b>	Specifies the <b>FiniteBurn</b> object activated by the <b>BeginFiniteBurn</b> command.	<b>Accepted Data Types</b> <b>Allowed Values</b> <b>Default Value</b> <b>Required Interfaces</b>	Reference Array <b>FiniteBurn</b> resource <b>DefaultFB</b> yes GUI, script

Option	Description										
<b>BeginFiniteBurn - SpacecraftList</b>	<p>Specifies the <b>Spacecraft</b> (currently only a single <b>Spacecraft</b> can be in this list) acted upon by the <b>BeginFiniteBurn</b> command. The <b>Spacecraft</b> listed in <b>SpacecraftList</b> will have thrusters activated according to the configuration of the <b>FiniteBurn</b> object defined by the <b>Burn</b> field.</p> <table> <tr> <td><b>Accepted Data Types</b></td><td>Reference Array</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>Spacecraft</b> Objects</td></tr> <tr> <td><b>Default Value</b></td><td><b>DefaultSC</b></td></tr> <tr> <td><b>Required</b></td><td>yes</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Accepted Data Types</b>	Reference Array	<b>Allowed Values</b>	<b>Spacecraft</b> Objects	<b>Default Value</b>	<b>DefaultSC</b>	<b>Required</b>	yes	<b>Interfaces</b>	GUI, script
<b>Accepted Data Types</b>	Reference Array										
<b>Allowed Values</b>	<b>Spacecraft</b> Objects										
<b>Default Value</b>	<b>DefaultSC</b>										
<b>Required</b>	yes										
<b>Interfaces</b>	GUI, script										
<b>EndFiniteBurn - Burn</b>	<p>Specifies the <b>FiniteBurn</b> object de-activated by the <b>EndFiniteBurn</b> command.</p> <table> <tr> <td><b>Accepted Data Types</b></td><td>Reference Array</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>FiniteBurn</b> Object</td></tr> <tr> <td><b>Default Value</b></td><td><b>DefaultFB</b></td></tr> <tr> <td><b>Required</b></td><td>yes</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Accepted Data Types</b>	Reference Array	<b>Allowed Values</b>	<b>FiniteBurn</b> Object	<b>Default Value</b>	<b>DefaultFB</b>	<b>Required</b>	yes	<b>Interfaces</b>	GUI, script
<b>Accepted Data Types</b>	Reference Array										
<b>Allowed Values</b>	<b>FiniteBurn</b> Object										
<b>Default Value</b>	<b>DefaultFB</b>										
<b>Required</b>	yes										
<b>Interfaces</b>	GUI, script										
<b>EndFiniteBurn - SpacecraftList</b>	<p>Specifies the <b>Spacecraft</b> (currently only a single <b>Spacecraft</b> can be in this list) acted upon by the <b>EndFiniteBurn</b> command. <b>Spacecraft</b> listed in <b>SpacecraftList</b> will have thrusters de-activated according to the configuration of the <b>FiniteBurn</b> object defined by the <b>Burn</b> field.</p> <table> <tr> <td><b>Accepted Data Types</b></td><td><b>Spacecraft</b></td></tr> <tr> <td><b>Allowed Values</b></td><td><b>Spacecraft</b> resource</td></tr> <tr> <td><b>Default Value</b></td><td><b>DefaultSC</b></td></tr> <tr> <td><b>Required</b></td><td>yes</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Accepted Data Types</b>	<b>Spacecraft</b>	<b>Allowed Values</b>	<b>Spacecraft</b> resource	<b>Default Value</b>	<b>DefaultSC</b>	<b>Required</b>	yes	<b>Interfaces</b>	GUI, script
<b>Accepted Data Types</b>	<b>Spacecraft</b>										
<b>Allowed Values</b>	<b>Spacecraft</b> resource										
<b>Default Value</b>	<b>DefaultSC</b>										
<b>Required</b>	yes										
<b>Interfaces</b>	GUI, script										

## GUI

The **BeginFiniteBurn** and **EndFiniteBurn** command dialog boxes allow you to implement a finite burn by specifying which finite burn model should be used and which space-craft the finite burn should be applied to. The dialog boxes for **BeginFiniteBurn** and **EndFiniteBurn** are shown below.



Use the **Burn** menu to select the **FiniteBurn** model for the maneuver. Use the **Spacecraft** text box to select the spacecraft for the finite burn. You can either type the spacecraft name in the Spacecraft text box or click the **Edit** button and select the spacecraft using the **ParameterSelectDialog** box.

If you add a **BeginFiniteBurn** command or **EndFiniteBurn** command to the mission sequence, without first creating a **FiniteBurn** object, GMAT will create a default **FiniteBurn** object called **DefaultFB**. However, you will need to configure the required **ChemicalTank** and **ChemicalThruster** objects required for a **FiniteBurn** object before you can run the mission. See the Remarks section for detailed instructions.

## Remarks

### Configuring a Finite Burn

To use the **BeginFiniteBurn** and **EndFiniteBurn** commands in your mission sequence, you must configure a **FiniteBurn** object along with **ChemicalTank** and **ChemicalThruster** objects as shown in the examples below and as described in these steps:

1. Create and configure a **ChemicalTank** model.
2. Create a **ChemicalThruster** model:
  - a. Set the parameters (direction, thrust, specific impulse, etc) for the thruster
  - b. Configure the **ChemicalThruster** to use the **ChemicalTank** created in Step 1.

3. Add the **ChemicalTank** and **ChemicalThruster** created in the previous two steps to the **Spacecraft**.
4. Create a **FiniteBurn** model and configure it to use the **ChemicalThruster** created in Step 2.

### Initial Thruster Status

When you configure the **Spacecraft**, **ChemicalTank**, **ChemicalThruster**, and **FiniteBurn** objects, GMAT initializes these objects with the thrusters turned off, so that no finite burns are active. You must use the **BeginFiniteBurn** command to turn on the thruster if you want to apply a finite burn during propagation.



#### Warning

Caution: If GMAT throws the error message “Propagator Exception: Mass-Flow is not a known propagation parameter on DefaultSC”, then you have not configured all of the required models to perform a finite burn. See detailed instructions above and examples to configure models required by the **EndFiniteBurn/BeginFiniteBurn** commands.

### BeginFiniteBurn and EndFiniteBurn commands are NOT branch commands

The **BeginFiniteBurn** and **EndFiniteBurn** commands are NOT branch commands, meaning, a **BeginFiniteBurn** command can exist without an **EndFiniteBurn** command (however, this may result in depleting all the fuel in the spacecraft model). For behavior when fuel mass is fully depleted during a finite burn see the **ChemicalTank** object.

Similarly, since the **BeginFiniteBurn** and **EndFiniteBurn** commands are used to turn on or off the thrusters, applying the same command multiple times in a script without its inverse is the same as applying it once. In other words, if you do this:

```
BeginFiniteBurn aFiniteBurn(aSat)
BeginFiniteBurn aFiniteBurn(aSat)
BeginFiniteBurn aFiniteBurn(aSat)
```

The effect is the same as only applying the **BeginFiniteBurn** command one time. The same holds true for the **EndFiniteBurn** command.

### Examples

Perform a finite burn while the spacecraft is between true anomaly of 300 degrees and 60 degrees.

```
% Create objects
Create Spacecraft aSat
Create ChemicalThruster aThruster
Create ChemicalTank aTank
Create FiniteBurn aFiniteBurn
Create Propagator aPropagator
```

```
% Configure the physical objects
aSat.Thrusters      = {aThruster}
aThruster.Tank      = {aTank}
aSat.Tanks          = {aTank}
aFiniteBurn.Thrusters = {aThruster}

BeginMissionSequence

% Prop to TA = 300 then maneuver until TA = 60
Propagate aPropagator(aSat, {aSat.TA = 300})
BeginFiniteBurn aFiniteBurn(aSat)
Propagate aPropagator(aSat, {aSat.TA = 60})
EndFiniteBurn aFiniteBurn(aSat)
```

Perform a velocity direction maneuver firing the thruster for 2 minutes.

```
% Create objects
Create Spacecraft aSat
Create ChemicalThruster aThruster
Create ChemicalTank aTank
Create FiniteBurn aFiniteBurn
Create Propagator aPropagator

% Configure the physical objects
aThruster.CoordinateSystem = Local
aThruster.Origin = Earth
aThruster.Axes = VNB
aThruster.ThrustDirection1 = 1
aThruster.ThrustDirection2 = 0
aThruster.ThrustDirection3 = 0

% Configure the physical objects
aSat.Thrusters      = {aThruster}
aThruster.Tank      = {aTank}
aSat.Tanks          = {aTank}
aFiniteBurn.Thrusters = {aThruster}

BeginMissionSequence

% Fire thruster for 2 minutes
BeginFiniteBurn aFiniteBurn(aSat)
Propagate aPropagator(aSat, {aSat.ElapsedSecs = 120})
EndFiniteBurn aFiniteBurn(aSat)
```

## EndFileThrust

Apply a piece-wise continuous thrust/acceleration and mass flow rate profile

### Description

To apply a piece-wise continuous thrust/acceleration and mass flow rate profile to a **Spacecraft** object, you use a pair of commands, the **BeginFileThrust** and the **EndFileThrust** command. The use of both of these commands is described in the [BeginFileThrust](#) command help.

## EndFiniteBurn

Model finite thrust maneuvers in the mission sequence

### Description

To implement a finite burn, you use a pair of commands, the **BeginFiniteBurn** command and the **EndFiniteBurn** command. The use of both of these commands is described in the [BeginFiniteBurn](#) command help.

## FindEvents

Execute an event location search

### Script Syntax

```
FindEvents Locator [{Append = true|false}]
```

### Description

The **FindEvents** command executes an event location search defined by either of the event location resources, **ContactLocator** or **EclipseLocator**. If configured, the search will result in a text-based event report.

An explicit **FindEvents** command is not necessary for most simple event location searches. If the locator resource is configured with **RunMode** = 'Automatic', **FindEvents** is executed automatically at the end of the mission sequence. Manual execution of the command is most useful to generate custom searches for part of a mission, or to change search intervals based on mission data.

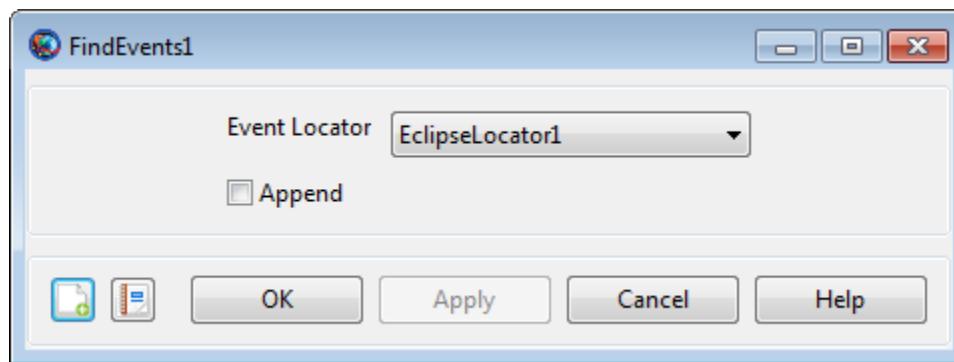
The **Append** option is used to configure how the report file is written. If **Append** is true, the new report will be appended to the end of the existing file. If **Append** is false, it will replace the old file. Note that if **Append** is true, the report may be appended to a file that existed prior to the current GMAT session.

See Also:[ContactLocator](#), [EclipseLocator](#)

### Options

Option	Description
<b>Locator</b>	The event locator to execute.  <b>Accepted Data Types</b> <b>ContactLocator</b> , <b>EclipseLocator</b> <b>Allowed Values</b> any valid <b>ContactLocator</b> or <b>EclipseLocator</b> resource <b>Default Value</b> none <b>Required</b> yes <b>Interfaces</b> GUI, script
<b>Append</b>	Append to an existing event report (if true) or replace it (if false).  <b>Accepted Data Types</b> Boolean <b>Allowed Values</b> true, false <b>Default Value</b> false <b>Required</b> no <b>Interfaces</b> GUI, script

## GUI



The **FindEvents** GUI panel is very simple. Choose the event locator to execute from the **Event Locator** list, which is populated by all existing **EclipseLocator** and **ContactLocator** resources. To append the report (if one is generated), enable the **Append** box.

## Remarks

### Using FindEvents in loops

The **FindEvents** command can be used inside loops like **For** and **While**, but not inside solver sequences, like **Target** and **Optimize**. To perform event location based on the result of a solver sequence, put the **FindEvents** command after the sequence.

When **FindEvents** is used inside a loop, but there are several potential issues to be aware of. The following snippet illustrates several.

```
Create EclipseLocator ec
ec.Spacecraft = sat
ec.OccultingBodies = {Mercury, Venus, Earth, Luna, Mars, Phobos, Deimos}
ec.Filename = 'ForLoop.report'
ec.InputEpochFormat = TAIGregorian

% Prevents automatic execution at end of mission
ec.RunMode = 'Manual'

% Lets us manually control search intervals
ec.UseEntireInterval = false

BeginMissionSequence

% Execute FindEvents once before loop, to clear
% out any existing file.
ec.InitialEpoch = sat.TAIGregorian
Propagate prop(sat) {sat.ElapsedSecs = 2400}
ec.FinalEpoch = sat.TAIGregorian
FindEvents ec {Append = false}

% Main loop
For I = 1:1:71
```

```
% Set initial epoch of search to current epoch
ec.InitialEpoch = sat.TAIGregorian
% Propagate
Propagate prop(sat) {sat.ElapsedSecs = 2400}
% Set final epoch of search to new epoch
ec.FinalEpoch = sat.TAIGregorian
% Execute search, appending to file
FindEvents ec {Append = true}
EndFor
```

## Examples

Perform a basic eclipse search in LEO:

```
SolarSystem.EphemerisSource = 'DE421'

Create Spacecraft sat
sat.DateFormat = UTCGregorian
sat.Epoch = '15 Sep 2010 16:00:00.000'
sat.CoordinateSystem = EarthMJ2000Eq
sat.DisplayStateType = Keplerian
sat.SMA = 6678.14
sat.ECC = 0.001
sat.INC = 0
sat.RAAN = 0
sat.AOP = 0
sat.TA = 180

Create ForceModel fm
fm.CentralBody = Earth
fm.PrimaryBodies = {Earth}
fm.GravityField.Earth.PotentialFile = 'JGM2.cof'
fm.GravityField.Earth.Degree = 0
fm.GravityField.Earth.Order = 0
fm.GravityField.Earth.TideModel = 'None'
fm.Drag.AtmosphereModel = None
fm.PointMasses = {}
fm.RelativisticCorrection = Off
fm.SRP = Off

Create Propagator prop
prop.FM = fm
prop.Type = RungeKutta89

Create EclipseLocator el
el.Spacecraft = sat
el.Filename = 'Simple.report'
el.OccultingBodies = {Earth}
el.EclipseTypes = {'Umbra', 'Penumbra', 'Antumbra'}
```

```
el.RunMode = 'Manual'

BeginMissionSequence

Propagate prop(sat) {sat.ElapsedSecs = 10800}

FindEvents el
```

Execute FindEvents in a loop, appending each time:

```
SolarSystem.EphemerisSource = 'SPICE'
SolarSystem.SPKFilename = 'de421.bsp'

Create Spacecraft sat
sat.DateFormat = UTCGregorian
sat.Epoch = '10 May 1984 00:00:00.000'
sat.CoordinateSystem = MarsMJ2000Eq
sat.DisplayStateType = Keplerian
sat.SMA = 6792.38
sat.ECC = 0
sat.INC = 45
sat.RAAN = 0
sat.AOP = 0
sat.TA = 0

Create ForceModel fm
fm.CentralBody = Mars
fm.PrimaryBodies = {Mars}
fm.GravityField.Mars.PotentialFile = 'Mars50c.cof'
fm.GravityField.Mars.Degree = 0
fm.GravityField.Mars.Order = 0
fm.Drag.AtmosphereModel = None
fm.PointMasses = {}
fm.RelativisticCorrection = Off
fm.SRP = Off

Create Propagator prop
prop.FM = fm
prop.Type = RungeKutta89

Create CoordinateSystem MarsMJ2000Eq
MarsMJ2000Eq.Origin = Mars
MarsMJ2000Eq.Axes = MJ2000Eq

Create Moon Phobos
Phobos.CentralBody = 'Mars'
Phobos.PosVelSource = 'SPICE'
Phobos.NAIFId = 401
Phobos.OrbitSpiceKernelName = {'mar063.bsp'}
```

```
Phobos.SpiceFrameId = 'IAU_PHOBOS'
Phobos.EquatorialRadius = 13.5
Phobos.Flattening = 0.3185185185185186
Phobos.Mu = 7.093399e-004

Create Moon Deimos
Deimos.CentralBody = 'Mars'
Deimos.PosVelSource = 'SPICE'
Deimos.NAIFId = 402
Deimos.OrbitSpiceKernelName = {'mar063.bsp'}
Deimos.SpiceFrameId = 'IAU_DEIMOS'
Deimos.EquatorialRadius = 7.5
Deimos.Flattening = 0.3066666666666666
Deimos.Mu = 1.588174e-004

Create EclipseLocator ec
ec.Spacecraft = sat
ec.OccultingBodies = {Mercury, Venus, Earth, Luna, Mars, Phobos, Deimos}
ec.Filename = 'ForLoop.report'
ec.RunMode = 'Manual'
ec.UseEntireInterval = false
ec.InputEpochFormat = TAIGregorian

Create Variable I

BeginMissionSequence

ec.InitialEpoch = sat.TAIGregorian
Propagate prop(sat) {sat.ElapsedSecs = 2400}
ec.FinalEpoch = sat.TAIGregorian
FindEvents ec {Append = false}

For I = 1:1:71
    ec.InitialEpoch = sat.TAIGregorian
    Propagate prop(sat) {sat.ElapsedSecs = 2400}
    ec.FinalEpoch = sat.TAIGregorian
    FindEvents ec {Append = true}
EndFor
```

Execute FindEvents in a loop, executing search in stages but not appending:

```
Create Spacecraft sat
sat.DateFormat = UTCGregorian
sat.Epoch = '1 Mar 2016 12:00:00.000'
sat.CoordinateSystem = EarthMJ2000Eq
sat.DisplayStateType = Keplerian
sat.SMA = 42164
sat.ECC = 0
sat.INC = 0
```

```
sat.RAAN = 0
sat.AOP = 0
sat.TA = 0

Create ForceModel fm
fm.CentralBody = Earth
fm.PrimaryBodies = {Earth}
fm.GravityField.Earth.PotentialFile = 'JGM2.cof'
fm.GravityField.Earth.Degree = 0
fm.GravityField.Earth.Order = 0
fm.GravityField.Earth.TideModel = 'None'
fm.Drag.AtmosphereModel = None
fm.PointMasses = {}
fm.RelativisticCorrection = Off
fm.SRP = Off

Create Propagator prop
prop.FM = fm
prop.Type = RungeKutta89
prop.MaxStep = 2700

Create EclipseLocator ec
ec.Spacecraft = sat
ec.OccultingBodies = {Mercury, Venus, Earth, Luna}
ec.Filename = 'WhileLoop.report'
ec.RunMode = 'Manual'

SolarSystem.EphemerisSource = 'DE421'

BeginMissionSequence

While sat.UTCModJulian <= 27480
    Propagate prop(sat) {sat.ElapsedSecs = 28800}
    FindEvents ec {Append = false}
EndWhile
```

## Maneuver

Perform an impulsive (instantaneous) maneuver

### Script Syntax

```
Maneuver BurnName (SpacecraftName)
```

### Description

The **Maneuver** command applies a selected **ImpulsiveBurn** to a selected **Spacecraft**. To perform an impulsive maneuver using the **Maneuver** command, you must create an **ImpulsiveBurn**. If you wish to model fuel depletion, you must associate a specific **ChemicalTank** hardware object with this **ImpulsiveBurn** and attach the **ChemicalTank** to the desired **Spacecraft**. See the Remarks and example shown below for more details.

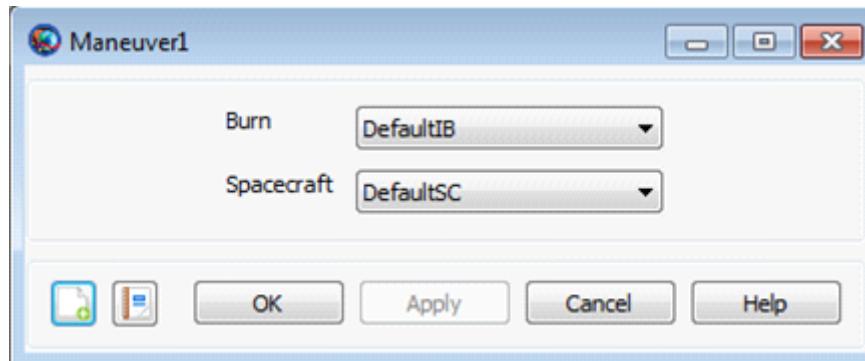
See Also: [ChemicalTank](#), [ImpulsiveBurn](#), [Spacecraft](#)

### Options

Option	Description
<b>ImpulsiveBurn-Name</b>	Allows the user to select which <b>ImpulsiveBurn</b> to apply. As an example, to maneuver DefaultSC using DefaultIB, the script line would appear as Maneuver DefaultIB(DefaultSC).  Accepted Data Types Any <b>ImpulsiveBurn</b> existing in the resource tree  Default Value <b>DefaultIB</b> Required Interfaces yes GUI, script
<b>SpacecraftName</b>	Allows the user to select which <b>Spacecraft</b> to maneuver. The maneuver applied is specified by the <b>ImpulsiveBurnName</b> option above.  Accepted Data Types Any <b>Spacecraft</b> resource  Default Value <b>DefaultSC</b> Required Interfaces yes GUI, script

### GUI

The **Maneuver** command dialog box, as shown below, allows you to select which previously created **ImpulsiveBurn** should be applied to which **Spacecraft**.



## Remarks

### Fuel Depletion

To model fuel depletion associated with your chosen **ImpulsiveBurn**, you must configure the **ImpulsiveBurn** object as follows:

- Set the **ImpulsiveBurn** parameter, **Decrement Mass**, equal to true.
- Select a **ChemicalTank** for the **ImpulsiveBurn** object and attach this selected **ChemicalTank** to the **Spacecraft**.
- Set values for the **ImpulsiveBurn** parameters, **Isp** and **GravitationalAccel**, which are used to calculate, via the Rocket Equation, the mass depleted.

### Interactions

<b>ImpulsiveBurn</b>	The <b>Maneuver</b> command applies the specified <b>ImpulsiveBurn</b> to the specified <b>Spacecraft</b> .
<b>ChemicalTank</b>	The <b>ChemicalTank</b> specified by the <b>ImpulsiveBurn</b> object is (optionally) used to power the <b>ImpulsiveBurn</b> .
<b>Spacecraft</b>	This is the object that the <b>ImpulsiveBurn</b> is applied to.

### Examples

Create a default **Spacecraft** and **ChemicalTank** and attach the **ChemicalTank** to the **Spacecraft**. Perform a 100 m/s impulsive maneuver in the Earth VNB-V direction.

```
% Create default Spacecraft and ChemicalTank and attach the ChemicalTank
% to the Spacecraft.
Create Spacecraft DefaultSC
Create ChemicalTank FuelTank1
DefaultSC.Tanks = {FuelTank1}

% Set ChemicalTank1 parameters to default values
FuelTank1.AllowNegativeFuelMass = false
FuelTank1.FuelMass = 756
FuelTank1.Pressure = 1500
FuelTank1.Temperature = 20
FuelTank1.RefTemperature = 20
```

```
FuelTank1.Volume = 0.75
FuelTank1.FuelDensity = 1260
FuelTank1.PressureModel = PressureRegulated

% Create ImpulsiveBurn associated with the created ChemicalTank
Create ImpulsiveBurn IB
IB.CoordinateSystem = Local
IB.Origin = Earth
IB.Axes = VNB
IB.Element1 = 0.1
IB.Element2 = 0
IB.Element3 = 0
IB.DecrementMass = true
IB.Tank = {FuelTank1}
IB.Isp = 300
IB.GravitationalAccel = 9.81000000000001

BeginMissionSequence
% Apply impulsive maneuver to DefaultSC
Maneuver IB(DefaultSC)
```

## Propagate

Propagates spacecraft to a requested stopping condition

### Script Syntax

The **Propagate** command is a complex command that supports multiple **Propagators**, multiple **Spacecraft**, and multiple stopping conditions. In the syntax definition below, **SatList** is a comma separated list of spacecraft and **StopList** is a comma separated list of stopping conditions. The general syntax of the **Propagate** command is:

```
Propagate [Mode] [BackProp] Propagator1Name(SatList1,{StopList1})...
          Propagator2Name(SatList2,{StopList2})
```

or

```
Propagate [Mode] [BackProp] Propagator1Name(SatList1)...
          Propagator2Name(SatList2){StopList}
```

Most applications propagate a single **Spacecraft**, forward, to a single stopping condition. In that case, the syntax simplifies to:

```
Propagate PropagatorName(SatName,{StopCond});
```

or

```
Propagate PropagatorName(SatName){StopCond};
```

In GMAT, syntax for setting orbit color on a **Propagate** command for a single **Spacecraft** propagating forward to a single stopping condition can be done by either identifying orbit color through ColorName or via RGB triplet value:

```
Propagate PropagatorName(SatName),{StopCond}, OrbitColor = ColorName;
```

or

```
Propagate PropagatorName(SatName),{StopCond}, OrbitColor = [RGB triplet value];
```

### Description

The **Propagate** command controls the time evolution of spacecraft. GMAT allows you to propagate single **Spacecraft**, multiple non-cooperative **Spacecraft**, and **Formations**

in a single **Propagate** command. The **Propagate** command is complex and controls the following aspects of the temporal modeling of spacecraft:

- The **Spacecraft** to be propagated
- The model(s) used for the propagation (numerical integration, ephemeris interpolation)
- The condition(s) to be satisfied at the termination of propagation
- The direction of propagation (forwards or backwards in time)
- The time synchronization of multiple **Spacecraft**
- Propagation of STM and computation of state Jacobian (A-matrix)
- Setting unique colors on different **Spacecraft** trajectory segments through **Propagate** commands

See Also: [Propagator](#), [Spacecraft](#), [Formation](#), [Color](#)

## Options

Option	Description	
<b>Mode</b>	Optional flag to time-synchronize propagation of <b>Spacecraft</b> performed by multiple <b>Propagators</b> in a single <b>Propagate</b> command. See <a href="#">the section called “Remarks”</a> for more details.	
	<b>Accepted Data Types</b>	String
	<b>Allowed Values</b>	<b>Synchronized</b>
	<b>Default Value</b>	Not used
	<b>Required</b>	no
<b>BackProp</b>	Optional flag to propagate all <b>Spacecraft</b> in a <b>Propagate</b> command backwards in time.	
	<b>Accepted Data Types</b>	String
	<b>Allowed Values</b>	<b>BackProp</b>
	<b>Default Value</b>	Not used
	<b>Required</b>	no
<b>StopList</b>	A comma separated list of stopping conditions. Stopping conditions must be parameters of propagated <b>Spacecraft</b> in <b>SatList</b> . See <a href="#">the section called “Remarks”</a> for more details.	
	<b>Accepted Data Types</b>	Reference array
	<b>Allowed Values</b>	Valid list of stopping conditions
	<b>Default Value</b>	<b>ElapsedSecs = 12000</b>
	<b>Required</b>	no
	<b>Interfaces</b>	GUI, script

Option	Description
<b>SatList</b>	A comma separated list of <b>Spacecraft</b> . For SPK type <b>Propagators</b> , the <b>Spacecraft</b> must be configured with valid SPK kernels.
	<b>Accepted Data Types</b> Resource array <b>Allowed Values</b> Valid list of spacecraft and/or formations <b>Default Value</b> <b>DefaultSC</b> <b>Required</b> yes <b>Interfaces</b> GUI, script
<b>PropagatorName</b>	A propagator name.
	<b>Accepted Data Types</b> <b>Propagator</b> <b>Allowed Values</b> Valid <b>Propagator</b> name <b>Default Value</b> <b>DefaultProp</b> <b>Required</b> yes <b>Interfaces</b> GUI, script
<b>StopTolerance</b>	Tolerance on the stopping condition root location. See <a href="#">the section called “Remarks”</a> for more details.
	<b>Accepted Data Types</b> Real <b>Allowed Values</b> Real number > 0 <b>Default Value</b> 0.0000001 <b>Required</b> no <b>Interfaces</b> GUI, script
<b>STM</b>	Optional flag to propagate the orbit STM. STM propagation only occurs for numerical integrator type propagators.
	<b>Accepted Data Types</b> String <b>Allowed Values</b> <b>STM</b> <b>Default Value</b> Not used <b>Required</b> no <b>Interfaces</b> GUI, script
<b>AMatrix</b>	The Jacobian of the orbital acceleration. The partial of the first order acceleration vector with respect to the state vector.
	<b>Accepted Data Types</b> String <b>Allowed Values</b> <b>AMatrix</b> <b>Default Value</b> Not used <b>Required</b> no <b>Interfaces</b> GUI, script

Option	Description	
<b>Covariance</b>	Optional flag to propagate the orbit Covariance. Covariance propagation only occurs for numerical integrator type propagators. Selecting this option will also propagate the STM.	
	<b>Accepted Data Types</b>	String
	<b>Allowed Values</b>	<b>Covariance</b>
	<b>Default Value</b>	Not used
	<b>Required Interfaces</b>	no script
<b>OrbitColor</b>	Sets orbit color on a <b>Propagate</b> command. Default color on <b>Propagate</b> segment is seeded from color that is set on <b>Spacecraft.OrbitColor</b> field. To set unique colors on <b>Propagate</b> command in script mode: Enter ColorName or RGB triplet value for the color of your choice. In GUI mode, select unique color of your choice on the <b>Propagate</b> command by clicking on Orbit Color Selectbox. For Example: Setting yellow color on <b>Propagate</b> segment in script mode can be done in either of the following two ways: Propagate DefaultProp(DefaultSC) {DefaultSC.Earth.Apoapsis, OrbitColor = Yellow} or Propagate DefaultProp(DefaultSC) {DefaultSC.Earth.Apoapsis, OrbitColor = [255 255 0]}.	
	<b>Accepted Data Types</b>	Integer Array or String
	<b>Allowed Values</b>	Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255.
	<b>Default Value</b>	Default color on <b>Propagate</b> command is color that is first set on <b>Spacecraft.OrbitColor</b> field. Default color on <b>Spacecraft.OrbitColor</b> is Red. Therefore default color for <b>Propagate</b> command is Red.
	<b>Required Interfaces</b>	no GUI, script

## GUI

### Introduction

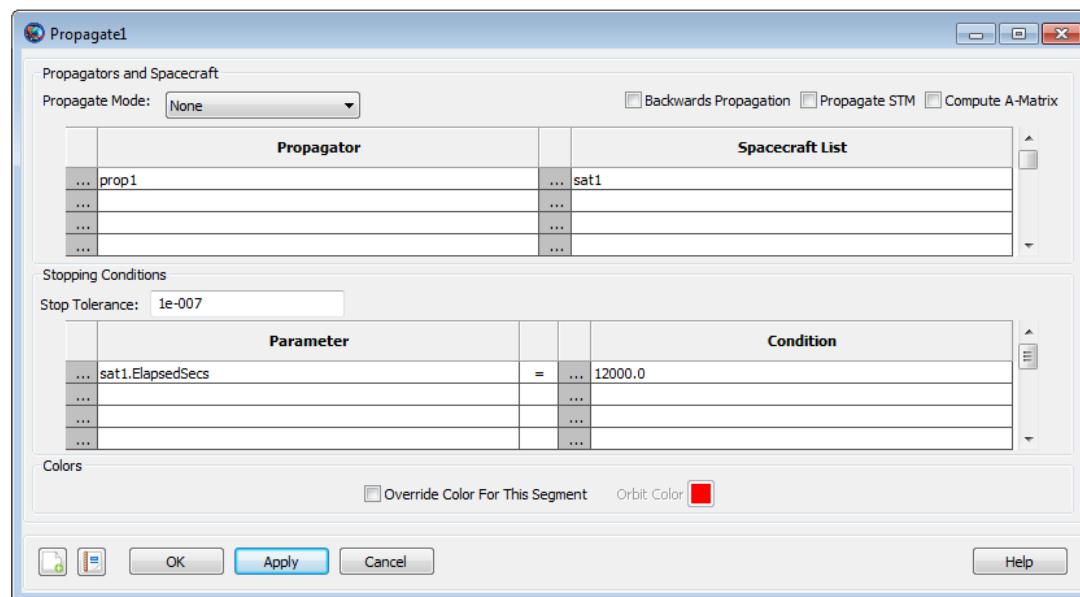
The **Propagate** command GUI provides an interface to assign **Spacecraft** to **Propagators** used for propagation and to define a set of conditions to terminate propagation. The GUI also allows you to define the direction of propagation, the synchronization mode for multiple spacecraft, and whether or not to propagate the STM and compute the A-Matrix.

To follow the examples below, you can load the following script snippet or create a new mission with three spacecraft (named **sat1**, **sat2**, and **sat3**) and two propagators (named **prop1** and **prop2**).

```
Create Spacecraft sat1 sat2 sat3
Create Propagator prop1 prop2
BeginMissionSequencer
```

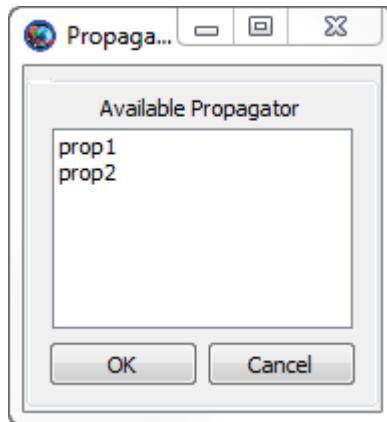
## Defining Spacecraft and Propagators

To demonstrate how to define a set of propagators and **Spacecraft** for propagation, you will set up a **Propagate** command to propagate a **Spacecraft** named **sat1** using a **Propagator** named **prop1** and **Spacecraft** named **sat2** and **sat3** using a **Propagator** named **prop2**. You will configure the command to propagate for 1 day or until **sat2** reaches periapsis, whichever happens first. You will need to configure GMAT as described in the [the section called “Introduction”](#) section and add a new **Propagate** command to your mission sequence. GMAT auto-populates the **Propagate** command GUI with the first **Propagator** in the GUI list and the first **Spacecraft** when you add a new **Propagate** command so you should start from this point.

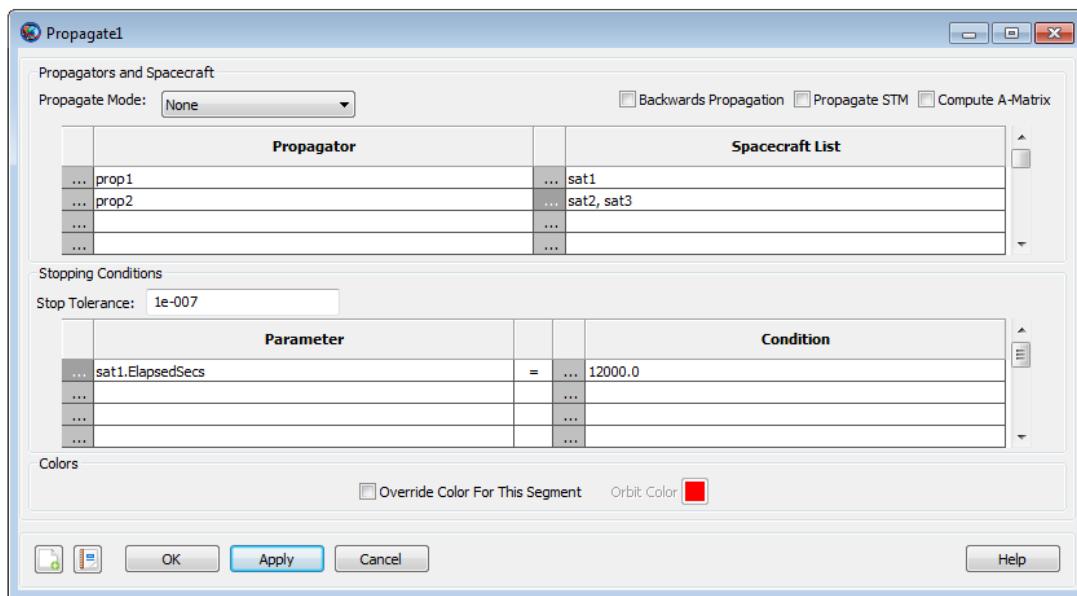


To add a second **Propagator** to propagate **sat2** and **sat3** using **prop2**:

1. In the **Propagator** list, click the ellipsis button in the second row to open the **Propagator Select Dialog**.



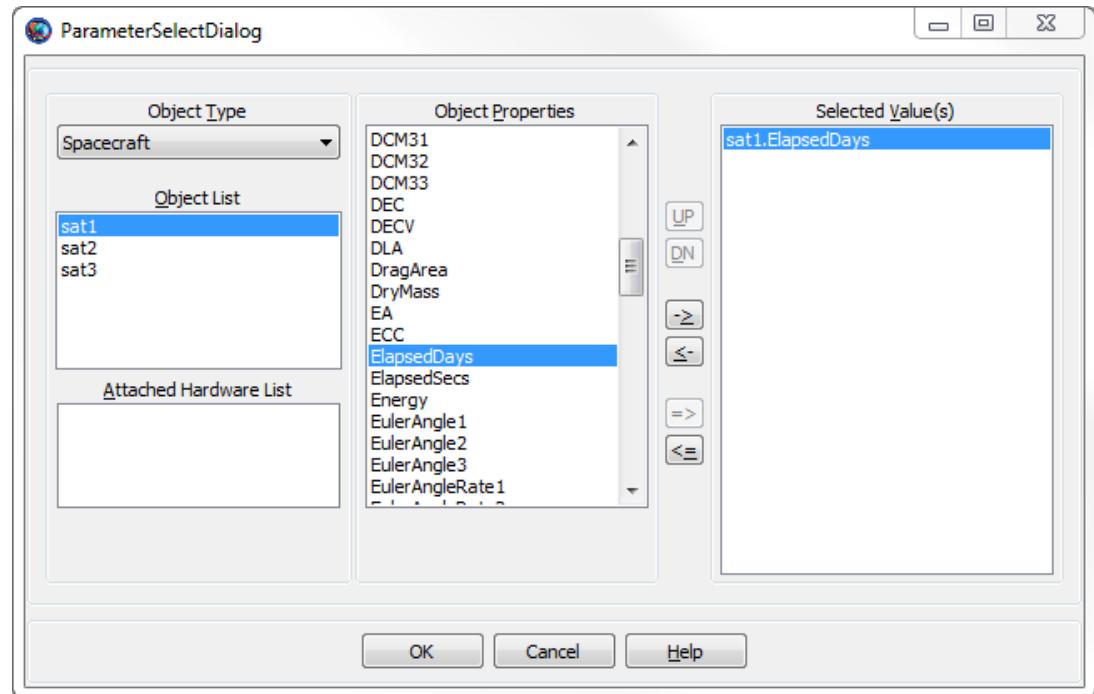
2. In the **Available Propagators** list, click on **prop2**, and click **OK**.
3. In the **Spacecraft List**, click the ellipsis button in the second row to open the **Space Object Select** dialog.
4. Click the right-arrow twice to add **sat2** and **sat3** to the list of selected spacecraft and click **Ok**.



### Stopping conditions

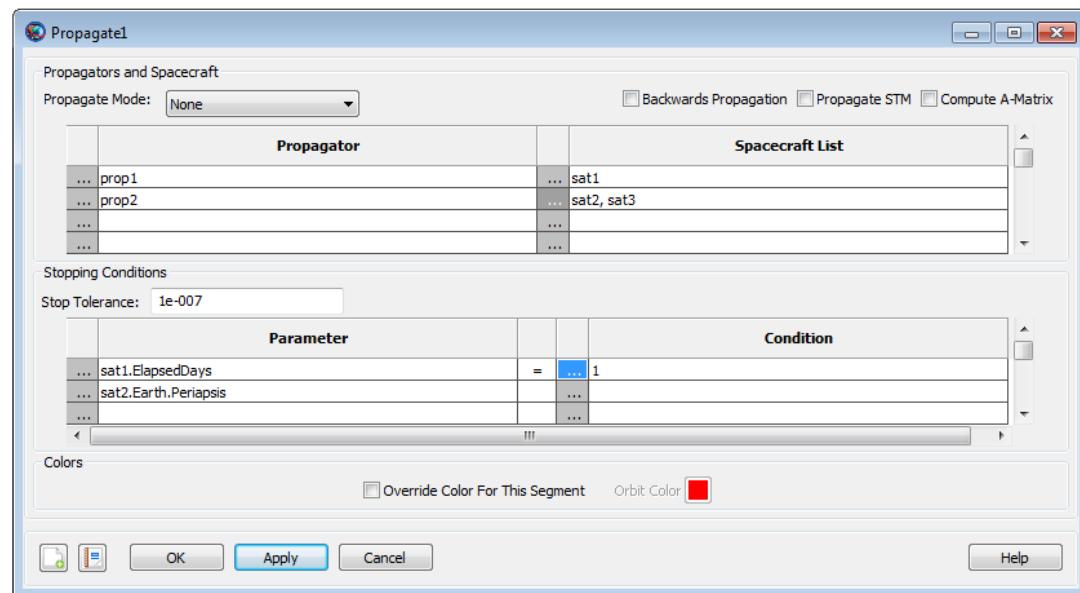
Continuing with the example above, now you will configure GMAT to propagate for one elapsed day or until **sat2** reaches periapsis.

1. In the **Parameter** list, click the ellipsis button in the first row to bring up the **Parameter Select Dialog**.
2. In the **ObjectProperties** list, double click **ElapsedDays**, and click **OK**.



3. In the **Condition** list, double click the first row containing 12000, type 1, and click OK.
4. In the **Parameter** list, click the ellipsis button in the second row to bring up the **Parameter Select Dialog**.
5. In the **Object** list, click **Sat2**.
6. In the **ObjectProperties** list, double click **Periapsis** and click **OK**.

The **Propagate1** dialog should now look like the image below.



## Remarks

### Introduction

The **Propagate** command documentation below describes how to propagate single and multiple **Spacecraft** to desired conditions forward and backwards in time. To streamline the script examples, the objects **numSat**, **spkSat**, **numProp**, and **spkProp** are assumed to be configured as shown below. GMAT is distributed with the SPK kernels used in the examples.

```
Create Spacecraft spkSat;
spkSat.Epoch.UTCGregorian = '02 Jun 2004 12:00:00.000'
spkSat.NAIFId = -123456789;
spkSat.OrbitSpiceKernelName = {'..\data\vehicle\ephem\spk\GEOSat.bsp'};

Create Spacecraft numSat
numSat.Epoch.UTCGregorian = '02 Jun 2004 12:00:00.000'

Create Propagator spkProp;
spkProp.Type = SPK;
spkProp.StartEpoch = FromSpacecraft

Create Propagator numProp
numProp.Type = PrinceDormand78

BeginMissionSequence
```

### How to Propagate a Single Spacecraft

Note: See the the section called “Introduction” section for a script snippet to configure GMAT to execute the examples in this section.

The **Propagate** command provides a simple interface to propagate a **Spacecraft** to a stopping condition or to take a single propagation step. To propagate a single **Spacecraft** you must specify the desired **Propagator**, the **Spacecraft** to propagate, and if desired, the stopping condition. The **Propagate** command supports numerical integrator and ephemeris type propagators. For single **Spacecraft** propagation, the syntax is the same regardless of propagator type. For example, to propagate a **Spacecraft** using a numerical integrator, you can use the following script snippet:

```
Propagate numProp(numSat){numSat.Periapsis}
% or
Propagate numProp(numSat,{numSat.Periapsis})
```

To propagate a single **Spacecraft** using a **Propagator** configured to use an SPK kernel use the following:

```
Propagate spkProp(spkSat){spkSat.TA = 90}
% or
Propagate spkProp(spkSat,{spkSat.TA = 90})
```

To take a single propagation step, simply omit the stopping conditions as shown below. The **Propagator** will take a step based on its step size control algorithm. See the [Propagator](#) documentation for more information on step size control.

```
Propagate numProp(numSat)
% or
Propagate spkProp(spkSat)
```

## How to Propagate Multiple Spacecraft

The **Propagate** command allows you to propagate multiple **Spacecraft** by including a list of **Spacecraft** in a single **Propagator**, by including a **Formation** in a **Propagator**, and/or by including multiple **Propagators** in a single command. For example purposes, here is a script snippet that propagates multiple **Spacecraft**.

```
Propagate Synchronized Prop1(Sat1,Sat2) Prop2(Sat3,Sat4)...
Prop3(aFormation){Sat1.Earth.Periapsis}
```

In the script line above **Sat1** and **Sat2** are propagated using **Prop1**; **Prop2** is used to propagate **Sat3** and **Sat4**; all **Spacecraft** added to **aFormation** are propagated using **Prop3**. The **Propagate** command configured above propagates all **Spacecraft** until **Sat1** reaches Earth periapsis.

All **Spacecraft** propagated by the same **Propagator** are time synchronized during propagation. By time synchronization, we mean that all **Spacecraft** are propagated across the same time step. The **Synchronized** keyword tells GMAT to keep **Spacecraft** propagated by different **Propagators** synchronized in time during propagation. Time synchronization among multiple **Propagators** is performed by taking a single step for all **Spacecraft** controlled by the first **Propagator** (**Prop1** in the above example), and then stepping all other **Propagators** to that time. When the **Synchronized** keyword is omitted, **Spacecraft** propagated by different **Propagators** are not synchronized in time. In that case, each **Propagator** takes steps determined by its step size control algorithm without regard to the other **Propagators** in the **Propagate** command. Time synchronization is particularly useful if you need ephemeris files for multiple spacecraft with consistent time tags, or if you are visualizing multiple spacecraft in an **OrbitView**.



### Warning

Caution: When using a **Propagator** configured to use SPK kernels, you can only have one **Spacecraft** per **Propagator**.

This is supported:

```
Propagate numProp(numSat) spkProp(spkSat1) spkProp(spkSat2)
```

This is NOT supported!

```
Propagate numProp(numSat) spkProp(spkSat1,spkSat2)
```

## Behavior of Stopping Conditions

GMAT allows you to define a set of stopping conditions when propagating **Spacecraft** that define conditions that must be satisfied at the termination of the **Propagate** command. For example, it is often useful to propagate to an orbital location such as Apogee. When no stopping condition is provided, the **Propagate** command takes a single step. When given a set of stopping conditions, the **Propagate** command propagates the **Spacecraft** to the condition that occurs first in elapsed propagation time and terminates propagation. There are several ways to define stopping conditions via the script interface. One is to include a comma separated list of stopping conditions with each **Propagator** like this.

```
Propagate Prop1(Sat1,{Sat1.Periapsis}) Prop2(Sat2,{Sat2.Periapsis})
```

A second approach is to define a comma separated list of stopping conditions at the end of the **Propagate** command like this.

```
Propagate Prop1(Sat1) Prop2(Sat2) {Sat1.Periapsis,Sat2.Periapsis}
```

Note that the above two methods result in the same stopping epoch. When you provide a set of stopping conditions, regardless of where in the command the stopping condition is defined, GMAT builds a list of all conditions and tracks them until the first condition occurs.

The **Propagate** command currently requires that the left hand side of a stopping condition is a valid **Spacecraft** parameter. For example, the first line in the following example is supported and the second line is not supported.

```
Propagate Prop1(Sat1) {Sat1.TA = 45} % Supported  
Propagate Prop1(Sat1) {45 = Sat1.TA} % Not supported
```

GMAT supports special built-in stopping conditions for apoapsis and periapsis like this:

```
Propagate Prop1(Sat1) {Sat1.Apoapsis}  
Propagate Prop1(Sat1) {Sat1.Mars.Periapsis}
```

You can define the tolerance on the stopping condition by including the **StopTolerance** keyword in the **Propagate** command as shown below. In this example, GMAT will propagate until the true anomaly of **Sat1** is 90 degrees to within +/- 1e-5 degrees.

```
Propagate Prop1(Sat1) {Sat1.TA = 90, StopTolerance = 1e-5}
```



## Warning

Caution: GMAT currently propagates **Spacecraft** to a time quantization of a few microseconds. Depending upon the rate of the stopping condition function, it may not be possible to locate the stopping condition to the requested **StopTolerance**. In that case, GMAT throws a warning to alert you that the tolerance was not satisfied and provides information on the achieved stopping value and the requested tolerance.

Note: GMAT does not currently support tolerances on a per stopping condition basis. If you include **StopTolerance** multiple times in a single **Propagate** command, GMAT uses the last value provided.

The **Propagate** command uses an algorithm called the First Step Algorithm (FSA) when back-to-back propagations occur and both propagations have at least one stopping condition that is the same in both commands. For example:

```
Propagate prop1(Sat1) {Sat1.TA = 90}  
Propagate prop1(Sat1) {Sat1.TA = 90, StopTolerance = 1e-4}
```

The **FSA** determines the behavior of the first step when the last propagation performed on a **Spacecraft** was terminated using a stopping condition listed in the current command. If the error in the stopping condition at the initial epoch of the second **Propagate** command is less than SafetyFactor\***StopTolerance**, the propagate command will take one integration step before attempting to locate the stopping condition again. In the FSA, SafetyFactor = 10, and the **StopTolerance** is from the second **Propagate** command. Continuing with the example above, if  $\text{abs}(\text{TA}_\text{Achieved} - \text{TA}_\text{Desired}) < 1e-3$  -- where  $\text{TA}_\text{Achieved}$  is the TA after the first **Propagate** command and  $\text{TA}_\text{Desired}$  is the requested value of TA in the second **Propagate** command -- then the **Propagate** command will take one step before attempting to locate the stopping condition. The first step algorithm works the same way for forward propagation, backwards propagation, and changing propagation directions.



## Warning

Caution: It is possible to specify a **StopTolerance** that cannot be satisfied by the stopping condition root locators and in that case, a warning is thrown. However, subsequent **Propagate** commands using the same stopping conditions may not behave as desired. For the FSA algorithm to work as designed, you must provide **StopTolerance** values that are achievable.

## How to Propagate Backwards

To propagate backwards using the script interface, include the keyword **BackProp** between the **Propagate** command and the first **Propagator** in the command as shown below. All **Propagators** in the command will propagate backwards.

```
Propagate Synchronized BackProp Prop1(Sat1,Sat2) Prop2(Sat3,Sat4)...
```

```
Prop3(aFormation){Sat1.Earth.Periapsis}  
Propagate Backprop numProp(numSat){numSat.Periapsis}
```

## How to Propagate the STM, Covariance, and Compute the Jacobian (A-matrix)

GMAT propagates the STM and Covariance for all **Spacecraft** propagated using numerical integrators by including the STM and Covariance keyword in a **Propagate** command as shown below. If the STM or Covariance keyword is included anywhere in a **Propagate** command, the STM and Covariance is propagated for all spacecraft using numerical propagators. When propagating multiple spacecraft with **ProcessNoiseModels** assigned, each **ProcessNoiseModel** must have the same value of the **UpdateTimeStep** parameter.

```
Propagate Backprop numProp(numSat, 'STM', 'Covariance') {numSat.Periapsis}
```

GMAT does not currently support propagating the STM or Covariance when propagating **Formation** resources or when using ephemeris type propagators.

## Special Considerations for Covariance Propagation

Covariance is propagated using a linearized model identical to that employed in the Extended Kalman Filter resource. The initial covariance is specified on the **Spacecraft OrbitErrorCovariance** parameter. If no process noise model is assigned to the spacecraft object, the covariance propagation steps are the integrator steps and the initial covariance is propagated without the inclusion of process noise. To include process noise in the covariance propagation, define a **ProcessNoiseModel** and assign it on the **Spacecraft ProcessNoiseModel** parameter.

When process noise is included, the covariance propagation steps depend on both the integrator step size and the **ProcessNoiseModel UpdateTimeStep** parameter. If **UpdateTimeStep** is set to 0, the covariance propagation steps solely at the integration step size. If **UpdateTimeStep** is non-zero, the **UpdateTimeSteps** form a grid of stopping points for the integrator. Propagation of the state and covariance will proceed to each **UpdateTimeStep** stopping point using the integrator step size setting. In particular, for example, if **UpdateTimeStep** is smaller than the integrator step size, the integrator will step at only the **UpdateTimeStep** intervals. If **UpdateTimeStep** is larger than the integration step size, the integrator will step to each **UpdateTimeStep** stopping point at steps equal to, or smaller than the integrator step size, depending on the difference between the current propagation epoch and the next stopping point.

No consider parameters are currently implemented for covariance propagation. GMAT will only propagate the 6x6 position/velocity covariance. Covariance propagation is currently only allowed when specifying the initial state and initial **OrbitErrorCovariance** in a reference frame using J2000Eq axes.

## Limitations of the Propagate Command

- When using an SPK-type **Propagator**, only a single **Spacecraft** can be propagated by a given **Propagator**.

- GMAT does not currently support propagating the STM when propagating **Formation** objects. Covariance cannot be propagated for a Formation object.
- When computing the A-matrix during propagation, the A-matrix values are only accessible via the C-Interface.

### Setting Colors on the Propagate Command

GMAT allows you to assign unique colors to **Spacecraft** trajectory segments by setting orbital colors on each **Propagate** command. If you do not set unique colors on each **Propagate** command, then by default, the color on each propagate segment is seeded from color that is set on **Spacecraft.OrbitColor** field. See the [Options](#) section for **OrbitColor** option that lets you set colors on the **Propagate** command. Also see [Color](#) documentation for discussion and examples on how to set unique colors on orbital trajectory segments through GMAT's **Propagate** command.

### Examples

Propagate a single **Spacecraft** to Earth periapsis

```
Create Spacecraft numSat
numSat.Epoch.UTCGregorian = '02 Jun 2004 12:00:00.000'

Create Propagator numProp
numProp.Type = PrinceDormand78

BeginMissionSequence

Propagate numProp(numSat) {numSat.Earth.Periapsis}
```

Propagate a single **Spacecraft** for one day.

```
Create Spacecraft numSat
numSat.Epoch.UTCGregorian = '02 Jun 2004 12:00:00.000'

Create Propagator numProp
numProp.Type = PrinceDormand78

BeginMissionSequence

Propagate numProp(numSat) {numSat.ElapsedDays = 1}
```

Propagate a single **Spacecraft** backwards to true anomaly of 90 degrees.

```
Create Spacecraft numSat
numSat.Epoch.UTCGregorian = '02 Jun 2004 12:00:00.000'

Create Propagator numProp
numProp.Type = PrinceDormand78

BeginMissionSequence
```

```
Propagate BackProp numProp(numSat) {numSat.TA = 90}
```

Propagate two **Spacecraft**, each using a different **Propagator**, but keep the **Spacecraft** synchronized in time. Propagate until either **Spacecraft** reaches a mean anomaly of 45 degrees.

```
Create Spacecraft aSat1 aSat2
aSat1.Epoch.UTCGregorian = '02 Jun 2004 12:00:00.000'
aSat2.Epoch.UTCGregorian = '02 Jun 2004 12:00:00.000'
aSat2.TA = 0;

Create Propagator aProp1
aProp1.Type = PrinceDormand78
Create Propagator aProp2
aProp2.Type = PrinceDormand78

BeginMissionSequence

Propagate Synchronized aProp1(aSat1) aProp2(aSat2) ...
    {aSat1.MA = 45,aSat2.MA = 45}
```

# Input/Output

This chapter contains documentation for Resources and Commands related to data and system I/O.

## Resources

## DynamicDataDisplay

A user-defined resource used in tandem with the **UpdateDynamicData** command to print current values of parameters to a table on the GUI.

### Description

The **DynamicDataDisplay** is a resource that generates a table of user chosen parameters that are updated during a mission sequence where the **UpdateDynamicData** command is used. The purpose of this display is to provide the user the option to directly see how data is changing during a mission as the changes happen.

Various options when using this resource include being able to set the parameter's text color, setting the background color of the data cell, setting warning condition bounds and setting critical condition bounds. The most common places to use this resource is in looping sequences such as a for loop, optimization, targeting, etc.

See Also: [UpdateDynamicData](#)

### Fields

Field	Description
<b>AddParameters</b>	Field to set the parameters the desired row, the first entry in this array must be the row number desired. Ex. MyDynamicDataDisplay.AddParameters = {1, Sat.X, Array(2, 1)};
<b>Data Type</b>	Reference Array
<b>Allowed Values</b>	Any variable, Array element, String, or Object parameter (an entire Array cannot be used)
<b>Access</b>	set
<b>Default Value</b>	2x2 empty table
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

---

Field	Description
<b>BackgroundColor</b>	<p>Field to set the background color of the cell showing the chosen parameter value, the first entry in this array must be the parameter to change the background color of followed by the desired color, i.e. MyDynamicDataDisplay.BackgroundColor = {ParamName, Color}.</p> <p><b>Data Type</b> String Array  <b>Allowed Values</b> Any parameter name from the DynamicDataDisplay object and any color available from the TextColorPicker in the GUI, a valid predefined color name, or RGB triplet value between 0 and 255  <b>Access</b> set  <b>Default Value</b> White  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>CritBounds</b>	<p>Field to set the critical bounds on a parameter, stepping outside these bounds will change the parameter value's text to the set critical color. The first entry is the parameter to which these bounds will be applied to while the second is a real array, i.e. MyDynamicDataDisplay.CritBounds = {ParamName, [LowerBound UpperBound]}.</p> <p><b>Data Type</b> String Array  <b>Allowed Values</b> Any Real number  <b>Access</b> set  <b>Default Value</b> [-9.999e300, 9.999e300]  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>CritColor</b>	<p>Field to set the text color that a parameter's value will change to once it has stepped outside the defined critical bounds.</p> <p><b>Data Type</b> Integer Array or String  <b>Allowed Values</b> Any color available from the TextColorPicker in the GUI, a valid predefined, or RGB triplet value between 0 and 255  <b>Access</b> set  <b>Default Value</b> Red  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>

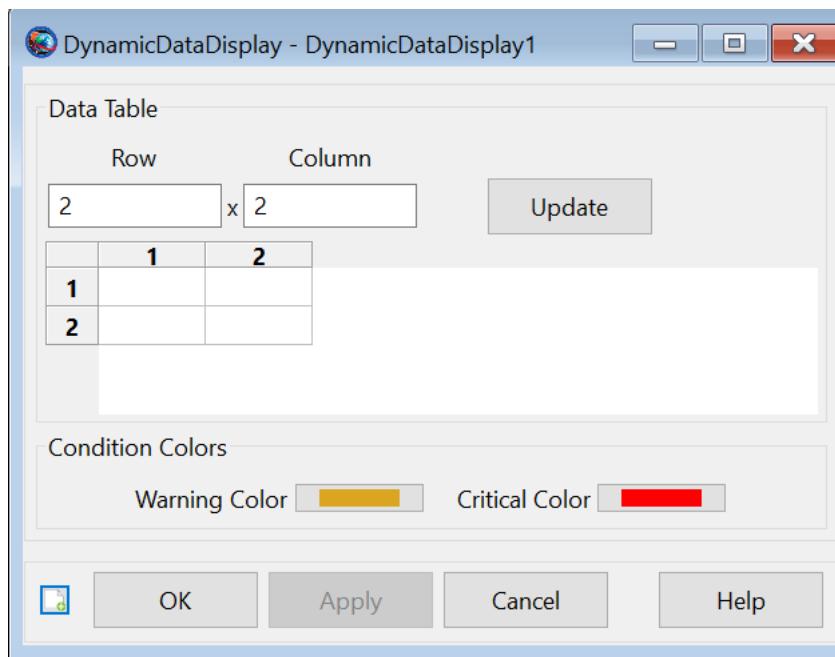
Field	Description												
<b>Maximized</b>	<p>Allows the user to maximize the <b>DynamicDataDisplay</b> window. This field cannot be modified in the Mission Sequence.</p> <table> <tr> <td data-bbox="567 348 796 382"><b>Data Type</b></td><td data-bbox="796 348 975 382">Boolean</td></tr> <tr> <td data-bbox="567 382 796 416"><b>Allowed Values</b></td><td data-bbox="796 382 975 416">true, false</td></tr> <tr> <td data-bbox="567 416 796 449"><b>Access</b></td><td data-bbox="796 416 975 449">set</td></tr> <tr> <td data-bbox="567 449 796 483"><b>Default Value</b></td><td data-bbox="796 449 975 483">false</td></tr> <tr> <td data-bbox="567 483 796 517"><b>Units</b></td><td data-bbox="796 483 975 517">N/A</td></tr> <tr> <td data-bbox="567 517 796 551"><b>Interfaces</b></td><td data-bbox="796 517 975 551">script</td></tr> </table>	<b>Data Type</b>	Boolean	<b>Allowed Values</b>	true, false	<b>Access</b>	set	<b>Default Value</b>	false	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Boolean												
<b>Allowed Values</b>	true, false												
<b>Access</b>	set												
<b>Default Value</b>	false												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>RelativeZOrder</b>	<p>Allows the user to select which <b>DynamicDataDisplay</b> to display first on the screen. The <b>DynamicDataDisplay</b> with the lowest <b>RelativeZOrder</b> value will be displayed last while the <b>DynamicDataDisplay</b> with the highest <b>RelativeZOrder</b> value will be displayed first. This field cannot be modified in the Mission Sequence.</p> <table> <tr> <td data-bbox="567 813 796 846"><b>Data Type</b></td><td data-bbox="796 813 975 846">Integer</td></tr> <tr> <td data-bbox="567 846 796 880"><b>Allowed Values</b></td><td data-bbox="796 846 975 880">Integer # 0</td></tr> <tr> <td data-bbox="567 880 796 914"><b>Access</b></td><td data-bbox="796 880 975 914">set</td></tr> <tr> <td data-bbox="567 914 796 948"><b>Default Value</b></td><td data-bbox="796 914 975 948">0</td></tr> <tr> <td data-bbox="567 948 796 982"><b>Units</b></td><td data-bbox="796 948 975 982">N/A</td></tr> <tr> <td data-bbox="567 982 796 1015"><b>Interfaces</b></td><td data-bbox="796 982 975 1015">script</td></tr> </table>	<b>Data Type</b>	Integer	<b>Allowed Values</b>	Integer # 0	<b>Access</b>	set	<b>Default Value</b>	0	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Integer												
<b>Allowed Values</b>	Integer # 0												
<b>Access</b>	set												
<b>Default Value</b>	0												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>RowTextColors</b>	<p>Field to set the colors of the text showing parameter values, the first entry in this array must be the row number desired entered as a string, i.e. MyDynamicDataDisplay.RowTextColors = {RowNum, Color1, Color2, ...}; The number of colors cannot exceed the number of parameters in the selected row.</p> <table> <tr> <td data-bbox="567 1235 796 1269"><b>Data Type</b></td><td data-bbox="796 1235 975 1269">String Array</td></tr> <tr> <td data-bbox="567 1269 796 1303"><b>Allowed Values</b></td><td data-bbox="796 1269 1390 1453">Any row number the DynamicDataDisplay object contains and any color available from the TextColorPicker in the GUI, a valid predefined color name, or RGB triplet value between 0 and 255</td></tr> <tr> <td data-bbox="567 1453 796 1486"><b>Access</b></td><td data-bbox="796 1453 975 1486">set</td></tr> <tr> <td data-bbox="567 1486 796 1520"><b>Default Value</b></td><td data-bbox="796 1486 975 1520">Black</td></tr> <tr> <td data-bbox="567 1520 796 1554"><b>Units</b></td><td data-bbox="796 1520 975 1554">N/A</td></tr> <tr> <td data-bbox="567 1554 796 1588"><b>Interfaces</b></td><td data-bbox="796 1554 975 1588">GUI, script</td></tr> </table>	<b>Data Type</b>	String Array	<b>Allowed Values</b>	Any row number the DynamicDataDisplay object contains and any color available from the TextColorPicker in the GUI, a valid predefined color name, or RGB triplet value between 0 and 255	<b>Access</b>	set	<b>Default Value</b>	Black	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String Array												
<b>Allowed Values</b>	Any row number the DynamicDataDisplay object contains and any color available from the TextColorPicker in the GUI, a valid predefined color name, or RGB triplet value between 0 and 255												
<b>Access</b>	set												
<b>Default Value</b>	Black												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

Field	Description
<b>Size</b>	<p>Allows the user to control the display size of generated DynamicDataDisplay. First value in [0 0] matrix controls horizontal size and second value controls vertical size of the DynamicDataDisplay. This field cannot be modified in the Mission Sequence.</p>
	<p><b>Data Type</b> Real array  <b>Allowed Values</b> Any Real number  <b>Access</b> set  <b>Default Value</b> [ 0 0 ]  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>TextColor</b>	<p>Field to set the color of the text showing the chosen parameter value, the first entry in this array must be the parameter to change the text color of followed by the desired color, i.e. MyDynamicDataDisplay.TextColor = {ParamName, Color}.</p>
	<p><b>Data Type</b> String Array  <b>Allowed Values</b> Any parameter name from the DynamicDataDisplay object and any color available from the TextColorPicker in the GUI, a valid predefined color name, or RGB triplet value between 0 and 255  <b>Access</b> set  <b>Default Value</b> Black  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>UpperLeft</b>	<p>Allows the user to pan the generated report file display window in any direction. First value in [0 0] matrix pans the DynamicDataDisplay horizontally and second value pans the window vertically. This field cannot be modified in the Mission Sequence.</p>
	<p><b>Data Type</b> Real array  <b>Allowed Values</b> Any Real number  <b>Access</b> set  <b>Default Value</b> [ 0 0 ]  <b>Units</b> N/A  <b>Interfaces</b> script</p>

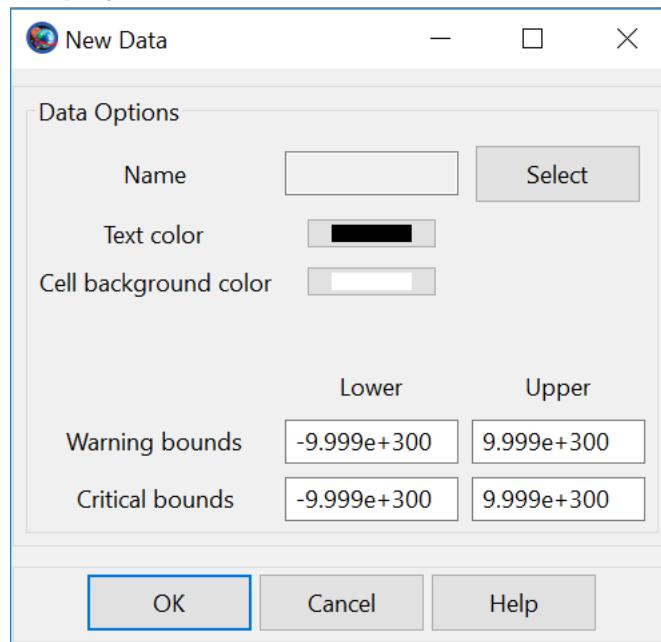
Field	Description												
<b>WarnBounds</b>	<p>Field to set the warning bounds on a parameter, stepping outside these bounds will change the parameter value's text to the set warning color. The first entry is the parameter to which these bounds will be applied to while the second is a real array, i.e. MyDynamicDataDisplay.WarnBounds = {ParamName, [LowerBound UpperBound]}.</p> <table> <tr> <td><b>Data Type</b></td><td>String Array</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any parameter name from the DynamicDataDisplay object and any real number</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>[ -9.999e300, 9.999e300 ]</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	String Array	<b>Allowed Values</b>	Any parameter name from the DynamicDataDisplay object and any real number	<b>Access</b>	set	<b>Default Value</b>	[ -9.999e300, 9.999e300 ]	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String Array												
<b>Allowed Values</b>	Any parameter name from the DynamicDataDisplay object and any real number												
<b>Access</b>	set												
<b>Default Value</b>	[ -9.999e300, 9.999e300 ]												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>WarnColor</b>	<p>Field to set the text color that a parameter's value will change to once it has stepped outside the defined warning bounds.</p> <table> <tr> <td><b>Data Type</b></td><td>Integer Array or String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any color available from the TextColorPicker in the GUI, a valid predefined, or RGB triplet value between 0 and 255</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>GoldenRod</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Integer Array or String	<b>Allowed Values</b>	Any color available from the TextColorPicker in the GUI, a valid predefined, or RGB triplet value between 0 and 255	<b>Access</b>	set	<b>Default Value</b>	GoldenRod	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Integer Array or String												
<b>Allowed Values</b>	Any color available from the TextColorPicker in the GUI, a valid predefined, or RGB triplet value between 0 and 255												
<b>Access</b>	set												
<b>Default Value</b>	GoldenRod												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

## GUI

The figure below shows default name and settings for the **DynamicDataDisplay** resource:



The figure below shows default name and settings for a parameter to be displayed in the **DynamicDataDisplay** resource:



The grid in the setup panel represents the current parameters added to this **DynamicDataDisplay**. To change the grid dimensions, enter integers into the "Row" and "Column" text boxes and click "Update". Double clicking with the left mouse button on one of the grid cells will open a dialog containing all the options for the parameter that will go in the selected cell. The "Select" button takes the user to a parameter selection window to choose the desired parameter. Once selected, the user can also change the options on this parameter if desired. Once "Ok" is clicked, the name of the chosen parameter will appear in the cell on the initial panel that was selected. To remove an undesired para-

meter from the grid, select a cell and hit the Delete key. This will remove the parameter and set all other settings of that cell back to default values.

## Remarks

### Behavior of display under various inputs

If the user skips a row or multiple rows in the script (for example only putting parameters in rows 1 and 4), then the rows in between are simply left as empty cells shown in the GUI. When the table is built, it will make the number of columns in each row match the row with the most parameters. For example, if row 1 has 5 parameters, but row 2 only has 3, the two extra columns in row 2 will still appear but they will simply be left empty. The user may also insert their own empty fields in the grid by adding an empty string using quotations or by leaving boxes in the grid blank when using the setup panel.

### Behavior of warning and critical conditions

The critical condition overrides the warning condition, i.e. if a parameter is currently the warning color and proceeds to step outside the critical bounds, the text color will be changed to the critical color. If a parameter returns within the critical or warning bounds, the critical or warning colors are removed respectively. If the user has specified a text color besides black to be used for a parameter, the warning and critical bound colors will not be applied even if bounds are violated.

## Examples

Create a **DynamicDataDisplay** resource named myDisplay with two rows, user set text colors, and setting condition bounds on mySC.X.

```
Create Spacecraft mySC;
Create DynamicDataDisplay myDisplay
GMAT myDisplay.AddParameters = {1, mySC.X, mySC.Y};
GMAT myDisplay.AddParameters = {2, ',', mySC.Z};
GMAT myDisplay.RowTextColors = {1, Red, Black};
GMAT myDisplay.TextColor = {mySC.Z, [200 0 200]};
GMAT myDisplay.BackgroundColor = {mySC.Y, Blue};
GMAT myDisplay.WarnBounds = {mySC.X, [-1000 1000]};
GMAT myDisplay.CritBounds = {mySC.X, [-3000 3000]};
GMAT myDisplay.WarnColor = Orange;
GMAT myDisplay.CritColor = [200 150 0];
```

Using a **DynamicDataDisplay** with an **UpdateDynamicData** command.

```
Create Spacecraft mySC;
Create Propagator myProp;

Create DynamicDataDisplay myDisplay;
GMAT myDisplay.AddParameters = {1, mySC.EarthMJ2000Eq.X};

BeginMissionSequence
Propagate myProp(mySC) {mySC.ElapsedSec = 12000.0};
```

```
UpdateDynamicData myDisplay;
```

## EphemerisFile

Generate spacecraft's ephemeris data

### Description

**EphemerisFile** is a user-defined resource that generates spacecraft's ephemeris in a report format. You can generate spacecraft's ephemeris data in any of the user-defined coordinate frames. GMAT allows you to output ephemeris data in CCSDS-OEM, SPK, Code-500 and STK .e (STK-TimePosVel) formats. See the [Remarks](#) section for more details. **EphemerisFile** resource can be configured to generate ephemeris data at default integration steps or by entering user-selected step sizes.

GMAT allows you to generate any number of ephemeris data files by creating multiple **EphemerisFile** resources. An **EphemerisFile** resource can be created using either the GUI or script interface. GMAT also provides the option of when to write and stop writing ephemeris data to a text file through the **Toggle On/Off** commands. See the [Remarks](#) section below for detailed discussion of the interaction between **EphemerisFile** resource and **Toggle** command.

See Also: [CoordinateSystem](#), [Toggle](#)

### Fields

Field	Description
<b>CoordinateSystem</b>	Allows you to generate spacecraft ephemeris w.r.t the coordinate system that you select for this field. Ephemeris can also be generated w.r.t a user-specified coordinate system. This field cannot be modified in the Mission Sequence. See Remarks below for restrictions on coordinate systems and ephemeris formats.
<b>DistanceUnit</b>	The unit for distance quantities written to STK ephemeris files. Only active when <b>FileFormat</b> is set to <b>STK-TimePosVel</b> .

Field	Description												
<b>EpochFormat</b>	<p>The field allows you to set the type of the epoch that you choose to enter for <b>InitialEpoch</b> and <b>FinalEpoch</b> fields. This field cannot be modified in the Mission Sequence.</p> <table> <tr> <td><b>Data Type</b></td><td>Enumeration</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any of the following epoch formats: <b>UTC-Gregorian</b>, <b>UTCModJulian</b>, <b>TAIGregorian</b>, <b>TAIModJulian</b>, <b>TTGregorian</b>, <b>TTModJulian</b>, <b>A1Gregorian</b>, <b>A1ModJulian</b></td></tr> <tr> <td><b>Access</b></td><td>Set</td></tr> <tr> <td><b>Default Value</b></td><td><b>UTCGregorian</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Enumeration	<b>Allowed Values</b>	Any of the following epoch formats: <b>UTC-Gregorian</b> , <b>UTCModJulian</b> , <b>TAIGregorian</b> , <b>TAIModJulian</b> , <b>TTGregorian</b> , <b>TTModJulian</b> , <b>A1Gregorian</b> , <b>A1ModJulian</b>	<b>Access</b>	Set	<b>Default Value</b>	<b>UTCGregorian</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Enumeration												
<b>Allowed Values</b>	Any of the following epoch formats: <b>UTC-Gregorian</b> , <b>UTCModJulian</b> , <b>TAIGregorian</b> , <b>TAIModJulian</b> , <b>TTGregorian</b> , <b>TTModJulian</b> , <b>A1Gregorian</b> , <b>A1ModJulian</b>												
<b>Access</b>	Set												
<b>Default Value</b>	<b>UTCGregorian</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>FileFormat</b>	<p>Allows the user to generate ephemeris file in four available ephemeris formats: CCSDS-OEM, SPK, Code-500 or STK-TimePosVel (i.e. STK .e format). This field cannot be modified in the Mission Sequence.</p> <table> <tr> <td><b>Data Type</b></td><td>Enumeration</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>CCSDS-OEM</b>, <b>SPK</b>, <b>Code-500</b>, <b>STK-TimePosVel</b></td></tr> <tr> <td><b>Access</b></td><td>Set</td></tr> <tr> <td><b>Default Value</b></td><td><b>CCSDS-OEM</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Enumeration	<b>Allowed Values</b>	<b>CCSDS-OEM</b> , <b>SPK</b> , <b>Code-500</b> , <b>STK-TimePosVel</b>	<b>Access</b>	Set	<b>Default Value</b>	<b>CCSDS-OEM</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Enumeration												
<b>Allowed Values</b>	<b>CCSDS-OEM</b> , <b>SPK</b> , <b>Code-500</b> , <b>STK-TimePosVel</b>												
<b>Access</b>	Set												
<b>Default Value</b>	<b>CCSDS-OEM</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>FileName</b>	<p>Allows the user to name the ephemeris file that is generated. Common file extensions for CCSDS-OEM, SPK, Code-500 and STK-TimePosVel ephemeris types are *.oem, *.bsp, *.eph and *.e respectively. This field cannot be modified in the Mission Sequence.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Valid File Path and Name</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>EphemerisFile1.eph</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Valid File Path and Name	<b>Access</b>	set	<b>Default Value</b>	EphemerisFile1.eph	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Valid File Path and Name												
<b>Access</b>	set												
<b>Default Value</b>	EphemerisFile1.eph												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

Field	Description
<b>FinalEpoch</b>	<p>Allows the user to specify the time span of an ephemeris file. The ephemeris file is generated up to final epoch that is specified in <b>FinalEpoch</b> field. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>IncludeCovariance</b>	<p>Flag to optionally include covariance data in the output ephemeris, for ephemeris formats that support covariance output. Currently only allowed for <b>STK-TimePosVel</b> ephemeris files. Select <b>Position</b> to output only position covariance values. Select <b>PositionAndVelocity</b> to output position and velocity covariance values.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Values</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>IncludeEvent-Boundaries</b>	<p>Flag to optionally write event data and boundaries to an STK ephem file. Only active when <b>FileFormat</b> is set to <b>STK-TimePosVel</b>. When set to true, if there are discontinuities in the ephemeris data, the times of the discontinuities are written to the file along with blank lines at the discontinuity.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Values</b>
	<b>Units</b>
	<b>Interfaces</b>

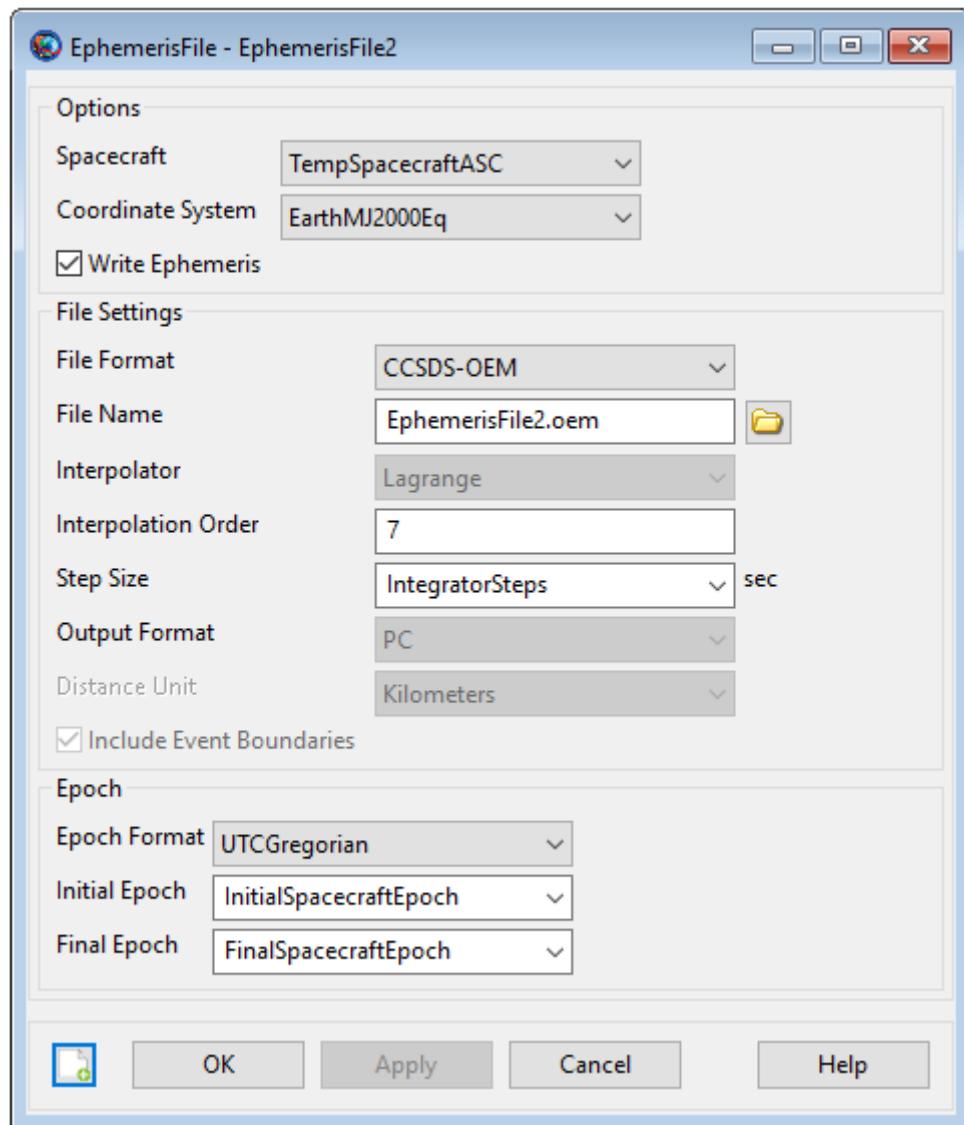
Field	Description
<b>InitialEpoch</b>	<p>Allows the user to specify the starting epoch of the ephemeris file. The ephemeris file is generated starting from the epoch that is defined in <b>InitialEpoch</b> field. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>InterpolationOrder</b>	<p>Allows you to set the interpolation order for the available interpolator methods (<b>Lagrange</b> or <b>Hermite</b>) for any of the ephemeris types. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>Interpolator</b>	<p>This field defines the available interpolator method that was used to generate ephemeris file. Available <b>Interpolators</b> are <b>Lagrange</b> or <b>Hermite</b>. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>Maximized</b>	<p>Allows the user to maximize the generated ephemeris file window. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>

Field	Description
<b>OutputFormat</b>	<p>Allows the user to specify what type of format they want GSFC Code-500 ephemeris to be generated in. GSFC Code-500 ephemeris can be generated in the Little-Endian or Big-Endian format. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>RelativeZOrder</b>	<p>Allows the user to select which generated ephemeris file display window is to displayed first on the screen. The <b>EphemerisFile</b> resource with lowest <b>RelativeZOrder</b> value will be displayed last while <b>EphemerisFile</b> resource with highest <b>RelativeZOrder</b> value will be displayed first. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>Size</b>	<p>Allows the user to control the display size of generated ephemeris file panel. First value in [0 0] matrix controls horizontal size and second value controls vertical size of ephemeris file display window. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>Spacecraft</b>	<p>Allows the user to generate ephemeris data of spacecraft(s) that are defined in <b>Spacecraft</b> field. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>

Field	Description
<b>StepSize</b>	The ephemeris file is generated at the step size that is specified for <b>StepSize</b> field. The user can generate ephemeris file at default Integration step size (using raw integrator steps) or by defining a fixed step size. For CCSDS-OEM and STK-TimePosVel file formats, you can generate ephemeris at either Integrator steps or fixed step size. For SPK file format, GMAT lets you generate ephemeris at only raw integrator step sizes. For Code-500 ephemeris file type, you can generate ephemeris at only fixed step sizes. This field cannot be modified in the Mission Sequence.
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real Number > 0.0 or equals Default Value Set
<b>Access</b>	<b>IntegratorSteps</b> for CCSDS-OEM, SPK, and STK-TimePosVel file formats and <b>60</b> seconds for Code-500 file format
<b>Default Value</b>	N/A
<b>Units</b>	GUI, script
<b>UpperLeft</b>	Allows the user to pan the generated ephemeris file display window in any direction. First value in [0 0] matrix helps to pan the window horizontally and second value helps to pan the window vertically. This field cannot be modified in the Mission Sequence.
<b>Data Type</b>	Real array
<b>Allowed Values</b>	Any Real number
<b>Access</b>	set
<b>Default Value</b>	[ 0 0 ]
<b>Units</b>	N/A
<b>Interfaces</b>	script
<b>WriteEphemeris</b>	Allows the user to optionally calculate/write or not calculate/write an ephemeris that has been created and configured. This field cannot be modified in the Mission Sequence.
<b>Data Type</b>	Boolean
<b>Allowed Values</b>	true,false
<b>Access</b>	set
<b>Default Value</b>	true
<b>Units</b>	Unit
<b>Interfaces</b>	GUI, script

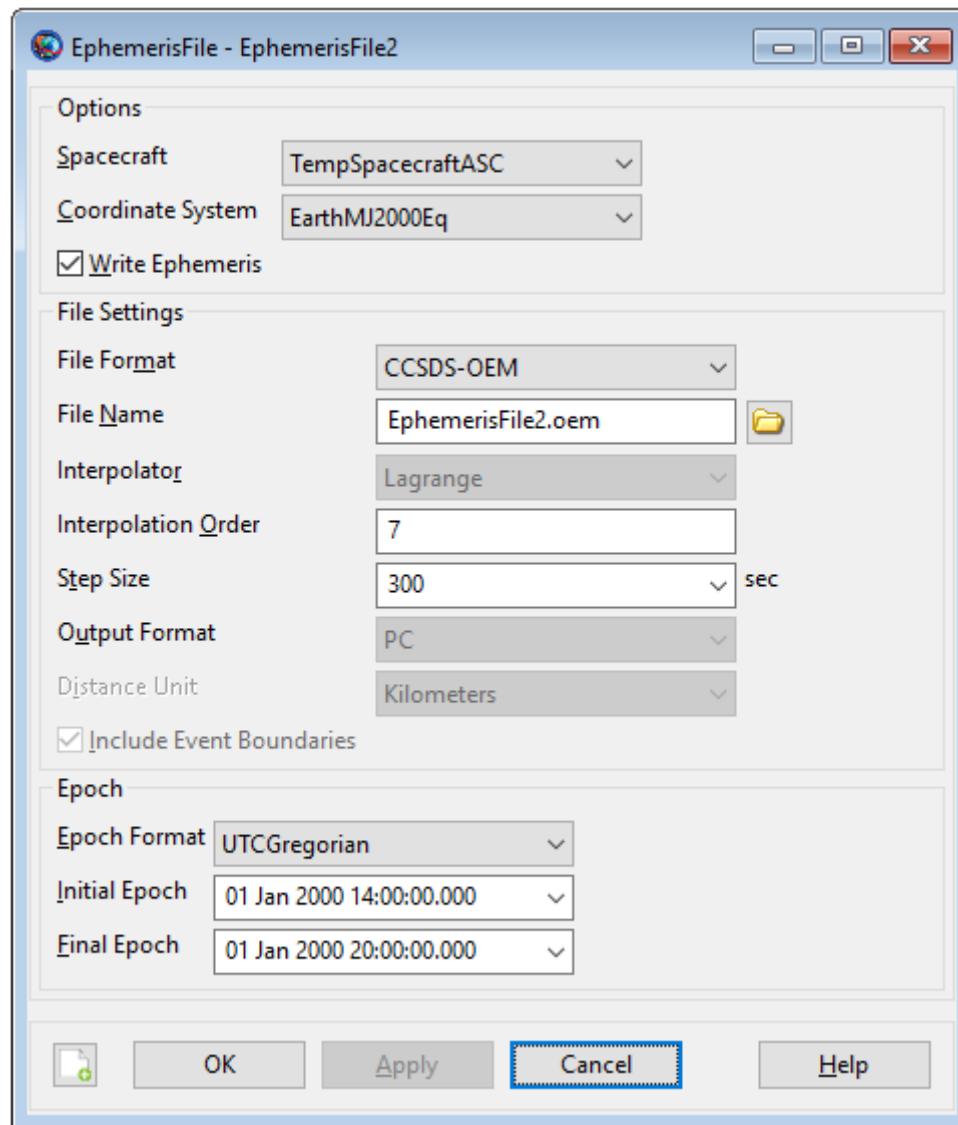
## GUI

The figure below shows the default settings for the **EphemerisFile** resource:



GMAT allows you to modify **InitialEpoch**, **FinalEpoch** and **StepSize** fields of **EphemerisFile** resource. Instead of always generating the ephemeris file at default time span settings of **InitialSpacecraftEpoch** and **FinalSpacecraftEpoch**, you can define your own initial and final epochs. Similarly, instead of using the default **IntegratorSteps** setting for **StepSize** field, you can generate the ephemeris file at the step size of your choice.

The GUI figure below shows ephemeris file which will be generated from initial epoch of 01 Jan 2000 14:00:00.000 to final epoch of 01 Jan 2000 20:00:00.000 while using non-default step size of 300 seconds:



## Remarks

### Behavior of Coordinate System Field for CCSDS, Code 500, and SPK Format Ephemeris Files

If the selected **CoordinateSystem** uses MJ2000Eq axes, the CCSDS ephemeris file contains “EME2000” for the REF\_FRAME according to CCSDS convention. By CCSDS requirements, non-standard axes names are allowed when documented in an ICD. The **CoordinateSystems** specifications document in the user’s guide is the ICD for all axes supported by GMAT. If you create a new coordinate system whose origin is Luna, then the CCSDS ephemeris file contains “Moon” for the CENTER\_NAME.

For Code-500 file format, GMAT can write ephemeris for a CoordinateSystem under **CoordinateSystem** field that references a MJ2000Eq, BodyFixed, or TOD axis for any central body. For SPK file format, GMAT can only write ephemeris for a coordinate

system under **CoordinateSystem** field that references MJ2000Eq axis type for any central body.

There is one important difference between GMAT and IAU conventions. By IAU convention, there is no name for the IAU2000 axes that is independent of the origin. GCRF is coordinate system centered at earth with IAU2000 axes, and ICRF is a coordinate system centered at the solar system barycenter with IAU2000 axes. We have chosen to name the IAU2000 axes ICRF regardless of the origin. Please refer to **CoordinateSystems** specifications document to read more about built-in coordinate systems and description of Axes types that GMAT supports.

### Behavior of Coordinate System Field for STK Format Ephemeris Files

GMAT does not permit use (reading or writing) of the TrueOfDate reference frame in STK format ephemeris files with central bodies other than Earth. GMAT defines a TrueOfDate frame around central bodies other than the Earth by translating the Earth TrueOfDate frame to the origin of other central body. STK instead defines a unique TrueOfDate frame for each central body. The GMAT and STK definitions are only consistent for the Earth.

The following coordinate systems are allowed for reading and writing STK ephemeris files:

- J2000 and ICRF are allowed for all central bodies
- Reading an STK TrueOfDate ephemeris file, or writing an ephemeris file with a coordinate system using GMAT's TODEq axes is allowed only for Earth-centered files
- Reading an STK J2000\_Ecliptic ephemeris file, or writing an ephemeris file with a coordinate system using GMAT's MJ2000Ec axes is allowed only for Sun-centered files

All other coordinate systems are disallowed. These rules apply to the **GetEphemStates()** function call as well.

### Behavior of Ephemeris File during Discontinuous & Iterative Processes

When generating an ephemeris file for a mission sequence, GMAT separately interpolates ephemeris segments that are bounded by discontinuous or discrete mission events. Discontinuous or discrete mission sequence events can range from impulsive or finite-burn maneuvers, changes in dynamics models or when using assignment commands. Furthermore, when a mission sequence employs iterative processes such as differential correction or optimization, GMAT only writes the ephemeris for the final solution from the iterative processes. See the [Examples](#) section below to see how an ephemeris file is generated during a discontinuous event such as an impulsive burn and iterative process like differential correction.

Version 1 of CCSDS Orbit Data Messages (ODMs) document used to require that the ephemeris be generated in increasing time order and only going forward. However version 2 of CCSDS ODM document now allows for ephemeris file to be generated backwards as well. Currently in GMAT, when you propagate a spacecraft backwards in time, then the CCSDS ephemeris is also generated backwards.



## Warning

The Code500 ephemeris file requires fixed time steps and has a pre-defined format for handling chunks of ephemeris data. The format does not allow chunking to stop and start at state discontinuities that occur at impulsive maneuvers. GMAT's current behavior is to interpolate across those discontinuities as the code 500 format does not elegantly support ephemerides with discontinuities. This is acceptable for small maneuvers but becomes less accurate as the maneuvers grow in magnitude. We recommend using more modern ephemeris file formats for this reason. In the event you must use a Code500 ephemeris file with a discontinuous trajectory, we recommend using a propagator with small, fixed times steps, and a small StepSize setting on the ephemeris file to reduce interpolation error near the discontinuity.

Similar to CCSDS ephemeris format, the STK-TimePosVel ephemeris is also generated in separate chunks of ephemeris data whenever an event such as an impulsive or a finite maneuver takes place or a change in dynamic models occurs. However, unlike the CCSDS ephemeris, STK-TimePosVel ephemeris is not generated during backward propagations and only forward propagation ephemeris is reported.

### Behavior of Ephemeris File When It Does Not Meet CCSDS File Format Requirements

When an ephemeris file is generated, it needs to follow the Recommended Standard for ODMs that has been prepared by the CCSDS. The set of orbit data messages described in the recommended standard is the baseline concept of trajectory representation in data interchange applications that are cross-supported between agencies of the CCSDS. The CCSDS-ODM recommended standard document establishes a common framework and provides a common basis for the interchange of orbit data.

Currently, the ephemeris file that is generated by GMAT meets most of the recommended standards that are prescribed by the CCSDS. However whenever there is a case when GMAT's ephemeris violates CCSDS file format requirements, then the generated ephemeris file will display a warning in ephemeris file's header section. More specifically, this warning will be given under COMMENT and it will let you know that this ephemeris file does not fully satisfy CCSDS file formatting requirements.

### Behavior of Interpolation Order Field for the Ephemeris File Formats:

For CCSDS file formats, whenever there is not enough raw data available to support the requested interpolation type and order, GMAT throws an error message and stops interpolation. GMAT still generates the ephemeris file but no spacecraft ephemeris data is written to the file and only the file's Header section will be there. Within the Header section and under COMMENT, a message will be thrown saying that not enough raw data is available to generate spacecraft ephemeris data at the requested interpolation order.

For SPK file formats, raw data is always collected at every integrator step for each segment and then sent to SPK kernel writer. GMAT does not perform any interpolation for SPK files as SPK contains its own interpolation. As a result, **InitialEpoch** and **FinalEpoch**

**poch** fields behave differently for SPK ephemerides. The first epoch on the file is the first step after **InitialEpoch**. The last epoch on the file is the last step before **FinalEpoch**.

For code 500 file formats, you can set the interpolation order and currently GMAT supports Lagrange as the available interpolator method. For code 500 file formats, if there is not enough raw data available to support interpolation type and order, GMAT will throw an error message and stop interpolation.

For the STK-TimePosVel ephemeris format, whenever there is not enough raw data available to support the generation of ephemeris at the requested interpolation order and fixed step size, GMAT will internally adjust the interpolation order such that at least the beginning and the last ephemeris points are reported in the STK .e ephemeris file. This new interpolation order will be reported at STK .e ephemeris's header data.

### Behavior When Using EphemerisFile Resource & Toggle Command

**EphemerisFile** resource generates ephemeris file at each propagation step of the entire mission duration. If you want to generate ephemeris data during specific points in your mission, then a **Toggle On/Off** command can be inserted into the **Mission** tree to control when the **EphemerisFile** resource writes data. When **Toggle Off** command is issued for an **EphemerisFile** subscriber, no data is sent to a file until a **Toggle On** command is issued. Similarly, when a **Toggle On** command is used, ephemeris data is sent to a file at each integration step until a **Toggle Off** command is used. The Toggle command can be used on all four ephemeris types that GMAT supports.

Below is an example script snippet that shows how to use **Toggle Off/On** commands while using the **EphemerisFile** resource. No ephemeris data is sent for first two days of propagation and only the data that is collected during last four days of propagation is sent to text file called 'EphemerisFile1.eph':

```
Create Spacecraft aSat
Create Propagator aProp

Create EphemerisFile anEphemerisFile

anEphemerisFile.Spacecraft = aSat
anEphemerisFile.Filename = 'EphemerisFile1.eph'

BeginMissionSequence

Toggle anEphemerisFile Off
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
Toggle anEphemerisFile On
Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

When using the **Toggle** command in conjunction with modeling finite burns in an ephemeris file, a certain order of operations must be observed. The ephemeris Toggle commands must be placed inside the Begin and EndFileThrust commands as shown in the example below. This order of operations must be observed when propagating, as well as when running estimators like the **BatchEstimator**, **ExtendedKalmanFilter**, or **Smoother**.

```
BeginFileThrust ThrustHistory(Sat);
Toggle Ephem On;
Propagate Prop(Sat) {Sat.ElapsedDays = 1};
Toggle Ephem Off;
EndFileThrust ThrustHistory(Sat);
```

### Behavior of Code 500 Ephemeris File During Discontinuous & Iterative Processes

Code 500 ephemeris file follows the ephemeris format and definitions that have been defined in *Flight Dynamics Division (FDD) Generic Data Product Formats Interface Control Document*.

Unlike CCSDS ephemeris file, the code 500 ephemeris format does not support separate chunks in the data blocks whenever discontinuous or discrete mission events such as impulsive/finite maneuvers, change in dynamics or assignment command takes place. Rather, the code 500 ephemeris is generated all in one continuous data block regardless of any number of mission events that may occur between initial and final epochs of ephemeris file. Furthermore, when a mission sequence employs iterative processes such as differential correction or optimization, GMAT will only write the ephemeris for the final solution from the iterative processes. Code 500 ephemeris does not allow non-monotonic ephemeris generation and an exception will be thrown if propagation direction changes. Furthermore, any discontinuities created by assignments may result in invalid code 500 files.

### Code 500 Ephemeris Header Records

The standard format for Code 500 ephemeris files has a logical record length of 2800 bytes. Code 500 files have two header records, ephemeris header record 1 and ephemeris record 2, followed by as many ephemeris data records as required for the file time span. Many parameters in ephemeris file's header records are mandatory while some fields are optional. GMAT's Code 500 ephemeris header records only specifies fields that are mandatory and optional fields have not been included. Code 500's ephemeris header record 1 is mandatory while ephemeris record 2 is optional. Complete description of ephemeris format and list of mandatory and optional ephemeris header record parameters is defined in *Flight Dynamics Division (FDD) Generic Data Product Formats Interface Control Document*. In GMAT, only required fields have been written in header record 1 while header record 2 is left blank. Table below lists header record 1's required fields and any additional comments pertaining to that field.

Required Fields	Comments
<b>productId</b>	'EPHEM'
<b>satId</b>	123.000000
<b>timeSystemIndicator</b>	2.000000
<b>StartDateOfEphem_YYYYMMDD</b>	value depends on run time
<b>startDayCountOfYear</b>	value depends on run time
<b>startSecondsOfDay</b>	value depends on run time
<b>endDateOfEphem_YYYYMMDD</b>	value depends on run time

Required Fields	Comments
<b>endDayCountOfYear</b>	value depends on run time
<b>endSecondsOfDay</b>	value depends on run time
<b>stepSize_SEC</b>	value depends on run time
<b>startYYYYMMDDHHMMSSsss.</b>	value depends on run time
<b>endYYYYMMDDHHMMSSsss.</b>	value depends on run time
<b>tapId</b>	'STANDARD'
<b>sourceld</b>	'GTDS '
<b>headerTitle</b>	'
<b>centralBodyIndicator</b>	Set to central body of coordinate system. Note GMAT allows users to change central body of integration.
<b>refTimeForDUT_YYMMDD</b>	570918.000000
<b>coordSystemIndicator1</b>	'2000'
<b>coordSystemIndicator2</b>	4
<b>orbitTheory</b>	'COWELL '
<b>timeIntervalBetweenPoints_DUT</b>	value depends on run time
<b>timeIntervalBetweenPoints_SEC</b>	value depends on run time
<b>outputIntervalIndicator</b>	1
<b>epochTimeOfElements_DUT</b>	value depends on run time
<b>epochTimeOfElements_DAY.</b>	value depends on run time
<b>epochA1Greg.</b>	value depends on run time
<b>epochUtcGreg.</b>	value depends on run time
<b>yearOfEpoch_YYY</b>	value depends on run time
<b>monthOfEpoch_MM</b>	value depends on run time
<b>dayOfEpoch_DD</b>	value depends on run time
<b>hourOfEpoch_HH</b>	value depends on run time
<b>minuteOfEpoch_MM</b>	value depends on run time
<b>secondsOfEpoch_MILSEC</b>	value depends on run time
<b>keplerianElementsAtEpoch_RAD[0]</b>	value depends on run time
<b>keplerianElementsAtEpoch_RAD[1]</b>	value depends on run time
<b>keplerianElementsAtEpoch_RAD[2]</b>	value depends on run time
<b>keplerianElementsAtEpoch_RAD[3]</b>	value depends on run time
<b>keplerianElementsAtEpoch_RAD[4]</b>	value depends on run time
<b>keplerianElementsAtEpoch_RAD[5]</b>	value depends on run time
<b>cartesianElementsAtEpoch_DULT[0]</b>	value depends on run time
<b>cartesianElementsAtEpoch_DULT[1]</b>	value depends on run time

Required Fields	Comments
<b>cartesianElementsAtEpoch_DULT[2]</b>	value depends on run time
<b>cartesianElementsAtEpoch_DULT[3]</b>	value depends on run time
<b>cartesianElementsAtEpoch_DULT[4]</b>	value depends on run time
<b>cartesianElementsAtEpoch_DULT[5]</b>	value depends on run time
<b>startTimeOfEphemeris_DUT</b>	value depends on run time
<b>endTimeOfEphemeris_DUT</b>	value depends on run time
<b>timeIntervalBetweenPoints_DUT</b>	value depends on run time
<b>dateOfInitiationOfEphemComp_YYYYMMDD</b>	value depends on run time
<b>timeOfInitiationOfEphemComp_HHMMSS</b>	value depends on run time
<b>utcTimeAdjustment_SEC</b>	0.000000
<b>Pecession/Nutation indicator</b>	1

For ephemeris header record 1, there are some required fields that have not been tabulated in GMAT's Code 500 ephemeris header record 1. These fields that have not been tabulated in header record 1 are listed in the table below. 0.0 indicates "used" and 1.0 means "not used".

Required Fields	Comments
<b>Zonal and tesseral harmonics indicator</b>	1.0
<b>Lunar gravitation perturbation indicator</b>	1.0
<b>Solar radiation perturbation indicator</b>	1.0
<b>Solar gravitation perturbation indicator</b>	1.0
<b>Atmospheric drag perturbation indicator</b>	1.0
<b>Greenwich hour angle at epoch</b>	1.0

## Examples

This example shows how to generate a simple ephemeris file. Ephemeris file is generated for two days of propagation. At default settings, ephemeris file is generated at each integrator step and in CCSDS file format. Ephemeris data is sent to text file called 'EphemerisFile2.eph':

```
Create Spacecraft aSat
Create Propagator aProp

Create EphemerisFile anEphemerisFile

anEphemerisFile.Spacecraft = aSat
anEphemerisFile.Filename = 'EphemerisFile2.eph'

BeginMissionSequence
```

```
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
```

This example shows how an ephemeris file is generated during an iterative process like differential correction that includes a discontinuous event like an impulsive burn. Ephemeris data is sent to text file called ‘EphemerisFile3.eph’:

```
Create Spacecraft aSat
Create Propagator aProp

Create ImpulsiveBurn TOI
Create DifferentialCorrector aDC

Create EphemerisFile anEphemerisFile

anEphemerisFile.Spacecraft = aSat
anEphemerisFile.Filename = 'EphemerisFile3.eph'

BeginMissionSequence

Propagate aProp(aSat) {aSat.Earth.Periapsis}

Target aDC
Vary aDC(TOI.Element1 = 0.24, {Perturbation = 0.001, Lower = 0.0, ...
Upper = 3.14159, MaxStep = 0.5})
Maneuver TOI(aSat)
Propagate aProp(aSat) {aSat.Earth.Apoapsis}
Achieve aDC(aSat.Earth.RMAG = 42165)
EndTarget

Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

This example shows how to generate a simple STK-TimePosVel (i.e. STK.e) ephemeris file. Ephemeris file is generated for 1 day of propagation, then a simple impulsive maneuver takes place and spacecraft propagates for another day. This ephemeris is generated at raw integrator steps.

```
Create Spacecraft aSat
Create Propagator aProp

Create ImpulsiveBurn IB
IB.Element1 = 0.5

Create EphemerisFile anEphemerisFile

anEphemerisFile.Spacecraft = aSat
anEphemerisFile.Filename = 'EphemerisFile.e'
anEphemerisFile.FileFormat = STK-TimePosVel

BeginMissionSequence
```

```
Propagate aProp(aSat) {aSat.ElapsedDays = 1}  
Maneuver IB(aSat)  
Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

## FileInterface

An interface to a data file

### Description

The **FileInterface** resource is an interface to a data file that can be used to load mission data, like **Spacecraft** state information and physical properties. Once an interface is established to a file, the **Set** command can be used to load the data and apply it to a destination.

The following file formats are currently supported:

- TVHF\_ASCII: ASCII format of the TCOPS Vector Hold File (TVHF), defined by the NASA Goddard Space Flight Center Flight Dynamics Facility. This file contains space-craft state and physical information that can be transferred to a **Spacecraft** resource.

See Also: [Set](#)

### Fields

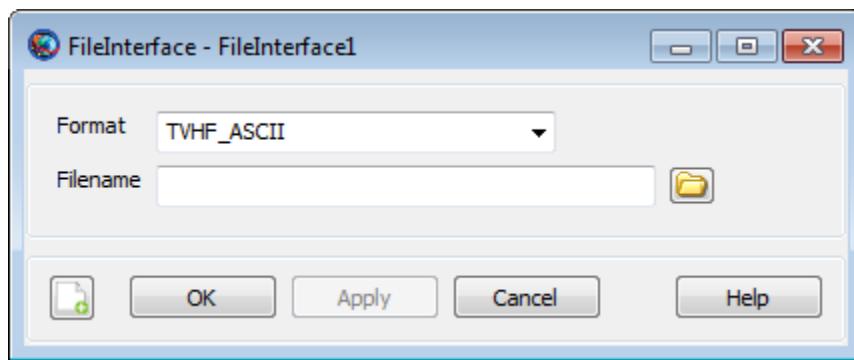
Field	Description												
<b>Filename</b>	Full path of the file to read. Relative paths are interpreted as relative to the directory containing the GMAT executable. If the path is omitted, it is assumed to be “./”.												
	<table><tr><td><b>Data Type</b></td><td>String</td></tr><tr><td><b>Allowed Values</b></td><td>Valid file path</td></tr><tr><td><b>Access</b></td><td>set</td></tr><tr><td><b>Default Value</b></td><td>(None)</td></tr><tr><td><b>Units</b></td><td>N/A</td></tr><tr><td><b>Interfaces</b></td><td>GUI, script</td></tr></table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Valid file path	<b>Access</b>	set	<b>Default Value</b>	(None)	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Valid file path												
<b>Access</b>	set												
<b>Default Value</b>	(None)												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

---

<b>Format</b>	Format of the file to read. Currently, the only allowed format is “TVHF_ASCII”.												
	<table><tr><td><b>Data Type</b></td><td>Enumerated value</td></tr><tr><td><b>Allowed Values</b></td><td><b>TVHF_ASCII</b></td></tr><tr><td><b>Access</b></td><td>set</td></tr><tr><td><b>Default Value</b></td><td><b>TVHF_ASCII</b></td></tr><tr><td><b>Units</b></td><td>N/A</td></tr><tr><td><b>Interfaces</b></td><td>GUI, script</td></tr></table>	<b>Data Type</b>	Enumerated value	<b>Allowed Values</b>	<b>TVHF_ASCII</b>	<b>Access</b>	set	<b>Default Value</b>	<b>TVHF_ASCII</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Enumerated value												
<b>Allowed Values</b>	<b>TVHF_ASCII</b>												
<b>Access</b>	set												
<b>Default Value</b>	<b>TVHF_ASCII</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

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## GUI



The **FileInterface** GUI has two fields: a list of accepted options for **Format** (currently only **TVHF\_ASCII**), and an input box for **Filename**. Click **Browse** to the right of the **Filename** box to interactively select a file.

## Remarks

Each file format supported by the **FileInterface** resource exposes a set of keywords that can be used to extract certain data elements. These keywords can be used in the **Data** option of the **Set** command, as follows:

```
Set destination source (Data = {keyword[, keyword]})
```

If the 'All' keyword is used, those fields with a checkmark in the "All" column are selected.

### TVHF\_ASCII

Keyword	Source field	Description	'All'
CartesianState	"CARTESIAN COORDINATES"	Cartesian state elements (X, Y, Z, VX, VY, VZ)	✓
Cr	"CSUBR"	Coefficient of reflectivity	✓
Epoch	"EPOCH FOR ELEMENTS"	TIME Epoch of state vector TS	✓

## Limitations

The following limitations apply to the TVHF\_ASCII format:

- Only the J2000 coordinate system is supported.
- Only the first record in a multiple-record file is loaded.

## Examples

Read a TVHF file and use it to configure a spacecraft.

```
Create Spacecraft aSat
```

```
Create FileInterface tvhf
tvhf.Filename = 'statevec.txt'
tvhf.Format = 'TVHF_ASCII'

BeginMissionSequence

Set aSat tvhf
```

## GroundTrackPlot

A user-defined resource that draws longitude and latitude time-history of a spacecraft

### Description

The **GroundTrackPlot** resource allows you to draw spacecraft's longitude and latitude time-history onto the texture map of a user-selected central body. GMAT allows you to draw ground track plots of any number of spacecrafts onto a single texture map. You can also create multiple **GroundTrackPlot** resources by using either the GUI or script interface of GMAT. GMAT also provides the option of when to plot and stop plotting ground track of a spacecraft to a **GroundTrackPlot** through the **Toggle On/Off** command. See the **Remarks** section below for detailed discussion of the interaction between **GroundTrackPlot** resource and the **Toggle** command. **GroundTrackPlot** resource also allows you to display any number of user-defined ground stations onto the texture map of the central body.

See Also: [Toggle](#), [GroundStation](#), [Color](#)

### Fields

Field	Description												
<b>Add</b>	<p>Allows the user to pick selected resources such as <b>Spacecrafts</b> or <b>GroundStations</b>. The <b>GroundTrackPlot</b> object is used to draw spacecraft's longitude and latitude time-history on a two-dimensional texture map of a central body that you select. After creating <b>GroundStation</b> object, you can also add ground stations onto the the texture map of the central body. To select multiple <b>Spacecrafts</b> or <b>GroundStations</b>, seperate the list by comma and enclose the list in curly brackets. For Example: DefaultGroundTrackPlot.Add = {aSat, bSat, aGroundStaton, bGroundStation}. This field cannot be modified in the Mission Sequence.</p> <table> <tr> <td><b>Data Type</b></td><td>Reference Array</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>Spacecraft</b>, <b>GroundStation</b></td></tr> <tr> <td><b>Access</b></td><td>Set</td></tr> <tr> <td><b>Default Value</b></td><td><b>DefaultSC</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Reference Array	<b>Allowed Values</b>	<b>Spacecraft</b> , <b>GroundStation</b>	<b>Access</b>	Set	<b>Default Value</b>	<b>DefaultSC</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Reference Array												
<b>Allowed Values</b>	<b>Spacecraft</b> , <b>GroundStation</b>												
<b>Access</b>	Set												
<b>Default Value</b>	<b>DefaultSC</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>CentralBody</b>	<p>The central body of the Ground track plot. This field cannot be modified in the Mission Sequence.</p> <table> <tr> <td><b>Data Type</b></td><td>Resource reference</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>CelestialBody</b></td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>Earth</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Resource reference	<b>Allowed Values</b>	<b>CelestialBody</b>	<b>Access</b>	set	<b>Default Value</b>	<b>Earth</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Resource reference												
<b>Allowed Values</b>	<b>CelestialBody</b>												
<b>Access</b>	set												
<b>Default Value</b>	<b>Earth</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

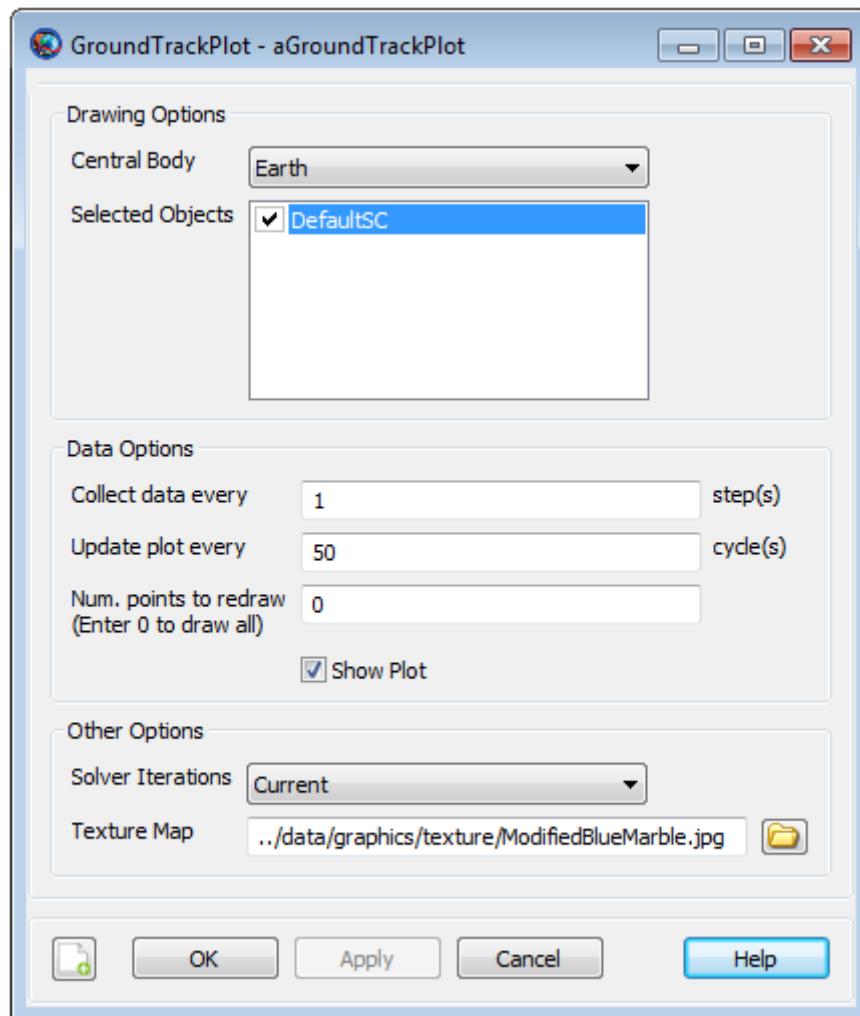
Field	Description
<b>DataCollectFrequency</b>	The number of integration steps to skip between plot points. This field cannot be modified in the Mission Sequence.
	<b>Data Type</b> Integer <b>Allowed Values</b> integer >= 1 <b>Access</b> set <b>Default Value</b> 1 <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>Maximized</b>	Allows the user to maximize the <b>GroundTrackPlot</b> window. This field cannot be modified in the Mission Sequence.
	<b>Data Type</b> Boolean <b>Allowed Values</b> true,false <b>Access</b> set <b>Default Value</b> false <b>Units</b> N/A <b>Interfaces</b> script
<b>NumPointsToRedraw</b>	The number of plot points to retain and redraw during propagation and animation. 0 indicates to redraw all. This field cannot be modified in the Mission Sequence.
	<b>Data Type</b> Integer <b>Allowed Values</b> integer >= 0 <b>Access</b> set <b>Default Value</b> 0 <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>RelativeZOrder</b>	Allows the user to select which <b>GroundTrackPlot</b> window to display first on the screen. The <b>GroundTrackPlot</b> with lowest <b>RelativeZOrder</b> value will be displayed last while <b>GroundTrackPlot</b> with highest <b>RelativeZOrder</b> value will be displayed first. This field cannot be modified in the Mission Sequence.
	<b>Data Type</b> Integer <b>Allowed Values</b> Integer # 0 <b>Access</b> set <b>Default Value</b> 0 <b>Units</b> N/A <b>Interfaces</b> script

Field	Description
<b>ShowPlot</b>	<p>This field specifies whether to show ground track plot during a mission run. This field cannot be modified in the Mission Sequence.</p> <p><b>Data Type</b> Boolean  <b>Allowed Values</b> True, False  <b>Access</b> set  <b>Default Value</b> True  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>Size</b>	<p>Allows the user to control the display size of <b>GroundTrackPlot</b> window. First value in [0 0] matrix controls horizontal size and second value controls vertical size of <b>GroundTrackPlot</b> display window. This field cannot be modified in the Mission Sequence.</p> <p><b>Data Type</b> Real array  <b>Allowed Values</b> Any Real number  <b>Access</b> set  <b>Default Value</b> [ 0 0 ]  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>SolverIterations</b>	<p>This field determines whether or not ground track data associated with perturbed trajectories during a solver (<b>Targeter</b>, <b>Optimize</b>) sequence is displayed in the <b>GroundTrackPlot</b>. When <b>SolverIterations</b> is set to <b>All</b>, all perturbations/iterations are plotted in the <b>GroundTrackPlot</b>. When <b>SolverIterations</b> is set to <b>Current</b> or <b>None</b> only the final nominal run is plotted on the <b>GroundTrackPlot</b>.</p> <p><b>Data Type</b> Enumeration  <b>Allowed Values</b> All, Current, None  <b>Access</b> set  <b>Default Value</b> Current  <b>Units</b> N/A  <b>Interfaces, Interfaces</b> GUI, script</p>

Field	Description														
<b>TextureMap</b>	<p>Allows you to enter or select any user-defined texture map image for the central body. This field cannot be modified in the Mission Sequence.</p> <table> <tr> <td data-bbox="595 382 807 413"><b>Data Type</b></td><td data-bbox="807 382 1390 413">String</td></tr> <tr> <td data-bbox="595 413 807 445"><b>Allowed Values</b></td><td data-bbox="807 413 1390 445">Valid File Path and Name</td></tr> <tr> <td data-bbox="595 445 807 477"><b>Access</b></td><td data-bbox="807 445 1390 477">set</td></tr> <tr> <td data-bbox="595 477 807 508"><b>Default Value</b></td><td data-bbox="807 477 1390 508">../ data/graphics/tex-</td></tr> <tr> <td data-bbox="595 508 807 540"></td><td data-bbox="807 508 1390 540">ture/ModifiedBlueMarble.jpg</td></tr> <tr> <td data-bbox="595 582 807 614"><b>Units</b></td><td data-bbox="807 582 1390 614">N/A</td></tr> <tr> <td data-bbox="595 614 807 646"><b>Interfaces</b></td><td data-bbox="807 614 1390 646">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Valid File Path and Name	<b>Access</b>	set	<b>Default Value</b>	../ data/graphics/tex-		ture/ModifiedBlueMarble.jpg	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String														
<b>Allowed Values</b>	Valid File Path and Name														
<b>Access</b>	set														
<b>Default Value</b>	../ data/graphics/tex-														
	ture/ModifiedBlueMarble.jpg														
<b>Units</b>	N/A														
<b>Interfaces</b>	GUI, script														
<b>UpdatePlotFrequency</b>	<p>The number of plot points to collect before updating a ground track plot. This field cannot be modified in the Mission Sequence.</p> <table> <tr> <td data-bbox="595 819 807 851"><b>Data Type</b></td><td data-bbox="807 819 1390 851">Integer</td></tr> <tr> <td data-bbox="595 851 807 882"><b>Allowed Values</b></td><td data-bbox="807 851 1390 882">integer &gt; 1</td></tr> <tr> <td data-bbox="595 882 807 914"><b>Access</b></td><td data-bbox="807 882 1390 914">set</td></tr> <tr> <td data-bbox="595 914 807 946"><b>Default Value</b></td><td data-bbox="807 914 1390 946">50</td></tr> <tr> <td data-bbox="595 946 807 977"><b>Units</b></td><td data-bbox="807 946 1390 977">N/A</td></tr> <tr> <td data-bbox="595 977 807 1009"><b>Interfaces</b></td><td data-bbox="807 977 1390 1009">GUI, script</td></tr> </table>	<b>Data Type</b>	Integer	<b>Allowed Values</b>	integer > 1	<b>Access</b>	set	<b>Default Value</b>	50	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script		
<b>Data Type</b>	Integer														
<b>Allowed Values</b>	integer > 1														
<b>Access</b>	set														
<b>Default Value</b>	50														
<b>Units</b>	N/A														
<b>Interfaces</b>	GUI, script														
<b>UpperLeft</b>	<p>Allows the user to pan the <b>GroundTrackPlot</b> display window in any direction. First value in [0 0] matrix helps to pan the <b>GroundTrackPlot</b> window horizontally and second value helps to pan the window vertically. This field cannot be modified in the Mission Sequence.</p> <table> <tr> <td data-bbox="595 1248 807 1279"><b>Data Type</b></td><td data-bbox="807 1248 1390 1279">Real array</td></tr> <tr> <td data-bbox="595 1279 807 1311"><b>Allowed Values</b></td><td data-bbox="807 1279 1390 1311">Any Real number</td></tr> <tr> <td data-bbox="595 1311 807 1343"><b>Access</b></td><td data-bbox="807 1311 1390 1343">set</td></tr> <tr> <td data-bbox="595 1343 807 1374"><b>Default Value</b></td><td data-bbox="807 1343 1390 1374">[ 0 0 ]</td></tr> <tr> <td data-bbox="595 1374 807 1406"><b>Units</b></td><td data-bbox="807 1374 1390 1406">None</td></tr> <tr> <td data-bbox="595 1406 807 1438"><b>Interfaces</b></td><td data-bbox="807 1406 1390 1438">script</td></tr> </table>	<b>Data Type</b>	Real array	<b>Allowed Values</b>	Any Real number	<b>Access</b>	set	<b>Default Value</b>	[ 0 0 ]	<b>Units</b>	None	<b>Interfaces</b>	script		
<b>Data Type</b>	Real array														
<b>Allowed Values</b>	Any Real number														
<b>Access</b>	set														
<b>Default Value</b>	[ 0 0 ]														
<b>Units</b>	None														
<b>Interfaces</b>	script														

## GUI

Default Name and Settings for the **GroundTrackPlot** Resource:



## Remarks

### Behavior when using **GroundTrackPlot** Resource & Toggle Command

The **GroundTrackPlot** resource draws the longitude and latitude time-history of a spacecraft at each propagation step of the entire mission duration. If you want to report data to a **GroundTrackPlot** at specific points in your mission, then a **Toggle On/Off** command can be inserted into the mission sequence to control when the **GroundTrackPlot** is to draw data. When **Toggle Off** command is issued for a **GroundTrackPlot**, no ground track data is drawn until a **Toggle On** command is issued. Similarly when a **Toggle On** command is used, ground track data is drawn at each integration step until a **Toggle Off** command is used.

Below is an example script snippet that shows how to use **Toggle Off** and **Toggle On** command while using the **GroundTrackPlot** resource. **GroundTrackPlot** is turned off for the first 2 days of the propagation:

```
Create Spacecraft aSat  
Create Propagator aProp
```

```
Create GroundTrackPlot aGroundTrackPlot
aGroundTrackPlot.Add = {aSat}

BeginMissionSequence

Toggle aGroundTrackPlot Off
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
Toggle aGroundTrackPlot On
Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

### Behavior when Plotting Data in Iterative Processes

GMAT allows you to specify how data is plotted onto a plot during iterative processes such as differential correction or optimization. The **SolverIterations** field of **GroundTrackPlot** resource supports 3 options which are described in the table below:

SolverIterations options	Description
<b>Current</b>	Shows only current iteration/perturbation in an iterative process and draws current iteration to a plot
<b>All</b>	Shows all iterations/perturbations in an iterative process and draws all iterations/perturbations to a plot
<b>None</b>	Shows only the final solution after the end of an iterative process and draws only final solution to a plot

### Behavior when Plotting Longitude and Latitude time-history of a Spacecraft

GMAT's **GroundTrackPlot** resource allows you to draw longitude and latitude time-history of a spacecraft. You can choose to draw ground track plot of multiple spacecrafts onto a single texture map of a central body.



#### Warning

The longitude and latitude of a spacecraft is drawn as an approximation that includes straight line segments and longitude/latitude data does not takes into account central body shape or its oblateness.

### Behavior When Specifying Empty Brackets in GroundTrackPlot's Add Field

When using **GroundTrackPlot.Add** field, if brackets are not populated with user-defined spacecrafts, then GMAT turns off **GroundTrackPlot** resource and no plot is generated. If you run the script with **Add** field having empty brackets, then GMAT throws in a warning message in the Message Window indicating that **GroundTrackPlot** resource will be turned off since no SpacePoints were added to the plot. Below is a sample script snippet that generates such a warning message:

```
Create Spacecraft aSat aSat2
```

```
Create Propagator aProp
Create GroundTrackPlot aGroundTrackPlot

aGroundTrackPlot.Add = {}

BeginMissionSequence;
Propagate aProp(aSat, aSat2) {aSat.ElapsedDays = 1}
```

## Examples

This example shows how to use **GroundTrackPlot** resource. A single spacecraft and a ground station is added to the **GroundTrackPlot**. Spacecraft's ground track is plotted for one day of propagation:

```
Create Spacecraft aSat
Create Propagator aProp

Create GroundStation aGroundStation

Create GroundTrackPlot aGroundTrackPlot
aGroundTrackPlot.Add = {aSat, aGroundStation}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

Propagate a spacecraft for two days around a non-default central body. Spacecraft's ground track is plotted on planet Mars:

```
Create Spacecraft aSat
aSat.CoordinateSystem = MarsJ2000Eq
aSat.SMA = 8000
aSat.ECC = 0.0003

Create ForceModel aFM
aFM.CentralBody = Mars
aFM.PointMasses = {Mars}

Create Propagator aProp
aProp.FM = aFM

Create CoordinateSystem MarsJ2000Eq
MarsJ2000Eq.Origin = Mars
MarsJ2000Eq.Axes = MJ2000Eq

Create GroundTrackPlot aGroundTrackPlot
aGroundTrackPlot.Add = {aSat}
aGroundTrackPlot.CentralBody = Mars

BeginMissionSequence
```

```
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
```

## OpenFramesInterface

A user-defined resource that provides high-performance 3D interactive visualizations of GMAT missions

### Description



#### Note

The main **OpenFramesInterface** documentation is available on its online [GitLab Wiki](#). You can directly access relevant Wiki sections by pressing the **Help** button on any GUI panel.

The **OpenFramesInterface (OFI)** resource allows you to visualize GMAT missions using interactive 3D graphics that are high-performance, customizable, and easy to use. **OFI** is developed as a replacement for **OrbitView**, so it provides greater functionality and performance while retaining a similar GUI and script format. You will be able to easily use the **OpenFramesInterface** regardless of your comfort level with **OrbitView**!

Features and benefits of **OFI** include:

- Create multiple interactive views per window. Each view can follow spacecraft or other bodies, and can even automatically rotate to track another object.
- Control simulation time, animate the scene at any desired rate (including realtime and backwards time), and synchronize time between multiple windows.
- Many visualization changes apply instantly without requiring a mission re-run.
- Use various 3D model formats for spacecraft and bodies: 3ds, lwo, obj, and more.
- View any GMAT mission in Virtual Reality using headsets such as the Oculus Rift or HTC Vive. VR provides information about nonplanar trajectories that is difficult to glean on a traditional monitor.



#### Tip

The GMAT samples/NeedOpenFramesInterface folder has examples of using **OFI** based on similarly-named **OrbitView** sample scripts.

See Also: [OrbitView](#)

## OrbitView

A user-defined resource that plots 3-Dimensional trajectories

### Description

The **OrbitView** resource allows you to plot trajectories of a spacecraft or a celestial body. GMAT also allows you to plot trajectories associated with multiple spacecrafts or celestial bodies. You can create multiple **OrbitView** resources by using either the GUI or script interface of GMAT. **OrbitView** plots also come with multiple options that allow you to customize the view of spacecraft's trajectories. See the [Fields](#) section below for detailed discussion on available plotting and drawing options.

GMAT also provides the option of when to start and stop plotting spacecraft's trajectories to an **OrbitView** resource through the **Toggle On/Off** command. See the [Remarks](#) section below for detailed discussion of the interaction between an **OrbitView** resource and the **Toggle** command. GMAT's **Spacecraft**, **SolarSystem** and **OrbitView** resources also interact with each other throughout the entire mission duration. Discussion of the interaction between these resources is also mentioned in the [Remarks](#) section.

See Also: [Toggle](#), [Spacecraft](#), [SolarSystem](#), [CoordinateSystem](#), [Color](#)

### Fields

Field	Description
<b>Add</b>	This field allows you to add a <b>Spacecraft</b> , <b>Celestial body</b> , <b>Libration Point</b> , or <b>Barycenter</b> resource to a plot. When creating a plot, the <b>Earth</b> is added as a default body and may be removed at any time. You can add a <b>Spacecraft</b> , <b>Celestial body</b> , <b>Libration Point</b> , or <b>Barycenter</b> to a plot by using the name used to create the resource. The GUI's <b>Selected</b> field is the equivalent of the script's <b>Add</b> field. In the event of no <b>Add</b> command or no resources in the <b>Selected</b> field, GMAT should run without the <b>OrbitView</b> plot and a warning message will be displayed in the message window. The following warning message is sufficient: The OrbitView named "DefaultOrbitView" will be turned off. No SpacePoints were added to plot. This field cannot be modified in the Mission Sequence.  <b>Data Type</b> Reference Array <b>Allowed Values</b> <b>Spacecraft</b> , <b>CelestialBody</b> , <b>LibrationPoint</b> , <b>Barycenter</b> <b>Access</b> set <b>Default Value</b> <b>DefaultSC</b> , <b>Earth</b> <b>Units</b> N/A <b>Interfaces</b> GUI, script

Field	Description
<b>Axes</b>	<p>Allows you to draw the Cartesian axis system associated with the coordinate system selected under the <b>CoordinateSystem</b> field of an <b>OrbitView</b> plot. This field cannot be modified in the Mission Sequence.</p>
<b>Data Type</b>	Boolean
<b>Allowed Values</b>	On, Off
<b>Access</b>	set
<b>Default Value</b>	On
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>EclipticPlane</b>	<p>Allows you to draw a grid representing the <b>Ecliptic Plane</b> in an <b>OrbitView</b> plot. This field cannot be modified in the Mission Sequence.</p>
<b>Data Type</b>	Boolean
<b>Allowed Values</b>	On, Off
<b>Access</b>	set
<b>Default Value</b>	Off
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>CoordinateSystem</b>	<p>Allows you to select which <b>coordinate system</b> to use to draw the plot data. A <b>coordinate system</b> is defined as an <b>origin</b> and an <b>axis system</b>. The <b>CoordinateSystem</b> field allows you to determine the <b>origin</b> and <b>axis system</b> of an <b>OrbitView</b> plot. See the <b>CoordinateSystem</b> resource fields for information of defining different types of <b>coordinate systems</b>. This field cannot be modified in the Mission Sequence.</p>
<b>Data Type</b>	String
<b>Allowed Values</b>	<b>CoordinateSystem</b> resource
<b>Access</b>	set
<b>Default Value</b>	<b>EarthMJ2000Eq</b>
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

Field	Description
<b>DataCollectFrequency</b>	Allows you to define how data is collected for plotting. It is often inefficient to draw every ephemeris point associated with a trajectory. Often, drawing a smaller subset of the data still results in smooth trajectory plots, while executing more quickly. The <b>DataCollectFrequency</b> is an integer that represents how often to collect data and store for plotting. If <b>DataCollectFrequency</b> is set to 10, then data is collected every 10 integration steps. This field cannot be modified in the Mission Sequence.
<b>Data Type</b>	Integer
<b>Allowed Values</b>	Integer # 1
<b>Access</b>	set
<b>Default Value</b>	1
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>DrawObject</b>	The <b>DrawObject</b> field allows you the option of displaying <b>Spacecraft</b> or <b>Celestial</b> resources on the <b>OrbitView</b> plot. This field cannot be modified in the Mission Sequence.
<b>Data Type</b>	Boolean array
<b>Allowed Values</b>	true, false
<b>Access</b>	set
<b>Default Value</b>	[true true]
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>EnableConstellations</b>	Allows you the option of displaying star constellations on the <b>OrbitView</b> Plot. This field cannot be modified in the Mission Sequence.
<b>Data Type</b>	Boolean
<b>Allowed Values</b>	On, Off
<b>Access</b>	set
<b>Default Value</b>	On
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

Field	Description
<b>EnableStars</b>	<p>This field gives you the option of displaying stars on the <b>OrbitView</b> Plot. When the <b>EnableStars</b> field is turned off, then <b>EnableConstellations</b> field is automatically disabled. This field cannot be modified in the Mission Sequence.</p>
	<p><b>Data Type</b> Boolean  <b>Allowed Values</b> On, Off  <b>Access</b> set  <b>Default Value</b> On  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>Grid</b>	<p>Allows you to draw a grid representing the longitude and latitude lines on the celestial bodies added to an <b>OrbitView</b> plot. This field cannot be modified in the Mission Sequence.</p>
	<p><b>Data Type</b> Boolean  <b>Allowed Values</b> On, Off  <b>Access</b> set  <b>Default Value</b> Off  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>Maximized</b>	<p>Allows you to maximize the <b>OrbitView</b> plot window. This field cannot be modified in the Mission Sequence.</p>
	<p><b>Data Type</b> Boolean  <b>Allowed Values</b> True, False  <b>Access</b> set  <b>Default Value</b> false  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>NumPointsToRedraw</b>	<p>When <b>NumPointsToRedraw</b> field is set to zero, all ephemeris points are drawn. When <b>NumPointsToRedraw</b> is set to a positive integer, say 10 for example, only the last 10 collected data points are drawn. See <b>DataCollectFrequency</b> for explanation of how data is collected for an <b>OrbitView</b> plot. This field cannot be modified in the Mission Sequence.</p>
	<p><b>Data Type</b> Integer  <b>Allowed Values</b> Integer # 1  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>

Field	Description												
<b>RelativeZOrder</b>	<p>Allows you to select which <b>OrbitView</b> window to display first on the screen. The <b>OrbitViewPlot</b> with lowest <b>RelativeZOrder</b> value will be displayed last while <b>OrbitViewPlot</b> with highest <b>RelativeZOrder</b> value will be displayed first. This field cannot be modified in the Mission Sequence.</p>												
	<table> <tr> <td data-bbox="595 454 816 485"><b>Data Type</b></td><td data-bbox="816 454 1019 485">Integer</td></tr> <tr> <td data-bbox="595 485 816 517"><b>Allowed Values</b></td><td data-bbox="816 485 1019 517">Integer # 0</td></tr> <tr> <td data-bbox="595 517 816 549"><b>Access</b></td><td data-bbox="816 517 1019 549">set</td></tr> <tr> <td data-bbox="595 549 816 580"><b>Default Value</b></td><td data-bbox="816 549 1019 580">0</td></tr> <tr> <td data-bbox="595 580 816 612"><b>Units</b></td><td data-bbox="816 580 1019 612">N/A</td></tr> <tr> <td data-bbox="595 612 816 665"><b>Interfaces</b></td><td data-bbox="816 612 1019 665">script</td></tr> </table>	<b>Data Type</b>	Integer	<b>Allowed Values</b>	Integer # 0	<b>Access</b>	set	<b>Default Value</b>	0	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Integer												
<b>Allowed Values</b>	Integer # 0												
<b>Access</b>	set												
<b>Default Value</b>	0												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>ShowPlot</b>	<p>Allows you to turn off a plot for a particular run, without deleting the plot, or removing it from the script. If you select true, then the plot will be shown. If you select false, then the plot will not be shown. This field cannot be modified in the Mission Sequence.</p>												
	<table> <tr> <td data-bbox="595 876 816 908"><b>Data Type</b></td><td data-bbox="816 876 1019 908">Boolean</td></tr> <tr> <td data-bbox="595 908 816 939"><b>Allowed Values</b></td><td data-bbox="816 908 1019 939">True, False</td></tr> <tr> <td data-bbox="595 939 816 971"><b>Access</b></td><td data-bbox="816 939 1019 971">set</td></tr> <tr> <td data-bbox="595 971 816 1003"><b>Default Value</b></td><td data-bbox="816 971 1019 1003">True</td></tr> <tr> <td data-bbox="595 1003 816 1034"><b>Units</b></td><td data-bbox="816 1003 1019 1034">N/A</td></tr> <tr> <td data-bbox="595 1034 816 1087"><b>Interfaces</b></td><td data-bbox="816 1034 1019 1087">GUI, script</td></tr> </table>	<b>Data Type</b>	Boolean	<b>Allowed Values</b>	True, False	<b>Access</b>	set	<b>Default Value</b>	True	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Boolean												
<b>Allowed Values</b>	True, False												
<b>Access</b>	set												
<b>Default Value</b>	True												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>ShowLabels</b>	<p>Allows you to turn on or off spacecraft and celestial body Object labels. If you select true, then spacecraft and celestial body object labels will show up in orbit view plot. If you select false, then spacecraft and celestial body labels will not be shown in the orbit plot. This field cannot be modified in the Mission Sequence.</p>												
	<table> <tr> <td data-bbox="595 1341 816 1372"><b>Data Type</b></td><td data-bbox="816 1341 1019 1372">Boolean</td></tr> <tr> <td data-bbox="595 1372 816 1404"><b>Allowed Values</b></td><td data-bbox="816 1372 1019 1404">True, False</td></tr> <tr> <td data-bbox="595 1404 816 1436"><b>Access</b></td><td data-bbox="816 1404 1019 1436">set</td></tr> <tr> <td data-bbox="595 1436 816 1467"><b>Default Value</b></td><td data-bbox="816 1436 1019 1467">True</td></tr> <tr> <td data-bbox="595 1467 816 1499"><b>Units</b></td><td data-bbox="816 1467 1019 1499">N/A</td></tr> <tr> <td data-bbox="595 1499 816 1552"><b>Interfaces</b></td><td data-bbox="816 1499 1019 1552">GUI, script</td></tr> </table>	<b>Data Type</b>	Boolean	<b>Allowed Values</b>	True, False	<b>Access</b>	set	<b>Default Value</b>	True	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Boolean												
<b>Allowed Values</b>	True, False												
<b>Access</b>	set												
<b>Default Value</b>	True												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

Field	Description
<b>Size</b>	<p>Allows you to control the display size of <b>OrbitViewPlot</b> window. First value in [0 0] matrix controls horizontal size and second value controls vertical size of <b>OrbitViewPlot</b> display window. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b> Real array
	<b>Allowed Values</b> Any Real number
	<b>Access</b> set
	<b>Default Value</b> [0 0]
	<b>Units</b> N/A
	<b>Interfaces</b> script
<b>SolverIterations</b>	<p>This field determines whether or not data associated with perturbed trajectories during a solver (<b>Targeter</b>, <b>Optimize</b>) sequence is plotted to <b>OrbitView</b>. When <b>SolverIterations</b> is set to <b>All</b>, all perturbations/iterations are plotted to an <b>OrbitView</b> plot. When <b>SolverIterations</b> is set to <b>Current</b>, only current solution is plotted to an <b>OrbitView</b>. When <b>SolverIterations</b> is set to <b>None</b>, this shows only final solution after the end of an iterative process and draws only final trajectory to an <b>OrbitView</b> plot.</p>
	<b>Data Type</b> Enumeration
	<b>Allowed Values</b> All, Current, None
	<b>Access</b> set
	<b>Default Value</b> Current
	<b>Units</b> N/A
	<b>Interfaces</b> GUI, script
<b>StarCount</b>	<p>Allows you to enter the number of stars that need to be displayed in an <b>OrbitView</b> plot. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b> Integer
	<b>Allowed Values</b> Integer # 1
	<b>Access</b> set
	<b>Default Value</b> 7000
	<b>Units</b> N/A
	<b>Interfaces</b> GUI, script

Field	Description
<b>SunLine</b>	<p>Allows you to draw a line that starts at the center of central body and points towards the <b>Sun</b>. This field cannot be modified in the Mission Sequence.</p>
<b>Data Type</b>	Boolean
<b>Allowed Values</b>	On, Off
<b>Access</b>	set
<b>Default Value</b>	Off
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>UpdatePlotFrequency</b>	<p>This field lets you specify how often to update an <b>OrbitView</b> plot is updated with new data collected during the process of propagating spacecraft and running a mission. Data is collected for a plot according to the value defined by <b>DataCollectFrequency</b>. An <b>OrbitView</b> plot is updated with the new data, according to the value set in <b>UpdatePlotFrequency</b>. If <b>UpdatePlotFrequency</b> is set to 10 and <b>DataCollectFrequency</b> is set to 2, then the plot is updated with new data every 20 (<math>10^2</math>) integration steps. This field cannot be modified in the Mission Sequence.</p>
<b>Data Type</b>	Integer
<b>Allowed Values</b>	Integer # 1
<b>Access</b>	set
<b>Default Value</b>	50
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>UpperLeft</b>	<p>Allows you to pan the <b>OrbitView</b> plot window in any direction. First value in [0 0] matrix helps to pan the <b>OrbitView</b> window horizontally and second value helps to pan the window vertically. This field cannot be modified in the Mission Sequence.</p>
<b>Data Type</b>	Real array
<b>Allowed Values</b>	Any Real number
<b>Access</b>	set
<b>Default Value</b>	[0 0]
<b>Units</b>	N/A
<b>Interfaces</b>	script

Field	Description
<b>UseInitialView</b>	<p>This field lets you control the view of an <b>OrbitView</b> plot between multiple runs of a mission sequence. The first time a specific <b>OrbitView</b> plot is created, GMAT will automatically use the view as defined by the fields associated with <b>View Definition</b>, <b>View Up Direction</b>, and <b>View Option</b>. However, if you change the view using the mouse, GMAT will retain this view upon rerunning the mission as long as <b>UseInitialView</b> is set to false. If <b>UseInitialView</b> is set to true, the view for an <b>OrbitView</b> plot will be returned to the view defined by the initial settings. This field cannot be modified in the Mission Sequence.</p>
	<p><b>Data Type</b> Boolean  <b>Allowed Values</b> On, Off  <b>Access</b> set  <b>Default Value</b> On  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>ViewDirection</b>	<p>Allows you to select the direction of view in an <b>OrbitView</b> plot. You can specify the view direction by choosing a resource to point at such as a <b>Spacecraft</b>, <b>Celestial body</b>, <b>Libration Point</b>, or <b>Barycenter</b>. Alternatively, you can also specify a vector of the form [x y z]. If the user specification of <b>ViewDirection</b>, <b>ViewPointReference</b>, and <b>ViewPointVector</b> results in a zero vector, GMAT uses [0 0 10000] for <b>ViewDirection</b>. This field cannot be modified in the Mission Sequence.</p>
	<p><b>Data Type</b> Reference array  <b>Allowed Values</b> <b>Spacecraft</b>, <b>CelestialBody</b>, <b>Libration-Point</b>, <b>Barycenter</b>, or a 3-vector of numerical values  <b>Access</b> set  <b>Default Value</b> Earth  <b>Units</b> km or N/A  <b>Interfaces</b> GUI, script</p>

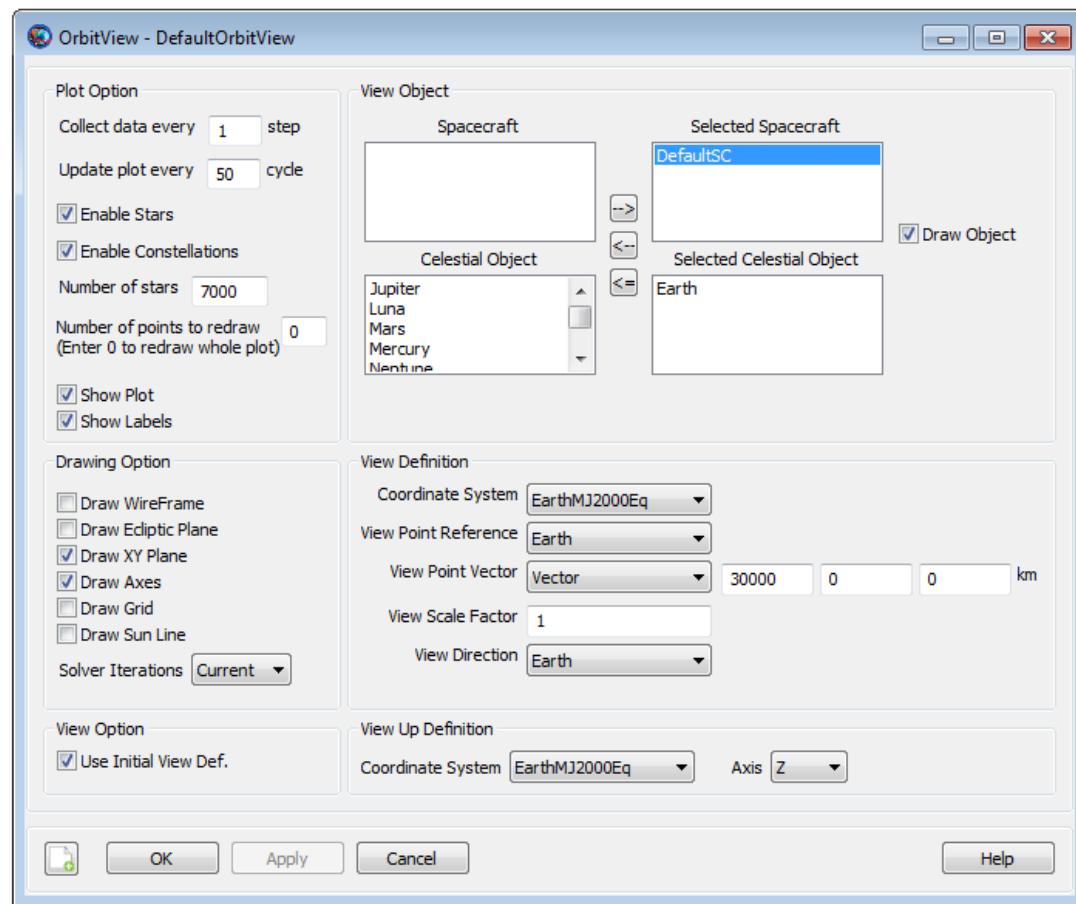
Field	Description
<b>ViewPointReference</b>	<p>This optional field allows you to change the reference point from which <b>ViewPointVector</b> is measured. <b>ViewPointReference</b> defaults to the origin of the coordinate system for the plot. A <b>ViewPointReference</b> can be any <b>Spacecraft</b>, <b>Celestial body</b>, <b>Libration Point</b>, or <b>Barycenter</b>. This field cannot be modified in the Mission Sequence.</p>
<b>Data Type</b>	Reference array
<b>Allowed Values</b>	<b>Spacecraft</b> , <b>CelestialBody</b> , <b>Libration-Point</b> , <b>Barycenter</b> , or a 3-vector of numerical values
<b>Access</b>	set
<b>Default Value</b>	Earth
<b>Units</b>	km or N/A
<b>Interfaces</b>	GUI, script
<b>ViewPointVector</b>	<p>The product of <b>ViewScaleFactor</b> and <b>ViewPointVector</b> field determines the view point location with respect to <b>ViewPointReference</b>. <b>ViewPointVector</b> can be a vector, or any of the following resources: <b>Spacecraft</b>, <b>Celestial body</b>, <b>Libration Point</b>, or <b>Barycenter</b>. The location of the view point in three-dimensional space is defined as the vector addition of <b>ViewPointReference</b> and the vector defined by product of <b>ViewScaleFactor</b> and <b>ViewPointVector</b> in the coordinate system chosen by you. This field cannot be modified in the Mission Sequence.</p>
<b>Data Type</b>	Reference array
<b>Allowed Values</b>	<b>Spacecraft</b> , <b>CelestialBody</b> , <b>Libration-Point</b> , <b>Barycenter</b> , or a 3-vector of numerical values
<b>Access</b>	set
<b>Default Value</b>	[30000 0 0]
<b>Units</b>	km or N/A
<b>Interfaces</b>	GUI, script
<b>ViewScaleFactor</b>	<p>This field scales <b>ViewPointVector</b> before adding it to <b>ViewPointReference</b>. The <b>ViewScaleFactor</b> allows you to back away from an object to fit in the field of view. This field cannot be modified in the Mission Sequence.</p>
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real Number # 0
<b>Access</b>	set
<b>Default Value</b>	1
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

Field	Description
<b>ViewUpAxis</b>	<p>This field lets you define which axis of the <b>ViewUpCoordinateSystem</b> field will appear as the up direction in an <b>OrbitView</b> plot. See the comments under <b>ViewUpCoordinateSystem</b> for more details of fields used to determine the up direction in an <b>OrbitView</b> plot. This field cannot be modified in the Mission Sequence.</p>
	<p><b>Data Type</b> Enumeration  <b>Allowed Values</b> X , -X , Y , -Y , Z , -Z  <b>Access</b> set  <b>Default Value</b> Z  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>ViewUpCoordinateSystem</b>	<p>The <b>ViewUpCoordinateSystem</b> and <b>ViewUpAxis</b> fields are used to determine which direction appears as up in an <b>OrbitView</b> plot and together with the fields associated with the <b>View Direction</b>, uniquely define the view. The fields associated with the <b>View Definition</b> allows you to define the point of view in three-dimensional space, and the direction of the line of sight. However, this information alone is not enough to uniquely define the view. We also must provide how the view is oriented about the line of sight. This is accomplished by defining what direction should appear as the up direction in the plot and is configured using the <b>ViewUpCoordinateSystem</b> field and the <b>ViewUpAxis</b> field. The <b>ViewUpCoordinateSystem</b> allows you to select a coordinate system to define the up direction. Most of the time this system will be the same as the coordinate system chosen under the <b>CoordinateSystem</b> field. This field cannot be modified in the Mission Sequence.</p>
	<p><b>Data Type</b> String  <b>Allowed Values</b> CoordinateSystem resource  <b>Access</b> set  <b>Default Value</b> EarthMJ2000Eq  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>

Field	Description
<b>WireFrame</b>	When the <b>WireFrame</b> field is set to <b>On</b> , celestial bodies are drawn using a wireframe model. When the <b>WireFrame</b> field is set to <b>Off</b> , then celestial bodies are drawn using a full map. This field cannot be modified in the Mission Sequence.
<b>Data Type</b>	Boolean
<b>Allowed Values</b>	Off, On
<b>Access</b>	set
<b>Default Value</b>	Off
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>XYPlane</b>	Allows you to draw a grid representing the <b>XY-plane</b> of the coordinate system selected under the <b>CoordinateSystem</b> field of the <b>OrbitView</b> plot. This field cannot be modified in the Mission Sequence.
<b>Data Type</b>	Boolean
<b>Allowed Values</b>	On, Off
<b>Access</b>	set
<b>Default Value</b>	On
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

## GUI

The figure below shows the default settings for the **OrbitView** resource:



### OrbitView Window Mouse Controls

The list of controls in the table below helps you navigate through the **OrbitView** graphics window. **"Left"** and **"Right"** designate the mouse button which have to be pressed.

Control	Description
<b>Left Drag</b>	Helps to change camera orientation. Camera orientation can be changed in <b>Up/Down/Left/Right</b> directions.
<b>Right Drag</b>	Helps to zoom in and out of the graphics window. Moving the cursor in <b>Up</b> direction leads to zoom out of the graphics window. Moving the cursor in <b>Down</b> direction helps to zoom into the graphics window.
<b>Shift+Right Drag</b>	Helps to adjust the <b>Field of View</b> .

### Remarks

#### Behavior when using OrbitView Resource & Toggle Command

The **OrbitView** resource plots spacecraft's trajectory at each propagation step of the entire mission duration. If you want to report data to an **OrbitView** plot at specific points

in your mission, then a **Toggle On/Off** command can be inserted into the mission sequence to control when **OrbitView** is to plot a given trajectory. When **Toggle Off** command is issued for an **OrbitView**, no trajectory is drawn until a **Toggle On** command is issued. Similarly, when a **Toggle On** command is used, trajectory is plotted at each integration step until a **Toggle Off** command is used.

```
Create Spacecraft aSat
Create Propagator aProp

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth}

BeginMissionSequence

Toggle anOrbitView Off
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
Toggle anOrbitView On
Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

### Behavior when using OrbitView, Spacecraft and SolarSystem Resources

**Spacecraft** resource contains information about spacecraft's orbit. **Spacecraft** resource interacts with **OrbitView** throughout the entire mission duration. The trajectory data retrieved from the spacecraft is what gets plotted at each propagation step of the entire mission duration. Similarly, the sun and all other planets available under the **SolarSystem** resource may be plotted or referenced in the **OrbitView** resource as well.

### Behavior when reporting data in Iterative Processes

GMAT allows you to specify how trajectories are plotted during iterative processes such as differential correction or optimization. The **SolverIterations** field of **OrbitView** resource supports 3 options which are described in the table below:

SolverIterations options	Description
<b>Current</b>	Shows only current iteration/perturbation in an iterative process and plots current trajectory.
<b>All</b>	Shows all iterations/perturbations in an iterative process and plots all perturbed trajectories.
<b>None</b>	Shows only the final solution after the end of an iterative process and plots only that final trajectory.

### Behavior when plotting multiple spacecrafts

GMAT allows you to plot trajectories of any number of spacecrafts when using the **OrbitView** resource. The initial epoch of all the spacecrafts must be same in order to plot the trajectories. If initial epoch of one of the spacecrafts does not match with initial epoch of other spacecrafts, then GMAT throws in an error alerting you that there is a coupled

propagation error mismatch between the spacecrafts. GMAT also allows you to propagate trajectories of spacecrafts using any combination of the propagators that you may create.

Below is an example script snippet that shows how to plot trajectories of multiple spacecrafts that use different propagators:

```
Create Spacecraft aSat aSat2 aSat3
aSat2.INC = 45.0
aSat3.INC = 90.0
aSat3.SMA = 9000

Create Propagator aProp
Create Propagator bProp

Create OrbitView anOrbitView anOrbitView2

anOrbitView.Add = {aSat, aSat2, Earth}
anOrbitView2.Add = {aSat3, Earth}

BeginMissionSequence

Propagate aProp(aSat, aSat2) bProp(aSat3) {aSat.ElapsedSecs = 12000.0}
```

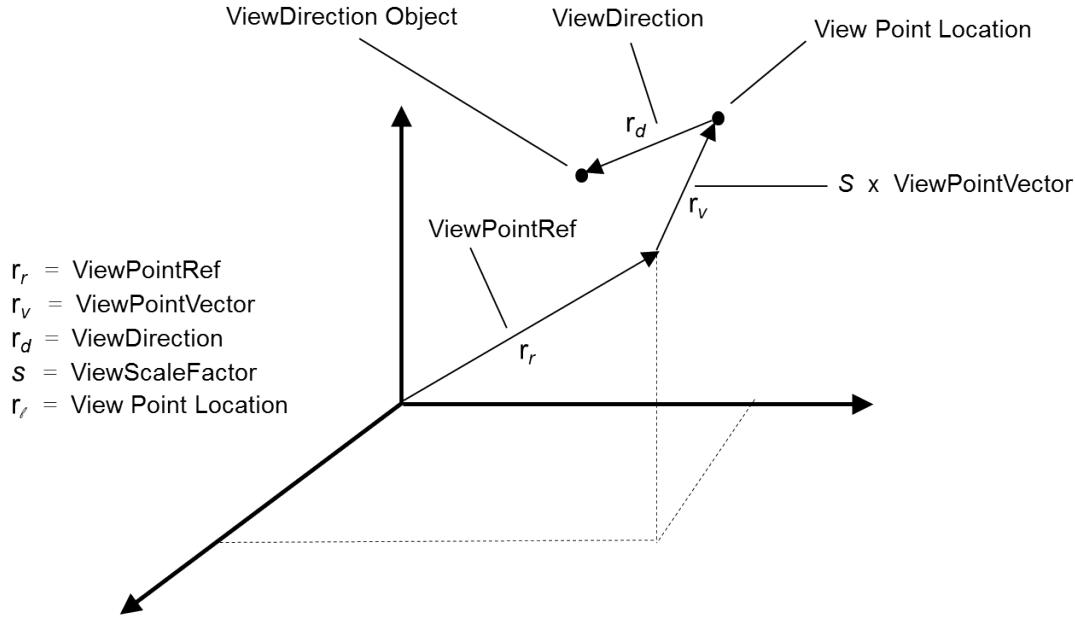
### OrbitView View Definition Controls

GMAT is capable of drawing orbit plots that allow you to visualize the motion of spacecraft and celestial bodies throughout the mission sequence. Here we discuss the options you can use in setting up and viewing Orbit plots. You can choose many properties including the coordinate system of the orbit view plot and the view location and direction from where visualizations can be seen. The script snippet below shows how to create **OrbitView** resource that includes key view definition controls fields as well. Detailed definitions of all fields for **OrbitView** resource can be found in [Fields](#) section.

```
Create OrbitView PlotName
PlotName.CoordinateSystemn      = CoordinateSystemName
PlotName.Add                     = [SpacecraftName, BodyName, ...
                                      LibrationPoint, Barycenter]
PlotName.ViewPointReference     = [ObjectName, VectorName]
PlotName.ViewPointVector        = [ObjectName, VectorName]
PlotName.ViewDirection          = [ObjectName, VectorName]
PlotName.ViewScaleFactor        = [Real Number]
PlotName.ViewUpCoordinateSystem = CoordinateSystemName
PlotName.ViewUpAxis              = [X, -X, Y, -Y, Z, -Z];
```

You can specify the view location and direction of **OrbitView** plot object by using the **ViewPointReference**, **ViewPointVector**, **ViewDirection**, **ViewUpCoordinateSystem** and **ViewUpAxis** fields. Figure below shows a graphical definition of **ViewPointReference**, **ViewPointVector**, and **ViewDirection** fields and how they determine the actual view location and view direction. You can supply **ViewPointReference**, **ViewPointVec-**

**tor** and **ViewDirection** fields by either giving a vector in the format [x y z] or by specifying an object name. If a vector is given for one of the quantities, then we simply use it in its appropriate place in the computations below. If an object is given, we must determine the vector associated with it. The rest of this section is devoted in determining **ViewPointReference**, **ViewPointVector** and **ViewDirection** fields if you specify an object.



**ViewPointReference** field defines the point from which **ViewPointVector** is measured. If an object is given for **ViewPointReference** field, i.e. when you have the following in the sample script:

```
MyOrbitViewPlot.CoordinateSystemm      = MyCoordSys
MyOrbitViewPlot.ViewPointReference     = ViewRefObject
```

then we need to determine  $r_r$  as illustrated in above figure. If ViewRefObject is the same as the origin of MyCoordSys, then  $r_r = [0 0 0]$ . Otherwise  $r_r$  is the cartesian position of **ViewPointReference** in MyCoordSys.

$$r_r = \begin{bmatrix} \text{ViewRefObject.MyCoordSys.X} \\ \text{ViewRefObject.MyCoordSys.Y} \\ \text{ViewRefObject.MyCoordSys.Z} \end{bmatrix}$$

**ViewPointVector** field points from **ViewPointReference** ( $r_r$ ) in the direction of the view point location. If an object is given for **ViewPointVector** field, i.e. you have the following in the sample script:

```
MyOrbitViewPlot.CoordinateSystemm      = MyCoordSys
MyOrbitViewPlot.ViewPointVector        = ViewPointObject
```

then we need to determine  $r_v$  as illustrated in above figure by using the coordinate system conversion routine to calculate the following:

$$\mathbf{r}_v = \begin{pmatrix} \text{ViewPointObject.MyCoordSys.X} \\ \text{ViewPointObject.MyCoordSys.Y} \\ \text{ViewPointObject.MyCoordSys.Z} \end{pmatrix}$$

We now know everything to calculate the location of the view point in the desired coordinate system. From inspection of the above figure, we see that the relation is:

$$\mathbf{r}_v = \mathbf{r}_r + s \mathbf{r}_v$$

Now that we know the view point location, we need to determine the ViewDirection:  $\mathbf{r}_d$  as illustrated in above figure. If a vector was specified for **ViewDirection** field, then no computations are required. However, if an object was given as shown in the following sample script:

```
MyOrbitViewPlot.CoordinateSystemm      = MyCoordSys
MyOrbitViewPlot.ViewDiction          = ViewDirectionObject
```

then we calculate  $\mathbf{r}_d$  from the following:

$$\mathbf{r}_d = \begin{pmatrix} \text{ViewDirectionObject.MyCoordSys.X} \\ \text{ViewDirectionObject.MyCoordSys.Y} \\ \text{ViewDirectionObject.MyCoordSys.Z} \end{pmatrix} - \mathbf{r}_r$$

Note that ViewDirection vector  $\mathbf{r}_d$  must not be zero vector [0 0 0].

**ViewUpCoordinateSystem** and **ViewUpAxis** fields are used to determine which direction appears as up in an **OrbitView** plot. Most of the time, coordinate system chosen under **ViewUpCoordinateSystem** field will be the same as the coordinate system selected under the **CoordinateSystem** field. **ViewUpAxis** field allows you to define which axis of the **ViewUpCoordinateSystem** field will appear as the up direction in an orbit plot.

Below are some examples that show how to generate **OrbitView** plots using different View Definition Controls configurations:

Earth Inertial view with spacecraft: This example shows orbit view plot with Earth and a spacecraft. Since **ViewPointReference** field is set to an object (i.e. Earth), hence ViewPointRef vector in above figure is [0 0 0] in EarthMJ2000Eq coordinate system. The **ViewPointVector** field is set to a vector ( i.e. set to [0 0 40000] ). This means that the view is from 40000 km above the Earth's equatorial plane on the z-axis of the EarthMJ2000Eq coordinate system. The view direction (specified in **ViewDirection** field) is towards the earth.

```
Create Spacecraft aSat
```

```

Create Propagator aProp

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth}

anOrbitView.CoordinateSystem = EarthMJ2000Eq
anOrbitView.ViewPointReference = Earth
anOrbitView.ViewPointVector = [ 0 0 40000 ]
anOrbitView.ViewDirection = Earth
anOrbitView.ViewScaleFactor = 1
anOrbitView.ViewUpCoordinateSystem = EarthMJ2000Eq
anOrbitView.ViewUpAxis = Z

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}

```

Earth Inertial view with spacecraft and Luna: This example shows orbit view plot with Earth, spacecraft and Moon. Note **ViewPointReference** field is set to an object (i.e. Earth), hence ViewPointRef vector in above figure = [0 0 0] in EarthMJ2000Eq coordinate system. **ViewPointVector** field is still set to a vector ( i.e. set to [0 0 500000] ). This means that the view is from 500000 km above the Earth's equatorial plane on the z-axis of the EarthMJ2000Eq coordinate system. **ViewDirection** field defines the view direction which is set towards the earth.

```

Create Spacecraft aSat

Create Propagator aProp

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth, Luna}

anOrbitView.CoordinateSystem = EarthMJ2000Eq
anOrbitView.ViewPointReference = Earth
anOrbitView.ViewPointVector = [ 0 0 500000 ]
anOrbitView.ViewDirection = Earth
anOrbitView.ViewScaleFactor = 1
anOrbitView.ViewUpCoordinateSystem = EarthMJ2000Eq
anOrbitView.ViewUpAxis = Z

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 5}

```

View of spacecraft from Luna in Earth inertial frame: This example of an orbit view plot shows spacecraft as viewed from Luna orbiting around Earth in an inertial reference frame. **ViewPointReference** field is set to an object (i.e. Earth), hence ViewPointRef vector is [0 0 0] in EarthMJ2000Eq coordinate system. This time **ViewPointVector** field is set to an object (i.e. Luna ). This means that the spacecraft will be seen from the vantage point of Luna. Note that **ViewDirection** field is set to spacecraft (aSat). This

means that view direction as seen from Luna is towards the spacecraft. After you run this example, re-run this example but this time with **ViewScaleFactor** field set to 2 and see what happens. You'll notice that **ViewScaleFactor** simply scales **ViewPointVector** field.

```
Create Spacecraft aSat

Create Propagator aProp

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth, Luna}

anOrbitView.CoordinateSystem = EarthMJ2000Eq
anOrbitView.ViewPointReference = Earth
anOrbitView.ViewPointVector = Luna
anOrbitView.ViewDirection = aSat
anOrbitView.ViewScaleFactor = 1
anOrbitView.ViewUpCoordinateSystem = EarthMJ2000Eq
anOrbitView.ViewUpAxis = Z

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 5}
```

View towards Luna from Earth as spacecraft orbits around Luna in inertial frame: This example of an orbit view plot shows view of Luna from vantage point of Earth as a spacecraft orbits around Luna. **ViewPointReference** field is set to an object (i.e. Luna), hence ViewPointRef vector in above figure is [0 0 0] in LunaMJ2000Eq coordinate system. **ViewPointVector** field is set to an object (i.e. Earth). This means that the camera or vantage point is located at Earth. **ViewDirection** field is also set to an object (i.e. Luna). This means that view direction as seen from Earth is towards Luna.

```
Create Spacecraft aSat

Create CoordinateSystem LunaMJ2000Eq
LunaMJ2000Eq.Origin = Luna
LunaMJ2000Eq.Axes = MJ2000Eq

aSat.CoordinateSystem = LunaMJ2000Eq
aSat.SMA = 7300
aSat.ECC = 0.4
aSat.INC = 90
aSat.RAAN = 270
aSat.AOP = 315
aSat.TA = 180

Create ForceModel aFM
aFM.CentralBody = Luna
aFM.PointMasses = {Luna}
```

```

Create Propagator aProp
aProp.FM = aFM

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Luna, Earth}
anOrbitView.CoordinateSystem = LunaMJ2000Eq
anOrbitView.ViewPointReference = Luna
anOrbitView.ViewPointVector = Earth
anOrbitView.ViewDirection = Luna
anOrbitView.ViewScaleFactor = 1;
anOrbitView.ViewUpCoordinateSystem = LunaMJ2000Eq;
anOrbitView.ViewUpAxis = Z;

BeginMissionSequence
Propagate aProp(aSat) {aSat.ElapsedDays = 5}

```

View towards spacecraft1 from spacecraft2 in inertial frame: This example of an orbit view plot shows spacecraft1 (aSat1) being viewed from spacecraft2 (aSat2) as they move in inertial reference frame. **ViewPointReference** field is set to an object (i.e. Earth), hence ViewPointRef vector in above figure is [0 0 0] in EarthMJ2000Eq coordinate system. **ViewPointVector** field is set to an object (i.e. aSat2 ) and **ViewDirection** field is also set to an object (i.e. aSat1). This means that aSat1 will be viewed from the vantage point of aSat2.

```

Create Spacecraft aSat aSat2

aSat2.X = 19500
aSat2.Z = 10000

Create Propagator aProp

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, aSat2, Earth,}

anOrbitView.CoordinateSystem = EarthMJ2000Eq
anOrbitView.ViewPointReference = Earth
anOrbitView.ViewPointVector = aSat2
anOrbitView.ViewDirection = aSat
anOrbitView.ViewScaleFactor = 1.0
anOrbitView.ViewUpCoordinateSystem = EarthMJ2000Eq
anOrbitView.ViewUpAxis = Z

BeginMissionSequence

Propagate aProp(aSat, aSat2){aSat.ElapsedSecs = 12000.0}

```

Orbit view plot of Sun-Earth-Moon L1 Rotating System: This example of an orbit view plot shows the Earth and spacecraft in the Sun-Earth-Moon rotating coordinate system. **ViewPointReference** field is set to an object (i.e. ESL1), hence ViewPointRef vector in above figure is [0 0 0] in SunEarthMoonL1 rotating coordinate system. **ViewPointVec-**

**tor** field is set to a vector (i.e. [0 0 30000] ). This means that the view is taken from 30000 km above the SunEarthMoonL1 coordinate system's XY plane on the z-axis of the SunEarthMoonL1 coordinate system. **ViewDirection** field is also set to an object (i.e. ESL1). This means that view direction as seen from 30000 km above the SunEarthMoonL1 coordinate system's XY plane is towards ESL1. Note that in this example, **ViewScaleFactor** is set to 25. This simply scales or amplifies **ViewPointVector** field 25 times its original value.

```
Create Spacecraft aSat
GMAT aSat.DateFormat = UTCGregorian;
GMAT aSat.Epoch = '01 Apr 2013 00:00:00.000'
GMAT aSat.CoordinateSystem = EarthMJ2000Eq
GMAT aSat.DisplayStateType = Cartesian
GMAT aSat.X = 1429457.8833484
GMAT aSat.Y = 147717.32846679
GMAT aSat.Z = -86529.655549364
GMAT aSat.VX = -0.037489820883615
GMAT aSat.VY = 0.32032521614858
GMAT aSat.VZ = 0.15762889268226

Create Barycenter EarthMoonBarycenter
GMAT EarthMoonBarycenter.BodyNames = {Earth, Luna}

Create LibrationPoint ESL1
GMAT ESL1.Primary = Sun
GMAT ESL1.Secondary = EarthMoonBarycenter
GMAT ESL1.Point = L1

Create ForceModel aFM
aFM.CentralBody = Earth
aFM.PointMasses = {Luna, Sun}

Create Propagator aProp
aProp.FM = aFM

Create CoordinateSystem SunEarthMoonL1
GMAT SunEarthMoonL1.Origin = ESL1
GMAT SunEarthMoonL1.Axes = ObjectReferenced
GMAT SunEarthMoonL1.XAxis = R
GMAT SunEarthMoonL1.ZAxis = N
GMAT SunEarthMoonL1.Primary = Sun
GMAT SunEarthMoonL1.Secondary = EarthMoonBarycenter

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth, Sun}
anOrbitView.CoordinateSystem = SunEarthMoonL1
anOrbitView.ViewPointReference = ESL1
anOrbitView.ViewPointVector = [ 0 0 30000 ]
```

```
anOrbitView.ViewDirection = ESL1  
anOrbitView.ViewScaleFactor = 25  
anOrbitView.ViewUpCoordinateSystem = SunEarthMoonL1  
anOrbitView.ViewUpAxis = Z  
  
BeginMissionSequence  
Propagate aProp(aSat) {aSat.ElapsedDays = 15}
```

### Behavior when using View Definition panel of OrbitView Resource

Currently in **OrbitView** resource's View Definition panel, fields like **ViewPointReference**, **ViewPointVector** and **ViewDirection** are initialized but not dynamically updated during a mission run. **OrbitView** resource's View Definition panel sets up geometry at initial epoch and then mouse controls geometry of the simulation from that point on.

### Spacecraft Model Considerations in GMAT's OrbitView

GMAT displays spacecraft models by reading model data from 3D Studio files describing the spacecraft shape and colors. These files have the file extension .3ds, and are generally called 3ds files. 3ds files contain data that defines the 3-dimensional coordinates of vertices outlining the spacecraft, a mapping of those vertices into triangles used to create the displayed surface of the spacecraft, and information about the colors and texture maps used to fill in the displayed triangles.

GMAT's implementation of the spacecraft model can display models consisting of up to 200,000 vertices that map up to 100,000 triangles. The GMAT model can use up 500 separate color or texture maps to fill in these triangles.

### Behavior When Specifying Empty Brackets in OrbitView's Add Field

When using **OrbitView.Add** field, if brackets are not populated with user-defined spacecrafts, then GMAT turns off **OrbitView** resource and no plot is generated. If you run the script with **Add** field having empty brackets, then GMAT throws in a warning message in the Message Window indicating that **OrbitView** resource will be turned off since no SpacePoints were added to the plot. Below is a sample script snippet that generates such a warning message:

```
Create Spacecraft aSat aSat2  
Create Propagator aProp  
  
Create OrbitView anOrbitView  
anOrbitView.Add = {}  
  
BeginMissionSequence  
Propagate aProp(aSat, aSat2){aSat.ElapsedSecs = 12000.0}
```

### Examples

Propagate spacecraft for 1 day and plot the orbit at every integrator step:

```
Create Spacecraft aSat
```

```
Create Propagator aProp  
  
Create OrbitView anOrbitView  
anOrbitView.Add = {aSat, Earth}  
  
BeginMissionSequence  
  
Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

Plotting orbit during an iterative process. Notice **SolverIterations** field is selected as **All**. This means all iterations/perturbations will be plotted.

```
Create Spacecraft aSat  
Create Propagator aProp  
  
Create ImpulsiveBurn TOI  
Create DifferentialCorrector aDC  
  
Create OrbitView anOrbitView  
anOrbitView.Add = {aSat, Earth}  
anOrbitView.SolverIterations = All  
  
BeginMissionSequence  
  
Propagate aProp(aSat) {aSat.Earth.Periapsis}  
  
Target aDC  
  Vary aDC(TOI.Element1 = 0.24, {Perturbation = 0.001, Lower = 0.0, ...  
    Upper = 3.14159, MaxStep = 0.5})  
  Maneuver TOI(aSat)  
  Propagate aProp(aSat) {aSat.Earth.Apoapsis}  
  Achieve aDC(aSat.Earth.RMAG = 42165)  
EndTarget
```

Plotting spacecraft's trajectory around non-default central body. This example shows how to plot a spacecraft's trajectory around Luna:

```
Create Spacecraft aSat  
  
Create CoordinateSystem LunaMJ2000Eq  
LunaMJ2000Eq.Origin = Luna  
LunaMJ2000Eq.Axes = MJ2000Eq  
  
aSat.CoordinateSystem = LunaMJ2000Eq  
aSat.SMA = 7300  
aSat.ECC = 0.4  
aSat.INC = 90  
aSat.RAAN = 270  
aSat.AOP = 315  
aSat.TA = 180
```

```
Create ForceModel aFM
aFM.CentralBody = Luna
aFM.PointMasses = {Luna}

Create Propagator aProp
aProp.FM = aFM

Create OrbitView anOrbitView

anOrbitView.Add = {aSat, Luna}
anOrbitView.CoordinateSystem = LunaMJ2000Eq
anOrbitView.ViewPointReference = Luna
anOrbitView.ViewDirection = Luna

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

Plotting spacecraft's trajectory around non-default central body. This example shows how to plot a spacecraft's trajectory around Mars:

```
Create Spacecraft aSat

Create CoordinateSystem MarsMJ2000Eq
MarsMJ2000Eq.Origin = Mars
MarsMJ2000Eq.Axes = MJ2000Eq

aSat.CoordinateSystem = MarsMJ2000Eq
aSat.SMA = 7300
aSat.ECC = 0.4
aSat.INC = 90
aSat.RAAN = 270
aSat.AOP = 315
aSat.TA = 180

Create ForceModel aFM
aFM.CentralBody = Mars
aFM.PointMasses = {Mars}

Create Propagator aProp
aProp.FM = aFM

Create OrbitView anOrbitView

anOrbitView.Add = {aSat, Mars}
anOrbitView.CoordinateSystem = MarsMJ2000Eq
anOrbitView.ViewPointReference = Mars
anOrbitView.ViewDirection = Mars
```

```
BeginMissionSequence  
Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

Plotting spacecraft's trajectory around non-default central body. This example shows how to plot a spacecraft's trajectory around Sun. This is an interplanetary trajectory. Spacecraft is shown on an out-going hyperbolic trajectory in an EarthView and then an interplanetary trajectory is drawn around Sun in a SunView. Mars Orbit around Sun is also shown:

```
Create Spacecraft aSat  
  
aSat.CoordinateSystem = EarthMJ2000Eq  
aSat.DateFormat = UTCGregorian  
aSat.Epoch = '18 Nov 2013 20:26:24.315'  
  
aSat.X = 3728.345810006184  
aSat.Y = 4697.943961035268  
aSat.Z = -2784.040094879185  
aSat.VX = -9.502477543864449  
aSat.VY = 5.935188001372066  
aSat.VZ = -2.696272103530009  
  
Create ForceModel aFM  
aFM.CentralBody = Earth  
aFM.PointMasses = {Earth}  
  
Create ForceModel bFM  
aFM.CentralBody = Sun  
aFM.PointMasses = {Sun}  
  
Create Propagator aProp  
aProp.FM = aFM  
  
Create Propagator bProp  
aProp.FM = bFM  
  
Create CoordinateSystem SunEcliptic  
SunEcliptic.Origin = Sun  
SunEcliptic.Axes = MJ2000Ec  
  
Create OrbitView EarthView SunView  
  
EarthView.Add = {aSat, Earth}  
EarthView.CoordinateSystem = EarthMJ2000Eq  
EarthView.ViewPointReference = Earth  
EarthView.ViewDirection = Earth
```

```
SunView.Add = {aSat, Mars, Sun}
SunView.CoordinateSystem = SunEcliptic
SunView.ViewPointReference = Sun
SunView.ViewDirection = Sun
SunView.ViewPointVector = [ 0 0 500000000 ]

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 3}
Propagate bProp(aSat) {aSat.ElapsedDays = 225}
```

## ReportFile

Report data to a text file

### Description

The **ReportFile** resource allows you to write data to a text file that can be viewed after a mission run has been completed. GMAT allows you to report user-defined **Variables**, **Arrays**, **Strings** and **Object Parameters**. GMAT gives you control over setting formatting properties of the output report file that is generated at the end of a mission run. You can create **ReportFile** resource in either the GUI or script interface. GMAT also provides the option of when to write and stop writing data to a text file through the **Toggle On/Off** command. See the **Remarks** section below for detailed discussion of the interaction between **ReportFile** resource and **Toggle** command.

See Also: [Report](#), [Toggle](#)

### Fields

Field	Description
<b>Add</b>	Allows a user to add any number of user-defined <b>Variables</b> , <b>Arrays</b> , <b>Strings</b> or <b>Object Parameters</b> to a report file. To add multiple user-defined variables or parameters, enclose the reported values with curly brackets. Ex. MyReportName.Add ={Sat.X, Sat.Y, Var1, Array(1,1)}; The GUI's <b>Selected Value(s)</b> field is the equivalent of the script's <b>Add</b> field. This field cannot be modified in the Mission Sequence.
<b>Data Type</b>	Reference array
<b>Allowed Values</b>	Any user-defined parameter. Ex. Variables, Arrays, Strings, or Object parameters set
<b>Access</b>	set
<b>Default Value</b>	{DefaultSC.A1ModJulian, DefaultSC.EarthMJ2000Eq.X}
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script
<b>AppendToExisting-File</b>	Allows a user to append text to an existing file rather than clearing it before use. If this field is set to <b>True</b> but the file does not already exist, a new file is created. See field <b>Filename</b> for setting the destination file.
<b>Data Type</b>	Boolean
<b>Allowed Values</b>	True, False
<b>Access</b>	set
<b>Default Value</b>	False
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

Field	Description
<b>ColumnWidth</b>	<p>This field defines the width of the data columns in a report file. The value for <b>ColumnWidth</b> is applied to all columns of data. For example, if <b>ColumnWidth</b> is set to 20, then each data column will be 20 white-spaces wide.</p>
	<b>Data Type</b> Integer
	<b>Allowed Values</b> Integer > 1
	<b>Access</b> set
	<b>Default Value</b> 23
	<b>Units</b> Characters
	<b>Interfaces</b> GUI, script
<b>Delimiter</b>	<p>When <b>FixedWidth</b> field is turned off, this field become active. The <b>Delimiter</b> field allows you to report data to a report file in Comma, Semicolon, Space and Tab delimited format.</p>
	<b>Data Type</b> Enumeration
	<b>Allowed Values</b> Comma, SemiColon, Space, Tab
	<b>Access</b> set
	<b>Default Value</b> When this field is active, then default is Space
	<b>Units</b> N/A
	<b>Interfaces</b> GUI, script
<b>Filename</b>	<p>Allows the user to define the file path and file name for a report file.</p>
	<b>Data Type</b> String
	<b>Allowed Values</b> Valid File Path and Name
	<b>Access</b> set
	<b>Default Value</b> ReportFile1.txt
	<b>Units</b> N/A
	<b>Interfaces</b> GUI, script
<b>FixedWidth</b>	<p>Allows you to enable or disable <b>Delimiter</b> and <b>ColumnWidth</b> fields. When this field is turned on, the <b>Delimiter</b> field is inactive and <b>ColumnWidth</b> field is active and can be used to vary the width of the data columns. When <b>FixedWidth</b> field is turned off, the <b>ColumnWidth</b> field becomes inactive and <b>Delimiter</b> field is active for use.</p>
	<b>Data Type</b> Boolean
	<b>Allowed Values</b> On, Off
	<b>Access</b> set
	<b>Default Value</b> On
	<b>Units</b> N/A
	<b>Interfaces</b> GUI, script

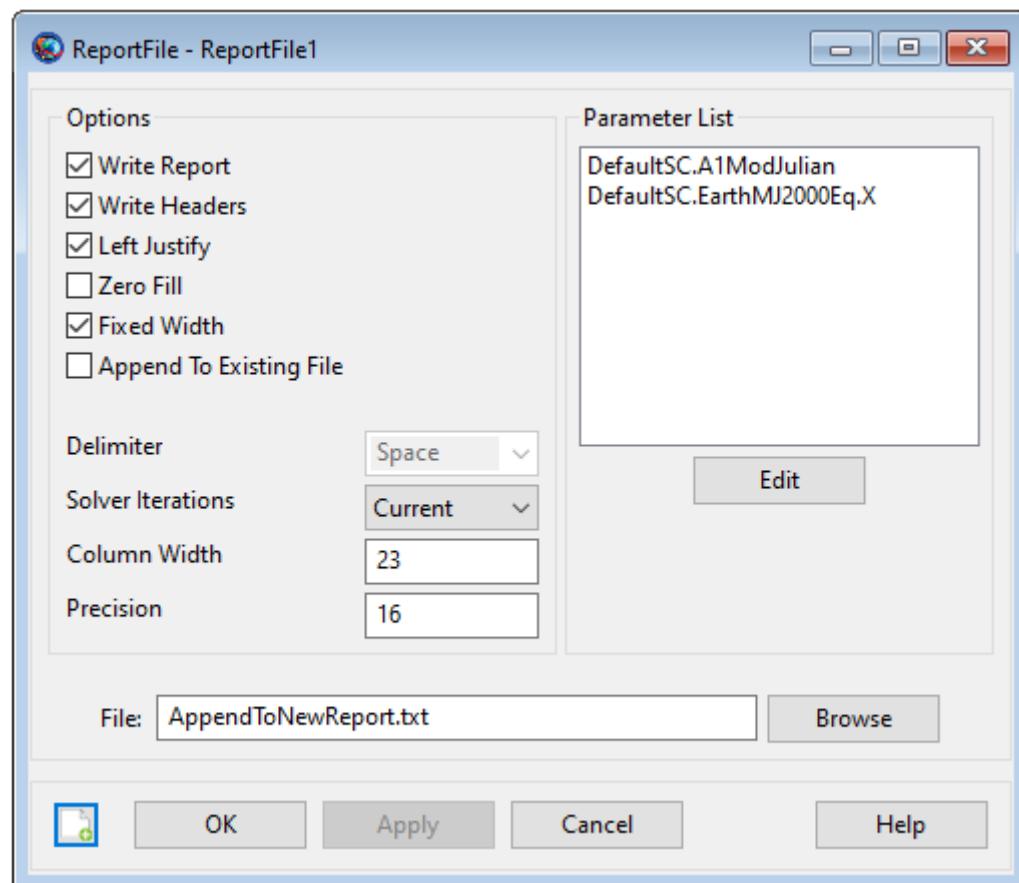
Field	Description
<b>LeftJustify</b>	When the <b>LeftJustify</b> field is set to <b>On</b> , then the data is left justified and appears at the left most side of the column. If the <b>LeftJustify</b> field is set to <b>Off</b> , then the data is centered in the column.
	<p><b>Data Type</b> Boolean</p> <p><b>Allowed Values</b> On, Off</p> <p><b>Access</b> set</p> <p><b>Default Value</b> On</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<b>Maximized</b>	Allows the user to maximize the <b>ReportFile</b> window. This field cannot be modified in the Mission Sequence.
	<p><b>Data Type</b> Boolean</p> <p><b>Allowed Values</b> true,false</p> <p><b>Access</b> set</p> <p><b>Default Value</b> false</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> script</p>
<b>Precision</b>	Allows the user to set the number of significant digits of the data written to a report.
	<p><b>Data Type</b> Integer</p> <p><b>Allowed Values</b> Integer &gt; 1</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 16</p> <p><b>Units</b> Same as variable being reported</p> <p><b>Interfaces</b> GUI, script</p>
<b>RelativeZOrder</b>	Allows the user to select which <b>ReportFile</b> to display first on the screen. The <b>ReportFile</b> with lowest <b>RelativeZOrder</b> value will be displayed last while <b>ReportFile</b> with highest <b>RelativeZOrder</b> value will be displayed first. This field cannot be modified in the Mission Sequence.
	<p><b>Data Type</b> Integer</p> <p><b>Allowed Values</b> Integer # 0</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 0</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> script</p>

Field	Description
<b>Size</b>	<p>Allows the user to control the display size of generated report file. First value in [0 0] matrix controls horizontal size and second value controls vertical size of report file window. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b> Real array
	<b>Allowed Values</b> Any Real number
	<b>Access</b> set
	<b>Default Value</b> [ 0 0 ]
	<b>Units</b> N/A
	<b>Interfaces</b> script
<b>SolverIterations</b>	<p>This field determines whether or not data associated with perturbed trajectories during a solver (<b>Targeter</b>, <b>Optimize</b>) sequence is written to a report file. When <b>SolverIterations</b> is set to <b>All</b>, all perturbations/iterations are written to a report file. When <b>SolverIterations</b> is set to <b>Current</b>, only current solution is written to a report file. When <b>SolverIterations</b> is set to <b>None</b>, this shows only final solution after the end of an iterative process and reports only final solution to a report file.</p>
	<b>Data Type</b> Enumeration
	<b>Allowed Values</b> All, Current, None
	<b>Access</b> set
	<b>Default Value</b> Current
	<b>Units</b> N/A
	<b>Interfaces</b> GUI, script
<b>UpperLeft</b>	<p>Allows the user to pan the generated report file display window in any direction. First value in [0 0] matrix helps to pan the report file window horizontally and second value helps to pan the window vertically. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b> Real array
	<b>Allowed Values</b> Any Real number
	<b>Access</b> set
	<b>Default Value</b> [ 0 0 ]
	<b>Units</b> N/A
	<b>Interfaces</b> script
<b>WriteHeaders</b>	<p>This field specifies whether to include headers that describe the variables in a report file.</p>
	<b>Data Type</b> Boolean
	<b>Allowed Values</b> True, False
	<b>Access</b> set
	<b>Default Value</b> True
	<b>Units</b> N/A
	<b>Interfaces</b> GUI, script

Field	Description
<b>WriteReport</b>	This field specifies whether to write data to the report <b>FileName</b> .  <b>Data Type</b> Boolean <b>Allowed Values</b> True, False <b>Access</b> set <b>Default Value</b> True <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>ZeroFill</b>	Allows zeros to be placed in data written to a report to match set precision.  <b>Data Type</b> Boolean <b>Allowed Values</b> On, Off <b>Access</b> set <b>Default Value</b> Off <b>Units</b> N/A <b>Interfaces</b> GUI, script

## GUI

Figure below shows default name and settings for the **ReportFile** resource:



## Remarks

### Behavior When using Filename field

GMAT allows you to specify the name of the report file in two ways. The default naming convention for a report file when using **FileName** field is shown below:

```
Create ReportFile aReport  
aReport.Filename = 'ReportFile1.txt'  
aReport.WriteReport = true
```

An alternate method for naming a report file is to name the file without using any single quotes around the report file's name.

```
Create ReportFile aReport  
aReport.Filename = ReportFile1.txt  
aReport.WriteReport = true
```

### How data is reported to a report file

GMAT allows you to report data to a report file in two ways: You can use **ReportFile.Add** field or a **Report** command.

You can add data using the **.Add** field of **ReportFile** resource and this method reports data to the report file at each propagation step. Below is an example script snippet that shows how to report epoch and selected orbital elements using the **.Add** field:

```
Create Spacecraft aSat  
Create ReportFile aReport  
  
aReport.Add = {aSat.UTCGregorian aSat.Earth.SMA, aSat.Earth.ECC, ...  
aSat.Earth.TA, aSat.EarthMJ2000Eq.RAAN}  
  
Create Propagator aProp  
  
BeginMissionSequence  
Propagate aProp(aSat) {aSat.ElapsedSecs = 8640.0}
```

GMAT's **ReportFile.Add** field will not report selected data to the report file at each propagation step if **Propagate** command is not included under the **BeginMissionSequence**.

An alternative method of reporting data to the report file is via the **Report** command. Using the **Report** command allows you to report data to the report file at specific points in your mission. Below is an example script snippet that shows how to report epoch and selected orbital elements using the **Report** command:

```
Create Spacecraft aSat  
Create ReportFile aReport  
  
Create Propagator aProp
```

```

BeginMissionSequence

Report aReport aSat.UTCGregorian aSat.Earth.SMA aSat.Earth.ECC ...
aSat.Earth.TA aSat.EarthMJ2000Eq.RAAN

Propagate aProp(aSat) {aSat.ElapsedSecs = 8640.0}

Report aReport aSat.UTCGregorian aSat.Earth.SMA aSat.Earth.ECC ...
aSat.Earth.TA aSat.EarthMJ2000Eq.RAAN

```

### Behavior and Interactions when using ReportFile Resource & Report Command

Suppose you utilize a **ReportFile** resource and opt not to write a report and select **false** for the field name **WriteReport**, as shown in the example below:

```

Create ReportFile aReport
aReport.Filename = ReportFile1.txt
aReport.Add = {aSat.A1ModJulian, aSat.Earth.SMA}
aReport.WriteReport = false

```

Now assume that at the same time, you decide to utilize **Report** command in the **Mission** tree, as shown in the example script snippet below:

```

BeginMissionSequence;
Report aReport aSat.A1ModJulian aSat.Earth.SMA aSat.Earth.ECC
Propagate aProp(aSat) {aSat.Earth.Periapsis}
Report aReport aSat.A1ModJulian aSat.Earth.SMA aSat.Earth.ECC

```

At this point, you may think that since false option is selected under the field name **WriteReport** in **ReportFile** resource, hence GMAT will not generate the report file called ReportFile1.txt. On the Contrary, GMAT will generate a report called ReportFile1.txt, but this report will only contain data that was requested using the **Report** command. ReportFile1.txt text file will contain epoch, semi-major-axis and eccentricity only at specific points of the mission.

### Behavior when reporting data in Iterative Processes

GMAT allows you to specify how data is written to reports during iterative processes such as differential correction or optimization. **SolverIterations** field of **ReportFile** resource supports 3 options which are described in the table below:

<b>SolverIterations</b> options	<b>Description</b>
<b>All</b>	Shows all iterations/perturbations in an iterative process and reports all iterations/perturbations to a report file.
<b>Current</b>	Shows only current iteration/perturbation after the end of an iterative process and reports current solution to a report file.

SolverIterations options	Description
<b>None</b>	Shows only final solution after the end of an iterative process and reports only final solution to a report file.

### Where Reports are written

GMAT allows you to write reports to any desired path or location. You can do this by going to GMAT's startup file called `gmat_startup_file.txt` and define an absolute path under `OUTPUT_PATH`. This allows you to save report files in the directory of your choice as oppose to saving report files in GMAT's default Output folder. In **ReportFile.FileName** field, If no path is provided and only name of the report file is defined, then report files are written to GMAT's default Output folder. The default path where reports are written to is the Output folder located in the main directory where GMAT is installed.

Below is an example script snippet that shows where generated reports are written when only report file's name is provided under the **FileName** field. In this example, '`ReportFile1.txt`' report is written to the Output folder located in the main directory where GMAT is installed:

```
Create ReportFile aReport

aReport.Filename = 'ReportFile1.txt'
aReport.Add = {aSat.A1ModJulian, aSat.Earth.ECC}
```

An alternate method where report files can be written is by defining a relative path. You can define the relative path in GMAT's startup file `gmat_startup_file.txt` under `OUTPUT_PATH`. For example, you can set a relative path by setting `OUTPUT_PATH = C:/Users/rqureshi/Desktop/GMAT/mytestfolder/..../output2/`. In this path, the syntax ".." means to "go up one level". After saving the startup file, when the script is executed, the generated report file named under **FileName** field will be written to a path `C:\Users\rqureshi\Desktop\GMAT\output2`.

Another method where report files can be written to is by defining an absolute path in GMAT's startup file `gmat_startup_file.txt` under `OUTPUT_PATH`. For example, you can set an absolute path by setting `OUTPUT_PATH = C:/Users/rqureshi/Desktop/GMAT/mytestfolder/`. When the script is executed, report file named under **FileName** field will be written to an absolute path `C:\Users\rqureshi\Desktop\GMAT\mytestfolder`.

Instead of defining a relative or an absolute path in GMAT's startup file, you can choose to define an absolute path under **FileName** field too. For example, if you set `ReportFile.FileName = C:\Users\rqureshi\Desktop\GMAT\mytestfolder\ReportFile.txt`, then report file will be saved in `mytestfolder`.

### Behavior when using ReportFile Resource & Toggle Command

GMAT allows you to use **Toggle** command while using the **Add** field of **ReportFile** resource. When **Toggle Off** command is issued for a **ReportFile**, not data is sent to a

report file until a **Toggle On** command is issued. Similarly, when a **Toggle On** command is used, data is sent to a report file at each integration step until a **Toggle Off** command is used.

Below is an example script snippet that shows how to use **Toggle Off** and **Toggle On** command while using the **ReportFile** resource. Spacecraft's cartesian position vector is reported to the report file.

```
Create Spacecraft aSat
Create Propagator aProp

Create ReportFile aReport
aReport.Filename = 'ReportFile1.txt'
aReport.Add = {aSat.UTCGregorian, aSat.EarthMJ2000Eq.X ...
aSat.EarthMJ2000Eq.Y aSat.EarthMJ2000Eq.Z}

BeginMissionSequence

Toggle aReport Off
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
Toggle aReport On
Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

### Behavior When Specifying Empty Brackets in ReportFile's Add Field

When using **ReportFile.Add** field, GMAT does not allow brackets to be left empty. The brackets must always be populated with values that you wish to report. If brackets are left empty, then GMAT throws in an exception. Below is a sample script snippet that shows an example of empty brackets. If you were to run this script, then GMAT throws in an exception reminding you that brackets cannot be left empty.

```
Create Spacecraft aSat
Create Propagator aProp
Create ReportFile aReport

aReport.Add = {}

BeginMissionSequence
Propagate aProp(aSat) {aSat.ElapsedSecs = 8640.0}
```

### Examples

Propagate an orbit and write cartesian state to a report file at every integrator step

```
Create Spacecraft aSat
Create Propagator aProp

Create ReportFile aReport
GMAT aReport.Filename = 'ReportFile1.txt'
aReport.Add = {aSat.EarthMJ2000Eq.X aSat.EarthMJ2000Eq.Y ...}
```

```
aSat.EarthMJ2000Eq.Z aSat.EarthMJ2000Eq.VX ...  
aSat.EarthMJ2000Eq.VY aSat.EarthMJ2000Eq.VZ}
```

```
BeginMissionSequence
```

```
Propagate aProp(aSat) {aSat.ElapsedSecs = 8640.0}
```

Propagate an orbit for 1 day and write cartesian state to a report file at specific points in your mission

```
Create Spacecraft aSat  
Create Propagator aProp
```

```
Create ReportFile aReport  
GMAT aReport.Filename = 'ReportFile1.txt'
```

```
BeginMissionSequence
```

```
Report aReport aSat.EarthMJ2000Eq.X aSat.EarthMJ2000Eq.Y ...  
aSat.EarthMJ2000Eq.Z aSat.EarthMJ2000Eq.VX ...  
aSat.EarthMJ2000Eq.VY aSat.EarthMJ2000Eq.VZ
```

```
Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

```
Report aReport aSat.EarthMJ2000Eq.X aSat.EarthMJ2000Eq.Y ...  
aSat.EarthMJ2000Eq.Z aSat.EarthMJ2000Eq.VX ...  
aSat.EarthMJ2000Eq.VY aSat.EarthMJ2000Eq.VZ
```

## XYPlot

Plots data onto the X and Y axes of a graph

### Description

The **XYPlot** resource allows you to plot data onto the X and Y axis of the graph. You can choose to plot any number of parameters as a function of a single independent variable. GMAT allows you to plot user-defined variables, array elements, or spacecraft parameters. You can create multiple **XYPlots** by using either the GUI or script interface of GMAT. GMAT also provides the option of when to plot and stop plotting data to a XY-Plot through the **Toggle On/Off** command. See the [Remarks](#) section below for detailed discussion of the interaction between an **XYPlot** resource and the **Toggle** command. GMAT's **Spacecraft** and **XYPlot** resources also interact with each other throughout the entire mission duration. Discussion of the interaction between **Spacecraft** and **XYPlot** resources can also be found in the [Remarks](#) section.

See Also: [Toggle](#), [Spacecraft](#)

### Fields

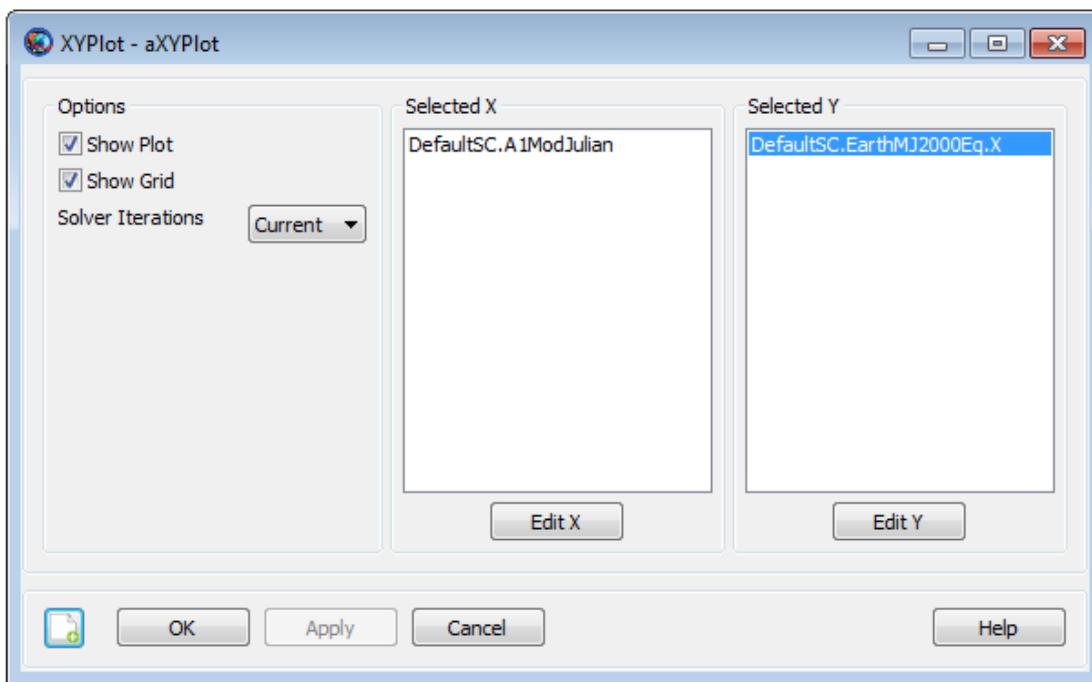
Field	Description
<b>Maximized</b>	Allows the user to maximize the <b>XYPlot</b> window. This field cannot be modified in the Mission Sequence.  <b>Data Type</b> Boolean <b>Allowed Values</b> true,false <b>Access</b> set <b>Default Value</b> false <b>Units</b> N/A <b>Interfaces</b> script
<b>UpperLeft</b>	Allows the user to pan the <b>XYPlot</b> display window in any direction. First value in [0 0] matrix helps to pan the <b>XYPlot</b> window horizontally and second value helps to pan the window vertically. This field cannot be modified in the Mission Sequence.  <b>Data Type</b> Real array <b>Allowed Values</b> Any Real number <b>Access</b> set <b>Default Value</b> [0 0] <b>Units</b> N/A <b>Interfaces</b> script

Field	Description
<b>RelativeZOrder</b>	<p>Allows the user to select which <b>XYPlot</b> window to display first on the screen. The <b>XYPlot</b> with lowest <b>RelativeZOrder</b> value will be displayed last while <b>XYPlot</b> with highest <b>RelativeZOrder</b> value will be displayed first. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b> Integer
	<b>Allowed Values</b> Integer # 0
	<b>Access</b> set
	<b>Default Value</b> 0
	<b>Units</b> N/A
	<b>Interfaces</b> script
<b>ShowGrid</b>	<p>When the <b>ShowGrid</b> field is set to <b>True</b>, then a grid is drawn on an xy-plot. When the <b>ShowGrid</b> field is set to <b>False</b>, then a grid is not drawn. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b> Boolean
	<b>Allowed Values</b> True,False
	<b>Access</b> set
	<b>Default Value</b> True
	<b>Units</b> N/A
	<b>Interfaces</b> GUI, script
<b>ShowPlot</b>	<p>Allows the user to turn off a plot for a particular run, without deleting the XYPlot resource, or removing it from the script. If you select <b>True</b>, then the plot will be shown. If you select <b>False</b>, then the plot will not be shown. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b> Boolean
	<b>Allowed Values</b> True,False
	<b>Access</b> set
	<b>Default Value</b> True
	<b>Units</b> N/A
	<b>Interfaces</b> GUI, script
<b>Size</b>	<p>Allows the user to control the display size of <b>XYPlot</b> window. First value in [ 0 0 ] matrix controls horizontal size and second value controls vertical size of <b>XYPlot</b> display window. This field cannot be modified in the Mission Sequence.</p>
	<b>Data Type</b> Real array
	<b>Allowed Values</b> Any Real number
	<b>Access</b> set
	<b>Default Value</b> [ 0 0 ]
	<b>Units</b> N/A
	<b>Interfaces</b> script

Field	Description
<b>SolverIterations</b>	<p>This field determines whether or not data associated with perturbed trajectories during a solver (<b>Targeter</b>, <b>Optimize</b>) sequence is displayed in the <b>XYPlot</b>. When <b>SolverIterations</b> is set to <b>All</b>, all perturbations/iterations are plotted in the <b>XYPlot</b>. When <b>SolverIterations</b> is set to <b>Current</b>, only the current solution or perturbation is plotted in <b>XYPlot</b>. When <b>SolverIterations</b> is set to <b>None</b>, only the final nominal run is plotted on the <b>XYPlot</b>.</p>
	<p><b>Data Type</b> Enumeration  <b>Allowed Values</b> All, Current, None  <b>Access</b> set  <b>Default Value</b> Current  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>XVariable</b>	<p>Allows the user to define the independent variable for an <b>XYPlot</b>. Only one variable can be defined as an independent variable. For example, the line <code>MyXYPlot.XVariable = DefaultSC.A1ModJulian</code> sets the independent variable to be the epoch of <b>DefaultSC</b> in the A1 time system and modified Julian format. This field cannot be modified in the Mission Sequence.</p>
	<p><b>Data Type</b> Resource reference  <b>Allowed Values</b> Variable, Array, array element, Spacecraft parameter that evaluates to a real number  <b>Access</b> get, set  <b>Default Value</b> DefaultSC.A1ModJulian  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>
<b>YVariables</b>	<p>Allows the user to add dependent variables to an xy-plot. All dependent variables are plotted on the y-axis vs the independent variable defined by <b>XVariable</b> field. The dependent variable(s) should always be included in curly braces. For example, <code>MyXYPlot.YVariables = {DefaultSC.EarthMJ2000Eq.Y, DefaultSC.EarthMJ2000Eq.Z}</code>. This field cannot be modified in the Mission Sequence.</p>
	<p><b>Data Type</b> Reference array  <b>Allowed Values</b> Any user variable, array element, or space-craft parameter that evaluates to a real number  <b>Access</b> get, set  <b>Default Value</b> DefaultSC.EarthMJ2000Eq.X  <b>Units</b> N/A  <b>Interfaces</b> GUI, script</p>

## GUI

The figure below shows the default settings for the **XYPlot** resource:



## Remarks

### Behavior when using XYPlot Resource & Toggle Command

The **XYPlot** resource plots data onto the X and Y axis of the graph at each propagation step of the entire mission duration. If you want to report data to an **XYPlot** at specific points in your mission, then a **Toggle On/Off** command can be inserted into the mission sequence to control when the **XYPlot** is to plot data. When **Toggle Off** command is issued for a **XYPlot**, no data is plotted onto the X and Y axis of the graph until a **Toggle On** command is issued. Similarly when a **Toggle On** command is used, data is plotted onto the X and Y axis at each integration step until a **Toggle Off** command is used.

Below is an example script snippet that shows how to use **Toggle Off** and **Toggle On** commands while using the **XYPlot** resource. **Spacecraft's** position magnitude and semi-major-axis are plotted as a function of time.

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aXYPlot
aXYPlot.XVariable = aSat.ElapsedDays
aXYPlot.YVariables = {aSat.Earth.RMAG, aSat.Earth.SMA}

BeginMissionSequence

Toggle aXYPlot Off
```

```
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
Toggle aXYPlot On
Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

### Behavior when using XYPlot & Spacecraft resources

**Spacecraft** resource contains information about spacecraft's orbit, its attitude, physical parameters (such as mass and drag coefficient) and any attached hardware, including thrusters and fuel tanks. **Spacecraft** resource interacts with **XYPlot** throughout the entire mission duration. The data retrieved from the spacecraft is what gets plotted onto the X and Y axis of the graph at each propagation step of the entire mission duration.

### Behavior When Specifying Empty Brackets in XYPlot's YVariables Field

When using **XYPlot.YVariables** field, GMAT does not allow brackets to be left empty. The brackets must always be populated with values that you wish to plot against a variable in **XVariable** field. If brackets are left empty, then GMAT throws in an exception. Below is a sample script snippet that shows an example of empty brackets. If you were to run this script, then GMAT throws in an execption reminding you that brackets for **YVariables** field cannot be left empty.

```
Create Spacecraft aSat
Create Propagator aProp
Create XYPlot aXYPlot

aXYPlot.XVariable = aSat.ElapsedDays
aXYPlot.YVariables = {}

BeginMissionSequence
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
```

### Behavior when Reporting Data in Iterative Processes

GMAT allows you to specify how data is plotted onto a plot during iterative processes such as differential correction or optimization. The **SolverIterations** field of an **XYPlot** resource supports three options which are described in the table below:

SolverIterations options	Description
<b>Current</b>	Shows only current iteration/perturbation in an iterative process and plots current iteration to a plot.
<b>All</b>	Shows all iterations/perturbations in an iterative process and plots all iterations/perturbations to a plot.
<b>None</b>	Shows only the final solution after the end of an iterative process and plots only that final solution to the plot.

### Examples

Propagate an orbit and plot the spacecraft's altitude as a function of time at every integrator step:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aXYPlot
aXYPlot.XVariable = aSat.ElapsedSecs
aXYPlot.YVariables = {aSat.Earth.Altitude}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

Plotting data during an iterative process. Notice **SolverIterations** field is selected as **All**. This means all iterations/perturbations will be plotted.

```
Create Spacecraft aSat
Create Propagator aProp

Create ImpulsiveBurn TOI
Create DifferentialCorrector aDC

Create XYPlot aXYPlot
aXYPlot.SolverIterations = All
aXYPlot.XVariable = aSat.ElapsedDays
aXYPlot.YVariables = {aSat.Earth.RMAG}

BeginMissionSequence

Propagate aProp(aSat) {aSat.Earth.Periapsis}
Target aDC
  Vary aDC(TOI.Element1 = 0.24, {Perturbation = 0.001, Lower = 0.0, ...
    Upper = 3.14159, MaxStep = 0.5})
  Maneuver TOI(aSat)
  Propagate aProp(aSat) {aSat.Earth.Apoapsis}
  Achieve aDC(aSat.Earth.RMAG = 42165)
EndTarget
```

## Commands

## ClearPlot

Allows you to clear all data from an XYPlot

### Script Syntax

```
ClearPlot OutputNames
```

#### *OutputNames*

*OutputNames* is the list of subscribers whose data is to be cleared. When data of multiple subscribers is to be cleared, then they need to be separated by a space.

### Description

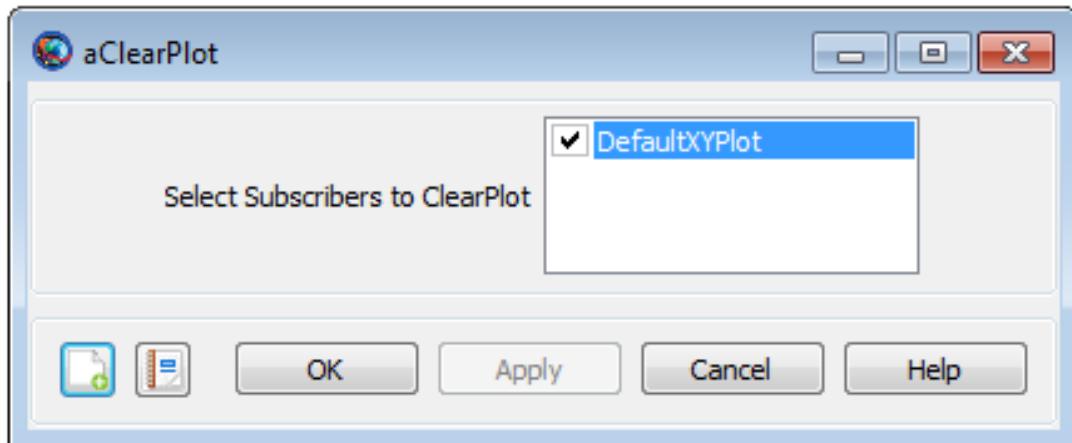
The **ClearPlot** command allows you to clear all data from an **XYPlot** after it has been plotted. The **ClearPlot** command works only for the **XYPlot** resource and data from multiple **XYPlot** resources can be cleared. **ClearPlot** command can be used through GMAT's GUI or the script interface.

### Options

Option	Description
<b>OutputNames</b>	The <b>ClearPlot</b> command allows the user to clear data from an <b>XYPlot</b> subscriber. When more than one subscriber is being used, the subscribers need to be separated by a space.
<b>Accepted Data Types</b>	Resource reference
<b>Allowed Values</b>	<b>XYPlot</b> resource
<b>Default Value</b>	<b>DefaultXYPlot</b>
<b>Required</b>	yes
<b>Interfaces</b>	GUI, script

### GUI

Figure below shows default settings for **ClearPlot** command.



## Remarks

GMAT allows you to insert **ClearPlot** command into the **Mission** tree at any location. This allows you to clear data output from an **XYPlot** at any point in your mission. The **XYPlot** subscriber plots data at each propagation step of the entire mission duration. If you want to report data to an **XYPlot** at specific points in your mission, then a **ClearPlot** command can be inserted into the mission sequence to control when a subscriber plots data. Refer to the [Examples](#) section below to see how **ClearPlot** command can be used in the **Mission** tree.

## Examples

This example shows how to use **ClearPlot** command on multiple subscribers. Data from **XYPlot** subscribers is cleared after 2 days of the propagation:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aPlot1 aPlot2 aPlot3

aPlot1.XVariable = aSat.ElapsedSecs
aPlot1.YVariables = {aSat.EarthMJ2000Eq.X}

aPlot2.XVariable = aSat.ElapsedSecs
aPlot2.YVariables = {aSat.EarthMJ2000Eq.Y}

aPlot3.XVariable = aSat.ElapsedSecs
aPlot3.YVariables = {aSat.EarthMJ2000Eq.VX, aSat.EarthMJ2000Eq.VY, ...
aSat.EarthMJ2000Eq.VZ}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 2}
ClearPlot aPlot1 aPlot2 aPlot3
```

This example shows how to use **ClearPlot** command on a single subscriber. Data from **XYPlot** is cleared for the first 3 days of the propagation and only the data retrieved from last day of propagation is plotted:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aPlot1

aPlot1.XVariable = aSat.ElapsedDays
aPlot1.YVariables = {aSat.EarthMJ2000Eq.X, aSat.EarthMJ2000Eq.Y}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 3}
```

```
ClearPlot aPlot1  
Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

## GetEphemStates()

Function used to output initial and final spacecraft states from an ephemeris file

### Script Syntax

```
[initialEpoch, initialState, finalEpoch, finalState] =  
    GetEphemStates(ephemType, sat, epochFormat, coordinateSystem)
```

#### Inputs:

ephemType : Ephemeris type ('STK', 'SPK', 'Code500', 'CCSDS-OEM')  
sat : Spacecraft with an associated ephemeris file  
epochFormat : String in single quotes containing a valid epoch  
format for the resulting epoch output  
coordSystem : CoordinateSystem for the resulting state output

#### Outputs:

initialEpoch : String of initial epoch on the file in requested  
epochFormat  
initialState : 6-element Array in the requested coordinateSystem  
finalEpoch : String of final epoch on the file in requested  
epochFormat  
finalState : 6-element Array in the requested coordinateSystem

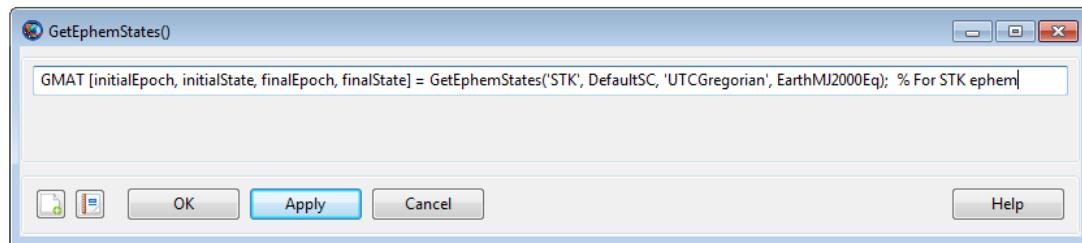
### Description

**GetEphemStates()** is a special function that allows you to output initial and final spacecraft ephemeris states from a generated spacecraft ephemeris file. The **GetEphemStates()** function can query the following ephemeris types: STK-TimePosVel (i.e. STK.e ephemeris), SPICE (SPK), CCSDS Orbit Ephemeris Message (CCSDS-OEM), and Code-500. You can request the resulting initial epoch, initial state, final epoch and final state in the epoch format and coordinate system of your choice.

The initial state output stored in the `initialState` array corresponds to the state in the ephemeris file at ephemeris file's initial epoch. Similarly, the final state output stored in the `finalState` array corresponds to the final state in the ephemeris file at ephemeris file's final epoch. You can request both the initial and final epochs in any of the epoch formats that GMAT supports. Also both initial and final states can be requested in any of GMAT's default or user-defined coordinate systems.

See Also: [EphemerisFile](#), [CoordinateSystem](#), [Spacecraft](#)

## GUI



The **GetEphemStates()** GUI is a very simple one and it simply reflects how you implement this function in the script mode. It is easiest to work with **GetEphemStates()** function in the script mode.

## Remarks

Before using **GetEphemStates()** function to query an STK .e, CCSDS-OEM, or Code-500 ephemeris file, you must first set the ephemeris file to a **Spacecraft** resource's script-only field called **EphemerisName** (i.e. **Spacecraft.EphemerisName**). The ephemeris file can be set to this script-only **EphemerisName** field either through a relative or an absolute path.

When using **GetEphemStates()** function to query a spice ephemeris, you do not have to use **EphemerisName** field at all. Rather you must set spice ephemeris file to a **Spacecraft** resource's field called **OrbitSpiceKernelName** (i.e. **Spacecraft.OrbitSpiceKernelName**). The spice ephemeris file can be set to **OrbitSpiceKernelName** field either through a relative or an absolute path.

The [Examples](#) section will show simple examples in how to use **GetEphemStates()** function to extract initial and final ephemeris states.

## Examples

First run only 'Example 1A' to generate STK-TimePosVel (i.e. STK .e) ephemeris file. Now run 'Example 1B' that shows you how to read through a generated STK .e ephemeris file and retrieve spacecraft's initial/final states in the desired epoch format and coordinate system. Before running Example 1B, make sure that you put 'STK\_Ephemeris.e' ephemeris file in the same directory as your main GMAT script

```
% Example 1A. Generate STK .e ephemeris file:  
  
Create Spacecraft aSat  
  
Create Propagator aProp  
  
Create EphemerisFile anEphemerisFile  
anEphemerisFile.Spacecraft = aSat  
anEphemerisFile.Filename = 'STK_Ephemeris.e'  
anEphemerisFile.FileFormat = STK-TimePosVel
```

```
BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}

%%% Example 1B. Read through .e ephemeris file using GetEphemStates():

Create Spacecraft aSat
aSat.EphemerisName = './STK_Ephemeris.e'

Create Propagator aProp

Create EphemerisFile anEphemerisFile
anEphemerisFile.Spacecraft = aSat
anEphemerisFile.Filename = 'STK_Ephemeris.e'
anEphemerisFile.FileFormat = STK-TimePosVel

Create Array initialState[6,1] finalState[6,1]
Create String initialEpoch finalEpoch

Create ReportFile rf

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}

[initialEpoch, initialState, finalEpoch, finalState] = ...
GetEphemStates('STK', aSat, 'UTCGregorian', EarthMJ2000Eq)

Report rf initialEpoch initialState finalEpoch finalState
```

First run only 'Example 2A' to generate a Code-500 ephemeris file. Now run 'Example 2B' that shows you how to read through a generated Code-500 ephemeris file and retrieve spacecraft's initial/final states in the desired epoch format and coordinate system. Before running Example 2B, make sure that you put 'Code500\_Ephemeris.eph' ephemeris file in the same directory as your main GMAT script

```
%% Example 2A. Generate Code-500 ephemeris file:

Create Spacecraft aSat

Create Propagator aProp

Create EphemerisFile anEphemerisFile
anEphemerisFile.Spacecraft = aSat
anEphemerisFile.Filename = 'Code500_Ephemeris.eph'
anEphemerisFile.FileFormat = Code-500

BeginMissionSequence
```

```
Propagate aProp(aSat) {aSat.ElapsedDays = 1}

%%% Example 2B. Read through Code-500 ephemeris file using GetEphemStates():

Create Spacecraft aSat
aSat.EphemerisName = './Code500_Ephemeris.eph'

Create Propagator aProp

Create EphemerisFile anEphemerisFile
anEphemerisFile.Spacecraft = aSat
anEphemerisFile.Filename = 'Code500_Ephemeris.eph'
anEphemerisFile.FileFormat = Code-500

Create Array initialState[6,1] finalState[6,1]
Create String initialEpoch finalEpoch

Create ReportFile rf

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}

[initialEpoch, initialState, finalEpoch, finalState] = ...
    GetEphemStates('Code500', aSat, 'TDBGregorian', EarthMJ2000Ec)

Report rf initialEpoch initialState finalEpoch finalState
```

First run only 'Example 3A' to generate a Spice ephemeris file. Now run 'Example 3B' that shows you how to read through a generated spice ephemeris file and retrieve spacecraft's initial/final states in the desired epoch format and coordinate system. Before running Example 3B, make sure that you put 'SPK\_Ephemeris.bsp' ephemeris file in the same directory as your main GMAT script

```
% Example 3A. Generate a Spice ephemeris file:

Create Spacecraft aSat
aSat.NAIFId = -10025001;
aSat.NAIFIdReferenceFrame = -9025001;

Create Propagator aProp

Create ImpulsiveBurn IB
IB.Element1 = 0.5

Create EphemerisFile anEphemerisFile
anEphemerisFile.Spacecraft = aSat
```

```
anEphemerisFile.Filename = 'SPK_Ephemeris.bsp'
anEphemerisFile.FileFormat = SPK

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 0.25}
Maneuver IB(aSat)
Propagate aProp(aSat) {aSat.ElapsedDays = 0.25}

%% Example 3B. Read through a Spice ephemeris file using GetEphemStates():

Create Spacecraft aSat
aSat.NAIFId = -10025001
aSat.NAIFIdReferenceFrame = -9025001
aSat.OrbitSpiceKernelName = {'./SPK_Ephemeris.bsp'}

Create Propagator aProp

Create ImpulsiveBurn IB
IB.Element1 = 0.5

Create EphemerisFile anEphemerisFile
anEphemerisFile.Spacecraft = aSat
anEphemerisFile.Filename = 'SPK_Ephemeris.bsp'
anEphemerisFile.FileFormat = SPK

Create Array initialState[6,1] finalState[6,1]
Create String initialEpoch finalEpoch

Create ReportFile rf

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 0.25}
Maneuver IB(aSat)
Propagate aProp(aSat) {aSat.ElapsedDays = 0.25}

[initialEpoch, initialState, finalEpoch, finalState] = ...
GetEphemStates('SPK', aSat, 'UTCGregorian', EarthMJ2000Eq)

Report rf initialEpoch initialState finalEpoch finalState
```

## MarkPoint

Allows you to add a special mark point character on an XYPlot

### Script Syntax

**MarkPoint** *OutputNames*

*OutputNames*

*OutputNames* is the list of subscribers and a special mark point will be added to each subscriber's **XYPlot**. When mark points need to be added to multiple subscribers, then the subscribers need to be separated by a space.

### Description

The **MarkPoint** command allows you to add a special mark point character to highlight a single data point on an **XYPlot**. **MarkPoint** command works only for **XYPlot** subscriber. This command also allows you to add special mark points on multiple **XYPlot** resources. **MarkPoint** command can be used through GMAT's GUI or the script interface.

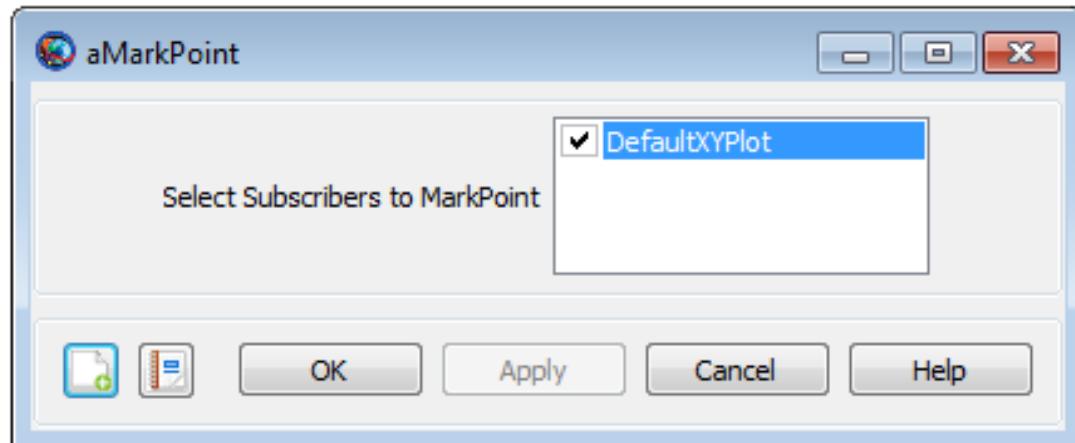
### Options

Option	Description
<b>OutputNames</b>	The <b>MarkPoint</b> command allows the user to add a special mark point character to highlight an individual data point on an <b>XYPlot</b> .

**Accepted Data Types**      Resource reference  
**Allowed Values**      **XYPlot** resource  
**Default Value**      **DefaultXYPlot**  
**Required**      yes  
**Interfaces**      GUI, script

### GUI

Figure below shows default settings for **MarkPoint** command:



## Remarks

GMAT allows you to insert **MarkPoint** command into the **Mission** tree at any location. This allows you to add special mark points on an **XYPlot** at any point in your mission. The **XYPlot** subscriber plots data at each propagation step of the entire mission duration. If you want to place mark points on an **XYPlot** at specific points, then a **MarkPoint** command can be inserted into the mission sequence to control when mark points are placed onto an **XYPlot**. Refer to the [Examples](#) section below to see how **MarkPoint** command can be used in the **Mission** tree.

## Examples

This example shows how to use **MarkPoint** command on multiple subscribers. Mark points are added on two **XYPlots** after every 0.2 days through an iterative loop:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aPlot1 aPlot2

aPlot1.XVariable = aSat.A1ModJulian
aPlot1.YVariables = {aSat.EarthMJ2000Eq.X}

aPlot2.XVariable = aSat.A1ModJulian
aPlot2.YVariables = {aSat.EarthMJ2000Eq.VX}

BeginMissionSequence;

While aSat.ElapsedDays < 1.0
    MarkPoint aPlot1 aPlot2
    Propagate aProp(aSat) {aSat.ElapsedDays = 0.2}
EndWhile
```

This example shows how to use **MarkPoint** on a single subscriber. In this example, mark points are placed on the **XYPlot** the moment spacecraft's altitude goes below 750 Km. Note that mark points are placed on the XYPlot at every integration step:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aPlot1

aPlot1.XVariable = aSat.A1ModJulian
aPlot1.YVariables = {aSat.Earth.Altitude}

BeginMissionSequence

While aSat.ElapsedDays < 2
    Propagate aProp(aSat)
    If aSat.Earth.Altitude < 750
```

```
MarkPoint aPlot1  
EndIf  
EndWhile
```

## PenUpPenDown

Allows you to stop or begin drawing data on a plot

### Script Syntax

**PenUp** *OutputNames*

*OutputNames*

*OutputNames* is the list of subscribers that **PenUp** command operates on. When **PenUp** command is used on multiple subscribers, then the subscribers need to be separated by a space.

**PenDown** *OutputNames*

*OutputNames*

*OutputNames* is the list of subscribers that **PenDown** command operates on. When **PenDown** command is used on multiple subscribers, then the subscribers need to be separated by a space.

### Description

The **PenUp** and **PenDown** commands allow you to stop or begin drawing data on a plot. The **PenUp** and **PenDown** commands operate on **XYPlot**, **OrbitView** and **Ground-TrackPlot** subscribers. GMAT allows you to insert **PenUp** and **PenDown** commands into the **Mission** tree at any location. This allows you to stop or begin drawing data output on a plot at any point in your mission. The **PenUp** and **PenDown** commands can be used through GMAT's GUI or the script interface.

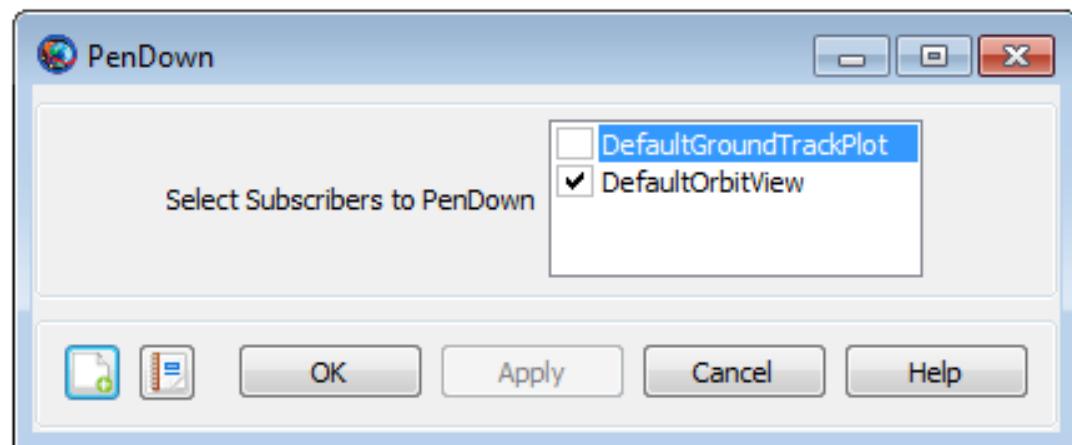
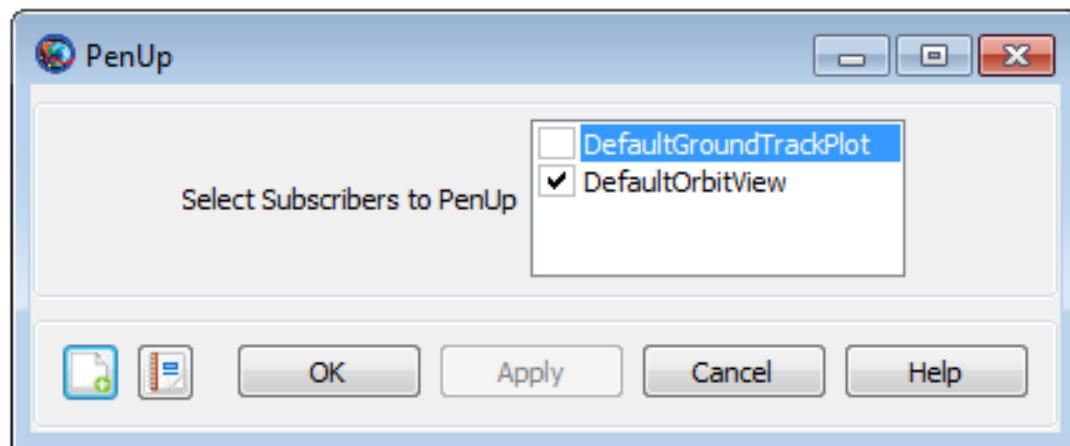
### Options

Option	Description
<b>OutputNames</b>	When a <b>PenUp</b> command is issued for a plot, no data is drawn to that plot until a <b>PenDown</b> command is issued for that plot  <b>Accepted Data Types</b> <b>Allowed Values</b> Resource reference <b>XYPlot</b> , <b>OrbitView</b> or <b>Ground-TrackPlot</b> resources  <b>Default Value</b> <b>Required Interfaces</b> <b>DefaultOrbitview</b> yes GUI, script

Option	Description
<b>OutputNames</b>	When a <b>PenDown</b> command is issued for a plot, data is drawn for each integration step until a <b>PenUp</b> command is issued for that plot.
<b>Accepted Data Types</b>	Resource reference
<b>Allowed Values</b>	<b>XYPlot</b> , <b>OrbitView</b> or <b>GroundTrackPlot</b> resources
<b>Default Value</b>	<b>DefaultOrbitview</b>
<b>Required</b>	yes
<b>Interfaces</b>	GUI, script

## GUI

Figures below show default settings for **PenUp** and **PenDown** commands:



## Remarks

**XYPlot**, **OrbitView** and **GroundTrackPlot** subscribers plot data at each integration step of the entire mission duration. If you want to plot data at specific points in your mission, then a **PenUp** and **PenDown** command can be inserted into the mission sequence to

control when a subscriber plots data. For example, when a **PenUp** command is issued for **XYPlot**, **OrbitView** or **GroundTrackPlot**, no data is drawn to that plot until a **PenDown** command is issued for that same plot. Similarly, when a **PenDown** command is issued for any of the three **subscribers**, then data is drawn for each integration step until a **PenUp** command is issued for that specific subscriber. Refer to the [Examples](#) section below to see how **PenUp** and **PenDown** commands can be used in the **Mission** tree.

## Examples

This example shows how to use **PenUp** and **PenDown** commands on multiple subscribers. **PenUp** and **PenDown** commands are used on **XYPlot**, **OrbitView** and **GroundTrackPlot**. Data is drawn to the plots for first day of the propagation, turned off for second day of propagation and then data is drawn for third day of the propagation:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aPlot
aPlot.XVariable = aSat.ElapsedDays
aPlot.YVariables = {aSat.Earth.SMA}

Create OrbitView anOrbitViewPlot
anOrbitViewPlot.Add = {aSat, Earth}

Create GroundTrackPlot aGroundTrackPlot
aGroundTrackPlot.Add = {aSat, Earth}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}
PenUp aGroundTrackPlot anOrbitViewPlot aPlot
Propagate aProp(aSat) {aSat.ElapsedDays = 1}
PenDown aGroundTrackPlot anOrbitViewPlot aPlot
Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

This example shows how to use **PenUp** and **PenDown** commands on a single **XYPlot** subscriber. Data is drawn to the plot for one-third of the day, turned off for second one-third of the day and then data is drawn again for last one-third of the day:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aPlot1
aPlot1.XVariable = aSat.ElapsedDays
aPlot1.YVariables = {aSat.Earth.Altitude}

Create Variable I
I = 0

BeginMissionSequence
```

```
While aSat.ElapsedDays < 1.0

    Propagate aProp(aSat) {aSat.ElapsedSecs = 60}
    If I == 480
        PenUp aPlot1
        EndIf

    If I == 960
        PenDown aPlot1
        EndIf

    GMAT I = I +1

EndWhile
```

## Report

Allows you to write data to a text file

### Script Syntax

```
Report ReportName DataList
```

#### *ReportName*

*ReportName* option allows you to specify the ReportFile for data output.

#### *DataList*

*DataList* option allows you to output data to the Filename specified by the *ReportName*. Multiple objects can be written in the *DataList* when they are separated by spaces.

### Description

The **Report** command allows you to report data at specific points in your mission sequence. GMAT allows you to insert **Report** command into the **Mission** tree at any location. **Report** command can be used through GMAT's GUI or via the script interface. The parameters reported by **Report** command are placed into a report file that can be accessed at the end of the mission run.

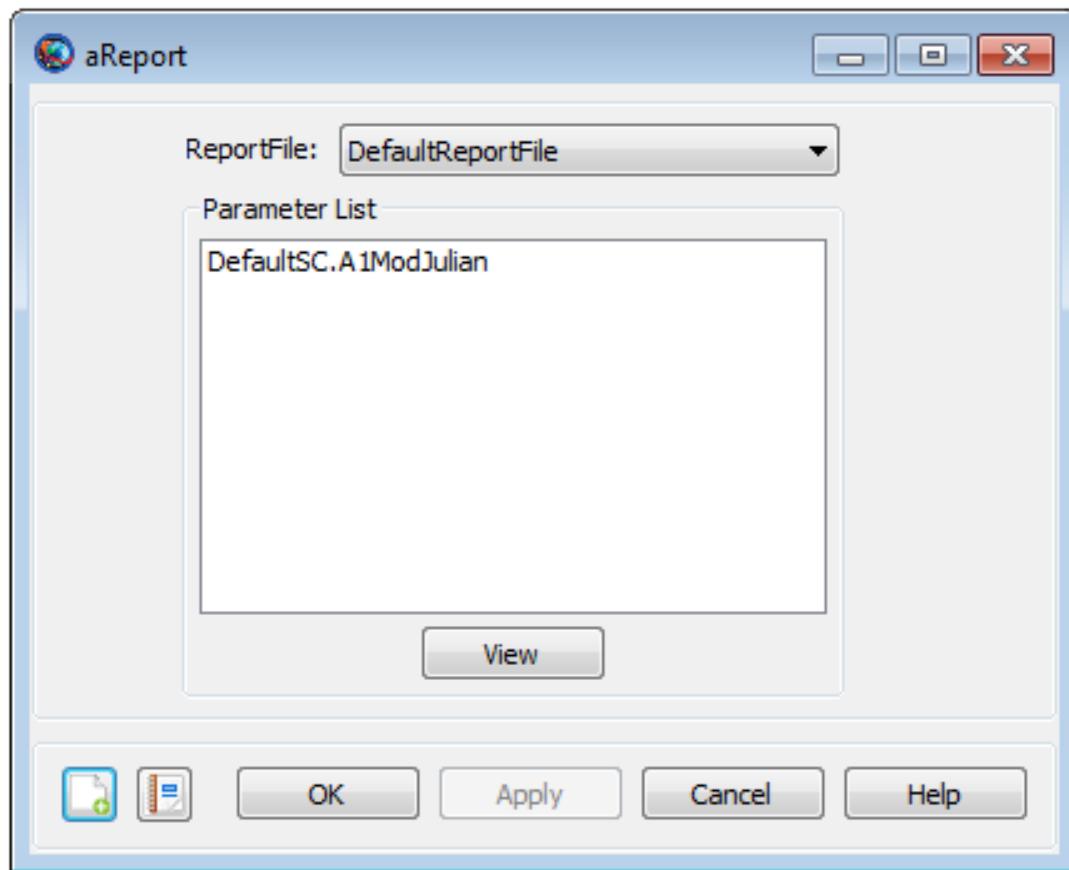
See Also: [ReportFile](#)

### Options

Option	Description										
<b>ReportName</b>	<p>The <b>ReportName</b> option allows the user to specify the <b>ReportFile</b> for data output.</p> <table> <tr> <td><b>Accepted Data Types</b></td><td>Resource reference</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>ReportFile</b> resource</td></tr> <tr> <td><b>Default Value</b></td><td><b>DefaultReportFile</b></td></tr> <tr> <td><b>Required</b></td><td>yes</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Accepted Data Types</b>	Resource reference	<b>Allowed Values</b>	<b>ReportFile</b> resource	<b>Default Value</b>	<b>DefaultReportFile</b>	<b>Required</b>	yes	<b>Interfaces</b>	GUI, script
<b>Accepted Data Types</b>	Resource reference										
<b>Allowed Values</b>	<b>ReportFile</b> resource										
<b>Default Value</b>	<b>DefaultReportFile</b>										
<b>Required</b>	yes										
<b>Interfaces</b>	GUI, script										
<b>DataList</b>	<p>The <b>DataList</b> option allows the user to output data to the file name that is specified by the <b>ReportName</b>. Multiple objects can be in the <b>DataList</b> when they are separated by spaces.</p> <table> <tr> <td><b>Accepted Data Types</b></td><td>Reference array</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>Spacecraft</b>, <b>ImpulsiveBurn</b> reportable parameters, <b>Array</b>, <b>Array Element</b>, <b>Variable</b>, or a <b>String</b>.</td></tr> <tr> <td><b>Default Value</b></td><td><b>DefaultSC.A1ModJulian</b></td></tr> <tr> <td><b>Required</b></td><td>yes</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Accepted Data Types</b>	Reference array	<b>Allowed Values</b>	<b>Spacecraft</b> , <b>ImpulsiveBurn</b> reportable parameters, <b>Array</b> , <b>Array Element</b> , <b>Variable</b> , or a <b>String</b> .	<b>Default Value</b>	<b>DefaultSC.A1ModJulian</b>	<b>Required</b>	yes	<b>Interfaces</b>	GUI, script
<b>Accepted Data Types</b>	Reference array										
<b>Allowed Values</b>	<b>Spacecraft</b> , <b>ImpulsiveBurn</b> reportable parameters, <b>Array</b> , <b>Array Element</b> , <b>Variable</b> , or a <b>String</b> .										
<b>Default Value</b>	<b>DefaultSC.A1ModJulian</b>										
<b>Required</b>	yes										
<b>Interfaces</b>	GUI, script										

## GUI

Figure below shows default settings for **Report** command:



## Remarks

**Report** command can be used to report data to a report file at specific points in your mission. If you want data to be reported at each propagation step of the entire mission duration, then you should not use **Report** command. Instead you should use **ReportFile** resource. See **ReportFile** resource section of the User's Guide to learn about the syntax that allows you to report data at each raw integrator steps.

## Examples

Propagate an orbit for two days and report epoch and selected orbital elements to a report file using the **Report** command.

```
Create Spacecraft aSat
Create ReportFile aReport

Create Propagator aProp

BeginMissionSequence
```

```
Report aReport aSat.UTCGregorian aSat.Earth.SMA aSat.Earth.ECC ...
aSat.EarthMJ2000Eq.RAAN
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
Report aReport aSat.UTCGregorian aSat.Earth.SMA aSat.Earth.ECC ...
aSat.EarthMJ2000Eq.RAAN
```

Report user-defined parameters such as variables, array elements and a string to a report file using the **Report** command.

```
Create ReportFile aReport

Create Variable aVar aVar2
aVar = 100
aVar2 = 2000

Create Array aArray[2,2]
aArray(1, 1) = 2
aArray(1, 2) = 3
aArray(2, 1) = 4
aArray(2, 2) = 5

Create String aString
aString = 'GMAT is awesome'

BeginMissionSequence

Report aReport aVar aVar2 aArray(1,1) aArray(1,2) aArray(2,1) ...
aArray(2,2) aString
```

While spacecraft propagates for less than a day, report spacecraft's true anomaly, eccentricity and altitude after every 3600 seconds using the **Report** command:

```
Create Spacecraft aSat
Create ReportFile aReport
Create Propagator aProp

BeginMissionSequence

While aSat.ElapsedDays < 1
    Propagate aProp(aSat) {aSat.ElapsedSecs = 3600 }
    Report aReport aSat.Earth.TA aSat.Earth.ECC aSat.Earth.Altitude
EndWhile
```

## Set

Configure a resource from a data interface

### Script Syntax

```
Set destination source (options)
```

### Description

The **Set** command retrieves data from *source* according to *options* and populates *destination*. Time systems, time formats, state types, and coordinate systems are automatically converted to those required by *destination*.

See Also: [FileInterface](#), [Spacecraft](#)

### Options

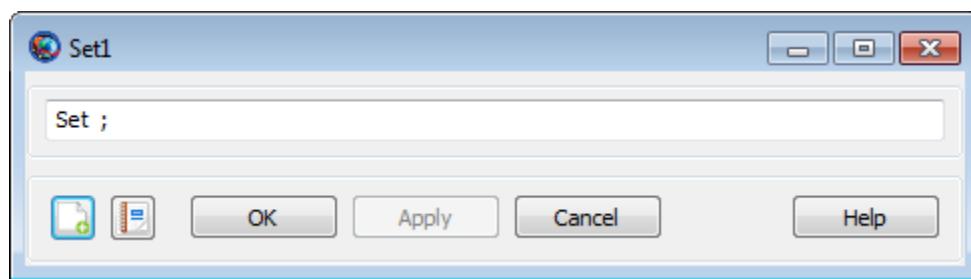
Option	Description
<i>destination</i>	The resource to populate from the data source.  Accepted Data Types <b>Spacecraft</b> Allowed Values            any <b>Spacecraft</b> resource Default Value             (None) Required                   yes Interfaces                GUI, script
<i>source</i>	The data source from which to obtain data.  Accepted Data Types <b>FileInterface</b> Allowed Values            any <b>FileInterface</b> resource Default Value             (None) Required                   yes Interfaces                GUI, script
<i>options</i>	Options specific to the chosen <i>source</i> . See the following sections for details.

The following options are available when *source* is a **FileInterface** and the **Format** is “TVHF\_ASCII”:

**Data={keyword[, keyword, ...]}**

Comma-separated list of values to retrieve from the file. Defaults to ‘All’, which retrieves all available elements. The available keywords are documented in the “TVHF\_ASCII” section of the [FileInterface](#) reference.

## GUI



The **Set** GUI is a very simple text box that lets you type the command directly. By default, it has no arguments, so you must finish the command yourself.

## Examples

Read a TVHF file and use it to configure a spacecraft.

```
Create Spacecraft aSat
Create FileInterface tvhf
tvhf.Filename = 'statevec.txt'
tvhf.Format = 'TVHF_ASCII'

BeginMissionSequence

Set aSat tvhf
```

Read a TVHF file and use it to set only the epoch and the Cartesian state.

```
Create Spacecraft aSat
Create FileInterface tvhf
tvhf.Filename = 'statevec.txt'
tvhf.Format = 'TVHF_ASCII'

BeginMissionSequence

Set aSat tvhf (Data = {'Epoch', 'CartesianState'})
```

## Toggle

Allows you to turn data output off or on

### Script Syntax

```
Toggle OutputNames Arg
```

#### *OutputNames*

*OutputNames* is the list of subscribers that are to be toggled. When multiple subscribers are being toggled in the *OutputNames*, then they need to be separated by a space.

#### *Arg*

*Arg* option allows you to turn off or on the data output to the selected subscribers listed in the *OutputNames*.

### Description

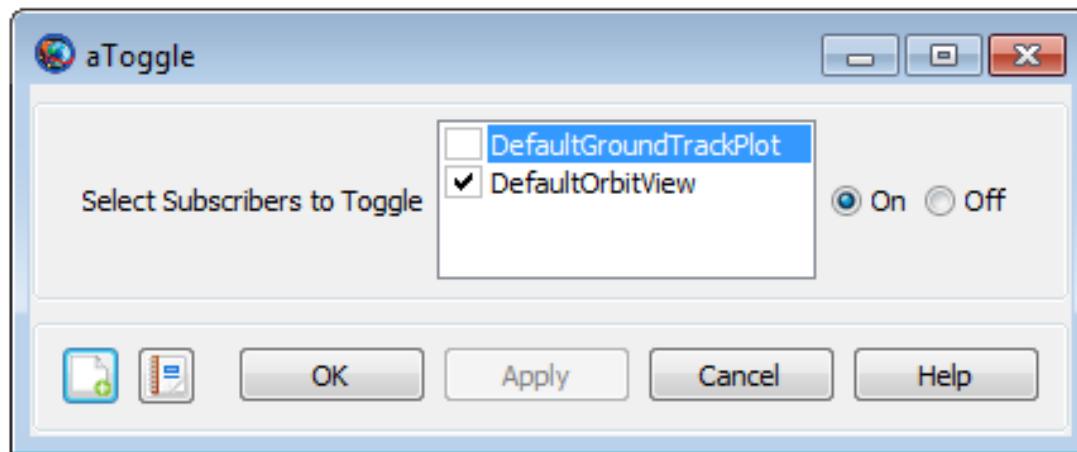
The **Toggle** command allows you to turn data output off or on for the subscribers that you select such as **ReportFile**, **XYPlot**, **OrbitView**, **GroundTrackPlot** and **EphemerisFile**. GMAT allows you to insert **Toggle** command into the **Mission** tree at any location and data output can be turned off or on at any point in your mission. **Toggle** command can be used through GMAT's GUI or the script interface.

### Options

Option	Description										
<b>OutputNames</b>	<p>The <b>Toggle</b> option allows the user to assign subscribers such as <b>ReportFile</b>, <b>XYPlot</b>, <b>OrbitView</b>, <b>GroundTrackPlot</b> or <b>EphemerisFile</b> to be toggled. When more than one subscriber is being toggled, they need to be separated by a space.</p> <table> <tr> <td><b>Accepted Data Types</b></td><td>Resource reference</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>ReportFile</b>, <b>XYPlot</b>, <b>OrbitView</b>, <b>GroundTrackPlot</b> or <b>EphemerisFile</b> resources</td></tr> <tr> <td><b>Default Value</b></td><td><b>DefaultOrbitView</b></td></tr> <tr> <td><b>Required</b></td><td>yes</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Accepted Data Types</b>	Resource reference	<b>Allowed Values</b>	<b>ReportFile</b> , <b>XYPlot</b> , <b>OrbitView</b> , <b>GroundTrackPlot</b> or <b>EphemerisFile</b> resources	<b>Default Value</b>	<b>DefaultOrbitView</b>	<b>Required</b>	yes	<b>Interfaces</b>	GUI, script
<b>Accepted Data Types</b>	Resource reference										
<b>Allowed Values</b>	<b>ReportFile</b> , <b>XYPlot</b> , <b>OrbitView</b> , <b>GroundTrackPlot</b> or <b>EphemerisFile</b> resources										
<b>Default Value</b>	<b>DefaultOrbitView</b>										
<b>Required</b>	yes										
<b>Interfaces</b>	GUI, script										
<b>Arg</b>	<p>The <b>Arg</b> option allows the user to turn off or on the data output to the selected subscriber.</p> <table> <tr> <td><b>Accepted Data Types</b></td><td>Boolean</td></tr> <tr> <td><b>Allowed Values</b></td><td>On, Off</td></tr> <tr> <td><b>Default Value</b></td><td>On</td></tr> <tr> <td><b>Required</b></td><td>yes</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Accepted Data Types</b>	Boolean	<b>Allowed Values</b>	On, Off	<b>Default Value</b>	On	<b>Required</b>	yes	<b>Interfaces</b>	GUI, script
<b>Accepted Data Types</b>	Boolean										
<b>Allowed Values</b>	On, Off										
<b>Default Value</b>	On										
<b>Required</b>	yes										
<b>Interfaces</b>	GUI, script										

## GUI

Figure below shows default settings for **Toggle** command:



## Remarks

The subscribers such as **ReportFile**, **XYPlot**, **OrbitView**, **GroundTrackPlot** and **EphemerisFile** report or plot data at each propagation step of the entire mission duration. If you want to report data to any of these subscribers at specific points in your mission, then a **Toggle On/Off** command can be inserted into the mission sequence to control when a subscriber reports or plots data. For example, when a **Toggle Off** command is issued for a **XYPlot**, no data is plotted onto the X and Y axis of the graph until a **Toggle On** command is issued. Similarly when a **Toggle On** command is used, data is plotted onto the X and Y axis at each integration step until a **Toggle Off** command is used.

When using the **Toggle** command in conjunction with modeling finite burns in an ephemeris file, a certain order of operations must be observed. The ephemeris Toggle commands must be placed inside the Begin and EndFileThrust commands as shown in the example below. This order of operations must be observed when propagating, as well as when running estimators like the **BatchEstimator**, **ExtendedKalmanFilter**, or **Smoother**.

```
BeginFileThrust ThrustHistory(Sat);
Toggle Ephem On;
Propagate Prop(Sat) {Sat.ElapsedDays = 1};
Toggle Ephem Off;
EndFileThrust ThrustHistory(Sat);
```

## Examples

This example shows how to use **Toggle Off** and **Toggle On** commands while using the **XYPlot** resource. Spacecraft's position magnitude and semi-major-axis are plotted as a function of time. **XYPlot** is turned off for the first 2 days of the propagation:

```
Create Spacecraft aSat
```

```
Create Propagator aProp

Create XYPlot aPlot
aPlot.XVariable = aSat.ElapsedDays
aPlot.YVariables = {aSat.Earth.RMAG, aSat.Earth.SMA}

BeginMissionSequence

Toggle aPlot Off
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
Toggle aPlot On
Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

This example shows how to use **Toggle Off** and **Toggle On** commands while using the **ReportFile** resource. Spacecraft's cartesian position vector is reported to the report file. Report file is turned off for the first day of the propagation:

```
Create Spacecraft aSat
Create Propagator aProp

Create ReportFile aReport
aReport.Filename = 'ReportFile1.txt'
aReport.Add = {aSat.ElapsedDays aSat.EarthMJ2000Eq.X ...
aSat.EarthMJ2000Eq.Y aSat.EarthMJ2000Eq.Z}

BeginMissionSequence

Toggle aReport Off
Propagate aProp(aSat) {aSat.ElapsedDays = 1}
Toggle aReport On
Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

This example shows how to toggle multiple subscribers. **Toggle Off** and **Toggle On** commands are used on multiple subscribers like **ReportFile**, **XYPlot** and **EphemerisFile**. Subscribers are turned off for first 3 days of the propagation:

```
Create Spacecraft aSat
Create Propagator aProp

Create ReportFile aReport
aReport.Filename = 'ReportFile1.txt'
aReport.Add = {aSat.ElapsedDays aSat.EarthMJ2000Eq.X ...
aSat.EarthMJ2000Eq.Y aSat.EarthMJ2000Eq.Z}

Create XYPlot aPlot
aPlot.XVariable = aSat.ElapsedDays
aPlot.YVariables = {aSat.Earth.RMAG, aSat.Earth.SMA}

Create EphemerisFile aEphemerisFile
aEphemerisFile.Spacecraft = aSat
```

```
BeginMissionSequence  
  
    Toggle aReport aPlot aEphemerisFile Off  
    Propagate aProp(aSat) {aSat.ElapsedDays = 3}  
    Toggle aReport aPlot aEphemerisFile On  
    Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

## UpdateDynamicData

A command used in tandem with a **DynamicDataDisplay** to update the data being shown in the display table on the GUI.

### Description

The **UpdateDynamicData** command is used to specify when in a mission sequence a **DynamicDataDisplay** will update its data to their current values. This allows the user to control what points in the mission sequence they will see the new data. The user may also specify certain data within a **DynamicDataDisplay** to update rather than the entire table if desired. This command can be placed at any desired point in a mission sequence and multiple can be used on the same **DynamicDataDisplay**.

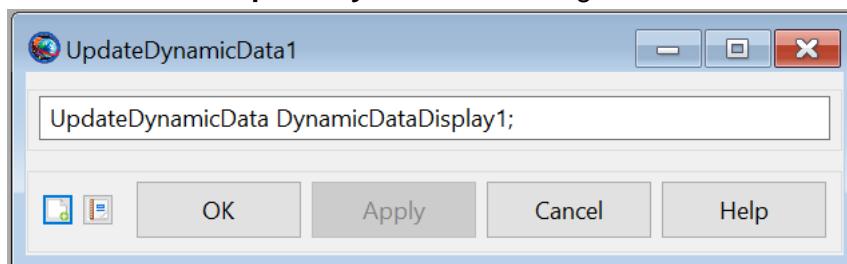
See Also: [DynamicDataDisplay](#)

### Fields

Field	Description
<b>DynamicTableName</b>	Field to set which DynamicDataDisplay object will be updated by this command  <b>Data Type</b> String <b>Allowed Values</b> Any DynamicDataTable object <b>Access</b> set <b>Default Value</b> N/A <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>DataList</b>	Field to set which parameters will be updated in the selected table while the rest of the data remains unchanged  <b>Data Type</b> Any parameter <b>Allowed Values</b> Any parameter in the currently selected DynamicDataDisplay <b>Access</b> set <b>Default Value</b> N/A <b>Units</b> N/A <b>Interfaces</b> GUI, script

### GUI

The figure below shows the **UpdateDynamicData** using the basic command GUI panel:



## Examples

Creation of a **DynamicDataDisplay** and the **UpdateDynamicData** command being used to update that display in a mission sequence.

```
Create Spacecraft DefaultSC;
Create Propagator DefaultProp;

Create DynamicDataDisplay myDisplay;
GMAT DynamicDataDisplay.AddParameters(1, DefaultSC.X, DefaultSC.Y);

BeginMissionSequence
Propagate DefaultProp(DefaultSC) (DefaultSC.ElapsedSecs = 12000.0);
UpdateDynamicData myDisplay;
Propagate DefaultProp(DefaultSC) (DefaultSC.ElapsedSecs = 24000.0);
UpdateDynamicData myDisplay DefaultSC.X;
```

## Write

Writes data to one or more of the following three destinations: the message window, the log file, or a **ReportFile** resource.

### Script Syntax

```
Write ResourceList [{ MessageWindow = true,LogFile = false,  
Style = Concise, ReportFile = myReport }]
```

### Description

The **Write** command allows you to selectively write information to GMAT output destinations during execution. The **Write** command can aid in automated QA by writing data to the GMAT log file or **ReportFile** resource for an independent QA systems to process, or to write data to the message window to aid in troubleshooting and debugging script configurations. This command can also be used to write information on attached resources in order to see how parameters change throughout a mission.

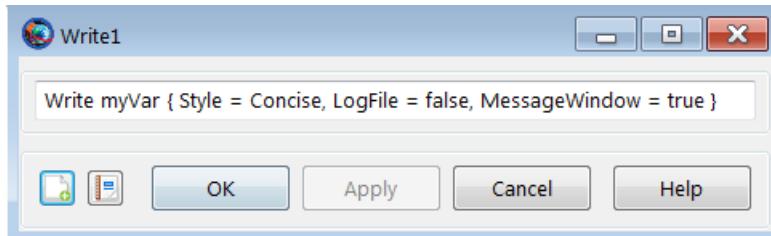
### Options

Option	Description
<b>LogFile</b>	Flag to specify if output should be written to the log file  <b>Accepted Data Types</b> Boolean <b>Allowed Values</b> {True, False} <b>Default Value</b> False <b>Required</b> no <b>Interfaces</b> GUI, script
<b>MessageWindow</b>	Flag to specify if output should be displayed in the Message Window  <b>Accepted Data Types</b> Boolean <b>Allowed Values</b> {True, False} <b>Default Value</b> True <b>Required</b> no <b>Interfaces</b> GUI, script
<b>ReportFile</b>	Name of <b>ReportFile</b> resource where output data will be written to. If this field is not set, no <b>ReportFile</b> resource will be written to. The user can set formatting options on a <b>ReportFile</b> like <b>Precision</b> and <b>ColumnWidth</b> . When writing data using the <b>Write</b> command, those settings are not used.  <b>Accepted Data Types</b> <b>ReportFile</b> resource <b>Allowed Values</b> Any user-defined <b>ReportFile</b> resource <b>Default Value</b> None <b>Required</b> no <b>Interfaces</b> GUI, script

Option	Description	
<b>ResourceList</b>	A list of one or more GMAT resources and/or resource fields whose values we wish to output	
	<b>Accepted Data Types</b>	<b>List of GMAT resources and/or resource fields</b>
	<b>Allowed Values</b>	Any GMAT resource name or resource.field name
	<b>Default Value</b>	<b>None</b>
	<b>Required</b>	no
	<b>Interfaces</b>	GUI, script
<b>Style</b>	Parameter to specify format of output. Concise means that, where appropriate, output will be values only and will not contain the object name. The exception to this is when you output an object with fields such as a <b>Spacecraft</b> . In this case, the object and field will be output. Verbose means that object names and fields will always be output. Script means that script-parseable (i.e., the output, when pasted into an existing GMAT script, will syntax check) output will be generated	
	<b>Accepted Data Types</b>	String
	<b>Allowed Values</b>	{Concise, Verbose, Script}
	<b>Default Value</b>	Concise
	<b>Required</b>	no
	<b>Interfaces</b>	GUI, script

## GUI

In the example below, the value of **myVar** would be written to the message window only.



## Examples

Below are some sample scripts using the **Write** command with the output shown in bold font.

```
Create ChemicalTank ChemicalTank1
Create Spacecraft Sat
Create String myString1 myString2
Create Variable myVar
Create Array myArray[2,2]

myVar      = 3.1415
```

```
myString1      = 'This is my string'
myArray(1,1)   = 1
myArray(2,2)   = 1

BeginMissionSequence

Write ChemicalTank1 {Style = Script}

Create ChemicalTank ChemicalTank1;

GMAT ChemicalTank1.AllowNegativeFuelMass = false;

GMAT ChemicalTank1.FuelMass = 756;

GMAT ChemicalTank1.Pressure = 1500;

GMAT ChemicalTank1.Temperature = 20;

GMAT ChemicalTank1.RefTemperature = 20;

GMAT ChemicalTank1.Volume = 0.75;

GMAT ChemicalTank1.FuelDensity = 1260;

GMAT ChemicalTank1.PressureModel = PressureRegulated;

Write Sat.X Sat.VZ

7100

1

Write myVar myString1

3.1415

'This is my string'

Write myArray

1 0

0 1

Write myArray(2,2)

1

myString2 = sprintf('%10.7f',Sat.X)
Write myString2 {Style = Script}

Create String myString2;
```

```
myString2 = '7100.0000000';
```

```
Write myString2
```

```
'7100.0000000'
```

The example below writes out a report that can be read into a GMAT script using the **#Include** capability.

```
Create Spacecraft Sat;
Create ReportFile rf;
rf.Filename = 'GMAT.script';
Create Variable myVar;
GMAT myVar = 11;

BeginMissionSequence;

Write Sat {Style = Script, MessageWindow = false, ReportFile = rf}
```

The example below writes out parameters for the fuel tank which is an attached resource to the spacecraft after a manuever is complete. The output is shown below the script, note the decrease in fuel mass was written using the **Write** command this way.

```
Create Spacecraft Sat;
Create ChemicalTank ChemicalTank1;
GMAT Sat.Tanks = {ChemicalTank1};

BeginMissionSequence;
Maneuver ImpulsiveBurn1(Sat);
Propagate DefaultProp(Sat) {Sat.ElapsedSecs = 12000};
Write Sat.ChemicalTank1

ChemicalTank1.AllowNegativeFuelMass = true;
ChemicalTank1.FuelMass = 386.9462121211856;
ChemicalTank1.Pressure = 1500;
ChemicalTank1.Temperature = 20;
ChemicalTank1.RefTemperature = 20;
ChemicalTank1.Volume = 0.75;
ChemicalTank1.FuelDensity = 1260;
ChemicalTank1.PressureModel = 'PressureRegulated';
```

## System

## Color

Color support in GMAT resources and commands

### Description

GMAT lets you assign different colors to orbital trajectory segments that are drawn by **Spacecraft**, **CelestialBody**, **LibrationPoint** and **Barycenter** resources. You can also assign unique colors to **Spacecraft** orbital trajectory segments by setting colors through the **Propagate** command. The orbital trajectories of these resources are drawn using the **OrbitView** 3D graphics resource. Additionally, GMAT allows you set colors on **GroundStation** facilities that are drawn on a spacecraft's ground track plot created by **GroundTrackPlot** 2D graphics resource.

In addition to setting colors on orbital trajectory segments of the following five resources and single command: **Spacecraft**, **CelestialBody**, **LibrationPoint**, **Barycenter**, **GroundStation** and **Propagate**, GMAT also allows you to assign colors to perturbing trajectories that may be drawn by the above five resources. These perturbing trajectories are drawn during iterative processes such as differential correction or optimization. The above five resources and single **Propagate** command each have a common field called **OrbitColor**. The **OrbitColor** field is used to set colors on orbital trajectory segments drawn by these resources and single command. Similarly, these five resources also have a common field called **TargetColor**. The **Propagate** command does not have a **TargetColor** field. The **TargetColor** field of these five resources can be used to set colors on perturbing trajectories that may be drawn during iterative processes.

You can set colors on the above five resources and **Propagate** command either via the GUI or script interface of GMAT. Setting colors on these five resources and single command via the GUI mode is very easy: After opening any of the five resources or **Propagate** command, you can choose colors for **OrbitColor** field by clicking on any available colors from Orbit Color selectbox. Similarly, for the five resources, you can select colors for the **TargetColor** field by choosing any available colors from the Target Color selectbox. See the [GUI](#) section below that walks you through an example of how to select colors through the GUI mode.

There are two ways to set colors on both **OrbitColor** and **TargetColor** fields via GMAT's script mode. The available colors are identified through a string or a three digit integer array. You can input color of your choice by either entering a color's **ColorName** or its corresponding RGB triplet value. The table below shows a list of 75 colors that are available for you to select from. Each row of the table lists an available color's **ColorName** and an equivalent RGB triplet value. Refer to the Fields section of the above five resources and **Propagate** command's Options section to learn more about **OrbitColor** and **TargetColor** fields and how to set colors. Also see the [Remarks](#) section below for additional script snippets that show how to assign colors through either **ColorName** or RGB triplet value input method for the above five resources and single command.

ColorName	Equivalent RGB Triplet Value
Aqua	0 255 255
AquaMarine	127 55 212

<b>ColorName</b>	<b>Equivalent RGB Triplet Value</b>
Beige	245 245 220
Black	0 0 0
Blue	0 0 255
BlueViolet	138 43 226
Brown	165 42 42
CadetBlue	95 158 160
Coral	255 127 80
CornflowerBlue	100 149 237
Cyan	0 255 255
DarkBlue	0 0 139
DarkGoldenRod	184 134 11
DarkGray	169 169 169
DarkGreen	0 100 0
DarkOliveGreen	85 107 47
DarkOrchid	153 50 204
DarkSlateBlue	72 61 139
DarkSlateGray	47 79 79
DarkTurquoise	0 206 209
DimGray	105 105 105
FireBrick	178 34 34
ForestGreen	34 139 34
Fuchsia	255 0 255
Gold	255 215 0
GoldenRod	218 165 32
Gray	128 128 128
Green	0 128 0
GreenYellow	173 255 47
IndianRed	205 92 92
Khaki	240 230 140
LightBlue	173 216 230
LightGray	211 211 211
Lime	0 255 0
LimeGreen	50 205 50
LightSteelBlue	176 196 222
Magenta	255 0 255

ColorName	Equivalent RGB Triplet Value
Maroon	128 0 0
MediumAquaMarine	102 205 170
MediumBlue	0 0 205
MediumOrchid	186 85 211
MediumSeaGreen	60 179 113
MediumSpringGreen	0 250 154
MediumTurquoise	72 209 204
MediumVioletRed	199 21 133
MidnightBlue	25 25 112
Navy	0 0 128
Olive	128 128 0
Orange	255 165 0
OrangeRed	255 69 0
Orchid	218 112 214
PaleGreen	152 251 152
Peru	205 133 63
Pink	255 192 203
Plum	221 160 221
Purple	128 0 128
Red	255 0 0
SaddleBrown	244 164 96
Salmon	250 128 114
SeaGreen	46 139 87
Sienna	160 82 45
Silver	192 192 192
SkyBlue	135 206 235
SlateBlue	106 90 205
SpringGreen	0 255 127
SteekBlue	70 130 180
Tan	210 180 140
Teal	0 128 128
Thistle	216 191 216
Turquoise	64 224 208
Violet	238 130 238
Wheat	245 222 179

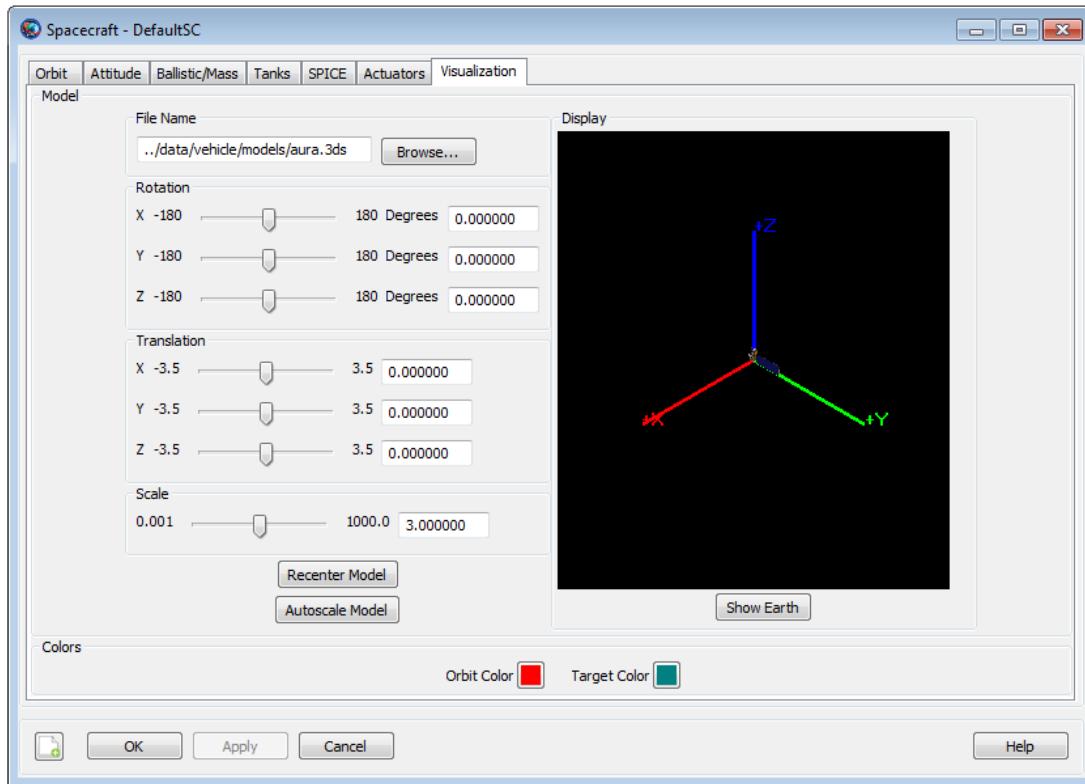
ColorName	Equivalent RGB Triplet Value
White	255 255 255
Yellow	255 255 0
YellowGreen	154 205 50

See Also: [Spacecraft Visualization Properties](#), [CelestialBody](#), [LibrationPoint](#), [Barycenter](#), [GroundStation](#), [Propagate](#)

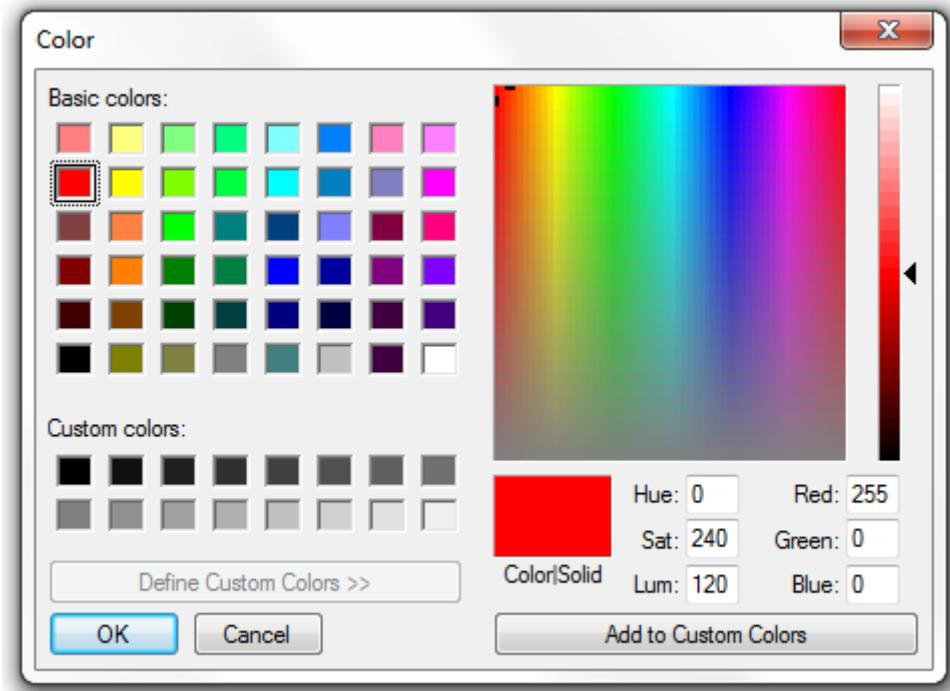
## GUI

Setting colors on **Spacecraft**, **GroundStation**, **CelestialBody**, **LibrationPoint** and **Barycenter** resources' **OrbitColor** and **TargetColor** fields via GMAT's GUI mode is very easy. Since the procedure for setting colors on these five resources is the same, hence only one GUI example is given below using the **Spacecraft** resource:

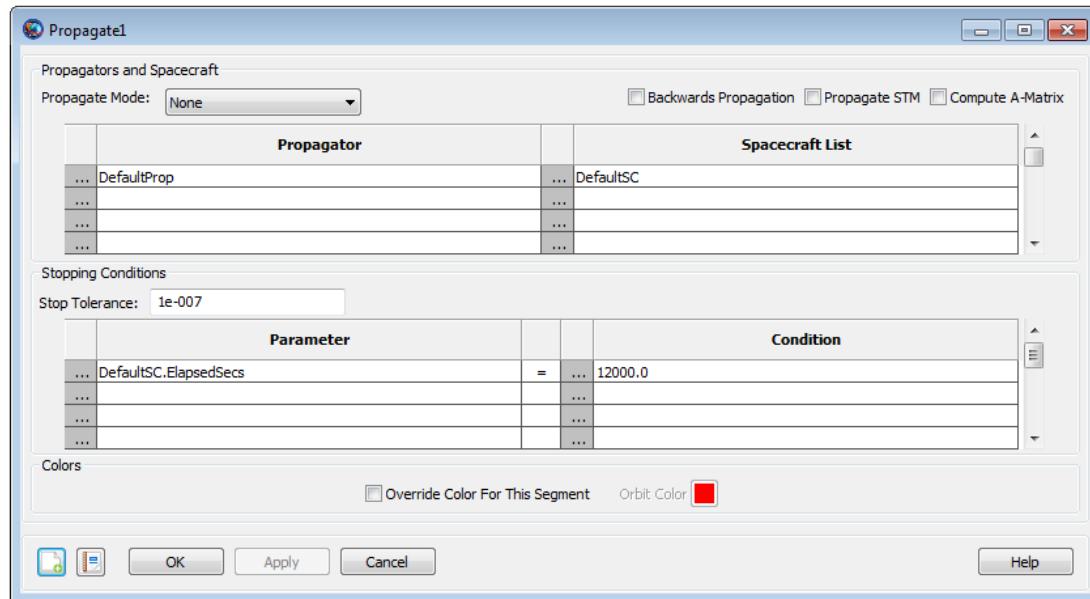
After opening the **Spacecraft** resource, click on Visualization tab.



In the Visualization window, you will see Orbit Color and Target Color Select boxes. You can choose colors for **OrbitColor** and **TargetColor** fields by clicking on the Orbit Color and Target Color select boxes respectively. For example, clicking either on the Orbit Color or Target Color select box opens the Color panel seen below. Using this Color panel, you can select basic colors, create custom colors of your choice and add custom colors to the list of available colors.

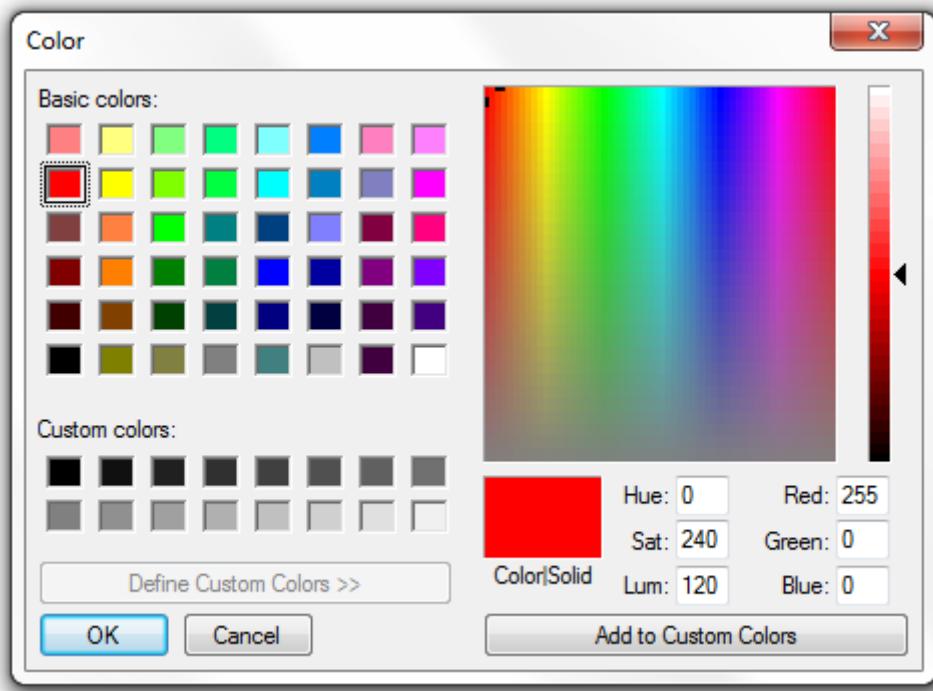


Selecting colors on **Propagate** command's **OrbitColor** option through the GUI mode is also very easy. Open any **Propagate** command. Below is screenshot of GMAT's default **Propagate** command:



In GMAT, the default orbit color on any **Propagate** command is the color that is set on **Spacecraft** resource's **OrbitColor** field (i.e. **Spacecraft.OrbitColor**). Whenever you do not set a unique color on the **Propagate** command's **OrbitColor** option, hence the color on the **Propagate** command will always be the color that is set on **Spacecraft** object's **OrbitColor** field.

To set your own unique colors to the **Propagate** command, click and check the **Override Color For This Segment** box. This makes the Orbit Color select box active. Clicking on the Orbit Color select box opens the Color panel shown below:



Using this Color panel, you can select basic colors, create custom colors of your choice and add custom colors to the list of available colors and set them on the **Propagate** command's **OrbitColor** option.

## Remarks

### Configuring Orbit and Target Colors on Spacecraft Resource

You can set unique colors of your choice on orbital trajectories of a **Spacecraft** by assigning colors to **Spacecraft** object's **OrbitColor** field. As long as you do not reset or reassign orbit color on the **Propagate** command, then all spacecraft trajectory colors that GMAT draws will be the same color that you first set on **Spacecraft** object's **OrbitColor** field. The default color on **Spacecraft** object's **OrbitColor** field is set to red. With this default setting of red color to **OrbitColor** field, all **Spacecraft** trajectories will be drawn in red color as long as you do not reset orbit color on any of the **Propagate** commands. Now for example, if you want all **Spacecraft** orbital trajectories to be drawn in yellow color alone, the script snippet below demonstrates two acceptable methods of setting yellow color to **Spacecraft** object's **OrbitColor** field:

```
Create Spacecraft aSat
aSat.OrbitColor = Yellow           % ColorName method
% or
aSat.OrbitColor = [255 255 0]    % RGB triplet value method
```

Similarly, setting colors of your choice on spacecraft's perturbing trajectories that may be drawn during iterative processes such as differential correction or optimization can be

done by assigning unique colors to **Spacecraft** object's **TargetColor** field. Setting colors on the **TargetColor** field is only useful when you want to assign colors on perturbed trajectories generated during iterative processes. Both **OrbitColor** and **TargetColor** fields of **Spacecraft** object can also be used and modified in the Mission Sequence as well. The example script snippet below shows two acceptable methods of setting blue violet color to **Spacecraft** resource's **TargetColor** field:

```
Create Spacecraft aSat
aSat.TargetColor = BlueViolet      % ColorName method
% or
aSat.TargetColor = [138 43 226]   % RGB triplet value method
```

The list of available colors that you can set on **Spacecraft** object's **OrbitColor** and **TargetColor** fields are tabulated in the table in [Description](#) section. You can assign colors either via the ColorName or RGB triplet value input method. Also see the [Examples](#) section below for complete sample scripts that show how to use **Spacecraft** object's **OrbitColor** and **TargetColor** fields.

### Setting Colors on Ground Station Resource

GMAT allows you to set unique colors of your choice on **GroundStation** object's **OrbitColor** or **TargetColor** fields. The list of available colors that you can set are tabulated in the table in [Description](#) section. You can assign colors either via the ColorName or RGB triplet value method. The custom ground station facility that you create shows up on the ground track plot of a spacecraft that is drawn on a 2D texture map of a central body. The colors that are assigned on **GroundStation** object's **TargetColor** field are only used whenever **GroundStation** object is drawn during iterative processes such as differential correction or optimization. The script snippet below shows how to set colors on **GroundStation's OrbitColor** and **TargetColor** fields using either the ColorName or RGB method:

```
Create GroundStation aGroundStation
aGroundStation.OrbitColor = Aqua          % ColorName method
% or
aGroundStation.OrbitColor = [0 255 255]  % RGB method
```

```
Create GroundStation aGroundStation
aGroundStation.TargetColor = Black        % ColorName method
% or
aGroundStation.TargetColor = [0 0 0]     % RGB method
```

See the [Examples](#) section below for complete sample script that shows how to use **GroundStation** object's **OrbitColor** field.

### Configuring Orbit and Target Colors on Celestial Body Resource

GMAT allows you to set available colors to orbits of built-in or custom-defined celestial bodies. GMAT contains built-in models for the Sun, the 8 planets, Earth's moon, and Pluto. You can create a custom **CelestialBody** resource to model a planet, asteroid, comet, or moon. The orbit colors on **CelestialBody** objects are set through the **OrbitColor** field. You can also set colors to a celestial body's perturbing trajectories that are

generated during iterative processes such as differential correction or optimization. This is done by setting colors to **CelestialBody** object's **TargetColor** field. Setting colors on the **TargetColor** field is only useful when you want to assign colors on perturbed trajectories that are generated during iterative processes. The list of available colors that you can set on **OrbitColor** and **TargetColor** fields are tabulated in the table shown in the [Description](#) section. To assign colors, you can either use the ColorName or RGB triplet value method. Both **OrbitColor** and **TargetColor** fields of the **CelestialBody** object can also be used and modified in the Mission Sequence as well. The script snippet below shows how to set colors on **OrbitColor** and **TargetColor** fields on a custom-built celestial body using either the ColorName or RGB method:

```
Create Planet aPlanet  
aPlanet.OrbitColor = CornflowerBlue    % ColorName method  
% or  
aPlanet.OrbitColor = [100 149 237]    % RGB method
```

```
Create Planet aPlanet  
aPlanet.TargetColor = DarkBlue        % ColorName method  
% or  
aPlanet.TargetColor = [0 0 139]       % RGB method
```

See the [Examples](#) section below for complete sample scripts that show how to use **CelestialBody** object's **OrbitColor** field

### Configuring Orbit and Target Colors on Libration Point Resource

GMAT lets you set available colors on an orbit that is drawn by a libration point. In order to see orbital trajectory that a libration point draws in space, you must draw the Lagrange points in an inertial space. The orbit colors on **LibrationPoint** resources are set through the **OrbitColor** field. GMAT also allows you to set colors on a libration point's perturbing trajectories that are drawn during iterative processes such as differential correction or optimization. Setting colors on perturbing libration point trajectories is done via the **TargetColor** field. Setting colors on the **TargetColor** field is only useful whenever perturbed libration point trajectories are generated during iterative processes. The available colors that can be set on **OrbitColor** and **TargetColor** fields are tabulated in the table shown in the [Description](#) section. You can either use the ColorName or RGB triplet value method to assign colors on **OrbitColor** and **TargetColor** fields. These two fields of **LibrationPoint** resource can also be used and modified to set colors in the Mission Sequence as well. The script snippet below shows how to set colors on **OrbitColor** and **TargetColor** fields using either the ColorName or RGB method:

```
Create LibrationPoint ESL1  
ESL1.OrbitColor = Magenta            % ColorName method  
% or  
ESL1.OrbitColor = [255 0 255]        % RGB method
```

```
Create LibrationPoint ESL1  
ESL1.TargetColor = Orchid            % ColorName method  
% or  
ESL1.TargetColor = [218 112 214]     % RGB method
```

See the [Examples](#) section below for complete sample script that shows how to use **LibrationPoint** object's **OrbitColor** field.

### Configuring Orbit and Target Colors on Barycenter Resource

In GMAT, you can assign available colors on an orbit that is drawn by a barycenter point. Since a barycenter is a center of mass of a set of celestial bodies, hence in order to see its orbital trajectory, the barycenters must be plotted in an inertial space. You can set orbit colors on GMAT's both built-in **SolarSystemBarycenter** resource or custom barycenters that you create through the **Barycenter** object. The orbit colors on **Barycenter** resources are set through the **OrbitColor** field. GMAT also allows you to set colors on a barycenter's perturbing trajectories that are drawn during iterative processes such as differential correction or optimization. Setting colors on perturbing barycenter trajectories is done via the **TargetColor** field. Setting colors on the **TargetColor** field is only useful whenever you want to set different colors on the perturbing trajectories. The available colors that can be set on **OrbitColor** and **TargetColor** fields are tabulated in the table shown in the [Description](#) section. You can either use the ColorName or RGB triplet value color input method to assign colors on **OrbitColor** and **TargetColor** fields. These two fields of **Barycenter** resource can also be used and modified in the Mission Sequence as well. The script snippet below shows how to set colors on **OrbitColor** and **TargetColor** fields using either the ColorName or RGB method:

```
Create Barycenter EarthMoonBarycenter
EarthMoonBarycenter.OrbitColor = Violet           % ColorName method
% or
EarthMoonBarycenter.OrbitColor = [238 130 238]   % RGB method
```

```
Create Barycenter EarthMoonBarycenter
EarthMoonBarycenter.TargetColor = Silver          % ColorName method
% or
EarthMoonBarycenter.TargetColor = [192 192 192]  % RGB method
```

See the [Examples](#) section below for complete sample script that shows how to use **Barycenter** object's **OrbitColor** field.

### Configuring Orbit Colors on Propagate Command

In GMAT, you can set unique colors on different **Spacecraft** trajectory segments by setting orbital colors on **Propagate** commands. If you do not select unique colors on each **Propagate** command, then by default, the color on all **Propagate** commands is seeded from color that is set on **Spacecraft** object's **OrbitColor** field. You can set orbit colors on each **Propagate** command through the **OrbitColor** option. The available colors that can be set on **Propagate** command's **OrbitColor** option are tabulated in the table shown in the [Description](#) section. You can either use the ColorName or RGB triplet value input method to assign colors on **OrbitColor** option. The script snippet below shows how to set colors on **OrbitColor** option using either the ColorName or RGB method:

```
% ColorName method:
Propagate aProp(aSat) {aSat.ElapsedSecs = 500, OrbitColor = Gold}
% or RGB method:
```

```
Propagate aProp(aSat) {aSat.ElapsedSecs = 500, OrbitColor = [255 215 0]}
```

See the [Examples](#) section below for complete sample scripts that show how to use **Propagate** command's **OrbitColor** option.

## Examples

Set non-default sky blue color to **Spacecraft** object's **OrbitColor** field through both **ColorName** and **RGB** triplet value methods. Both methods draw spacecraft orbital trajectory in sky blue color. Note: Since orbit color was not re-set in the **Propagate** command, hence entire spacecraft orbital trajectory is drawn in sky blue color:

```
Create Spacecraft aSat
aSat.OrbitColor = SkyBlue    % ColorName method
Create Propagator aProp

Create OrbitView anOrbitView
GMAT anOrbitView.Add = {aSat, Earth}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}

% or

Create Spacecraft aSat
aSat.OrbitColor = [135 206 235]    % RGB triplet value method
Create Propagator aProp

Create OrbitView anOrbitView
GMAT anOrbitView.Add = {aSat, Earth}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

Set unique colors on **Spacecraft** object's **OrbitColor** field multiple times through combination of both **ColorName** and **RGB** method. Notice that **Spacecraft.OrbitColor** is used and modified in the Mission Sequence as well:

```
Create Spacecraft aSat
aSat.OrbitColor = Yellow    % ColorName method
Create Propagator aProp

Create OrbitView anOrbitView
GMAT anOrbitView.Add = {aSat, Earth}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedSecs = 1000}
```

```
aSat.OrbitColor = Green    % ColorName method  
Propagate aProp(aSat) {aSat.ElapsedSecs = 1000}  
aSat.OrbitColor = [255 165 0 ]    % RGB value for Orange  
Propagate aProp(aSat) {aSat.ElapsedSecs = 2000}
```

Set non-default yellow color on **Spacecraft** object's **TargetColor** field. Setting color on the **TargetColor** field is only useful when perturbed trajectories are generated during iterative processes such as differential correction. Note yellow color was set via the ColorName method. It could've been also set through the RGB triplet value method as well.

```
Create Spacecraft aSat  
aSat.OrbitColor = Red        % Default OrbitColor  
aSat.TargetColor = Yellow   % ColorName method  
  
Create Propagator aProp  
  
Create ImpulsiveBurn TOI  
  
Create DifferentialCorrector aDC  
  
Create OrbitView anOrbitView  
anOrbitView.Add = {aSat, Earth}  
anOrbitView.SolverIterations = All  
anOrbitView.ViewScaleFactor = 2  
  
BeginMissionSequence  
  
Propagate aProp(aSat) {aSat.Earth.Periapsis}  
  
Target aDC;  
Vary aDC(TOI.Element1 = 0.24, {Perturbation = 0.001, Lower = 0.0, ...  
Upper = 3.14159, MaxStep = 0.5})  
Maneuver TOI(aSat);  
Propagate aProp(aSat) {aSat.Earth.Apoapsis}  
Achieve aDC(aSat.Earth.RMAG = 20000)  
EndTarget  
  
Propagate aProp(aSat) {aSat.ElapsedDays = 0.25}
```

Set non-default colors on multiple **GroundStation** objects through the **OrbitColor** field. The colors are assigned through combination of both ColorName and RGB input methods:

```
Create Spacecraft aSat  
Create Propagator aProp  
  
Create GroundStation aGroundStation aGroundStation2 aGroundStation3
```

```
aGroundStation.StateType = Spherical  
aGroundStation.Latitude = 45  
aGroundStation.OrbitColor = Black  
  
aGroundStation2.StateType = Spherical  
aGroundStation2.Longitude = 20  
aGroundStation2.OrbitColor = [165 42 42] % RGB value for Brown  
  
aGroundStation3.StateType = Spherical  
aGroundStation3.Latitude = 30  
aGroundStation3.Longitude = 45  
aGroundStation3.OrbitColor = [255 127 80] % RGB value for Coral  
  
Create GroundTrackPlot aGroundTrackPlot  
aGroundTrackPlot.Add = {aSat, aGroundStation, aGroundStation2, ...  
aGroundStation3 }  
  
BeginMissionSequence  
  
Propagate aProp(aSat) {aSat.ElapsedDays = 0.25 }
```

Set non-default colors on built-in celestial body orbits. In this example, **CelestialBody** object's **OrbitColor** field is assigned colors through mixture of both ColorName and RGB triplet value methods. By default, GMAT sets **Spacecraft** orbit color to red:

```
Create Spacecraft aSat  
aSat.CoordinateSystem = SunMJ2000Ec  
aSat.DisplayStateType = Keplerian  
aSat.SMA = 150000000  
  
Mercury.OrbitColor = Orange  
Venus.OrbitColor = [255 255 0] % RGB value for Yellow  
Earth.OrbitColor = Cyan  
Mars.OrbitColor = [0 128 0] % RGB value for Green  
  
Create CoordinateSystem SunMJ2000Ec  
SunMJ2000Ec.Origin = Sun  
SunMJ2000Ec.Axes = MJ2000Ec  
  
Create ForceModel aFM  
aFM.CentralBody = Sun  
aFM.PointMasses = {Sun}  
  
Create Propagator aProp  
aProp.FM = aFM  
  
Create OrbitView anOrbitView  
anOrbitView.Add = {aSat, Earth, Venus, Mars, Mercury}  
anOrbitView.CoordinateSystem = SunMJ2000Ec
```

```
anOrbitView.ViewPointReference = Sun
anOrbitView.ViewPointVector = [0 0 150000000]
anOrbitView.ViewDirection = Sun
anOrbitView.ViewScaleFactor = 6
anOrbitView.ViewUpCoordinateSystem = SunMJ2000Ec

BeginMissionSequence
Propagate aProp(aSat) {aSat.ElapsedDays = 150}
```

Set unique non-default orbit colors on built-in **CelestialBody** object's **OrbitColor** field multiple times through combination of both ColorName and RGB triplet value methods. Notice that **CelestialBody.OrbitColor** is used and modified in the Mission Sequence as well:

```
Create Spacecraft aSat
aSat.CoordinateSystem = SunMJ2000Ec
aSat.DisplayStateType = Keplerian
aSat.SMA = 150000000

Mars.OrbitColor = Orange

Create CoordinateSystem SunMJ2000Ec
SunMJ2000Ec.Origin = Sun
SunMJ2000Ec.Axes = MJ2000Ec

Create ForceModel aFM
aFM.CentralBody = Sun
aFM.PointMasses = {Sun}

Create Propagator aProp
aProp.FM = aFM
aProp.MaxStep = 20000

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Mars}
anOrbitView.CoordinateSystem = SunMJ2000Ec
anOrbitView.ViewPointReference = Sun
anOrbitView.ViewPointVector = [0 0 150000000]
anOrbitView.ViewDirection = Sun
anOrbitView.ViewScaleFactor = 6
anOrbitView.ViewUpCoordinateSystem = SunMJ2000Ec

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 150}
Mars.OrbitColor = [255 255 0] % RGB value for Yellow
Propagate aProp(aSat) {aSat.ElapsedDays = 150}
Mars.OrbitColor = Cyan
Propagate aProp(aSat) {aSat.ElapsedDays = 150}
```

```
Mars.OrbitColor = [0 128 0] % RGB value for Green  
Propagate aProp(aSat) {aSat.ElapsedDays = 150}
```

Set unique non-default orbit colors on Earth-Sun L1 libration point orbit. ESL1 libration point is plotted in an inertial space in order to see its orbit around sun. The orbit colors on **LibrationPoint** object's **OrbitColor** field are set multiple times through combination of both ColorName and RGB triplet value input methods. Notice that in this example, **LibrationPoint.OrbitColor** is also set in the Mission Sequence as well. By default, GMAT sets **Spacecraft** orbit color to red:

```
Create Spacecraft aSat  
aSat.CoordinateSystem = SunMJ2000Ec  
aSat.DisplayStateType = Keplerian  
aSat.SMA = 150000000  
  
Create LibrationPoint ESL1  
ESL1.OrbitColor = Orange  
ESL1.Primary = Sun  
ESL1.Secondary = Earth  
ESL1.Point = L1  
  
Create CoordinateSystem SunMJ2000Ec  
SunMJ2000Ec.Origin = Sun  
SunMJ2000Ec.Axes = MJ2000Ec  
  
Create ForceModel aFM  
aFM.CentralBody = Sun  
aFM.PointMasses = {Sun}  
  
Create Propagator aProp  
aProp.FM = aFM  
  
Create OrbitView anOrbitView  
anOrbitView.Add = {aSat, ESL1}  
anOrbitView.CoordinateSystem = SunMJ2000Ec  
anOrbitView.ViewPointReference = Sun  
anOrbitView.ViewPointVector = [0 0 150000000]  
anOrbitView.ViewDirection = Sun  
anOrbitView.ViewScaleFactor = 3  
anOrbitView.ViewUpCoordinateSystem = SunMJ2000Ec  
  
BeginMissionSequence  
  
Propagate aProp(aSat) {aSat.ElapsedDays = 75}  
ESL1.OrbitColor = [255 255 0] % RGB value for Yellow  
Propagate aProp(aSat) {aSat.ElapsedDays = 75}  
ESL1.OrbitColor = Cyan  
Propagate aProp(aSat) {aSat.ElapsedDays = 75}  
ESL1.OrbitColor = [0 128 0] % RGB value for Green
```

```
Propagate aProp(aSat) {aSat.ElapsedDays = 75}
```

Set unique non-default orbit colors on Earth-Moon barycenter. The Earth Moon barycenter had to be plotted in an inertial space in order to see its orbit around the sun. The orbit colors on **Barycenter** object's **OrbitColor** field are set multiple times through combination of both ColorName and RGB triplet value input methods. Notice that in this example, **Barycenter.OrbitColor** is also set in the Mission Sequence as well. By default, GMAT sets **Spacecraft** orbit color to red:

```
Create Spacecraft aSat
aSat.CoordinateSystem = SunMJ2000Ec
aSat.DisplayStateType = Keplerian
aSat.SMA = 150000000

Create Barycenter EarthMoonBarycenter
EarthMoonBarycenter.OrbitColor = Cyan
EarthMoonBarycenter.BodyNames = {Earth, Luna}

Create CoordinateSystem SunMJ2000Ec
SunMJ2000Ec.Origin = Sun
SunMJ2000Ec.Axes = MJ2000Ec

Create ForceModel aFM
aFM.CentralBody = Sun
aFM.PointMasses = {Sun}

Create Propagator aProp
aProp.FM = aFM

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, EarthMoonBarycenter}
anOrbitView.CoordinateSystem = SunMJ2000Ec
anOrbitView.ViewPointReference = Sun
anOrbitView.ViewPointVector = [0 0 150000000]
anOrbitView.ViewDirection = Sun
anOrbitView.ViewScaleFactor = 4
anOrbitView.ViewUpCoordinateSystem = SunMJ2000Ec

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 75}
EarthMoonBarycenter.OrbitColor = [255 255 0] % RGB value for Yellow
Propagate aProp(aSat) {aSat.ElapsedDays = 75}
EarthMoonBarycenter.OrbitColor = Orange
Propagate aProp(aSat) {aSat.ElapsedDays = 75}
EarthMoonBarycenter.OrbitColor = [250 128 114] % RGB value for Salmon
Propagate aProp(aSat) {aSat.ElapsedDays = 75}
```

Set unique colors on spacecraft's various trajectory segments through **Propagate** command's **OrbitColor** option. The colors are set through combination of both Color-

Name and RGB input methods. Notice that although by default, red color is set on **aSat.OrbitColor** field, however since orbit color has been reset on all **Propagate** commands, hence red color is never drawn:

```
Create Spacecraft aSat
aSat.OrbitColor = Red
aSat.X = 10000

Create Propagator aProp

Create OrbitView anOrbitView
GMAT anOrbitView.Add = {aSat, Earth}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedSecs = 1000, OrbitColor = Yellow}
Propagate aProp(aSat) {aSat.ElapsedSecs = 1000, OrbitColor = Cyan}
Propagate aProp(aSat) {aSat.ElapsedSecs = 1000, OrbitColor = [154 205 50]}
Propagate aProp(aSat) {aSat.ElapsedSecs = 1000, OrbitColor = [255 0 255]}
```

Set colors on spacecraft's various trajectory segments through **Propagate** command's **OrbitColor** option. This time, colors are only set through ColorName input method. Default color set on **aSat.OrbitColor** field is red. Notice that the orbit color has been reset on only the first three **Propagate** commands. However since **OrbitColor** option has not been used on the last **Propagate** command, therefore the trajectory drawn by the last **Propagate** command is in red color which is the color assigned on **aSat.OrbitColor** field:

```
Create Spacecraft aSat
aSat.OrbitColor = Red
aSat.X = 10000

Create Propagator aProp

Create OrbitView anOrbitView
GMAT anOrbitView.Add = {aSat, Earth}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedSecs = 1000, OrbitColor = Orange}
Propagate aProp(aSat) {aSat.ElapsedSecs = 1000, OrbitColor = Blue}
Propagate aProp(aSat) {aSat.ElapsedSecs = 1000, OrbitColor = Yellow}
Propagate aProp(aSat) {aSat.ElapsedSecs = 1000}
```

Set colors on **Propagate** commands when used with **Target** resource and during differential correction iterative process. This time, since colors have been set on all **Propagate** commands, hence default color of red which is set on **aSat.OrbitColor** field is never plotted. Also notice that although **aSat.TargetColor** is set to Yellow, but since **anOrbitView.SolverIterations** is set to None, hence perturbed trajectories that are drawn during iterative process are not plotted and only final solution is plotted

```
Create Spacecraft aSat
aSat.OrbitColor = Red
aSat.TargetColor = Yellow

Create Propagator aProp

Create ImpulsiveBurn TOI

Create DifferentialCorrector aDC

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth}
anOrbitView.SolverIterations = None %Set to 'All' to see perturbations
anOrbitView.ViewScaleFactor = 2

BeginMissionSequence

Propagate aProp(aSat) {aSat.Earth.Periapsis, OrbitColor = Salmon}

Target aDC;
Vary aDC(TOI.Element1 = 0.24, {Perturbation = 0.001, Lower = 0.0, ...
    Upper = 3.14159, MaxStep = 0.5})
Maneuver TOI(aSat);
Propagate aProp(aSat) {aSat.Earth.Apoapsis, OrbitColor = Blue}
Achieve aDC(aSat.Earth.RMAG = 2000)
EndTarget

Propagate aProp(aSat) {aSat.Earth.Periapsis, OrbitColor = Orange}
```



# Targeting/Parameter Optimization

This chapter contains documentation for Resources and Commands related to targeting and parameter optimization.

## Resources

## DifferentialCorrector

A numerical solver

### Description

A **DifferentialCorrector** (DC) is a numerical solver for solving boundary value problems. It is used to refine a set of variable parameters in order to meet a set of goals defined for the modeled mission. The DC in GMAT supports several numerical techniques. In the mission sequence, you use the **DifferentialCorrector** resource in a **Target** control sequence to solve the boundary value problem. In GMAT, differential correctors are often used to determine the maneuver components required to achieve desired orbital conditions, say, B-plane conditions at a planetary flyby.

You must create and configure a **DifferentialCorrector** resource for your application by setting numerical properties of the solver such as the algorithm type, the maximum number of allowed iterations and choice of derivative method used to calculate the finite differences. You can also select among different output options that show increasing levels of information for each differential corrector iteration.

This resource cannot be modified in the Mission Sequence.

See Also: [Target](#), [Vary](#), [Achieve](#)

### Fields

Field	Description
<b>Algorithm</b>	The numerical method used to solve the boundary value problem.  Data Type String Allowed Values <b>NewtonRaphson</b> , <b>Broyden</b> , <b>Modified-Broyden</b> Access set Default Value <b>NewtonRaphson</b> Units N/A Interfaces GUI, script
<b>DerivativeMethod</b>	Chooses between one-sided and central differencing for numerically determining the derivative. Only used when <b>Algorithm</b> is set to <b>NewtonRaphson</b> .  Data Type String Allowed Values <b>ForwardDifference</b> , <b>BackwardDifference</b> , <b>CentralDifference</b> Access set Default Value <b>ForwardDifference</b> Units N/A Interfaces GUI, script

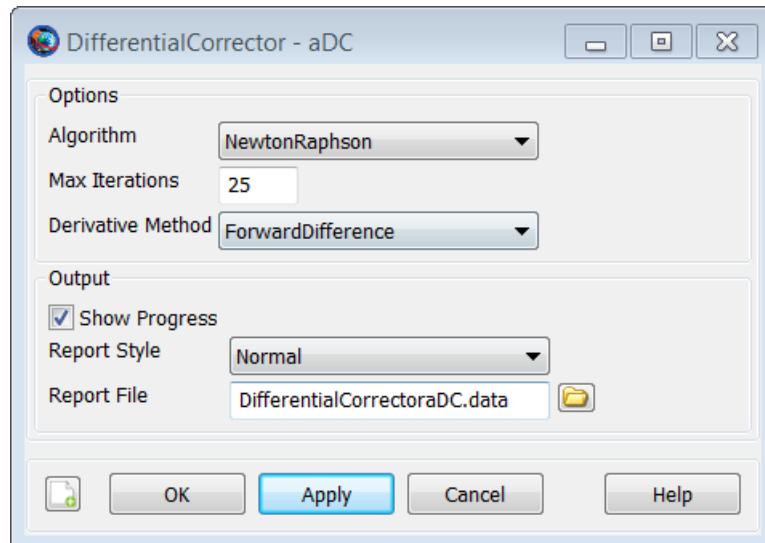
Field	Description												
<b>MaximumIterations</b>	<p>Sets the maximum number of nominal passes the <b>DifferentialCorrector</b> is allowed to take during the attempt to find a solution. If the maximum iterations is reached, GMAT exits the target loop and continues to the next command in the mission sequence. In this case, the objects retain their states as of the last nominal pass through the targeting loop.</p> <table> <tr> <td><b>Data Type</b></td><td>Integer</td></tr> <tr> <td><b>Allowed Values</b></td><td>Integer &gt;= 1</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>25</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Integer	<b>Allowed Values</b>	Integer >= 1	<b>Access</b>	set	<b>Default Value</b>	25	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Integer												
<b>Allowed Values</b>	Integer >= 1												
<b>Access</b>	set												
<b>Default Value</b>	25												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>ReportFile</b>	<p>Specifies the path and file name for the <b>DifferentialCorrector</b> report. The report is only generated if <b>ShowProgress</b> is set to true.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Filename consistent with OS</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>DifferentialCorrectorDCName.data, where DCname is the name of the <b>DifferentialCorrector</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Filename consistent with OS	<b>Access</b>	set	<b>Default Value</b>	DifferentialCorrectorDCName.data, where DCname is the name of the <b>DifferentialCorrector</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Filename consistent with OS												
<b>Access</b>	set												
<b>Default Value</b>	DifferentialCorrectorDCName.data, where DCname is the name of the <b>DifferentialCorrector</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												
<b>ReportStyle</b>	<p>Controls the amount and type of information written to the file defined in the <b>ReportFile</b> field. Currently, the <b>Normal</b> and <b>Concise</b> options contain the same information: the Jacobian, the inverse of the Jacobian, the current values of the control variables, and achieved and desired values of the constraints. <b>Verbose</b> contains values of the perturbation variables in addition to the data for <b>Normal</b> and <b>Concise</b>. <b>Debug</b> contains detailed script snippets at each iteration for objects that have control variables.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>Normal, Concise, Verbose, Debug</b></td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>Normal</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	<b>Normal, Concise, Verbose, Debug</b>	<b>Access</b>	set	<b>Default Value</b>	<b>Normal</b>	<b>Units</b>	N/A	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	<b>Normal, Concise, Verbose, Debug</b>												
<b>Access</b>	set												
<b>Default Value</b>	<b>Normal</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	GUI, script												

Field	Description
<b>ShowProgress</b>	When the <b>ShowProgress</b> field is set to true, then data illustrating the progress of the differential correction process are written to the message window and the <b>ReportFile</b> . The message window is updated with information on the current control variable values and the constraint variances. When the <b>ShowProgress</b> field is set to false, no information on the progress of the differential correction process is displayed to the message window or written to the <b>ReportFile</b> .
<b>Data Type</b>	String
<b>Allowed Values</b>	true, false
<b>Access</b>	set
<b>Default Value</b>	true
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

## GUI

The **DifferentialCorrector** dialog box allows you to specify properties of a **DifferentialCorrector** such as the numerical algorithm, maximum iterations, choice of derivative method used to calculate the finite differences, and choice of reporting options.

To create a **DifferentialCorrector** resource, navigate to the **Resources** tree, expand the **Solvers** folder, right-click on the **Boundary Value Solvers** folder, point to **Add**, and click **DifferentialCorrector**. A resource named **DC1** will be created. Double-click on the **DC1** resource to bring up the following **Differential Corrector** dialog box.



## Remarks

### Supported Algorithm Details

GMAT supports several algorithms for solving boundary value problems including **Newton Raphson**, **Broyden**, and **Modified Broyden**. These algorithms use finite differenc-

ing or other numerical approximations to compute the Jacobian of the constraints and independent variables. The default algorithm is currently **NewtonRaphson**. **Broden's** method and **ModifiedBroyden** usually take more iterations but fewer function evaluations than **NewtonRaphson** and so are often faster. A description of each algorithm is provided below. We recommend trying different algorithm options for your application to determine which algorithm provides the best balance of performance and robustness.

### Newton-Raphson

The **NewtonRaphson** algorithm is a quasi-Newton method that computes the Jacobian using finite differencing. GMAT supports forward, central, and backward differencing to compute the Jacobian.

### Broyden

**Broyden's** method uses the slope between state iterations as an approximation of the first derivative instead of numerically calculating the first derivative using finite differencing. This results in substantially fewer function evaluations. The Broyden iterate is updated using the following equation.

$$J_k = J_{k-1} + \frac{f(x_k) - f(x_{k-1}) - J_{k-1}(x_k - x_{k-1})}{\|x_k - x_{k-1}\|^2} (x_k - x_{k-1})^T$$

### ModifiedBroyden

The modified **Broyden's** method updates the inverse of the Jacobian matrix to avoid numerical issues in matrix inversion when solving near singular problems. Like **Broyden's** method, it requires fewer function evaluations than the **NewtonRaphson** algorithm. The inverse of the Jacobian, H, is updated using the following equation,

$$H_{k+1} = H_k + (s_k - H_k y_k) v_k^T$$

where

$$s_k = x_{k+1} - x_k$$

$$y_k = f(x_{k+1}) - f(x_k)$$

$$v_k = \frac{H_k^T s_k}{s_k^T H_k y_k}$$

### Resource and Command Interactions

The **DifferentialCorrector** object can only be used in the context of targeting-type commands. Please see the documentation for **Target**, **Vary**, and **Achieve** for more information and worked examples.

## Examples

Create a **DifferentialCorrector** configured to use **Broyden**'s method and use it to solve for an apogee raising maneuver.

```
Create Spacecraft aSat
Create Propagator aProp
Create ImpulsiveBurn aDeltaV
Create OrbitView a3DPlot
a3DPlot.Add = {aSat,Earth};

Create DifferentialCorrector aDC
aDC.Algorithm = 'Broyden'

BeginMissionSequence

Propagate aProp(aSat){aSat.Periapsis}

Target aDC

    Vary aDC(aDeltaV.Element1 = 0.01)
    Maneuver aDeltaV(aSat)
    Propagate aProp(aSat){aSat.Apoapsis}
    Achieve aDC(aSat.RMAG = 12000)

EndTarget
```

To see further examples for how the **DifferentialCorrector** object is used in conjunction with **Target**, **Vary**, and **Achieve** commands to solve orbit problems, see the **Target** command examples.

## FminconOptimizer

The Sequential Quadratic Programming (SQP) optimizer, fmincon

### Description

**fmincon** is a Nonlinear Programming solver provided in MATLAB's Optimization Toolbox. **fmincon** performs nonlinear constrained optimization and supports linear and nonlinear constraints. To use this solver, you must configure the solver options including convergence criteria, maximum iterations, and how the gradients will be calculated. In the mission sequence, you implement an optimizer such as fmincon by using an **Optimize/EndOptimize** sequence. Within this sequence, you define optimization variables by using the **Vary** command, and define cost and constraints by using the **Minimize** and **NonlinearConstraint** commands respectively.

This resource cannot be modified in the Mission Sequence. This resource is unavailable for use in the API.

See Also: [VF13ad,Optimize,Vary, NonlinearConstraint, Minimize](#)

### Fields

Field	Description
<b>DiffMaxChange</b>	Upper limit on the perturbation used in MATLAB's finite differencing algorithm. For fmincon, you don't specify a single perturbation value, but rather give MATLAB a range, and it uses an adaptive algorithm that attempts to find the optimal perturbation.  <b>Data Type</b> String <b>Allowed Values</b> Real Number > 0 <b>Access</b> Set <b>Default Value</b> 0.1 <b>Units</b> None <b>Interfaces</b> GUI, script
<b>DiffMinChange</b>	Lower limit on the perturbation used in MATLAB's finite differencing algorithm. For fmincon, you don't specify a single perturbation value, but rather give MATLAB a range, and it uses an adaptive algorithm that attempts to find the optimal perturbation.  <b>Data Type</b> String <b>Allowed Values</b> Real Number > 0 <b>Access</b> Set <b>Default Value</b> 1e-8 <b>Units</b> None <b>Interfaces</b> GUI, script

Field	Description
<b>MaxFunEvals</b>	Specifies the maximum number of cost function evaluations used in an attempt to find an optimal solution. This is equivalent to setting the maximum number of passes through an optimization loop in a GMAT script. If a solution is not found before the maximum function evaluations, fmincon outputs an ExitFlag of zero, and GMAT continues.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> Integer &gt; 0</p> <p><b>Access</b> Set</p> <p><b>Default Value</b> 1000</p> <p><b>Units</b> None</p> <p><b>Interfaces</b> GUI, script</p>
<b>MaximumIterations</b>	Specifies the maximum allowable number of nominal passes through the optimizer. Note that this is not the same as the number of optimizer iterations that is shown for the <b>VF13ad</b> optimzer.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> Integer &gt; 0</p> <p><b>Access</b> Set</p> <p><b>Default Value</b> 25</p> <p><b>Units</b> None</p> <p><b>Interfaces</b> GUI, script</p>
<b>ReportFile</b>	Contains the path and file name of the report file.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> Any user-defined file name</p> <p><b>Access</b> Set</p> <p><b>Default Value</b> FminconOptimizerSQP1.data</p> <p><b>Units</b> None</p> <p><b>Interfaces</b> GUI, script</p>
<b>ReportStyle</b>	Determines the amount and type of data written to the message window and to the report specified by field <b>ReportFile</b> for each iteration of the solver (when <b>ShowProgress</b> is true). Currently, the <b>Normal</b> , <b>Debug</b> , and <b>Concise</b> options contain the same information: the values for the control variables, the constraints, and the objective function. In addition to this information, the <b>Verbose</b> option also contains values of the optimizer-scaled control variables.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> <b>Normal</b>, <b>Concise</b>, <b>Verbose</b>, <b>Debug</b></p> <p><b>Access</b> Set</p> <p><b>Default Value</b> <b>Normal</b></p> <p><b>Units</b> None</p> <p><b>Interfaces</b> GUI, script</p>

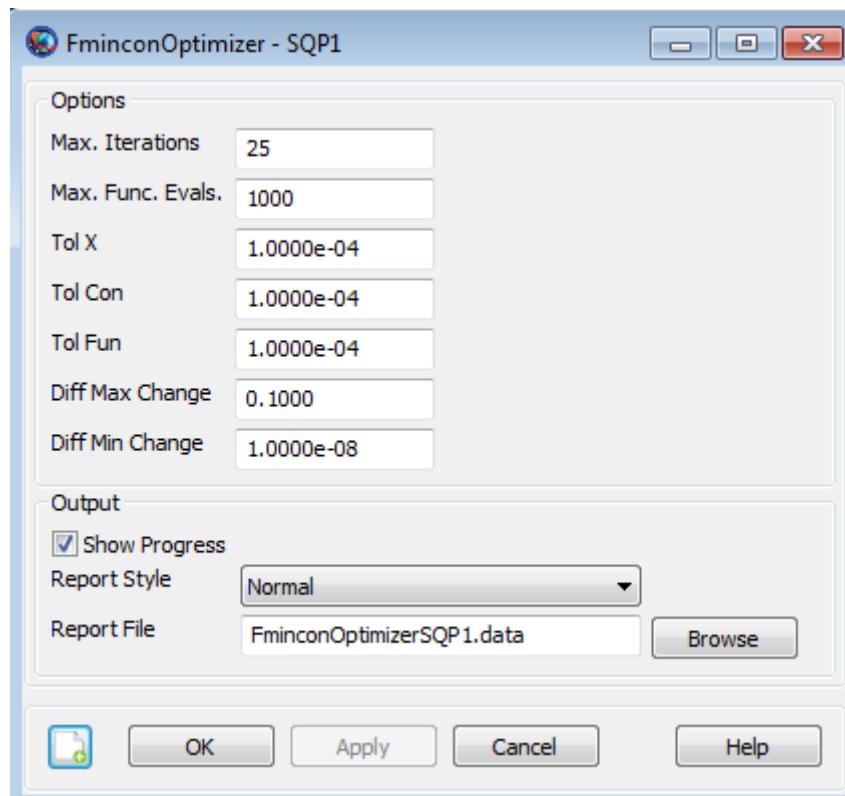
Field	Description
<b>ShowProgress</b>	Determines whether data pertaining to iterations of the solver is both displayed in the message window and written to the report specified by the <b>ReportFile</b> field. When <b>ShowProgress</b> is true, the amount of information contained in the message window and written in the report is controlled by the <b>ReportStyle</b> field.
	<p><b>Data Type</b> Boolean</p> <p><b>Allowed Values</b> true, false</p> <p><b>Access</b> Set</p> <p><b>Default Value</b> true</p> <p><b>Units</b> None</p> <p><b>Interfaces</b> GUI, script</p>
<b>TolCon</b>	Specifies the convergence tolerance on the constraint functions.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> Real Number &gt; 0</p> <p><b>Access</b> Set</p> <p><b>Default Value</b> 1e-4</p> <p><b>Units</b> None</p> <p><b>Interfaces</b> GUI, script</p>
<b>TolFun</b>	Specifies the convergence tolerance on the cost function value.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> Real Number &gt; 0</p> <p><b>Access</b> Set</p> <p><b>Default Value</b> 1e-4</p> <p><b>Units</b> None</p> <p><b>Interfaces</b> GUI, script</p>
<b>TolX</b>	Specifies the termination tolerance on the vector of independent variables, and is used only if the user sets a value for this field.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> Real Number &gt; 0</p> <p><b>Access</b> Set</p> <p><b>Default Value</b> 1e-4</p> <p><b>Units</b> None</p> <p><b>Interfaces</b> GUI, script</p>

## GUI

The **FminconOptimizer** dialog box allows you to specify properties of a **FminconOptimizer** resource such as maximum iterations, maximum function evaluations, control variable termination tolerance, constraint tolerance, cost function tolerance, finite difference algorithm parameters, and choice of reporting options.

To create a **FminconOptimizer** resource, navigate to the **Resources** tree, expand the **Solvers** folder, highlight and then right-click on the **Optimizers** sub-folder, point to **Add**

and then select **SQP** (**fmincon**). This will create a new **FminconOptimizer** resource, **SQP1**. Double-click on **SQP1** to bring up the **FminconOptimizer** dialog box shown below.



## Remarks

### fmincon Optimizer Availability

This optimizer is only available if you have access to both MATLAB and MATLAB's Optimization toolbox. GMAT contains an interface to the fmincon optimizer and it will appear to you that fmincon is a built in optimizer in GMAT. Field names for this resource have been copied from those used in MATLAB'S optimset function for consistency with MATLAB in contrast with other solvers in GMAT.

### GMAT Stop Button Does Not work, in Some Situations, When Using Fmincon

Sometimes, when developing GMAT scripts, you may inadvertently create a situation where GMAT goes into an infinite propagation loop. The usual remedy for this situation is to apply the GMAT **Stop** button. Currently, however, if the infinite loop occurs within an **Optimize** sequence using fmincon, there is no way to stop GMAT and you have to shut GMAT down. Fortunately, there are some procedures you can employ to avoid this situation. You should use multiple stopping conditions so that a long propagation cannot occur. For example, if fmincon controls variable, **myVar**, and we know **myVar** should never be more than 2, then do this.

```
Propagate myProp(mySat){mySat.ElapsedDays = myVar, mySat.ElapsedDays = 2}
```

## Resource and Command Interactions

The **FminconOptimizer** resource can only be used in the context of optimization-type commands. Please see the documentation for **Optimize**, **Vary**, **NonlinearConstraint**, and **Minimize** for more information and worked examples.

## Examples

Create a **FminconOptimizer** resource named SQP1.

```
Create FminconOptimizer SQP1
SQP1.ShowProgress = true
SQP1.ReportStyle = Normal
SQP1.ReportFile = 'FminconOptimizerSQP1.data'
SQP1.MaximumIterations = 25
SQP1.DiffMaxChange = '0.1000'
SQP1.DiffMinChange = '1.0000e-08'
SQP1.MaxFunEvals = '1000'
SQP1.TolX = '1.0000e-04'
SQP1.TolFun = '1.0000e-04'
SQP1.TolCon = '1.0000e-04'
```

For an example of how a **FminconOptimizer** resource can be used within an optimize sequence, see the **Optimize** command examples.

## SNOPT

The Sequential Quadratic Programming (SQP) optimizer, SNOPT

### Description

The **SNOPT** optimizer is a SQP-based Nonlinear Programming solver developed by Stanford Business Software, Inc. It is a proprietary component that is not distributed with GMAT and must be obtained from the vendor. **SNOPT** performs nonlinear constrained optimization and supports both linear and nonlinear constraints. To use this solver, you must configure the solver options including convergence criteria, maximum iterations, among other options. In the mission sequence, you implement an optimizer such as SNOPT by using an **Optimize/EndOptimize** sequence. Within this sequence, you define optimization variables by using the **Vary** command, and define cost and constraints by using the **Minimize** and **NonlinearConstraint** commands respectively.

This resource cannot be modified in the Mission Sequence.

See Also: [FminconOptimizer](#), [Optimize](#), [Vary](#), [NonlinearConstraint](#), [Minimize](#)

### Fields

Field	Description
<b>MajorFeasibilityTolerance</b>	Specifies how accurately the nonlinear constraints should be satisfied.
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real > 0
<b>Access</b>	set
<b>Default Value</b>	1e-5
<b>Units</b>	None
<b>Interfaces</b>	GUI, script
<b>MajorIterationsLimit</b>	The maximum number of major iterations allowed. It is intended to guard against an excessive number of linearizations of the constraints
<b>Data Type</b>	Integer
<b>Allowed Values</b>	Integer > 0
<b>Access</b>	set
<b>Default Value</b>	1e-5
<b>Units</b>	None
<b>Interfaces</b>	GUI, script

Field	Description
<b>MajorOptimalityTolerance</b>	Specifies the final accuracy of the dual variables. See the SNOPT user guide for further details.
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>OutputFileName</b>	Contains the path and file name of the report file. This report contains data written by SNOPT regarding optimization progress and information.
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>OverrideSpecsFileValues</b>	Flag to indicate if options settable in the GMAT script/GUI should override values set in the <b>SNOPT Specs</b> file. Note that if the specs file is not found during initialization, GMAT configurations are applied even if the <b>OverrideSpecsFileValues</b> field is set to <b>false</b> .
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>ReportFile</b>	Contains the path and file name of the report file. This report contains data written by GMAT regarding optimization progress and information.
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>

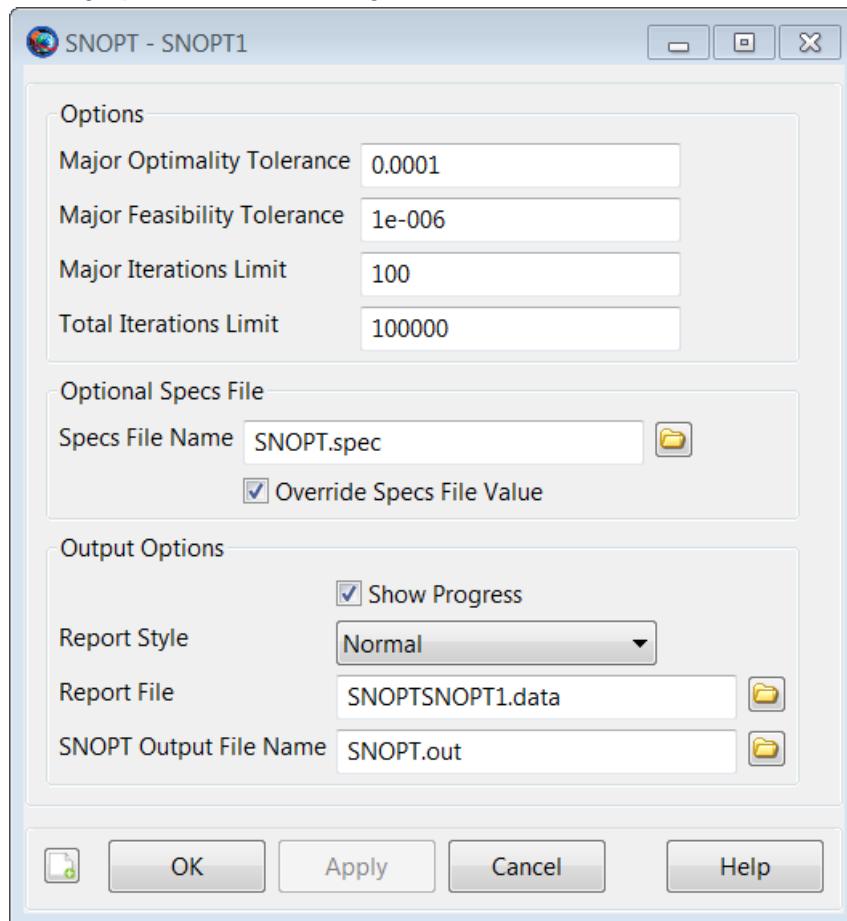
Field	Description
<b>ReportStyle</b>	<p>Determines the amount and type of data written to the message window and to the report specified by field <b>ReportFile</b> for each iteration of the solver (When <b>ShowProgress</b> is true). Currently, the <b>Normal</b>, <b>Debug</b>, and <b>Concise</b> options contain the same information: the values for the control variables, the constraints, and the objective function. In addition to this information, the <b>Verbose</b> option also contains values of the optimizer-scaled control variables.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>ShowProgress</b>	<p>Determines whether data pertaining to iterations of the solver is both displayed in the message window and written to the report specified by the <b>ReportFile</b> field. When <b>ShowProgress</b> is true, the amount of information contained in the message window and written in the report is controlled by the <b>ReportStyle</b> field.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>SpecsFileName</b>	<p>File read by SNOPT to configure all settings of the optimizer. The GMAT script/gui interface only supports a small subset of the SNOPT configuration options. This file allows you to set any options supported by SNOPT. This file is only loaded if it is found during initialization and selected values set on the file can be overwritten by the GMAT configuration by <b>OverrideSpecsFile-Values = true</b>. See the <a href="#">Remarks</a> section for more information.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>

Field	Description
<b>TotalIterationsLimit</b>	The maximum number of minor iterations allowed.
<b>Data Type</b>	Integer
<b>Allowed Values</b>	Integer > 0
<b>Access</b>	set
<b>Default Value</b>	100000
<b>Units</b>	None
<b>Interfaces</b>	GUI, script

## GUI

The **SNOPT** dialog box allows you to specify properties of a **SNOPT** such as as maximum iterations, cost function tolerance, feasibility tolerance, choice of reporting options, and choice of whether or not to use the central difference derivative method.

To create a **SNOPT** resource, navigate to the **Resources** tree, expand the **Solvers** folder, highlight and then right-click on the **Optimizers** sub-folder, point to **Add** and then select **SNOPT**. This will create a new **SNOPT** resource, **SNOPT1**. Double-click on **SNOPT1** to bring up the **SNOPT** dialog box shown below.



## Remarks

### SNOPT Optimizer Version and Availability

GMAT currently uses SNOPT 7.2-12.2. This optimizer is not included as part of the nominal GMAT installation and is only available if you have created and installed the SNOPT plug-in or obtained SNOPT from the vendor.

### SPECS File Configuration

The Specs file contains a list of options and values in the following general form::

```
Begin options
    Iterations limit 500
    Minor feasibility tolerance 1.0e-7
    Solution Yes
End options
```

The file starts with the keyword Begin and ends with End. The file is in free format. Each line specifies a single option, using one or more items as follows:

1. A keyword (required for all options).
2. A phrase (one or more words) that qualifies the keyword (only for some options).
3. A number that specifies an integer or real value (only for some options). Such numbers may be up to 16 contiguous characters in Fortran 77's I, F, E or D formats, terminated by a space or new line.

The items may be entered in upper or lower case or a mixture of both. Some of the keywords have synonyms, and certain abbreviations are allowed, as long as there is no ambiguity. Blank lines and comments may be used to improve readability. A comment begins with an asterisk (\*) anywhere on a line. All subsequent characters on the line are ignored. The Begin line is echoed to the Summary file.

For a complete list of SNOPT options, see the SNOPT user guide.

### Configuring SNOPT for Effective Optimization

When using **SNOPT**, the **Upper** and **Lower** bounds in the **Vary** commands are required fields. By setting these values appropriately for your problem, you reduce the likelihood that **SNOPT** will try values that are unphysical or that can result in numerical singularities in the physical models. It is important to set bounds carefully when using **SNOPT**.

Additionally, **SNOPT** is quite sensitive to scaling and care must be taken to provide acceptable values of **AdditiveScaleFactor** and **MultiplicativeScaleFactor** in the **Vary** commands. When using **SNOPT**, derivatives are computed by **SNOPT** via the optimizer's built-in finite differencing. If an optimization problem is not appropriately scaled, optimization may fail, or take an un-necessarily long time. Note that SNOPT has built-in scaling options that can be set via the Specs file and are described in further detail in the SNOPT user guide.

## Resource and Command Interactions



### Warning

GMAT's **Vary** command is a generic interface designed to support many optimizers and not all settings supported by the **Vary** command are supported by **SNOPT**. See the [Vary](#) command documentation for details on which **Vary** command settings are supported by **SNOPT**.

The **SNOPT** resource can only be used in the context of optimization-type commands. Please see the documentation for **Optimize**, **Vary**, **NonlinearConstraint**, and **Minimize** for more information and worked examples.

### Examples

A simple mathematical optimization problem using SNOPT.

```
Create SNOPT NLP
GMAT NLP.ShowProgress = true
GMAT NLP.ReportStyle = Normal
GMAT NLP.ReportFile = output.report
GMAT NLP.MajorOptimalityTolerance = 0.001
GMAT NLP.MajorFeasibilityTolerance = 0.0001
GMAT NLP.MajorIterationsLimit = 456
GMAT NLP.TotalIterationsLimit = 789012
GMAT NLP.OutputFileName = 'SNOPTName123.out'
GMAT NLP.SpecsFileName = 'SNOPT.spec'
GMAT NLP.OverrideSpecsFileValues = true

Create Variable X1 X2 J G

BeginMissionSequence

Optimize NLP {SolveMode = Solve, ExitMode = DiscardAndContinue}

    % Vary the independent variables
    Vary 'Vary X1' NLP(X1 = 0, {Perturbation = 0.0000001, Upper = 10, ...
        Lower = -10, AdditiveScaleFactor = 0.0, ...
        MultiplicativeScaleFactor = 1.0})
    Vary 'Vary X2' NLP(X2 = 0, {Perturbation = 0.0000001, Upper = 10, ...
        Lower = -10, AdditiveScaleFactor = 0.0, ...
        MultiplicativeScaleFactor = 1.0})

    % The cost function and Minimize command
    J = ( X1 - 2 )^2 + ( X2 - 2 )^2
    Minimize 'Minimize Cost (J)' NLP(J)

    % Calculate constraint and use NonLinearConstraint command
    GMAT G = X2 + X1
```

```
NonlinearConstraint NLP(G<=8)
```

```
EndOptimize
```

## VF13ad

The Sequential Quadratic Programming (SQP) optimizer, VF13ad

### Description

The **VF13ad** optimizer is a SQP-based Nonlinear Programming solver available in the Harwell Subroutine Library. **VF13ad** performs nonlinear constrained optimization and supports both linear and nonlinear constraints. To use this solver, you must configure the solver options including convergence criteria, maximum iterations, and gradient computation method. In the mission sequence, you implement an optimizer such as VF13ad by using an **Optimize/EndOptimize** sequence. Within this sequence, you define optimization variables by using the **Vary** command, and define cost and constraints by using the **Minimize** and **NonlinearConstraint** commands respectively.

This resource cannot be modified in the Mission Sequence.

See Also: [FminconOptimizer](#), [Optimize](#), [Vary](#), [NonlinearConstraint](#), [Minimize](#)

### Fields

Field	Description
<b>FeasibilityTolerance</b>	Specifies the accuracy to which you want constraints to be satisfied.  <b>Data Type</b> Real <b>Allowed Values</b> Real > 0 <b>Access</b> set <b>Default Value</b> 1e-3 <b>Units</b> None <b>Interfaces</b> GUI, script
<b>UseFeasibility</b>	Toggles application of the optimization constraints.  <b>Data Type</b> Boolean <b>Allowed Values</b> true or false <b>Access</b> set <b>Default Value</b> true <b>Units</b> None <b>Interfaces</b> GUI, script
<b>MaximumIterations</b>	Specifies the maximum allowable number of nominal passes through the Solver Control Sequence.  <b>Data Type</b> Integer <b>Allowed Values</b> Integer > 0 <b>Access</b> set <b>Default Value</b> 200 <b>Units</b> None <b>Interfaces</b> GUI, script

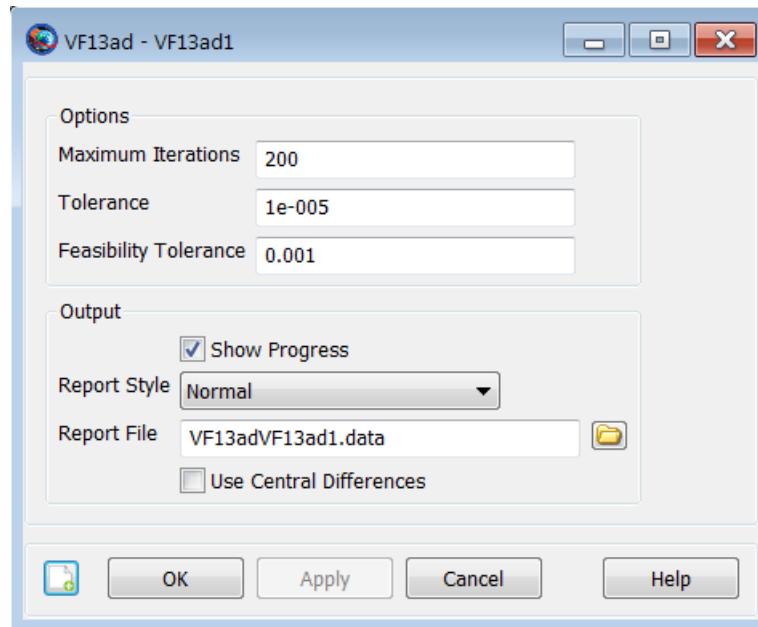
Field	Description												
<b>ReportFile</b>	<p>Contains the path and file name of the report file.</p> <table> <tr> <td data-bbox="567 312 796 344"><b>Data Type</b></td><td data-bbox="845 312 926 344">String</td></tr> <tr> <td data-bbox="567 346 796 378"><b>Allowed Values</b></td><td data-bbox="845 346 1204 378">Any user-defined file name</td></tr> <tr> <td data-bbox="567 380 796 411"><b>Access</b></td><td data-bbox="845 380 886 411">set</td></tr> <tr> <td data-bbox="567 413 796 445"><b>Default Value</b></td><td data-bbox="845 413 1139 445">VF13advF13ad1.data</td></tr> <tr> <td data-bbox="567 447 796 479"><b>Units</b></td><td data-bbox="845 447 918 479">None</td></tr> <tr> <td data-bbox="567 481 796 513"><b>Interfaces</b></td><td data-bbox="845 481 984 513">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Any user-defined file name	<b>Access</b>	set	<b>Default Value</b>	VF13advF13ad1.data	<b>Units</b>	None	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Any user-defined file name												
<b>Access</b>	set												
<b>Default Value</b>	VF13advF13ad1.data												
<b>Units</b>	None												
<b>Interfaces</b>	GUI, script												
<b>ReportStyle</b>	<p>Determines the amount and type of data written to the message window and to the report specified by field <b>ReportFile</b> for each iteration of the solver (When <b>ShowProgress</b> is true). Currently, the <b>Normal</b>, <b>Debug</b>, and <b>Concise</b> options contain the same information: the values for the control variables, the constraints, and the objective function. In addition to this information, the <b>Verbose</b> option also contains values of the optimizer-scaled control variables.</p> <table> <tr> <td data-bbox="567 846 796 878"><b>Data Type</b></td><td data-bbox="845 846 926 878">String</td></tr> <tr> <td data-bbox="567 880 796 912"><b>Allowed Values</b></td><td data-bbox="845 880 1318 912"><b>Normal</b>, <b>Concise</b>, <b>Verbose</b>, <b>Debug</b></td></tr> <tr> <td data-bbox="567 914 796 946"><b>Access</b></td><td data-bbox="845 914 886 946">set</td></tr> <tr> <td data-bbox="567 948 796 979"><b>Default Value</b></td><td data-bbox="845 948 951 979"><b>Normal</b></td></tr> <tr> <td data-bbox="567 982 796 1013"><b>Units</b></td><td data-bbox="845 982 918 1013">None</td></tr> <tr> <td data-bbox="567 1015 796 1047"><b>Interfaces</b></td><td data-bbox="845 1015 984 1047">GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	<b>Normal</b> , <b>Concise</b> , <b>Verbose</b> , <b>Debug</b>	<b>Access</b>	set	<b>Default Value</b>	<b>Normal</b>	<b>Units</b>	None	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	<b>Normal</b> , <b>Concise</b> , <b>Verbose</b> , <b>Debug</b>												
<b>Access</b>	set												
<b>Default Value</b>	<b>Normal</b>												
<b>Units</b>	None												
<b>Interfaces</b>	GUI, script												
<b>ShowProgress</b>	<p>Determines whether data pertaining to iterations of the solver is both displayed in the message window and written to the report specified by the <b>ReportFile</b> field. When <b>ShowProgress</b> is true, the amount of information contained in the message window and written in the report is controlled by the <b>ReportStyle</b> field.</p> <table> <tr> <td data-bbox="567 1273 796 1305"><b>Data Type</b></td><td data-bbox="845 1273 951 1305">Boolean</td></tr> <tr> <td data-bbox="567 1307 796 1339"><b>Allowed Values</b></td><td data-bbox="845 1307 1008 1339">true, false</td></tr> <tr> <td data-bbox="567 1341 796 1372"><b>Access</b></td><td data-bbox="845 1341 886 1372">set</td></tr> <tr> <td data-bbox="567 1374 796 1406"><b>Default Value</b></td><td data-bbox="845 1374 918 1406">true</td></tr> <tr> <td data-bbox="567 1408 796 1440"><b>Units</b></td><td data-bbox="845 1408 918 1440">None</td></tr> <tr> <td data-bbox="567 1442 796 1474"><b>Interfaces</b></td><td data-bbox="845 1442 984 1474">GUI, script</td></tr> </table>	<b>Data Type</b>	Boolean	<b>Allowed Values</b>	true, false	<b>Access</b>	set	<b>Default Value</b>	true	<b>Units</b>	None	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Boolean												
<b>Allowed Values</b>	true, false												
<b>Access</b>	set												
<b>Default Value</b>	true												
<b>Units</b>	None												
<b>Interfaces</b>	GUI, script												
<b>Tolerance</b>	<p>Specifies the measure the optimizer will use to determine when an optimal solution has been found based on the value of the goal set in a <b>Minimize</b> command.</p> <table> <tr> <td data-bbox="567 1638 796 1670"><b>Data Type</b></td><td data-bbox="845 1638 910 1670">Real</td></tr> <tr> <td data-bbox="567 1672 796 1704"><b>Allowed Values</b></td><td data-bbox="845 1672 959 1704">Real &gt; 0</td></tr> <tr> <td data-bbox="567 1706 796 1738"><b>Access</b></td><td data-bbox="845 1706 886 1738">set</td></tr> <tr> <td data-bbox="567 1740 796 1771"><b>Default Value</b></td><td data-bbox="845 1740 910 1771">1e-5</td></tr> <tr> <td data-bbox="567 1774 796 1805"><b>Units</b></td><td data-bbox="845 1774 918 1805">None</td></tr> <tr> <td data-bbox="567 1807 796 1839"><b>Interfaces</b></td><td data-bbox="845 1807 984 1839">GUI, script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real > 0	<b>Access</b>	set	<b>Default Value</b>	1e-5	<b>Units</b>	None	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real > 0												
<b>Access</b>	set												
<b>Default Value</b>	1e-5												
<b>Units</b>	None												
<b>Interfaces</b>	GUI, script												

Field	Description
<b>UseCentralDifferences</b>	Allows you to choose whether or not to use central differencing for numerically determining the derivative. For the default, 'false' value of this field, forward differencing is used to calculate the derivative.
	<p><b>Data Type</b> Boolean</p> <p><b>Allowed Values</b> true, false</p> <p><b>Access</b> set</p> <p><b>Default Value</b> false</p> <p><b>Units</b> None</p> <p><b>Interfaces</b> GUI, script</p>
<b>Maximum-LineSearches</b>	Allows you to specify the number of searches performed in the downhill direction for each iteration of the optimization process. This setting enables optimization to proceed for very flat objective functions, even when the number of searches performed exceed typical search counts. Values less than 20 (the VF13ad default) are discouraged, but not prevented.
	<p><b>Data Type</b> Integer</p> <p><b>Allowed Values</b> Integer &gt; 0</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 20</p> <p><b>Units</b> None</p> <p><b>Interfaces</b> GUI, script</p>
<b>CheckPhysicalTolerances</b>	Enables monitoring of the optimization process on each nominal pass iteration. This monitoring allows termination of optimization when nonlinear constraints fall within tolerance if the objective function values are in tolerance. Constraint tolerances can be set individually for the scripted constraints.
	<p><b>Data Type</b> Boolean</p> <p><b>Allowed Values</b> true, false</p> <p><b>Access</b> set</p> <p><b>Default Value</b> false</p> <p><b>Units</b> None</p> <p><b>Interfaces</b> GUI, script</p>

## GUI

The **VF13ad** dialog box allows you to specify properties of a **VF13ad** such as maximum iterations, cost function tolerance, feasibility tolerance, choice of reporting options, and choice of whether or not to use the central difference derivative method.

To create a **VF13ad** resource, navigate to the **Resources** tree, expand the **Solvers** folder, highlight and then right-click on the **Optimizers** sub-folder, point to **Add** and then select **VF13ad**. This will create a new **VF13ad** resource, VF13ad1. Double-click on VF13ad1 to bring up the **VF13ad** dialog box shown below.



## Remarks

### VF13ad Optimizer Availability

This optimizer is not included as part of the nominal GMAT installation and is only available if you have created or downloaded and installed the VF13ad plug-in.

### Resource and Command Interactions

The **VF13ad** resource can only be used in the context of optimization-type commands. Please see the documentation for **Optimize**, **Vary**, **NonlinearConstraint**, and **Minimize** for more information and worked examples.

### Examples

Create a **VF13ad** resource named VF13ad1.

```
Create VF13ad VF13ad1;
VF13ad1.ShowProgress = true;
VF13ad1.ReportStyle = Normal;
VF13ad1.ReportFile = 'VF13adVF13ad1.data';
VF13ad1.MaximumIterations = 200;
VF13ad1.Tolerance = 1e-05;
VF13ad1.UseCentralDifferences = false;
VF13ad1.UseFeasibility = true;
VF13ad1.FeasibilityTolerance = 0.001;
VF13ad1.MaximumLineSearches = 20;
VF13ad1.CheckPhysicalTolerances = false;
```

For an example of how a **VF13ad** resource can be used within an Optimization sequence, see the **Optimize** command examples.

## Yukon

The Sequential Quadratic Programming (SQP) optimizer, Yukon

### Description

The **Yukon** optimizer is a SQP-based Non-Linear Programming solver that uses an active-set line search algorithm method and a modified BFGS update to approximate the Hessian matrix.

**Yukon** performs nonlinear constrained optimization and supports both linear and nonlinear constraints. To use this solver, you must configure the solver options including convergence criteria, maximum iterations, and gradient computation method. In the mission sequence, you implement an optimizer such as Yukon by using an **Optimize/EndOptimize** sequence. Within this sequence, you define optimization variables by using the **Vary** command, and define cost and constraints by using the **Minimize** and **NonlinearConstraint** commands respectively.

This resource cannot be modified in the Mission Sequence.

See Also: [FminconOptimizer](#), [VF13ad](#), [Optimize](#), [Vary](#), [NonlinearConstraint](#), [Minimize](#)

### Fields

Field	Description
<b>FeasibilityTolerance</b>	The tolerance on the maximum non-dimensional constraint violation that must be satisfied for convergence.  <b>Data Type</b> Real <b>Allowed Values</b> Real > 0 <b>Access</b> set <b>Default Value</b> 1e-4 <b>Units</b> None <b>Interfaces</b> GUI, script
<b>FunctionTolerance</b>	The tolerance on the change in the cost function value to trigger convergence. If the change in the cost function from one iteration to the next is less than FunctionTolerance, and the maximum (non-dimensional) constraint violation is less than <b>OptimalityTolerance</b> , then the algorithm terminates.  <b>Data Type</b> Real <b>Allowed Values</b> Real > 0 <b>Access</b> set <b>Default Value</b> 1e-4 <b>Units</b> None <b>Interfaces</b> GUI, script

Field	Description												
<b>HessianUpdateMethod</b>	<p>The method used to approximate the Hessian of the Lagrangian. These methods are based on the BFGS but are more robust to possible numerical issues that can occur using BFGS updates with finite precision arithmetic.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>DampedBFGS, SelfScaledBFGS</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>SelfScaledBFGS</td></tr> <tr> <td><b>Units</b></td><td>None</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	DampedBFGS, SelfScaledBFGS	<b>Access</b>	set	<b>Default Value</b>	SelfScaledBFGS	<b>Units</b>	None	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	String												
<b>Allowed Values</b>	DampedBFGS, SelfScaledBFGS												
<b>Access</b>	set												
<b>Default Value</b>	SelfScaledBFGS												
<b>Units</b>	None												
<b>Interfaces</b>	GUI, script												
<b>MaximumElasticWeight</b>	<p>The maximum elastic weight allowed when attempting to minimize constraint infeasibilities if the problem appears to be infeasible. When possible infeasibility is detected, the elastic weight is initialized to zero, and increases by a factor of 10 for every failed iterations, until the <b>MaximumElasticWeight</b> setting is reached and the algorithm terminates.</p> <table> <tr> <td><b>Data Type</b></td><td>Integer</td></tr> <tr> <td><b>Allowed Values</b></td><td>Integer &gt; 0</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>10000</td></tr> <tr> <td><b>Units</b></td><td>None</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Integer	<b>Allowed Values</b>	Integer > 0	<b>Access</b>	set	<b>Default Value</b>	10000	<b>Units</b>	None	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Integer												
<b>Allowed Values</b>	Integer > 0												
<b>Access</b>	set												
<b>Default Value</b>	10000												
<b>Units</b>	None												
<b>Interfaces</b>	GUI, script												
<b>MaximumFunctionEvals</b>	<p>Number of passes through the control sequence before termination.</p> <table> <tr> <td><b>Data Type</b></td><td>Integer</td></tr> <tr> <td><b>Allowed Values</b></td><td>Integer &gt; 0</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>1000</td></tr> <tr> <td><b>Units</b></td><td>None</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Integer	<b>Allowed Values</b>	Integer > 0	<b>Access</b>	set	<b>Default Value</b>	1000	<b>Units</b>	None	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Integer												
<b>Allowed Values</b>	Integer > 0												
<b>Access</b>	set												
<b>Default Value</b>	1000												
<b>Units</b>	None												
<b>Interfaces</b>	GUI, script												
<b>MaximumIterations</b>	<p>The maximum number of optimizer iterations allowed before termination.</p> <table> <tr> <td><b>Data Type</b></td><td>Integer</td></tr> <tr> <td><b>Allowed Values</b></td><td>Integer &gt; 0</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>200</td></tr> <tr> <td><b>Units</b></td><td>None</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Integer	<b>Allowed Values</b>	Integer > 0	<b>Access</b>	set	<b>Default Value</b>	200	<b>Units</b>	None	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Integer												
<b>Allowed Values</b>	Integer > 0												
<b>Access</b>	set												
<b>Default Value</b>	200												
<b>Units</b>	None												
<b>Interfaces</b>	GUI, script												

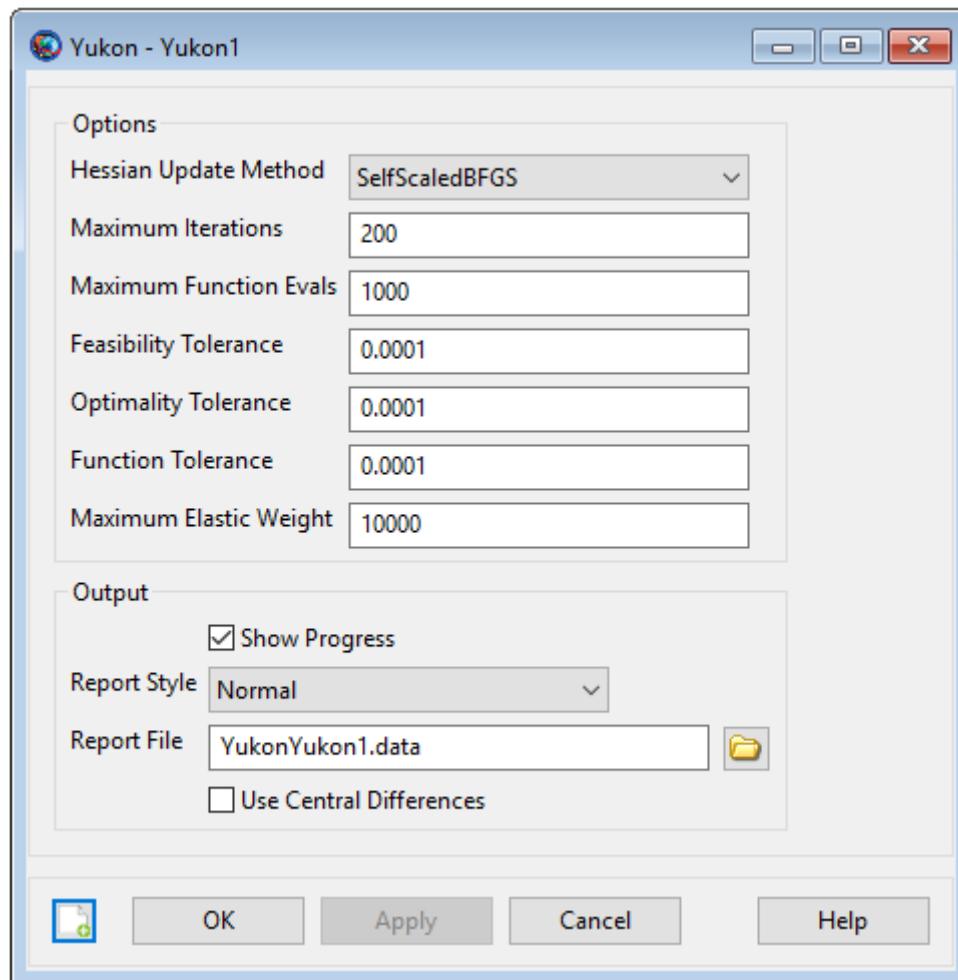
Field	Description
<b>OptimalityTolerance</b>	The tolerance on the change in the gradient of the Lagrangian to trigger convergence. If the gradient of the Lagrangian is less than <b>FeasibilityTolerance</b> and the maximum (non-dimensional) constraint violation is less than <b>Optimality Tolerance</b> , then the algorithm terminates.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Real &gt; 0</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 1e-4</p> <p><b>Units</b> None</p> <p><b>Interfaces</b> GUI, script</p>
<b>ReportFile</b>	Contains the path and file name of the report file containing iteration and convergence information.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> Any user-defined file name</p> <p><b>Access</b> set</p> <p><b>Default Value</b> YukonOptimizer.data</p> <p><b>Units</b> None</p> <p><b>Interfaces</b> GUI, script</p>
<b>ReportStyle</b>	Determines the amount and type of data written to the message window and to the report specified by field <b>ReportFile</b> for each iteration of the solver (when <b>ShowProgress</b> is true). Currently, the <b>Normal</b> , <b>Debug</b> , and <b>Concise</b> options contain the same information: the values for the control variables, the constraints, and the objective function. In addition to this information, the <b>Verbose</b> option also contains values of the optimizer-scaled control variables and the constraint Jacobian. The constraint Jacobian values are useful when scaling optimization problems. See the Remarks section for more information.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> <b>Normal</b>, <b>Concise</b>, <b>Verbose</b>, <b>Debug</b></p> <p><b>Access</b> set</p> <p><b>Default Value</b> <b>Normal</b></p> <p><b>Units</b> None</p> <p><b>Interfaces</b> GUI, script</p>

Field	Description												
<b>ShowProgress</b>	Determines whether data pertaining to iterations of the solver is both displayed in the message window and written to the report specified by the <b>ReportFile</b> field. When <b>ShowProgress</b> is true, the amount of information contained in the message window and written in the report is controlled by the <b>ReportStyle</b> field.												
	<table> <tr> <td><b>Data Type</b></td><td>Boolean</td></tr> <tr> <td><b>Allowed Values</b></td><td>true, false</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>true</td></tr> <tr> <td><b>Units</b></td><td>None</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Boolean	<b>Allowed Values</b>	true, false	<b>Access</b>	set	<b>Default Value</b>	true	<b>Units</b>	None	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Boolean												
<b>Allowed Values</b>	true, false												
<b>Access</b>	set												
<b>Default Value</b>	true												
<b>Units</b>	None												
<b>Interfaces</b>	GUI, script												
<b>UseCentralDifferences</b>	Allows you to choose whether or not to use central differencing for numerically determining the derivative. For the default, 'false' value of this field, forward differencing is used to calculate the derivative.												
	<table> <tr> <td><b>Data Type</b></td><td>Boolean</td></tr> <tr> <td><b>Allowed Values</b></td><td>true, false</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>false</td></tr> <tr> <td><b>Units</b></td><td>None</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Data Type</b>	Boolean	<b>Allowed Values</b>	true, false	<b>Access</b>	set	<b>Default Value</b>	false	<b>Units</b>	None	<b>Interfaces</b>	GUI, script
<b>Data Type</b>	Boolean												
<b>Allowed Values</b>	true, false												
<b>Access</b>	set												
<b>Default Value</b>	false												
<b>Units</b>	None												
<b>Interfaces</b>	GUI, script												

## GUI

The **Yukon** dialog box allows you to specify properties of a **Yukon** such as maximum iterations, cost function tolerance, feasibility tolerance, choice of reporting options, and choice of whether or not to use the central difference derivative method.

To create a **Yukon** resource, navigate to the **Resources** tree, expand the **Solvers** folder, highlight and then right-click on the **Optimizers** sub-folder, point to **Add** and then select **Yukon**. This will create a new **Yukon** resource, Yukon1. Double-click on Yukon1 to bring up the **Yukon** dialog box shown below.



## Remarks

### Yukon Optimizer Availability

This optimizer is distributed in the public and internal distribution.

### Resource and Command Interactions

The **Yukon** resource can only be used in the context of optimization-type commands. Please see the documentation for **Optimize**, **Vary**, **NonlinearConstraint**, and **Minimize** for more information and worked examples.

## Examples

Create a **Yukon** resource named Yukon1.

```
Create Yukon Yukon1
GMAT Yukon1.ShowProgress = true;
GMAT Yukon1.ReportStyle = Normal;
GMAT Yukon1.ReportFile = 'YukonYukon1.data';
GMAT Yukon1.MaximumIterations = 200;
```

```
GMAT Yukon1.UseCentralDifferences = false;
GMAT Yukon1.FeasibilityTolerance = 0.0001;
GMAT Yukon1.HessianUpdateMethod = SelfScaledBFGS;
GMAT Yukon1.MaximumFunctionEvals = 1000;
GMAT Yukon1.OptimalityTolerance = 0.0001;
GMAT Yukon1.FunctionTolerance = 0.0001;
GMAT Yukon1.MaximumElasticWeight = 10000;
```

Below is a simple optimization example with a nonlinear constraint configured to use the Yukon optimizer.

```
%----- Create and Setup the Optimizer
Create Yukon NLPSolver;

%----- Arrays, Variables, Strings
Create Variable X1 X2 J G;

%----- Mission Sequence
BeginMissionSequence;

Optimize NLPSolver {SolveMode = Solve, ExitMode = DiscardAndContinue};

    % Vary the independent variables
    Vary 'Vary X1' NLPSolver(X1 = 0, {Perturbation = 0.0000001});
    Vary 'Vary X2' NLPSolver(X2 = 0, {Perturbation = 0.0000001});

    % The cost function and Minimize command
    GMAT 'Compute Cost (J)' J = ( X1 - 2 )^2 + ( X2 - 2 )^2;
    Minimize 'Minimize Cost (J)' NLPSolver(J);

    % Calculate constraint and use NonLinearConstraint command
    GMAT 'Compute Constraint (G)' G = X2 + X1;
    NonlinearConstraint 'G = 8' NLPSolver(G =8);

EndOptimize; % For optimizer NLPSolver
```

## Commands

## Achieve

Specify a goal for a **Target** sequence

### Script Syntax

```
Achieve SolverName (Goal = Arg1, [{Tolerance = Arg2}])
```

### Description

The **Achieve** command is used in conjunction with the **Target** command as part of the **Target** sequence. The purpose of the **Achieve** command is to define a goal for the targeter (currently, the differential corrector is the only targeter available within a **Target** sequence) to achieve. To configure the **Achieve** command, you specify the goal object, its corresponding desired value, and an optional tolerance so the differential corrector can find a solution. The **Achieve** command must be accompanied and preceded by a **Vary** command in order to assist in the targeting process.

See Also: [DifferentialCorrector](#), [Target](#), [Vary](#)

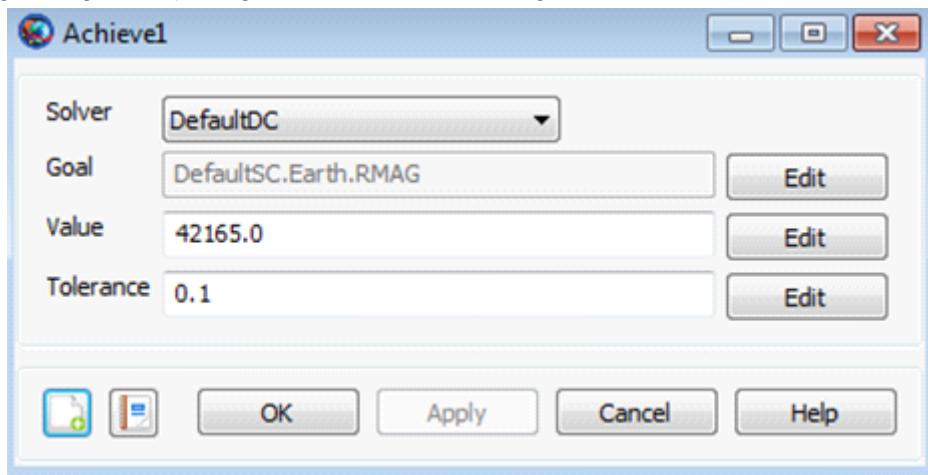
### Options

Option	Description
Arg1	<p>Specifies the desired value for the <b>Goal</b> after the <b>DifferentialCorrector</b> has converged.</p> <p><b>Accepted Data Types</b>      Array, ArrayElement, Variable, String <b>Allowed Values</b>            Real Number, Array element, or Variable <b>Default Value</b>             42165 <b>Required</b>                  yes <b>Interfaces</b>                GUI, script</p>
Arg2	<p>Convergence tolerance for how close <b>Goal</b> equals <b>Arg1</b></p> <p><b>Accepted Data Types</b>      Real Number, Array element, Variable, or any user-defined parameter &gt; 0 <b>Allowed Values</b>            Real Number, Array element, Variable, or any user-defined parameter &gt; 0 <b>Default Value</b>             0.1 <b>Required</b>                  no <b>Interfaces</b>                GUI, script</p>

Option	Description
<b>Goal</b>	Allows you to select any single element user defined parameter, except a number, as a targeter goal.
<b>Accepted Data Types</b>	Object parameter, ArrayElement, Variable
<b>Allowed Values</b>	<b>Spacecraft</b> parameter, <b>Array</b> element, <b>Variable</b> , or any other single element user defined parameter, excluding numbers
<b>Default Value</b>	DefaultSC.Earth.RMAG
<b>Required Interfaces</b>	yes
<b>Solver-Name</b>	GUI, script
<b>Accepted Data Types</b>	Specifies the <b>DifferentialCorrector</b> being used in the <b>Target</b> sequence
<b>Allowed Values</b>	String
<b>Default Value</b>	Any user defined <b>DifferentialCorrector</b>
<b>Required Interfaces</b>	<b>DefaultDC</b>
<b>Default Value</b>	yes
<b>Required Interfaces</b>	GUI, script

## GUI

You use an **Achieve** command, which is only valid within a **Target** sequence, to define your desired goal. More than one **Achieve** command may be used within a **Target** command sequence. The **Achieve** command dialog box, which allows you to specify the targeter, goal object, goal value, and convergence tolerance, is shown below.



## Remarks

### Command Interactions

A **Target** sequence must contain at least one **Vary** and one **Achieve** command.

<b>Target command</b>	An <b>Achieve</b> command only occurs within a <b>Target</b> sequence
-----------------------	---

**Vary com-** Associated with any **Achieve** command is at least one **Vary** command.  
**mand** The **Vary** command identifies the control variable used by the targeter. The goal specified by the **Achieve** command is obtained by varying the control variables.

---

## Examples

As mentioned above, an **Achieve** command only occurs within a **Target** sequence. See the **Target** command help for examples showing the use of the **Achieve** command.

## Minimize

Define the cost function to minimize

### Script Syntax

```
Minimize OptimizerName (ObjectiveFunction)
```

### Description

The **Minimize** command is used within an **Optimize/EndOptimize** Optimization sequence to define the objective function that you want to minimize.

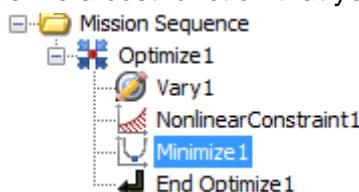
See Also: [Vary](#), [NonlinearConstraint](#), [Optimize](#)

### Options

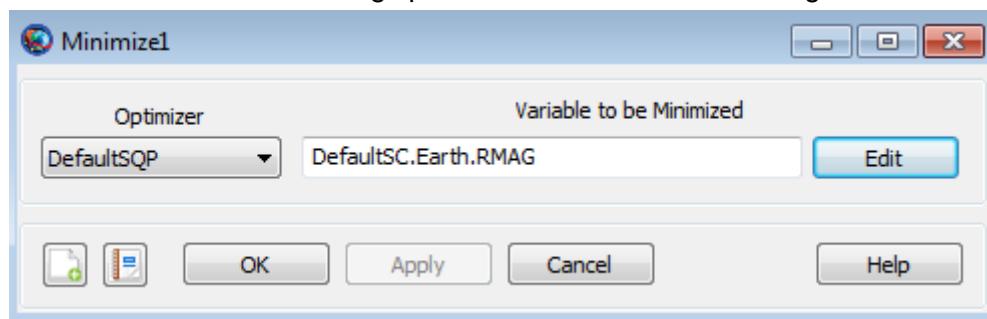
Option	Description
<b>ObjectiveFunction</b>	Specifies the objective function that the optimizer will try to minimize.
<b>Accepted Data Types</b>	String
<b>Allowed Values</b>	Spacecraft parameter, Array element, Variable, or any other single element user defined parameter, excluding numbers
<b>Default Value</b>	DefaultSC.Earth.RMAG
<b>Required Interfaces</b>	yes
<b>GUI, script</b>	
<b>OptimizerName</b>	Specifies which optimizer to use to minimize the cost function
<b>Accepted Data Types</b>	Reference Array
<b>Allowed Values</b>	Any <b>VF13ad</b> or <b>fminconOptimizer</b> resource
<b>Default Value</b>	<b>DefaultSQP</b>
<b>Required Interfaces</b>	yes
<b>GUI, script</b>	

### GUI

You use a **Minimize** command, within an **Optimize/EndOptimize** Optimization sequence as shown below, to define a cost function that you wish to minimize.



Double click on **Minimize1** to bring up the **Minimize** command dialog box shown below..



You must provide two inputs for the **Minimize** command dialog box above:

- Choice of optimizer.
- Object (and associated variable) to be minimized. You can input an object directly or you can click the **Edit** button to the right of this field to select the type of object from three possible choices, **Spacecraft**, **Variable**, or **Array**.

## Remarks

### Number of Vary, NonlinearConstraint, and Minimize Commands Within an Optimization Sequence

An Optimization sequence must contain one or more **Vary** commands. **Vary** commands must occur before any **Minimize** or **NonlinearConstraint** commands.

At most, a single **Minimize** command is allowed within an optimization sequence.

It is possible for an **Optimize/EndOptimize** optimization sequence to contain no **Minimize** commands. In this case, since every optimization sequence must contain (a) one or more **NonlinearConstraint** commands and/or (b) a single **Minimize** command, the optimization sequence must contain at least one **NonlinearConstraint** command.

## Command Interactions

The **Minimize** command is only used within an **Optimize/EndOptimize** Optimization sequence. See the **Optimize** command documentation for a complete worked example using the **Minimize** command.

<b>Vary command</b>	Every Optimization sequence must contain at least one <b>Vary</b> command. <b>Vary</b> commands are used to define the control variables associated with an Optimization sequence.
<b>NonlinearConstraint command</b>	<b>NonlinearConstraint</b> commands are used to define the constraints (i.e., goals) associated with an Optimization sequence. Note that multiple <b>NonlinearConstraint</b> commands are allowed within an Optimization sequence.
<b>Optimize command</b>	A <b>Minimize</b> command can only occur within an <b>Optimize/EndOptimize</b> command sequence.

## Examples

```
% Minimize the eccentricity of Sat, using SQP1
Minimize SQP1(Sat.ECC)

% Minimize the Variable DeltaV, using SQP1
Minimize SQP1(DeltaV)

% Minimize the first component of MyArray, using VF13ad1
Minimize VF13ad1(MyArray(1,1))
```

As mentioned above, the **Minimize** command only occurs within an **Optimize** sequence. See the **Optimize** command help for complete examples showing the use of the **Minimize** command.

## NonlinearConstraint

Specify a constraint used during optimization, with an optional tolerance used when checking physical constraint values

### Script Syntax

```
NonlinearConstraint OptimizerName ({logical expression})  
or  
NonlinearConstraint OptimizerName ({logical expression}, {Tolerance=Arg})
```

### Description

The **NonlinearConstraint** command is used within an **Optimize/EndOptimize** optimization sequence to apply a linear or nonlinear constraint.

When a supporting optimizer is toggled to check the physical constraint values using the **CheckPhysicalTolerances** setting, the **Tolerance** setting on the **NonlinearConstraint** sets the tolerance used for that specific constraint, overriding the optimizer's **FeasibilityTolerance** setting during the physical constraint check. If the **Tolerance** is not specified, the **FeasibilityTolerance** is used for the constraint.

Physical tolerance checks are performed outside of the optimizer mathematics; optimization of the constraints is performed using the algorithm defined for the optimizer.

Note: The **Tolerance** setting works with optimizers that implement the **CheckPhysicalTolerances** setting when that setting is true. The VF13ad and SNOPT optimizers implement this setting.

See Also: [Vary](#), [Optimize](#), [Minimize](#)

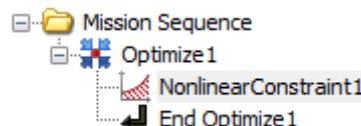
### Options

Option	Description
<b>LHS</b>	Allows you to select any single element user defined parameter, except a number, to define the constraint variable. The constraint function is of the form <b>LHS Operator RHS</b>
<b>Accepted Data Types</b>	String
<b>Allowed Values</b>	Spacecraft parameter, Array element, Variable, or any other single element user defined parameter, excluding numbers
<b>Default Value</b>	DefaultSC.SMA
<b>Required</b>	yes
<b>Interfaces</b>	GUI, script

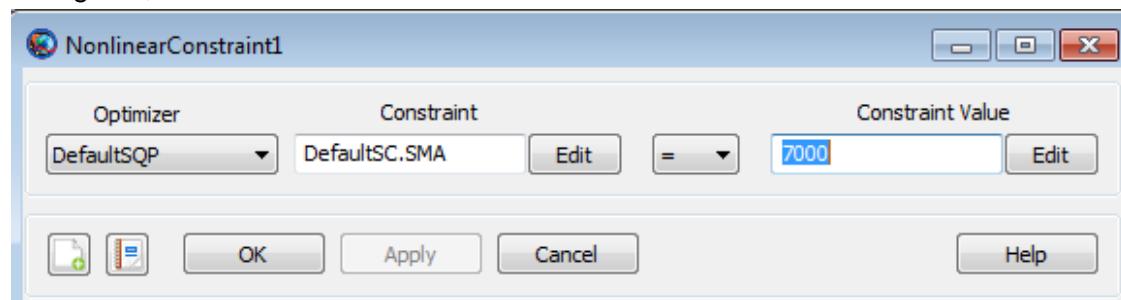
Option	Description	
<b>Operator</b>	logical operator used to specify the constraint function. The constraint function is of the form <b>LHS Operator RHS</b>	
	<b>Accepted Data Types</b>	Reference Array
	<b>Allowed Values</b>	$\geq$ , $\leq$ , $=$
	<b>Default Value</b>	=
	<b>Required Interfaces</b>	yes GUI, script
<b>OptimizerName</b>	Specifies the solver/optimizer object used to apply a constraint.	
	<b>Accepted Data Types</b>	Reference Array
	<b>Allowed Values</b>	Any <b>VF13ad</b> or <b>fminconOptimizer</b> object.
	<b>Default Value</b>	<b>DefaultSQP</b>
	<b>Required Interfaces</b>	yes GUI, script
<b>RHS</b>	Allows you to select any single element user defined parameter, including a number, to specify the desired value of the constraint variable. The constraint function is of the form <b>LHS Operator RHS</b>	
	<b>Accepted Data Types</b>	String
	<b>Allowed Values</b>	Spacecraft parameter, Array element, Variable, or any other single element user defined parameter, including numbers
	<b>Default Value</b>	7000
	<b>Required Interfaces</b>	yes GUI, script
<b>Tolerance</b>	Specifies the physical tolerance setting for a constraint, overriding the optimizer's <b>FeasibilityTolerance</b> setting.	
	<b>Accepted Data Types</b>	String
	<b>Allowed Values</b>	Spacecraft parameter, Array element, Variable, or any other single element user defined parameter, including numbers
	<b>Default Value</b>	1.0e-3
	<b>Required Interfaces</b>	no Script

## GUI

You use a **NonlinearConstraint** command, within an Optimize/EndOptimize sequence as shown below, to define an equality or inequality constraint that you want to be satisfied at the end of the optimization process.



Double click on **NonlinearConstraint1** to bring up the **NonlinearConstraint** command dialog box, shown below.



You must provide four inputs for the **NonlinearConstraint** command dialog box above:

- Choice of **Optimizer**.
- **Constraint** Object. Click the **Edit** button to the right of this field to select the type of constraint object from three possible choices, **Spacecraft**, **Variable**, or **Array**.
- Logical operator. Select one from three choices,  $=$ ,  $\leq$ , or  $\geq$ .
- **Constraint Value**.

Note that Inputs 2-4 define a logical expression. In the example above, we have:  
DefaultSC.SMA = 7000

## Remarks

### Number of Vary, NonlinearConstraint, and Minimize Commands Within an Optimization Sequence

An Optimization sequence must contain one or more **Vary** commands. **Vary** commands must occur before any **Minimize** or **NonlinearConstraint** commands.

Multiple **NonlinearConstraint** commands are allowed. There is exactly one **NonlinearConstraint** command for every constraint.

It is possible for an **Optimize/EndOptimize** optimization sequence to contain no **NonlinearConstraint** commands. In this case, since every optimization sequence must contain (a) one or more **NonlinearConstraint** commands and/or (b) a single **Minimize** command, the optimization sequence must contain a single **Minimize** command.

## Command Interactions

The **Minimize** command is only used within an **Optimize/EndOptimize** Optimization sequence. See the **Optimize** command documentation for a complete worked example using the **NonlinearConstraint** command.

---

**Optimize NonlinearConstraint** commands can only occur within an **Optimize/EndOptimize** command sequence.

---

**Vary com-** Every Optimization sequence must contain at least one **Vary** command.  
**mand**      **Vary** commands are used to define the control variables associated with an Optimization sequence.

**Minimize command** A **Minimize** command is used within an Optimization sequence to define the objective function that will be minimized. Note that an optimization sequence is allowed to contain, at most, one **Minimize** command. (An Optimization sequence is not required to contain a **Minimize** command)

## Examples

```
% Constrain SMA of Sat to be 7000 km, using SQP1
NonlinearConstraint SQP1( Sat.SMA = 7000 )

% Constrain SMA of Sat to be less than or equal to 7000 km,
% using SQP1
NonlinearConstraint SQP1( Sat.SMA <= 7000 )

% Constrain the SMA of Sat to be greater than or equal to 7000 km,
% using VF13ad1
NonlinearConstraint VF13ad1( Sat.SMA >= 7000 )

% Constrain SMA of Sat to be within 10 km of 7000 km, using SNOPT1
NonlinearConstraint SNOPT1( Sat.SMA = 7000, {Tolerance = 10.0} )
```

As mentioned above, the **NonlinearConstraint** command only occurs within an **Optimize** sequence. See the **Optimize** command help for complete examples showing the use of the **NonlinearConstraint** command.

## Optimize

Solve for condition(s) by varying one or more parameters

### Script Syntax

```
Optimize SolverName {[ [SolveMode = value], [ExitMode = value],  
[ShowProgressWindow = value] ]}  
    Vary command ...  
    script statement ...  
    NonLinearConstraint command ...  
    Minimize command ...  
EndOptimize
```

### Description

The **Optimize** command in GMAT allows you to solve optimization problems by using a solver object. Currently, you can choose from one of two available solvers, the **FminconOptimizer** solver object available to all GMAT users with access to the Matlab optimization toolbox and the **VF13ad** solver object plug-in that you must install yourself.

You use the **Optimize** and **EndOptimize** commands to define an **Optimize** sequence to determine, for example, the maneuver components required to raise orbit apogee to 42164 km while simultaneously minimizing the DeltaV required to do so. **Optimize** sequences in GMAT are applicable to a wide variety of problems and this is just one example. Let's define the quantities that you don't know precisely, but need to determine, as the Control Variables. We define the conditions that must be satisfied as the Constraints and we define the quantity to be minimized (e.g., DeltaV) as the Objective function. An **Optimize** sequence numerically solves a boundary value problem to determine the value of the Control Variables required to satisfy the Constraints while simultaneously minimizing the Objective function. As was the case for the **Target/EndTarget** command sequence, you define your control variables by using **Vary** commands. You define the constraints that must be satisfied by using the **NonlinearConstraint** command and you define the objective function to be minimized by using the **Minimize** command. The **Optimize/EndOptimize** sequence is an advanced command. The examples later in this section give a more detailed explanation.

See Also: [Vary](#), [NonlinearConstraint](#), [Minimize](#), [VF13ad](#)

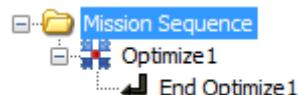
## Options

Option	Description
<b>ApplyCorrections</b>	The <b>ApplyCorrections</b> GUI button replaces the initial guess values specified in the <b>Vary</b> commands with those computed by the optimizer during a run. If the <b>Optimize</b> sequence converged, the converged values are applied. If the <b>Optimize</b> sequence did not converge, the last calculated values are applied. There is one situation where the action specified above, where the initial guess values specified in the <b>Vary</b> commands are replaced, does not occur. This happens when the initial guess value specified in the <b>Vary</b> command is given by a variable.
	<b>Accepted Data Types</b> N/A <b>Allowed Values</b> N/A <b>Default Value</b> N/A <b>Required</b> no <b>Interfaces</b> GUI, script
<b>ExitMode</b>	Controls the initial guess values for <b>Optimize</b> sequences nested in control flow. If <b>ExitMode</b> is set to <b>SaveAndContinue</b> , the solution of an <b>Optimize</b> sequence is saved and used as the initial guess for the next time this <b>Optimize</b> sequence is run. The rest of the mission sequence is then executed. If <b>ExitMode</b> is set to <b>DiscardAndContinue</b> , then the solution is discarded and the initial guess values specified in the <b>Vary</b> commands are used for each <b>Optimize</b> sequence execution. The rest of the mission sequence is then executed. If <b>ExitMode</b> is set to <b>Stop</b> , the <b>Optimize</b> sequence is executed, the solution is discarded, and the rest of the mission sequence is not executed.
	<b>Accepted Data Types</b> Reference Array <b>Allowed Values</b> <b>DiscardAndContinue, SaveAndContinue, Stop</b> <b>Default Value</b> <b>DiscardAndContinue</b> <b>Required</b> no <b>Interfaces</b> GUI, script
<b>ShowProgressWin</b> - <b>dow</b>	Flag to indicate if solver progress window should be displayed.
	<b>Accepted Data Types</b> Boolean <b>Allowed Values</b> true, false <b>Default Value</b> true <b>Required</b> no <b>Interfaces</b> GUI, script

Option	Description
<b>SolveMode</b>	Specifies how the optimization loop behaves during mission execution. When <b>SolveMode</b> is set to <b>Solve</b> , the optimization loop executes and attempts to solve the optimization problem. When <b>SolveMode</b> is set to <b>RunInitialGuess</b> , the Optimizer does not attempt to solve the optimization problem and the commands in the <b>Optimize</b> sequence execute using the initial guess values defined in the <b>Vary</b> commands.
<b>Accepted Data Types</b>	Reference Array
<b>Allowed Values</b>	<b>Solve</b> , <b>RunInitialGuess</b>
<b>Default Value</b>	<b>Solve</b>
<b>Required</b>	no
<b>Interfaces</b>	GUI, script
<b>SolverName</b>	Specifies the solver/optimizer object used in the <b>Optimize</b> sequence
<b>Accepted Data Types</b>	Reference Array
<b>Allowed Values</b>	Any <b>VD13ad</b> or <b>FminconOptimizer</b> resource
<b>Default Value</b>	<b>DefaultSQP</b>
<b>Required</b>	yes
<b>Interfaces</b>	GUI, script

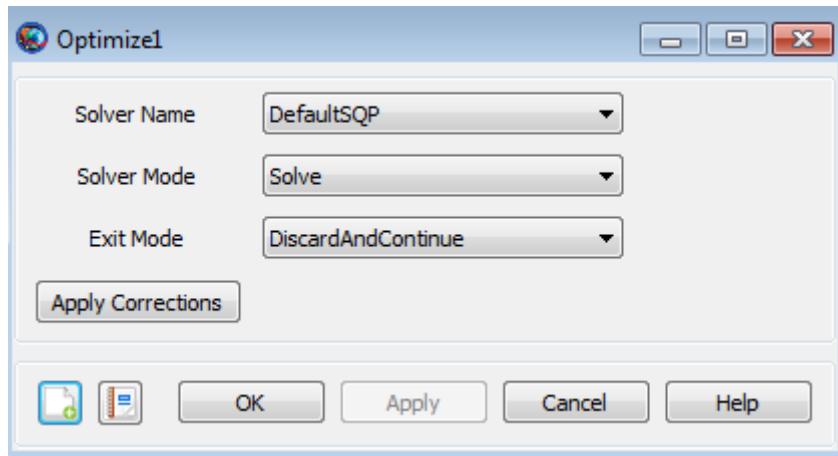
## GUI

The **Optimize** command allows you to use an optimization process to solve problems. To solve a given problem, you need to create a so-called **Optimize** sequence which we now define. When you add an **Optimize** command to the mission sequence, an **EndOptimize** command is automatically added as shown below.



In the example above, the **Optimize** command sequence is defined as all of the commands between the **Optimize1** and **EndOptimize1** commands, inclusive. Although not shown above, an **Optimize** command sequence must contain a **Vary** command which is used to define the control variables that can be varied in order to help solve our problem. An **Optimize** command must also contain a **Minimize** command and/or one or more **NonlinearConstraint** commands. You use a **Minimize** command to define a cost function that you wish to minimize and you use the **NonlinearConstraint** command to define either an equality or inequality constraint that you want to be satisfied at the end of the optimization process.

Double click on the **Optimize1** command above to open the **Optimize** command dialog box, shown below, which allows you to specify your choice of Solver (i.e., your choice of optimizer), **Solver Mode**, and **Exit Mode**. As described in the Remarks section, the **Optimize** command dialog box also allows you to apply corrections to your **Optimize** command sequence.



If you set **ShowProgressWindow** to true, then a dynamic display is shown during optimization that contains values of variables and constraints as shown below.

Solver Window - Optimize 'Optimal Transfer' SQP1 (SolveMode = Solve, ExitMode = DiscardAndContinue, ShowProgressWindow = True)			
Control Variable	Current Value	Last Value	Difference
TOI.Element1	0.1490094273682808	0.1490094273682808	2.775557561562891e-17
TOI.Element2	-0.003719561842226636	-0.003719561842226636	-4.336808689942018e-19
TOI.Element3	0.134253869565613	0.134253869565613	0
LOI.Element1	-0.7391206230620296	-0.7391206230620296	0
Constraints	Desired	Achieved	Difference
(==) MMSRef.Luna.SMA	2300	2303.170299080401	3.170299080400582
(==) MMSRef.MoonMJ2000Eq.INC	65	65.00220269255118	0.002202692551179553
(==) MMSRef.Luna.ECC	0.01	0.01137510492527216	0.00137510492527216
Objective Function	Current Value	Last Value	Difference
Cost	0.3496128821696918	0.3496215137222523	-8.63155256053405e-06

**CONVERGED**  
Optimization Completed in 21 passes through the Solver Control Sequence

## Remarks

### Content of an Optimize/EndOptimize Sequence

An **Optimize/EndOptimize** sequence must contain at least one **Vary** command and at least one of the following commands: **NonlinearConstraint** and **Minimize**. See the **Vary**, **NonlinearConstraint**, and **Minimize** command sections for details on the syntax for those commands. The first **Vary** command must occur before the first **NonlinearConstraint** or **Minimize** command. Each **Optimize** command field in the curly braces is optional. You can omit the entire list and the curly braces and the default values will be used for **Optimize** configuration fields such as **SolveMode** and **ExitMode**.

### Relation to Target/EndTarget Command Sequence

There are some functional similarities between the **Target/EndTarget** and **Optimize/EndOptimize** command sequences. In both cases, we define Control Variables and Constraints. For both **Target** and **Optimize** sequences, we use the **Vary** command to define the Control Variables. For the **Target** sequence, we use the **Achieve** com-

mand to define the constraints whereas, for an **Optimize** sequence, we use the **NonlinearConstraint** command. The big difference between the **Target** and **Optimize** sequences is that the **Optimize** sequence allows for the minimization of an Objective function through the use of the **Minimize** command.

## Command Interactions

<b>Vary command</b>	Every <b>Optimize</b> sequence must contain at least one <b>Vary</b> command. <b>Vary</b> commands are used to define the control variables associated with an <b>Optimize</b> sequence.
<b>NonlinearConstraint command</b>	<b>NonlinearConstraint</b> commands are used to define the constraints associated with an <b>Optimize</b> sequence. Note that multiple <b>NonlinearConstraint</b> commands are allowed within an <b>Optimize</b> sequence.
<b>Minimize command</b>	A <b>Minimize</b> command is used within an <b>Optimize</b> sequence to define the Objective function that will be minimized. Note that an <b>Optimize</b> sequence is allowed to contain, at most, one <b>Minimize</b> command. (An <b>Optimize</b> sequence is not required to contain a <b>Minimize</b> command)

## Examples

Use an **Optimize** sequence with the fmincon solver object to find the point,  $(x, y)$ , on the unit circle with the smallest  $y$  value. Note that the use of the **FminconOptimizer** solver assumes you have access to the Matlab optimization toolbox.

```
Create FminconOptimizer SQP1
SQP1.MaximumIterations = 50
Create Variable x y Circle

BeginMissionSequence
Optimize SQP1
    Vary SQP1(x = 1)
    Vary SQP1(y = 1)
    Circle = x*x + y*y
    NonlinearConstraint SQP1(Circle = 1)
    Minimize SQP1(y)
EndOptimize
```

Similar to the example given in the **Target** command Help, use an **Optimize** sequence to raise orbit apogee. In the **Target** command example, we had one control variable, the velocity component of an **ImpulsiveBurn** object, and the single constraint that the position vector magnitude at orbit apogee equals 42164. For this example, we keep this control variable and constraint but we now add a second control variable, the true anomaly of where the burn occurs. In addition, we ask the optimizer to minimize the Delta-V cost of the burn. As expected, the best (DV minimizing) orbit location to perform an apogee raising burn is near perigee (i.e.,  $\text{nearTA} = 0$ ). In this example, since the force model in use is not perfectly two body Keplerian, the optimal TA value obtained is close to but not exactly 0. Note that the use of the **VF13ad** solver object in this example

assumes that you have installed this optional plug-in. Finally, report the convergence status to a file.

```
Create Spacecraft aSat
Create Propagator aPropagator
Create ImpulsiveBurn aBurn
Create VF13ad VF13ad1
VF13ad1.Tolerance = 1e-008
Create OrbitView EarthView
EarthView.Add = {Earth, aSat}
EarthView.ViewScaleFactor = 5
Create Variable ApogeeRadius DVCost
Create ReportFile aReport

BeginMissionSequence
Optimize VF13ad1
  Vary VF13ad1(aSat.TA = 100, {MaxStep = 10})
  Vary VF13ad1(aBurn.Element1 = 1, {MaxStep = 1})
  Maneuver aBurn(aSat)
  Propagate aPropagator(aSat) {aSat.Apoapsis}
  GMAT ApogeeRadius = aSat.RMAG
  NonlinearConstraint VF13ad1(ApogeeRadius=42164)
  GMAT DVCost = aBurn.Element1
  Minimize VF13ad1(DVCost)
EndOptimize
Report aReport VF13ad1.SolverStatus VF13ad1.SolverState
```

## Target

Solve for condition(s) by varying one or more parameters

### Script Syntax

```
Target SolverName {[ [SolveMode = value], [ExitMode = value],  
[ShowProgressWindow = value] ]]  
    Vary command ...  
    script statement ...  
    Achieve command ...  
EndTarget
```



#### Note

See the section called “Remarks” and the section called “Description” for this complex command. Multiple **Vary** and **Achieve** commands are permitted. Script statements can appear anywhere in the **Target** sequence.

## Description

The **Target** and **EndTarget** commands are used to define a **Target** sequence to determine, for example, the maneuver components required to raise the orbit apogee to 42164 km. Another common targeting example is to determine the parking orbit orientation required to align a lunar transfer orbit with the moon. **Target** sequences in GMAT are general and these are just examples. Let’s define the quantities whose values you don’t know precisely, but need to determine, as the *control variables*. Define the conditions that must be satisfied as the *constraints*. A **Target** sequence numerically solves a boundary value problem to determine the value of the control variables required to satisfy the constraints. You define your control variables by using **Vary** commands and you define the problems constraints using **Achieve** commands. The **Target/EndTarget** sequence is an advanced command. The examples later in this section give additional details.

See also: [DifferentialCorrector](#), [Vary](#), [Achieve](#), [Optimize](#),

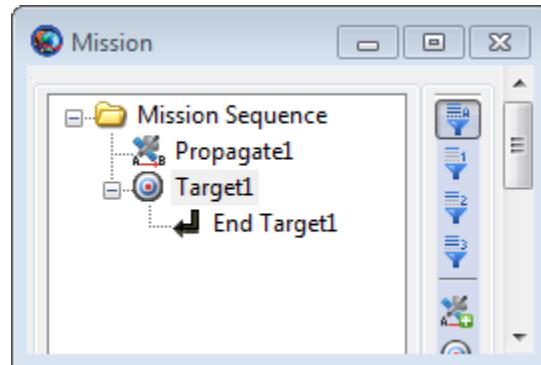
## Options

Option	Description										
<b>ApplyCorrections</b>	<p>This GUI button replaces the initial guess values specified in the <b>Vary</b> commands. If the <b>Target</b> sequence converged, the converged values are applied. If the <b>Target</b> sequence did not converge, the last calculated values are applied. There is one situation where the action specified above, where the initial guess values specified in the <b>Vary</b> commands are replaced, does not occur. This happens when the initial guess value specified in the <b>Vary</b> command is given by a variable. See the Remarks section of the help for additional details.</p> <table> <tr> <td><b>Accepted Data Types</b></td><td>N/A</td></tr> <tr> <td><b>Allowed Values</b></td><td>N/A</td></tr> <tr> <td><b>Default Value</b></td><td>N/A</td></tr> <tr> <td><b>Required</b></td><td>no</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI</td></tr> </table>	<b>Accepted Data Types</b>	N/A	<b>Allowed Values</b>	N/A	<b>Default Value</b>	N/A	<b>Required</b>	no	<b>Interfaces</b>	GUI
<b>Accepted Data Types</b>	N/A										
<b>Allowed Values</b>	N/A										
<b>Default Value</b>	N/A										
<b>Required</b>	no										
<b>Interfaces</b>	GUI										
<b>ExitMode</b>	<p>Controls the initial guess values for <b>Target</b> sequences nested in control flow. If <b>ExitMode</b> is set to <b>SaveAndContinue</b>, the solution of a <b>Target</b> sequence is saved and used as the initial guess for the next <b>Target</b> sequence execution. The rest of the mission sequence is then executed. If <b>ExitMode</b> is set to <b>DiscardAndContinue</b>, then the solution is discarded and the initial guess values specified in the <b>Vary</b> commands are used for each <b>Target</b> sequence execution. The rest of the mission sequence is then executed. If <b>ExitMode</b> is set to <b>Stop</b>, the <b>Target</b> sequence is executed, the solution is discarded, and the rest of the mission sequence is not executed.</p> <table> <tr> <td><b>Accepted Data Types</b></td><td>Reference Array</td></tr> <tr> <td><b>Allowed Values</b></td><td><b>DiscardAndContinue</b>, <b>SaveAndContinue</b>, <b>Stop</b></td></tr> <tr> <td><b>Default Value</b></td><td><b>DiscardAndContinue</b></td></tr> <tr> <td><b>Required</b></td><td>no</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Accepted Data Types</b>	Reference Array	<b>Allowed Values</b>	<b>DiscardAndContinue</b> , <b>SaveAndContinue</b> , <b>Stop</b>	<b>Default Value</b>	<b>DiscardAndContinue</b>	<b>Required</b>	no	<b>Interfaces</b>	GUI, script
<b>Accepted Data Types</b>	Reference Array										
<b>Allowed Values</b>	<b>DiscardAndContinue</b> , <b>SaveAndContinue</b> , <b>Stop</b>										
<b>Default Value</b>	<b>DiscardAndContinue</b>										
<b>Required</b>	no										
<b>Interfaces</b>	GUI, script										
<b>ShowProgressWin</b> - <b>dow</b>	<p>Flag to indicate if solver progress window should be displayed.</p> <table> <tr> <td><b>Accepted Data Types</b></td><td>Boolean</td></tr> <tr> <td><b>Allowed Values</b></td><td>true, false</td></tr> <tr> <td><b>Default Value</b></td><td>true</td></tr> <tr> <td><b>Required</b></td><td>no</td></tr> <tr> <td><b>Interfaces</b></td><td>GUI, script</td></tr> </table>	<b>Accepted Data Types</b>	Boolean	<b>Allowed Values</b>	true, false	<b>Default Value</b>	true	<b>Required</b>	no	<b>Interfaces</b>	GUI, script
<b>Accepted Data Types</b>	Boolean										
<b>Allowed Values</b>	true, false										
<b>Default Value</b>	true										
<b>Required</b>	no										
<b>Interfaces</b>	GUI, script										

Option	Description
<b>SolveMode</b>	Specifies how the <b>Target</b> sequence behaves during mission execution. When <b>SolveMode</b> is set to <b>Solve</b> , the <b>Target</b> sequence executes and attempts to solve the boundary value problem satisfying the targeter constraints (i.e, goals). When <b>SolveMode</b> is set to <b>RunInitialGuess</b> , the targeter does not attempt to solve the boundary value problem and the commands in the <b>Target</b> sequence execute using the initial guess values defined in the <b>Vary</b> commands.
Accepted Data Types	Reference Array
Allowed Values	<b>Solve</b> , <b>RunInitialGuess</b>
Default Value	<b>Solve</b>
Required	no
Interfaces	GUI, script
<b>SolverName</b>	Identifies the <b>DifferentialCorrector</b> used for a <b>Target</b> sequence.
Accepted Data Types	<b>DifferentialCorrector</b>
Allowed Values	Any user-defined or default <b>DifferentialCorrector</b>
Default Value	<b>DefaultDC</b>
Required	yes
Interfaces	GUI, script

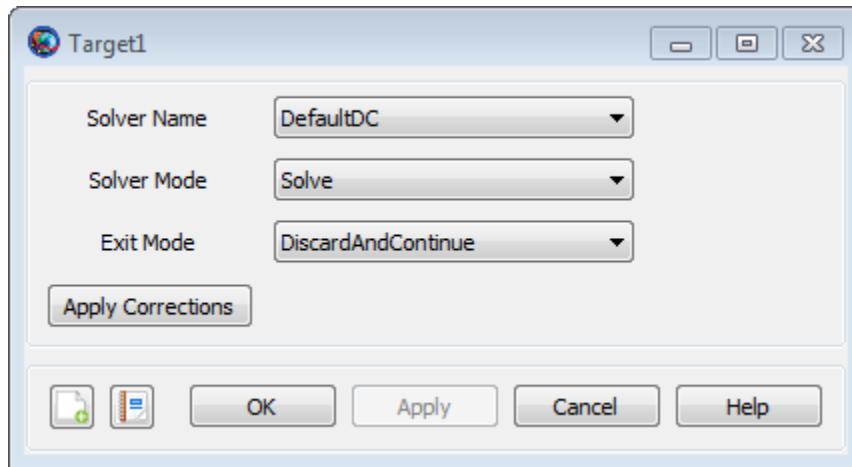
## GUI

The **Target** command allows you to use a differential correction process to solve problems. To solve a given problem, you need to create a so-called **Target** sequence which we now define. When you add a **Target** command to the mission sequence, an **End-Target** command is automatically added as shown below.



In the example above, the **Target** command sequence is defined as all of the commands between the **Target1** and **End Target1** commands, inclusive. Although not shown above, a **Target** command sequence must contain both a **Vary** command and an **Achieve** command. The **Vary** command is used to define the control variables which can be varied in order to achieve a certain goal. The **Achieve** command is used to define the desired goal. In order for the **Target** sequence to be well formed, there must be at least one **Vary** command before any **Achieve** commands, so that the variable

defined in the **Vary** command can affect the goal specified in the subsequent **Achieve** commands. Double click on **Target1** command above to bring up the **Target** command dialog box, shown below, which allows you to specify your choice of **Solver** (i.e., your choice of **DifferentialCorrector**), **Solver Mode**, and **Exit Mode**. As described in the Remarks section, the **Target** command dialog box also allows you to apply corrections to your **Target** command sequence.



If you set **ShowProgressWindow** to true, then a dynamic display is shown during targeting that contains values of variables and constraints as shown below.

Solver Window - Target 'Change Plane/Perigee' DC (SolveMode = Solve, ExitMode = DiscardAndContinue, Sho...			
Control Variable	Current Value	Last Value	Difference
MCC.Element1	0.7597813500198917	0.7597813500198917	0
MCC.Element2	0.7881136874688297	0.7881136874688297	0
Constraints	Desired	Achieved	Difference
(==) geoSat.EarthMJ2000Eq.INC	2	1.99999999997844	-2.156053113822054e-11
(==) geoSat.RMAG	42195	42195.00000083651	8.365095709450543e-07
<b>CONVERGED</b>			

## Remarks

### Content of a Target/EndTarget Sequence

A **Target/EndTarget** sequence must contain at least one **Vary** command and at least one **Achieve** Command. See the **Vary** and **Achieve** command sections for details on the syntax for those commands. The First **Vary** command must occur before the first **Achieve** command. **Target** commands must be coupled with one and only one **End-Target** command. Each **Target** command field in the curly braces is optional. You can omit the entire list and the curly braces and the default values will be used for **Target** configuration fields such as **SolveMode** and **ExitMode**.

### Use of a Target/EndTarget Sequence

GMAT **Target** sequences can solve square problems (the number of Control Variables equals the number of constraints), over-determined problems (the number of Control Variables is less than the number of constraints) and under-determined problems (the

number of Control Variables is greater than the number of constraints). In any of these cases, there may not be a solution and the type of solution found depends on the selection of the targeter (currently, only differential correctors are supported). Assuming a solution to the problem exists and assuming certain mathematical conditions are satisfied, there is often one solution for a square problem and many solutions to an under-determined problem. Problems with more goals (i.e., constraints) than variables may not have a solution. If your problem is under-determined, consider using an **Optimize** sequence to find an optimal solution in the space of feasible solutions.



### Caution

If you configure a **Target** sequence and get the error “Rmatrix error: matrix is singular”, then your control variables defined in the **Vary** commands do not affect the constraints defined in the **Achieve** commands. A common mistake in this case is that you forgot to apply a maneuver.

### Note on Using Apply Corrections

After the **Target** sequence has been run, you may choose to apply corrections by navigating to the **Mission** tree, right-clicking the **Target** command to bring up the **Target** window, and clicking the **Apply Corrections** button. The **Apply Corrections** button replaces the initial guess values specified in the **Vary** commands . If the **Target** sequence converged, the converged values are applied. If the **Target** sequence did not converge, the last calculated values are applied. Note that the **Apply Corrections** feature is only currently available through the GUI interface.

There is one situation where the action specified above, where the initial guess values specified in the **Vary** commands are replaced, does not occur. This happens, as illustrated in the example below, when the initial guess value specified in the **Vary** command is given by a variable. In this situation, the **Apply Corrections** button has no effect since GMAT does not allow variables to be overwritten.

```
Create Variable InitialGuess_BurnDuration BurnDuration
Create DifferentialCorrector aDC
BeginMissionSequence
Target aDC
Vary aDC(BurnDuration = InitialGuess_BurnDuration)
Achieve aDC(BurnDuration = 10) % atypical Achieve command for
                                % illustrative purposes only
EndTarget
```

### Command Interactions

**Vary com-** Every **Target** sequence must contain at least one **Vary** command. **Vary mand** commands are used to define the control variables associated with a **Tar- get** sequence.

**Achieve command** Every **Target** sequence must contain at least one **Achieve** command. **Achieve** commands are used to define the goals associated with a **Target** sequence.

## Examples

Use a **Target** sequence to solve for a root of an algebraic equation. Here we provide an initial guess of 5 for the Control Variable (or independent variable)  $x$ , and solve for the value of  $x$  that satisfies the Constraint  $y = 0$ , where  $y := 3*x^3 + 2*x^2 - 4*x + 8$ . After executing this example you can look in the message window to see the solution for the variable  $x$ . You can easily check that the value obtained does indeed satisfy the constraint.

```
Create Variable x y
Create DifferentialCorrector aDC

BeginMissionSequence

Target aDC
  Vary aDC(x = 5)
  y = 3*x^3 + 2*x^2 - 4*x + 8
  Achieve aDC(y = 0,{Tolerance = 0.0000001})
EndTarget
```

Use a **Target** sequence to raise orbit apogee. Here the control variable is the velocity component of an **ImpulsiveBurn** object. The Constraint is that the position vector magnitude at orbit apogee is 42164. Report the convergence status to a file.

```
Create Spacecraft aSat
Create Propagator aPropagator
Create Variable I

Create ImpulsiveBurn aBurn
Create DifferentialCorrector aDC
Create OrbitView EarthView
EarthView.Add = {Earth,aSat}
EarthView.ViewScaleFactor = 5

Create ReportFile aReport

BeginMissionSequence
Target aDC
  Vary aDC(aBurn.Element1 = 1.0, {Upper = 3})
  Maneuver aBurn(aSat)
  Propagate aPropagator(aSat,{aSat.Apoapsis})
  Achieve aDC(aSat.RMAG = 42164)
EndTarget
Report aReport aDC.SolverStatus aDC.SolverState
```

Similar to the previous example, we use a **Target** sequence to raise orbit apogee except that this time we use a finite burn. Here the control variable is the duration of the Velocity component of a **FiniteBurn** object. The Constraint is that the position vector magnitude at orbit apogee is 12000. Additional detail on the example below can be found in the Target Finite Burn to Raise Apogee tutorial.

```
Create Spacecraft DefaultSC
Create Propagator DefaultProp
Create ChemicalThruster Thruster1
GMAT Thruster1.C1 = 1000
GMAT Thruster1.DecrementMass = true
Create ChemicalTank FuelTank1
GMAT Thruster1.Tank = {FuelTank1}
Create FiniteBurn FiniteBurn1
GMAT FiniteBurn1.Thrusters = {Thruster1}
GMAT DefaultSC.Tanks = {FuelTank1}
GMAT DefaultSC.Thrusters = {Thruster1}
Create Variable BurnDuration
Create DifferentialCorrector DC1

BeginMissionSequence

Propagate DefaultProp(DefaultSC) {DefaultSC.Earth.Periapsis}
Target DC1
  Vary DC1(BurnDuration = 200, {Upper = 10000})
  BeginFiniteBurn FiniteBurn1(DefaultSC)
  Propagate DefaultProp(DefaultSC){DefaultSC.ElapsedSecs=BurnDuration}
  EndFiniteBurn FiniteBurn1(DefaultSC)
  Propagate DefaultProp(DefaultSC) {DefaultSC.Earth.Apoapsis}
  Achieve DC1(DefaultSC.Earth.RMAG = 12000)
EndTarget
```

## Vary

Specifies variables used by a solver

### Script Syntax

```
Vary SolverName(<UserSelectedControl>=InitialGuess,
[{{[Perturbation=Arg1], [MaxStep=Arg2],
[Lower=Arg3], [Upper=Arg4],
[AdditiveScalefactor=Arg5], [MultiplicativeScalefactor=Arg6]}])
```

### Description

The **Vary** command is used in conjunction with either the **Target** or the **Optimize** command. The **Vary** command defines the control variable used by the targeter or optimizer. The **Target** or **Optimize** sequence then varies these control variables until certain desired conditions are met. Every **Target** or **Optimize** sequence must contain at least one **Vary** command.

See Also: [DifferentialCorrector](#), [FminconOptimizer](#), [VF13ad](#), [Target](#), [Optimize](#)

### Options

Option	Description
<b>AdditiveScaleFactor</b>	Number used to nondimensionalize the independent variable. The solver sees only the nondimensional form of the variable. The nondimensionalization is performed using the following equation: $x_n = m (x_d + a)$ . ( $x_n$ is the non-dimensional parameter. $x_d$ is the dimensional parameter. $a$ = additive scale factor. $m$ = multiplicative scale factor.) Note the nondimensionalization process occurs after the perturbation to the control variable has been applied. Thus, $x_d$ represents a perturbed control variable.
<b>Accepted Data Types</b>	Real Number, Array element, Variable, or any user defined parameter
<b>Allowed Values</b>	Real Number, Array element, Variable, or any user defined parameter
<b>Default Value</b>	0
<b>Required</b>	no
<b>Interfaces</b>	GUI, script

Option	Description
<b>InitialGuess</b>	Specifies the initial guess for the selected <b>Variable</b>
	<b>Accepted Data Types</b> Real Number, Array element, Variable, or any user-defined parameter that obeys the conditions for the selected Variable object
	<b>Allowed Values</b> Real Number, Array element, Variable, or any user-defined parameter that obeys the conditions for the selected Variable object
	<b>Default Value</b> 0.5
	<b>Required Interfaces</b> yes
	<b>GUI, script</b>
<b>Lower</b>	The <b>Lower</b> option is used to set the lower bound of the control <b>Variable</b> . <b>Lower</b> must be less than <b>Upper</b> . See <a href="#">the section called “ Vary Command Options ”</a> for information on which solvers support this setting.
	<b>Accepted Data Types</b> Real Number, Array element, Variable, or any user defined parameter
	<b>Allowed Values</b> Real Number, Array element, Variable, or any user defined parameter (Upper > Lower )
	<b>Default Value</b> 0
	<b>Required Interfaces</b> no
	<b>GUI, script</b>
<b>MaxStep</b>	The <b>MaxStep</b> option is the maximum allowed change in the control variable during a single iteration of the solver. See <a href="#">the section called “ Vary Command Options ”</a> for information on which solvers support this setting.
	<b>Accepted Data Types</b> Real Number, Array element, Variable, or any user defined parameter $> 0$
	<b>Allowed Values</b> Real Number, Array element, Variable, or any user defined parameter $> 0$
	<b>Default Value</b> 0.2
	<b>Required Interfaces</b> no
	<b>GUI, script</b>

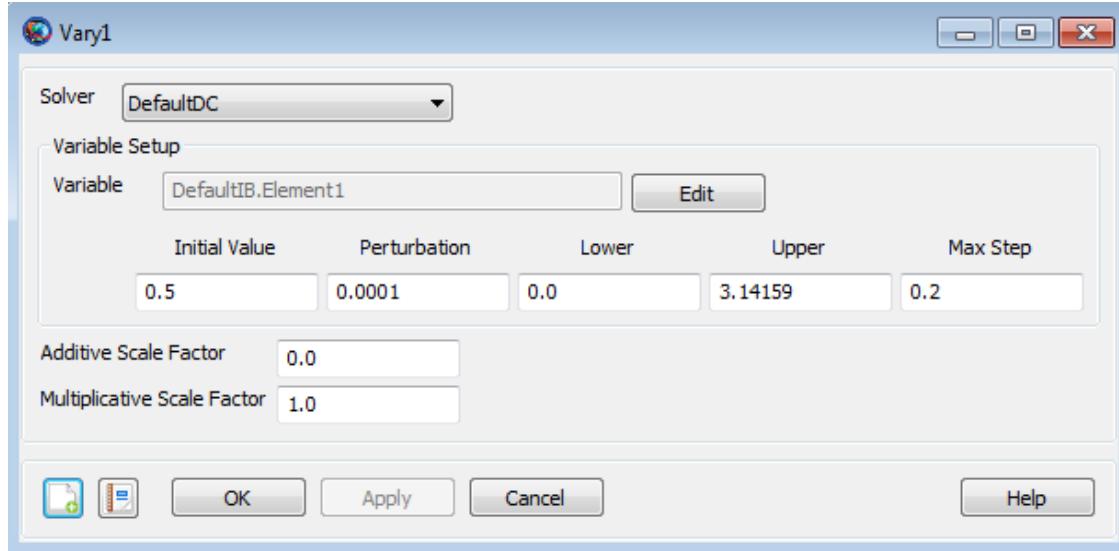
Option	Description
<b>MultiplicativeScaleFactor</b>	<p>Number used to nondimensionalize the independent variable. The solver sees only the nondimensional form of the variable. The nondimensionalization is performed using the following equation: <math>x_n = m(x_d + a)</math>. (<math>x_n</math> is the non-dimensional parameter. <math>x_d</math> is the dimensional parameter. <math>a</math>= additive scale factor. <math>m</math>= multiplicative scale factor.) Note the nondimensionalization process occurs after the perturbation to the control variable has been applied. Thus, <math>x_d</math> represents a perturbed control variable.</p>
	<p><b>Accepted Data Types</b> Real Number, Array element, Variable, or any user defined parameter</p>
	<p><b>Allowed Values</b> Real Number, Array element, Variable, or any user defined parameter <math>&gt; 0</math></p>
	<p><b>Default Value</b> 1</p>
	<p><b>Required Interfaces</b> no</p>
<b>Perturbation</b>	<p>The <b>Perturbation</b> option is the perturbation step size used to calculate the finite difference derivative. See <a href="#">the section called “Vary Command Options”</a> for information on which solvers support this setting.</p>
	<p><b>Accepted Data Types</b> Real Number, Array element, Variable, or any user defined parameter</p>
	<p><b>Allowed Values</b> Real Number, Array element, Variable, or any user defined parameter <math>\neq 0</math></p>
	<p><b>Default Value</b> 0.0001</p>
	<p><b>Required Interfaces</b> no</p>
	<p><b>GUI, script</b></p>

Option	Description
<b>SolverName</b>	Allows you to choose which solver to assign to the <b>Vary</b> command. In the context of a <b>Target</b> sequence, you will choose a <b>DifferentialCorrector</b> object. In the context of an <b>Optimize</b> sequence, you will choose either a <b>FminconOptimizer</b> or <b>VF13ad</b> object.
	<b>Accepted Data Types</b> Solver (either an Optimizer or a Targeter) <b>Allowed Values</b> Any user defined Optimizer or Targeter <b>Default Value</b> DefaultDC in a <b>Target</b> sequence and DefaultSQP in an <b>Optimize</b> sequence <b>Required Interfaces</b> yes GUI, script
<b>Upper</b>	<p>The <b>Upper</b> option is used to set the upper bound of the control <b>Variable</b>. <b>Lower</b> must be less than <b>Upper</b>. See <a href="#">the section called “ Vary Command Options ”</a> section for information on which solvers support this setting.</p>
	<b>Accepted Data Types</b> Real Number, Array element, Variable, or any user defined parameter <b>Allowed Values</b> Real Number, Array element, Variable, or any user defined parameter (Upper > Lower ) <b>Default Value</b> 3.14159 <b>Required Interfaces</b> no GUI, script

Option	Description
<b>UserSelectedControl</b>	Allows you to select any single element user-defined parameter, except a number, to vary. For example, DefaultIB.V, DefaultIB.N, DefaultIB.Element1, DefaultSC.TA, Array(1,1), and <b>Variable</b> are all valid values. The three element burn vector or multidimensional Arrays are not valid values.
<b>Accepted Data Types</b>	Parameter, Array element, <b>Variable</b> , or any other single element user-defined parameter, excluding numbers. Note that the variable chosen must be settable in the <b>Mission</b> tree.
<b>Allowed Values</b>	Spacecraft parameter, Array element, <b>Variable</b> , or any other single element user-defined parameter, excluding numbers
<b>Default Value</b>	DefaultIB.Element1
<b>Required Interfaces</b>	yes GUI, script

## GUI

The **Vary** command, only valid within either a **Target** or an **Optimize** sequence, is used to define the control variables which will be used to solve a problem. The **Vary** command dialog box is shown below.



The **Vary** command dialog box allows you to specify

- Choice of **Solver** (a differential corrector if using a **Target** sequence or an optimizer if using an **Optimize** sequence).
- Control **Variable** object. To define the control **Variable** used in the **Vary** command, click the **Edit** button to bring up the **ParameterSelectDialog** as shown below. Use the arrow to select the desired object and then click **OK**.
- **Initial Value** for the control variable object.
- **Perturbation** Step size used as part of the finite differencing algorithm. As noted in the Remarks section, this field is only used if the solver chosen is a differential corrector or a VF13AD optimizer.
- **Lower** allowed limit for the converged control variable object. As noted in the Remarks section, this field is only used if the solver chosen is a differential corrector or a fmincon optimizer.
- **Upper** allowed limit for the converged control variable object. As noted in the Remarks section, this field is only used if the solver chosen is a differential corrector or a fmincon optimizer.
- Maximum step size (**Max Step**), per iteration, for the control variable object. As noted in the Remarks section, this field is only used if the solver chosen is a differential corrector or a VF13AD optimizer.
- **Additive Scale Factor** used to scale the control variable object.
- **Multiplicative Scale Factor** used to scale the control variable object.

## Remarks

### Vary Command Options

The **Vary** command is designed to work with all three of the GMAT targeters and optimizers (Differential Corrector, fmincon, and VF13AD). The solvers, which are developed by different parties, all work slightly differently and thus have different needs. The table below shows which command options are available for a given solver.

	Differen- tial Cor- rector	fmincon	VF13AD	SNOPT	Yukon
<b>SolverName</b>	X	X	X	X	X
<b>Variable</b>	X	X	X	X	X
<b>InitialGuess</b>	X	X	X	X	X
<b>AdditiveScaleFactor</b>	X	X	X	X	X
<b>MultiplicativeScaleFactor</b>	X	X	X	X	X
<b>Lower</b>	X	X		X	X
<b>Upper</b>	X	X		X	X
<b>Perturbation</b>	X		X		X
<b>MaxStep</b>	X		X		X

The **Vary** syntax allows you to specify the value of an option even if a particular solver would not use the information.

## Vary Command Accepts Repeated Parameters

As shown in the example below, the **Vary** command accepts repeated parameters.

```
Vary DefaultDC(ImpulsiveBurn1.Element1 = 2, ...
{Perturbation = 1e99, Perturbation = .001})
```

The accepted best practice is not to repeat parameters in any given command. However, for the **Vary** command, if you accidentally sets the same parameter multiple times, the last setting takes precedence. Thus, in the example above, the perturbation step size is set to 0.001.

## Use of Thruster Parameters in a Vary Command

If you wish to use thruster parameters, such as thrust direction, in a **Vary** command, then you must reference the cloned (child) object directly. In the example below, we first show syntax, using the parent object that does not work. We then show the correct syntax using the cloned (child) object.

```
%Referencing the parent object, thruster1, does not work.
Vary DC1(thruster1.ThrustDirection1 = 0.4)
Vary DC1(thruster1.ThrustDirection2 = 0.5)
```

```
%Referencing the cloned (child) object, Sc.thruster1, does work.
Vary DC1(Sc.thruster1.ThrustDirection1 = 0.4)
Vary DC1(Sc.thruster1.ThrustDirection2 = 0.5)
```

## Command Interactions

<b>Target command</b>	A <b>Vary</b> command only occurs within a <b>Target</b> or <b>Optimize</b> sequence.
<b>Optimize command</b>	A <b>Vary</b> command only occurs within a <b>Target</b> or <b>Optimize</b> sequence.
<b>Achieve command</b>	The <b>Achieve</b> command, used as part of a <b>Target</b> sequence, specifies the desired result or goal (obtained by using the <b>Vary</b> command to vary the control variables).
<b>NonlinearConstraint command</b>	The <b>NonlinearConstraint</b> command, used as part of an <b>Optimize</b> sequence, specifies the desired result or goal (obtained by using the <b>Vary</b> command to vary the control variables).
<b>Minimize command</b>	The <b>Minimize</b> command, used as part of an <b>Optimize</b> sequence, specifies the desired quantity to be minimized (obtained by using the <b>Vary</b> command to vary the control variables).

## Examples

As mentioned above, the **Vary** command only occurs within either a **Target** or an **Optimize** sequence. See the **Target** and **Optimize** command help for examples showing the use of the **Vary** command.



# Orbit Determination

This chapter contains documentation for Resources and Commands related to orbit determination.

## Resources

## AcceptFilter

Allows selection of data subsets for processing by the batch least squares estimator.

### Description

The **AcceptFilter** object is used to create criteria for the inclusion of subsets of the available data in the estimation process based on observation frequency, tracker, measurement type, record number, or time. Instances of **AcceptFilter** are specified for use on the **DataFilters** field of a **TrackingFileSet** or **BatchEstimator** object.

GMAT implements two levels of data editing for estimation. First-level editing criteria are specified on the **DataFilters** field of the **TrackingFileSet** instance. At this level, the user may choose what data is admitted into the overall pool of observations provided to the estimator. Any data excluded at the tracking file set level will be immediately discarded and not available to the estimation process.

Second-level data editing is specified on the **DataFilters** field of the **BatchEstimator** instance. At this level, the user may choose what data is used in the estimation state update. Residuals will be computed for any observations admitted through first-level editing, but any data excluded at the estimator level will be flagged as user edited, and will not affect the computation of the state correction. This allows the user to evaluate the quality of untrusted data against a solution computed using a trusted set of measurements.

A single **AcceptFilter** may employ multiple selection criteria (for example simultaneously thinning different stations or data types by differing intervals). Multiple criteria on a single filter are considered in an AND sense. When multiple criteria are specified on a single filter, an observation must meet all specified criteria to be accepted.

Multiple **AcceptFilters** with different selection criteria may be specified on a single **TrackingFileSet** or **BatchEstimator**. When multiple filters are specified, these act in an OR sense. Data meeting criteria for any of the specified filters will be accepted.

See Also [RejectFilter](#), [TrackingFileSet](#), [BatchEstimator](#)

### Fields

Field	Description	
<b>DataTypes</b>	List of data types	
	<b>Data Type</b>	String Array
	<b>Allowed Values</b>	A set of any supported GMAT measurement types, or 'All'
	<b>Access</b>	set
	<b>Default Value</b>	{All}
	<b>Units</b>	N/A
	<b>Interfaces</b>	script

Field	Description
<b>EpochFormat</b>	Allows user to select format of the epoch
<b>Data Type</b>	String
<b>Allowed Values</b>	UTCGregorian, UTCModJulian, TAIGregorian, TAIModJulian, TTGregorian, TTModJulian A1Gregorian, A1ModJulian, TDBGregorian, TDBModJulian
<b>Access</b>	set
<b>Default Value</b>	<b>TAIModJulian</b>
<b>Units</b>	N/A
<b>Interfaces</b>	script
<b>FileNames</b>	List of file names (a subset of the relevant <b>TrackingFileSet</b> 's <b>FileName</b> field) containing the tracking data. If this field equals From_AddTrackingConfig, then two things happen; (1) All of the files in the relevant <b>TrackingFileSet</b> are used as a starting point, and (2) Of the data in all of the files, only the data defined by the <b>AddTrackingConfig</b> field of the relevant <b>TrackingFileSet</b> are used. This field is only applicable when the <b>AcceptFilter</b> is used on a <b>TrackingFileSet</b> .
<b>Data Type</b>	StringArray
<b>Allowed Values</b>	valid file name, 'All', or 'From_AddTrackingConfig'
<b>Access</b>	set
<b>Default Value</b>	{All}
<b>Units</b>	N/A
<b>Interfaces</b>	script
<b>FinalEpoch</b>	Final epoch of desired data to process
<b>Data Type</b>	String
<b>Allowed Values</b>	any valid epoch
<b>Access</b>	set
<b>Default Value</b>	<b>latest day defined in GMAT</b>
<b>Units</b>	N/A
<b>Interfaces</b>	script
<b>InitialEpoch</b>	Initial epoch of desired data to process
<b>Data Type</b>	String
<b>Allowed Values</b>	any valid epoch
<b>Access</b>	set
<b>Default Value</b>	<b>earliest day defined in GMAT</b>
<b>Units</b>	N/A
<b>Interfaces</b>	script

Field	Description												
<b>ObservedObjects</b>	<p>List of user-created tracked objects (e.g., name of the <b>Spacecraft</b> resource being tracked)</p> <table> <tr> <td><b>Data Type</b></td><td>Object Array</td></tr> <tr> <td><b>Allowed Values</b></td><td>User defined observed object or 'All'</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>{All}</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Object Array	<b>Allowed Values</b>	User defined observed object or 'All'	<b>Access</b>	set	<b>Default Value</b>	{All}	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Object Array												
<b>Allowed Values</b>	User defined observed object or 'All'												
<b>Access</b>	set												
<b>Default Value</b>	{All}												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>RecordNumbers</b>	<p>A list of one or more single record numbers or spans of record numbers to accept. Observation record numbers are reported in the GMAT estimator output file. This field is only applicable when the <b>AcceptFilter</b> is used on the estimator level.</p> <table> <tr> <td><b>Data Type</b></td><td>String array</td></tr> <tr> <td><b>Allowed Values</b></td><td>Integers or spans of integers (see examples)</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>{All}</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String array	<b>Allowed Values</b>	Integers or spans of integers (see examples)	<b>Access</b>	set	<b>Default Value</b>	{All}	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	String array												
<b>Allowed Values</b>	Integers or spans of integers (see examples)												
<b>Access</b>	set												
<b>Default Value</b>	{All}												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>ThinMode</b>	<p>'Frequency' for record count frequency mode and 'Time' for time interval mode. This field is only applicable when the <b>AcceptFilter</b> is used on a <b>TrackingFileSet</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>'Frequency' or 'Time'</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>Frequency</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	'Frequency' or 'Time'	<b>Access</b>	set	<b>Default Value</b>	<b>Frequency</b>	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	String												
<b>Allowed Values</b>	'Frequency' or 'Time'												
<b>Access</b>	set												
<b>Default Value</b>	<b>Frequency</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												

Field	Description
<b>ThinningFrequency</b>	If <b>ThinMode</b> is Frequency, the integer 'n' is used to specify that every nth data point should be accepted. For example, 3 specifies that every third data point, meeting all the accept criteria, should be accepted and 1 specifies that every data point, meeting all the accept criteria, should be accepted. If <b>ThinMode</b> is Time, the integer 'n' is a number of seconds between accepted observations, using the first available observation as the anchor epoch. For example, a value of 300 means that observations will be accepted every 300 seconds, starting from the first available observation. This field is only applicable when the <b>AcceptFilter</b> is used on a <b>TrackingFileSet</b> .
	<p><b>Data Type</b> Integer</p> <p><b>Allowed Values</b> Positive Integer</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 1</p> <p><b>Units</b> Depends on <b>ThinMode</b> value</p> <p><b>Interfaces</b> script</p>
<b>Trackers</b>	List of user-created trackers (e.g., name of the <b>GroundStation</b> resource being used)
	<p><b>Data Type</b> Object Array</p> <p><b>Allowed Values</b> any valid user-created Tracker object (e.g., <b>GroundStation</b>) or 'All'</p> <p><b>Access</b> set</p> <p><b>Default Value</b> {All}</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> script</p>

## Remarks

Some fields of **AcceptFilter** are not applicable at either the first-level (tracking file set) or second-level (estimator) editing stages. The **RecordNumbers** field has no functionality when applied to an accept filter at the tracking file set level. The **FileNames**, **ThinningFrequency**, and **ThinMode** fields have no functionality when applied to an accept filter at the estimator level.

Use of combinations of instances of **AcceptFilter** and **RejectFilter** at both levels is permitted.

## Examples

### First-level (**TrackingFileSet**) Data Editing

The following examples illustrate use of an **AcceptFilter** for first-level data editing. At this level, the **AcceptFilter** instance should be assigned to the **DataFilters** field of a **TrackingFileSet**. In these examples, only data meeting the criteria specified by the accept filter will be admitted through. All other data is immediately discarded.

This example shows how to create an **AcceptFilter** to sample the data at a frequency of 1:10 (thinning the data to one tenth of its volume).

```
Create AcceptFilter af;  
  
af.ThinningFrequency = 10;  
  
Create TrackingFileSet estData;  
  
estData.DataFilters = {af};  
  
BeginMissionSequence;
```

The next example will accept all data from station **GDS** and accept every 5th observation from station **CAN**. Only data from stations **GDS** and **CAN** will be accepted.

```
Create AcceptFilter af1;  
Create AcceptFilter af2;  
  
Create GroundStation GDS CAN;  
  
af1.Trackers      = {'GDS'};  
af2.Trackers      = {'CAN'};  
af2.ThinningFrequency = 5;  
  
Create TrackingFileSet estData;  
  
estData.DataFilters = {af1, af2};  
  
BeginMissionSequence;
```

The last example illustrates thinning data by time interval, using a 300-second thinning interval.

```
Create AcceptFilter saf;  
  
af.ThinMode        = 'Time';  
af.ThinningFrequency = 300;  
  
Create TrackingFileSet estData;  
  
estData.DataFilters = {af};  
  
BeginMissionSequence;
```

### Second-level (estimator) Data Editing

The following examples illustrate use of an **AcceptFilter** for second-level data editing. At this level, the **AcceptFilter** instance should be assigned to the **DataFilters** field of a **BatchEstimator**. In these examples, only data meeting the criteria specified by the

accept filter will be used in the estimation state update. Residuals will be computed for all available data (all data admitted at the first level), but data not accepted at the estimator level will be flagged as user edited.

This example shows how to create an **AcceptFilter** to accept specific data records by record number.

```
Create AcceptFilter af;  
  
af.RecordNumbers = {10, 11, 20-150, 155-300};  
  
Create BatchEstimator bls;  
  
bls.DataFilters = {af};  
  
BeginMissionSequence;
```

The next example will accept only range data from station **MAD** over the time span 10 Jun 2012 02:56 to 13:59.

```
Create AcceptFilter af;  
Create GroundStation MAD;  
  
af.Trackers      = {'MAD'};  
af.DataTypes     = {'Range'};  
af.EpochFormat   = UTCGregorian;  
af.InitialEpoch  = '10 Jun 2012 02:56:00.000';  
af.FinalEpoch    = '10 Jun 2012 13:59:00.000';  
  
Create BatchEstimator bls;  
  
bls.DataFilters = {af};  
  
BeginMissionSequence;
```

The last example illustrates accepting all data from station **MAD** and only range data from station **CAN**.

```
Create AcceptFilter af1 af2;  
Create GroundStation MAD CAN;  
  
af1.Trackers      = {'MAD'};  
af2.Trackers      = {'CAN'};  
af2.DataTypes     = {'Range'};  
  
Create BatchEstimator bls;  
  
bls.DataFilters = {af1, af2};  
  
BeginMissionSequence;
```

## Antenna

Transmits or receives an RF signal.

### Description

A number of GMAT resources including **Spacecraft**, **GroundStation**, **Transponder**, **Receiver**, and **Transmitter**, use an **Antenna** resource to transmit and/or receive RF signals.



#### Note

Currently, none of the **Antenna** parameters have any effect on orbit determination processing and do not need to be set for orbit estimation. (e.g., Light time solutions do not currently take into account **Antenna** location within the spacecraft body.)

See Also: [GroundStation](#), [Transponder](#), [Receiver](#), [Transmitter](#)

### Fields

Field	Description	
<b>FieldOfView</b>	Reference to optional field-of-view object which models the area visible to the antenna.	 <b>Data Type</b> FOV Resource <b>Allowed Values</b> <b>CustomFOV</b> , <b>ConicalFOV</b> , or <b>RectangularFOV</b> Resource. <b>Access</b> set <b>Default Value</b> empty <b>Units</b> N/A <b>Interfaces</b> script
<b>DirectionX</b>	X-component of the field-of-view boresight vector expressed in spacecraft body coordinates.	 <b>Data Type</b> Real <b>Allowed Values</b> Real number <b>Access</b> set <b>Default Value</b> 1 <b>Units</b> N/A <b>Interfaces</b> script

<b>Field</b>	<b>Description</b>
<b>DirectionY</b>	Y-component of the field-of-view boresight vector expressed in spacecraft body coordinates.
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real number  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>DirectionZ</b>	Z-component of the field-of-view boresight vector expressed in spacecraft body coordinates.
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real number  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>SecondDirectionX</b>	X-component of the vector, expressed in the body frame, used to resolve the sensor's orientation about the boresite vector.
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 0  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>SecondDirectionY</b>	Y-component of the vector, expressed in the body frame, used to resolve the sensor's orientation about the boresite vector.
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real  <b>Access</b> set  <b>Default Value</b> 1  <b>Units</b> N/A  <b>Interfaces</b> script</p>

Field	Description
<b>SecondDirectionZ</b>	Z-component of the vector, expressed in the body frame, used to resolve the sensor's orientation about the boresite vector.
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	Real
	<b>Access</b>
	set
	<b>Default Value</b>
	0
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	script
<b>HWOriginInBCSX</b>	X-component of the origin of the antenna's coordinate system expressed in the spacecraft's body coordinate system.
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	Real
	<b>Access</b>
	set
	<b>Default Value</b>
	0
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	script
<b>HWOriginInBCSY</b>	Y-component of the origin of the antenna's coordinate system expressed in the spacecraft's body coordinate system.
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	Real
	<b>Access</b>
	set
	<b>Default Value</b>
	0
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	script
<b>HWOriginInBCSZ</b>	Z-component of the origin of the antenna's coordinate system expressed in the spacecraft's body coordinate system.
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	Real
	<b>Access</b>
	set
	<b>Default Value</b>
	0
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	script

## Remarks

The antenna model supports mask, orientation and location settings. The mask is provided by the object designated by **FieldOfView**. The location is the position of the origin of the sensor frame, expressed in the spacecraft body coordinate frame. The orientation is represented as a direction cosine matrix that is initially computed from two non-colin-

ear vectors, provided by the user as **Direction** and **SecondDirection** components. The three axes for the sensor coordinate frame expressed in Body coordinates are computed as follow:

1. Normalize **z** & **v**, where **z** is the boresight represented by **Direction** and **v** is the **SecondDirection** vector.
2. Compute the normal **N** = **z** x **v** and its magnitude **m**.
3. Verify magnitude of **N** isn't 0.0, send message if it is too close. This will happen if one of the input vectors is a zero vector or if the two vectors are co-linear, including the case where they point in opposite directions.
4. **x** = **N** / **m**
5. **y** = **z** x **x**
6. The rotation matrix **Rsb** is constructed with **x** on the first row, **y** on the second, and **z** on the third. This matrix rotates vectors from the body frame to the sensor frame.

**Rsb** is used as part of the chain checking if an object is in the field of view. The general approach is to have a vector from the antenna to the object in a given reference frame and do a series of rotations, the last of which would use **Rsb** to rotate the vector from spacecraft to antenna coordinates.

## Examples

Attach an **Antenna** to hardware, **Spacecraft** and **GroundStation Resource** types.

```
Create Antenna SatTranponderAntenna
Create Antenna DSNReceiverAntenna DSNTransmitterAntenna

Create Transponder SatTransponder;
SatTransponder.PrimaryAntenna = SatTranponderAntenna

Create Spacecraft Sat
Sat.AddHardware = {SatTransponder, SatTranponderAntenna};

Create Transmitter DSNTransmitter
DSNTransmitter.PrimaryAntenna = DSNTransmitterAntenna

Create Receiver DSNReceiver
DSNReceiver.PrimaryAntenna = DSNReceiverAntenna;

Create GroundStation DSN;
DSN.AddHardware = {DSNTransmitter, DSNReceiver}
DSN.AddHardware = {DSNTransmitterAntenna, DSNReceiverAntenna};
BeginMissionSequence;
```

Define the field-of-view, orientation, and location of an antenna.

```
% Define a conical FOV
Create ConicalFOV coneFOV;
GMAT coneFOV.FieldOfViewAngle = 20;
```

```
% Create an antenna and attache a FOV
Create Antenna myAntenna;
GMAT myAntenna.FieldOfView = coneFOV;

% Define the antenna boresight direction in body coordinates
GMAT myAntenna.DirectionX = 1;
GMAT myAntenna.DirectionY = 0;
GMAT myAntenna.DirectionZ = 0;

% Define the vector to resolve orientation about boresight
GMAT myAntenna.SecondDirectionX = 0;
GMAT myAntenna.SecondDirectionY = 1;
GMAT myAntenna.SecondDirectionZ = 0;

% Define the location of antenna in body coordinates
GMAT myAntenna.HWOriginInBCSX = 100;
GMAT myAntenna.HWOriginInBCSY = -100;
GMAT myAntenna.HWOriginInBCSZ = 0;
```

## BatchEstimator

A batch least squares estimator

### Description

A batch least squares estimator is a method for obtaining an estimate for a parameter vector,  $x_0$ , such that a performance index, which is a function of that parameter,  $J = J(x_0)$ , is minimized. For our application,  $x_0$  typically includes the spacecraft position and velocity at a specific epoch and the performance index is a weighted sum of the squares of the measurement residuals.

See Also: [TrackingFileSet](#), [RunEstimator](#)

### Fields

Field	Description
<b>AbsoluteTol</b>	Absolute Weighted RMS convergence criteria tolerance  <b>Data Type</b> Real <b>Allowed Values</b> Real > 0 <b>Access</b> set <b>Default Value</b> 0.001 <b>Units</b> dimensionless <b>Interfaces</b> script
<b>DataFilters</b>	Defines filters to be applied to the data. One or more filters of either type ( <b>AcceptFilter</b> , <b>RejectFilter</b> ) may be specified. Rules specified by data filters on a <b>BatchEstimator</b> are applied to determine what data is accepted or rejected from the computation of the state update.  <b>Data Type</b> Resource array <b>Allowed Values</b> User defined instances of <b>AcceptFilter</b> and <b>RejectFilter</b> resources <b>Access</b> set <b>Default Value</b> None <b>Units</b> N/A <b>Interfaces</b> script
<b>DataFile</b>	Path and file name for an output JSON file containing full-precision records of the observations, residuals, and other data from the run. See the <b>Remarks</b> below for a description of the contents of this file.  <b>Data Type</b> String <b>Allowed Values</b> Unset, or a valid path and file name <b>Access</b> set <b>Default Value</b> None <b>Units</b> N/A <b>Interfaces</b> script

Field	Description												
<b>EstimationEpoch</b>	<p>Estimation Epoch. This is the epoch associated with the "solv-fors." The only allowed setting is FromParticipants, which defines the estimation epoch to be the current (a priori) epoch of the satellite to be estimated. The user should use a <b>Propagate</b> command to advance the estimated satellite to the desired estimation epoch prior to the <b>RunEstimator</b> command.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>'FromParticipants'</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>'FromParticipants'</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	'FromParticipants'	<b>Access</b>	set	<b>Default Value</b>	<b>'FromParticipants'</b>	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	String												
<b>Allowed Values</b>	'FromParticipants'												
<b>Access</b>	set												
<b>Default Value</b>	<b>'FromParticipants'</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>Estima-tionEpochFormat</b>	<p>Estimation Epoch format. This is the desired input format for the <b>EstimationEpoch</b> field. Currently has no functionality.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>'FromParticipants'</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>'FromParticipants'</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	'FromParticipants'	<b>Access</b>	set	<b>Default Value</b>	<b>'FromParticipants'</b>	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	String												
<b>Allowed Values</b>	'FromParticipants'												
<b>Access</b>	set												
<b>Default Value</b>	<b>'FromParticipants'</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>FreezeIteration</b>	<p>Specifies which iteration to freeze the selection of measurements that are edited out.</p> <table> <tr> <td><b>Data Type</b></td><td>integer</td></tr> <tr> <td><b>Allowed Values</b></td><td>any positive integer</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>4</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	integer	<b>Allowed Values</b>	any positive integer	<b>Access</b>	set	<b>Default Value</b>	<b>4</b>	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	integer												
<b>Allowed Values</b>	any positive integer												
<b>Access</b>	set												
<b>Default Value</b>	<b>4</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>FreezeMeasure-mentEditing</b>	<p>Allows the selection of measurements that are edited out to be frozen.</p> <table> <tr> <td><b>Data Type</b></td><td>true/false</td></tr> <tr> <td><b>Allowed Values</b></td><td>true or false</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>false</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	true/false	<b>Allowed Values</b>	true or false	<b>Access</b>	set	<b>Default Value</b>	<b>false</b>	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	true/false												
<b>Allowed Values</b>	true or false												
<b>Access</b>	set												
<b>Default Value</b>	<b>false</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												

Field	Description
<b>ILSEMaximumIterations</b>	Specifies maximum number of iterations allowed for the inner loop sigma editor (ILSE).
	<p><b>Data Type</b> integer</p> <p><b>Allowed Values</b> any positive integer</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 15</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> script</p>
<b>ILSEMultiplicativeConstant</b>	Multiplicative constant used for inner loop sigma editing (ILSE).
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Real &gt; 0.0</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 3.0</p> <p><b>Units</b> dimensionless</p> <p><b>Interfaces</b> script</p>
<b>InversionAlgorithm</b>	Algorithm used to invert the normal equations
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> Internal, Cholesky, Schur</p> <p><b>Access</b> set</p> <p><b>Default Value</b> Internal</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> script</p>
<b>MatlabFile</b>	(Deprecated) File name for the output MATLAB file. Leaving this parameter unset means that no MATLAB file will be generated. A MATLAB data file can only be generated if GMAT is configured for connection to an instance of MATLAB.
	This parameter is deprecated and replaced with the <b>DataFile</b> parameter and JSON output, which does not require MATLAB. The JSON file can be read in MATLAB, see the <b>Remarks</b> below for more details.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> Any valid file name.</p> <p><b>Access</b> set</p> <p><b>Default Value</b> (unset)</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> script</p>

Field	Description
<b>MaxConsecutiveDivergences</b>	Specifies maximum number of consecutive diverging iterations allowed before batch estimation processing is stopped
	<b>Data Type</b> integer <b>Allowed Values</b> any positive integer <b>Access</b> set <b>Default Value</b> 3 <b>Units</b> N/A <b>Interfaces</b> script
<b>MaximumIterations</b>	Specifies maximum number of iterations allowed for batch estimation.
	<b>Data Type</b> integer <b>Allowed Values</b> any positive integer <b>Access</b> set <b>Default Value</b> 15 <b>Units</b> N/A <b>Interfaces</b> script
<b>Measurements</b>	Specifies a list of measurements used for batch estimation.
	<b>Data Type</b> ObjectArray <b>Allowed Values</b> one or more valid <b>TrackingFileSet</b> objects <b>Access</b> set <b>Default Value</b> empty list <b>Units</b> N/A <b>Interfaces</b> script
<b>OLSEAdditiveConstant</b>	Additive constant used for outer loop sigma editing (OLSE). See <b>Behavior of Outer Loop Sigma Editing (OLSE)</b> in the <b>Remarks</b> section for details.
	<b>Data Type</b> Real <b>Allowed Values</b> any real number <b>Access</b> set <b>Default Value</b> 0.0 <b>Units</b> N/A <b>Interfaces</b> script
<b>OLSEInitialRMSSigma</b>	Initial predicted root-mean-square value used for outer loop sigma editing (OLSE).
	<b>Data Type</b> Real <b>Allowed Values</b> Real > 0.0 <b>Access</b> set <b>Default Value</b> 3000.0 <b>Units</b> dimensionless <b>Interfaces</b> script

Field	Description
<b>OLSEMultiplicativeConstant</b>	Multiplicative constant used for outer loop sigma editing (OLSE).
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real > 0.0
<b>Access</b>	set
<b>Default Value</b>	<b>3.0</b>
<b>Units</b>	dimensionless
<b>Interfaces</b>	script
<b>OLSEUseRMSP</b>	Flag used to specify editing algorithm used for outer loop sigma editing (OLSE) for iterations greater than 1. See <b>Behavior of Outer Loop Sigma Editing (OLSE)</b> in the <b>Remarks</b> section for details.
<b>Data Type</b>	true/false
<b>Allowed Values</b>	true or false
<b>Access</b>	set
<b>Default Value</b>	<b>true</b>
<b>Units</b>	dimensionless
<b>Interfaces</b>	script
<b>Propagator</b>	Propagator object used to advance a spacecraft through time for batch estimation. For estimation runs using multiple spacecraft, separate <b>Propagator</b> fields can be used to identify the propagator for each spacecraft in the estimator's configuration, as described below. See also the example at the end of this section.
<b>Data Type</b>	Object
<b>Allowed Values</b>	valid <b>Propagator</b> object optionally followed by a set of valid <b>Spacecraft</b> objects
<b>Access</b>	<i>Propagator, or {Propagator, Spacecraft[1, Spacecraft2, Spacecraft3, ...]}</i>
<b>Default Value</b>	<b>None</b>
<b>Units</b>	N/A
<b>Interfaces</b>	script
<b>RelativeTol</b>	Relative Weighted RMS convergence criteria tolerance.
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real > 0
<b>Access</b>	set
<b>Default Value</b>	<b>0.0001</b>
<b>Units</b>	dimensionless
<b>Interfaces</b>	script

Field	Description
<b>ReportFile</b>	Specifies the name of estimation report file.  <b>Data Type</b> String <b>Allowed Values</b> string containing a valid file name <b>Access</b> set <b>Default Value</b> 'BatchEstimator' + instancename + '.data' <b>Units</b> N/A <b>Interfaces</b> script
<b>ReportStyle</b>	Specifies the type of estimation report. The <b>Normal</b> style excludes reporting of observation TAI, partials, and frequency information. Selection of <b>Verbose</b> mode requires the user to assign RUN_MODE = Testing in the GMAT startup file.  <b>Data Type</b> String <b>Allowed Values</b> Normal, Verbose <b>Access</b> set <b>Default Value</b> <b>Normal</b> <b>Units</b> N/A <b>Interfaces</b> script
<b>ResetBestRMSIfDiverging</b>	If set true and the estimation process has diverged, then the Best RMS is reset to the current RMS.  <b>Data Type</b> true/false <b>Allowed Values</b> true or false <b>Access</b> set <b>Default Value</b> <b>false</b> <b>Units</b> N/A <b>Interfaces</b> script
<b>ShowAllResiduals</b>	Allows residuals plots to be shown.  <b>Data Type</b> On/Off <b>Allowed Values</b> On or Off <b>Access</b> set <b>Default Value</b> <b>On</b> <b>Units</b> N/A <b>Interfaces</b> script
<b>ShowProgress</b>	Allows detailed output of the batch estimator to be shown in the message window.  <b>Data Type</b> true/false <b>Allowed Values</b> true or false <b>Access</b> set <b>Default Value</b> <b>true</b> <b>Units</b> N/A <b>Interfaces</b> script

Field	Description
<b>UseInitialCovariance</b>	If set true, a <i>priori</i> error covariance term is added to the estimation cost function. This option should be set to true when estimating with an applied <b>Spacecraft.OrbitErrorCovariance</b> , <b>Spacecraft.CdSigma</b> , <b>Spacecraft.CrSigma</b> , or <b>ErrorModel.BiasSigma</b> . See the <b>Remarks</b> section below for some restrictions on the use of this field.
	<p><b>Data Type</b> true/false  <b>Allowed Values</b> true or false  <b>Access</b> set  <b>Default Value</b> <b>false</b>  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>UseInnerLoopEditing</b>	If set true, enables an iterated residual editing procedure to edit measurements predicted to be sigma edited in future iterations. See <b>Behavior of Inner Loop Sigma Editing (ILSE)</b> in the <b>Remarks</b> section for details.
	<p><b>Data Type</b> true/false  <b>Allowed Values</b> true or false  <b>Access</b> set  <b>Default Value</b> <b>false</b>  <b>Units</b> N/A  <b>Interfaces</b> script</p>

## Remarks



### Note

When configuring a numerical integrator for the batch estimator, you must use the fixed-step option. The **ErrorControl** parameter of the **ForceModel** used by the **BatchEstimator** must be set to 'None.' Of course, when using fixed step control, the user must choose a step size that yields the desired accuracy for the chosen orbit regime and force profile. Step size for fixed-step integration is configured on the **Propagator.InitialStepSize** and **Propagator.MaxStep** fields. The smaller of the two values assigned to these parameters will be the integration step size. It is usually convenient to set both to the same value, to avoid confusion.

## Behavior of Convergence Criteria

GMAT has four input fields, **RelativeTol**, **AbsoluteTol**, **MaximumIterations**, and **MaxConsecutiveDivergences** that are used to determine if the estimator has converged after each new iteration. Associated with these input fields are the two convergence tests shown below:

### Absolute Weighted RMS convergence criteria

Weighted RMScurrent <= AbsoluteTol

### Relative Weighted Root Mean Square (RMS) convergence criteria

$|RMSP - RMSB| / RMSB \leq RelativeTol$

where

RMSB = smallest Weighted RMS achieved during the current and previous iterations

RMSP = predicted Weighted RMS of next iteration

Batch estimation is considered to have converged when either or both of the above criteria is met within **MaximumIterations** iterations or less.

Batch estimation is considered to have diverged when number of consecutive diverging iterations is equal to or greater than **MaxConsecutiveDivergences** or the number of iterations exceeds **MaximumIterations**.

### Behavior of Outer Loop Sigma Editing (OLSE)

GMAT has four input fields, **OLSEMultiplicativeConstant**, **OLSEAdditiveConstant**, **OLSEUseRMSP**, and **OLSEInitialRMSSigma**, that are used to 'edit' (i.e., reject or throw away) bad measurement data. This editing procedure is done on a per iteration basis. Data that is edited is not used to calculate the state vector estimate for the current iteration but the data is available as a candidate measurement for subsequent iterations. On the first outer loop iteration, data is edited if

$|Weighted\ Measurement\ Residual| > OLSEInitialRMSSigma$

where the Weighted Measurement Residual for a single given measurement is given by

$(O-C)/NoiseSigma$

and where **NoiseSigma** is the input noise (one sigma) for the measurement type associated with the given measurement. On subsequent outer loop iterations, the data is edited if

$|Weighted\ Measurement\ Residual| > OLSEMultiplicativeConstant * RMS + OLSEAdditiveConstant$

The editing algorithm above depends upon the user input value of **OLSEUseRMSP**. If **OLSEUseRMSP** = True, then RMS = **WRMSP** where **WRMSP** is the predicted weighted RMS calculated at the end of the previous iteration. Otherwise, If **OLSEUseRMSP** = False, then RMS = **WRMS** where **WRMS** is the actual weighted RMS calculated at the end of the previous iteration.

### Behavior of Inner Loop Sigma Editing (ILSE)

The inner loop, when enabled, runs immediately after each iteration of the outer loop calculates which measurements to edit. The benefit of the inner loop lies in that it can quickly iterate as it does not need to propagate the spacecraft each iteration. Instead,

it uses the measurement derivatives to compute a linearized approximation to the next outer loop iteration residuals. This generally increases the amount of data sigma-edited from the run, but the result is that in many cases a solution will require fewer outer loop iterations to converge and may therefore run faster overall.

GMAT has three input fields, **ILSEMaximumIterations**, **ILSEMultiplicativeConstant**, and **UseInnerLoopEditing**, that are used by the inner loop to predict which measurements will be sigma edited by the following outer loop iteration. On each inner loop iteration, the data is edited if

$$|\text{Predicted Weighted Measurement Residual}| > \text{ILSEMultiplicativeConstant} * \text{RMS}$$

The value of RMS above again depends on the user input value of **OLSEUseRMSP**. If **OLSEUseRMSP** = True, then RMS = **WRMSP** where **WRMSP** is the previously calculated predicted weighted RMS . Otherwise, If **OLSEUseRMSP** = False, then RMS = **WRMS** where **WRMS** is the previously calculated actual weighted RMS. On the first inner loop iteration, these RMS values from the most recent outer loop are used, while on subsequent inner loop iterations, they are taken from the previous inner loop iteration.

The inner loop converges when the selection of measurements edited exactly match the selection of measurements edited by the previous inner loop iteration. The value of **ILSEMaximumIterations** also provides an upper-bound on the number of iterations to perform. Like the outer loop, data that is edited is not used to calculate the state vector estimate for the current iteration but the data is available as a candidate measurement for subsequent iterations. The inner loop can only remove measurements from estimation, it does not reintroduce measurements that were previously edited.

### Behavior of Freezing Measurement Editing

GMAT has two input fields, **FreezeMeasurementEditing** and **Freezelteration**, that are used to determine if and when to 'freeze' (i.e., no longer change) the selection of measurements which are edited out by the Outer Loop Sigma Editor. Freezing the measurement editing only takes place when **FreezeMeasurementEditing** is true.

If freezing is enabled, the selection of measurements to edit is locked after the iteration specified by **Freezelteration**. If the value of **Freezelteration** is 1, the estimator uses the value of **OLSEInitialRMSSigma**, as defined above, to determine which measurements are used to calculate the first iteration of the state vector deviation vector. Afterwards, the same measurements edited out by the initial RMS sigma filter are edited out for the remainder of the iterations. If the value of **Freezelteration** is 2 or greater, the estimator uses the above defined outer loop sigma editing to determine the state vector deviation vector up to the iteration specified by **Freezelteration**, at which point whichever measurements are edited out by the outer loop sigma editor stay edited out for the remainder of the iterations. If inner loop sigma editing is enabled, the measurements edited out by the last iteration of the inner loop sigma editor will also be frozen. Frozen measurements that are edited out will retain the edit flag the outer and inner loop sigma editor used the iteration they were edited out.

Freezing measurement editing can be useful in situations where a solution takes an excessive number of iterations to converge and latter iterations are only editing a small

amount of data. If this is the case, enabling the editing freeze on an appropriate iteration will generally force the solution to converge quickly after reaching the frozen iteration.

### Propagator Settings

The **BatchEstimator** resource has a **Propagator** field containing the name of the **Propagator** resource that will be used during the estimation process. The minimum step size, **MinStep**, of your propagator should always be set to 0.

The **BatchEstimator** resource uses the first **Propagator** identified as the default propagator for spacecraft that are simulated. The user can specify a different **Propagator** for specific spacecraft using an optional list of spacecraft assigned to other propagator components. An example of this usage is shown the examples below. This capability is also described in more detail in [Configuration of Propagators for Orbit Determination](#)

### Normal Matrix Reduction

If an estimated state is unobservable, usually due to measurement data editing, the normal matrix will contain a row and column of zeros corresponding to the unobservable state, and will therefore be singular. This can happen in operations if, for example, the user attempts to estimate an observation bias, but all the measurements associated with that bias are sigma-edited out of the solution. This occurrence yields a singular normal matrix along the row and column of the bias state. However, rather than terminating with a matrix inversion error, GMAT will detect this condition and compensate for it by removing the unobservable state from the normal matrix prior to inversion. The unobservable state will be restored after inversion, in case it may become observable on later iterations. When GMAT takes this action, a message will be reported to both the GMAT log file and the batch estimator report file State Information report, which will indicate which state component was removed from the normal matrix prior to inversion.

### UseInitialCovariance Restrictions

As mentioned in the Field spec above, if this field is set to true, then the *a priori* error covariance term is added to the estimation cost function. For the current GMAT release, there are some restrictions on the use of this field as given below.

1. The user must input the *a priori* orbit state covariance in the EarthMJ200Eq coordinate system.
2. If the user is solving for the Cartesian orbit state, e.g., Sat.SolveFors = {CartesianState}, then the input *a priori* orbit state covariance must be in terms of Cartesian elements. Likewise, if the user is solving for the Keplerian orbit state, e.g., Sat.SolveFors = {KeplerianState}, then the input *a priori* orbit state covariance must be in terms of Keplerian elements.
3. If the user is solving for the Keplerian orbit state, e.g., Sat.SolveFors = {KeplerianState}, then the input *a priori* orbit state covariance must be expressed in terms in terms of spacecraft Mean Anomaly (MA) and not True Anomaly (TA). To be more specific, in this situation, the diagonal elements of the 6x6 orbit state error covariance are the variance of the SMA ( $\text{km}^2$ ), eccentricity (dimensionless), INC ( $\text{deg}^2$ ), RAAN ( $\text{deg}^2$ ), AOP ( $\text{deg}^2$ ), and MA ( $\text{deg}^2$ ). Note that, in this case, we require the *a priori*

covariance to be input in terms of MA even though, for the current release of GMAT, the associated orbit state can not be set using MA.

### Batch Estimator MATLAB Data File



#### Note

MATLAB data file output has been deprecated and replaced by the **DataFile** JSON output file. Those wishing to continue to use MATLAB can load the JSON file in MATLAB using the following code sample.

```
str = fileread(json_file_path);
bls_data = jsondecode(str);
```

If MATLAB is installed and properly configured to interface with GMAT (see [MATLAB Interface](#)), the user may generate a mat-file containing useful analysis data from the **BatchEstimator** run. This option is enabled by specifying a path and filename for the output file on the **MatlabFile** field of the configured **BatchEstimator** resource. The file contains three top-level data structures - **EstimationConfig**, **Iteration**, and **Observed**. Except as noted in the tables below, the units for data in the mat-file are the same as those in the BatchEstimator output file; km, km/sec, DSN Range Units, Hz, and degrees.

**EstimationConfig** contains general information about the estimation run configuration. Contents of the **EstimationConfig** structure are described in the table below.

Variable	Description
CartesianStateNames	Names of estimated parameters; spacecraft elements names are Cartesian
FinalEpochUTC	A 1x2 column vector containing the measurement end epoch as a MATLAB datenum in the first row and GMAT TAIModJulian in the second row
GravitationalParameter	The gravitational parameter of the primary central body of the run, in km^3/sec^2
InitialEpochUTC	A 1x2 column vector containing the measurement starting epoch as a MATLAB datenum in the first row and GMAT TAIModJulian in the second row
KeplerianStateNames	Names of estimated parameters; spacecraft elements names are Keplerian

The **Observed** structure contains the tracking data observation measurement data. Contents of the **Observed** structure are described in the table below. When working with the mat-file, it is good to keep in mind that the GMAT output file indexes iterations, observations, and residuals from 0 but MATLAB performs indexing starting with 1.

Variable	Description
DopplerCountInterval	For each Doppler-type measurement, the Doppler counting interval. Set to NaN for other data types.

Variable	Description
EpochTAI	The TAI epoch of each measurement. Each member is a column vector where the first row is the epoch as a MATLAB datenum and the second row is the epoch as a GMAT TAIModJulian date.
EpochUTC	The UTC epoch of each measurement. Each member is a column vector where the first row is the epoch as a MATLAB datenum and the second row is the epoch as a GMAT UTCModJulian date.
Frequency	Signal receive frequency in Hertz. Set to NaN for GPS_PosVec data.
Measurement	Observed measurements. For GPS_PosVec, each cell holds a 1x3 column vector of X, Y, Z measurements.
MeasurementNumber	Measurement record number
MeasurementType	The GMAT observation type name
MeasurementWeight	Measurement weights (1/noise^2). For GPS_PosVec, each cell holds a 1x3 column vector of X, Y, Z weights.
Participants	For each measurement, a cell array whose members are the ID's of the participants in the measurement path
RangeModulo	For each DSN_SeqRange measurement, the range ambiguity interval in Range Units. Set to NaN for other data types.

Contents of the **Iteration** structure are described in the table below. The iteration structure is an array with one element for each iteration performed by the estimator. Each iteration has the following fields. Some fields are not applicable to some measurement types (for example Elevation, Frequency, and FrequencyBand do not apply for GPS\_PosVec measurements) and are set to NaN or zero.

Variable	Description
CartesianCorrelation	Cartesian correlation matrix at the end of the iteration. The order of the rows and columns is given by EstimationConfig.CartesianStateNames.
CartesianCovariance	Cartesian covariance matrix at the end of the iteration. The order of the rows and columns is given by EstimationConfig.CartesianStateNames.
CartesianState	Spacecraft Cartesian elements and other estimated parameters at the end of the iteration. The order of elements matches that given in EstimationConfig.CartesianStateNames.
Elevation	Computed elevation in degrees at the measurement epoch. Does not apply (set to 0) for GPS_PosVec data.

Variable	Description
IonosphericCorrection	The magnitude of the ionospheric measurement correction. Units are the same as the measurement. See note below regarding media corrections for X/Y angle measurements.
IterationNumber	Numerical iteration count number, starting from 0
KeplerianCorrelation	Keplerian correlation matrix at the end of the iteration. The order of the rows and columns is given by EstimationConfig.KeplerianStateNames.
KeplerianCovariance	Keplerian covariance matrix at the end of the iteration. The order of the rows and columns is given by EstimationConfig.KeplerianStateNames.
KeplerianState	Spacecraft Keplerian elements and other estimated parameters at the end of the iteration. The order of elements matches that given in EstimationConfig.KeplerianStateNames.
Measurement	Computed measurements. For GPS_PosVec, each cell holds a 1x3 column vector of X, Y, Z computed measurements.
MeasurementEditFlag	The string observation edit flag. 'N' indicates unedited/accepted observations
MeasurementNumber	Measurement record number
MeasurementPartials	A cell array of matrices. Each member is a matrix of the partial derivatives of the measurement with respect to each element of the state. The partials are taken with respect to the element type selected on the Spacecraft <b>SolveFor</b> s field. For example, if the user has chosen to estimate the KeplerianState, the partials are with respect to the Keplerian elements. The order of elements matches that given in the EstimationConfig state names. For GPS_PosVec data, each cell holds a 3xN matrix, where N is the number of estimated states. Each row contains the partials with respect to the X, Y, and Z GPS_PosVec measurement in order.
PreviousCartesianState	Spacecraft Cartesian elements and other estimated parameters at the beginning of the iteration. The order of elements matches that given in EstimationConfig.CartesianStateNames.
PreviousKeplerianState	Spacecraft Keplerian elements and other estimated parameters at the beginning of the iteration. The order of elements matches that given in EstimationConfig.KeplerianStateNames.
Residual	Measurement residuals. For GPS_PosVec, each cell holds a 1x3 column vector of X, Y, Z residuals.

Variable	Description
TroposphericCorrection	The magnitude of the tropospheric measurement correction. Units are the same as the measurement. See note below regarding media corrections for X/Y angle measurements.

Many of the fields in the Iteration and Observations structures are cell arrays. In most cases some simple MATLAB commands are all that are needed to extract the cell array data to arrays for plotting and analysis. The code below shows a few examples.

```
% We assume a BatchEstimator mat-file has already been loaded

% Plot scalar residuals

t = Observed.EpochUTC(1,:);
y = cell2mat(Iteration(1).Residual);

plot(t, y, 'ko');
datetick;

% Plot measurement partials

parts = Iteration(1).MeasurementPartials;
parts = cat(1, parts{:});

plot(t, parts);
datetick;

% Compute WRMS

iter = Iteration(1);

IACC = find(strcmp(iter.MeasurementEditFlag, 'N'));

dy = cell2mat(iter.Residual(IACC));
w = diag(cell2mat(Observed.MeasurementWeight(IACC)));
m = length(IACC);

wrms = sqrt((1/m) * dy * w * dy');
```

Users might find it useful to work with ObsEditFlag or Type as MATLAB categorical arrays. See the MATLAB help for the categorical command for more details.

Working with a MATLAB file containing GPS\_PosVec data requires a little more attention. Some examples are shown below.

```
% We assume a BatchEstimator mat-file from a GPS_PosVec data
% run has already been loaded
```

```
% Plot GPS_PosVec residuals

t = Observed.EpochUTC(1,:);
y = cell2mat(Iteration(2).Residual);

plot(t, y, '.');
datetick;

% Extract partials with respect to the GPS_PosVec
% X-component measurement

parts = Iteration(1).MeasurementPartials;
parts = cat(3, parts{:});

part_x = parts(1,:,:);
part_x = squeeze(part_x);

plot(t, part_x);
```

### Batch Estimator JSON Data File

The user may generate a JSON-formatted file containing useful analysis data from the **BatchEstimator** run. This option is enabled by specifying a path and filename for the output file on the **DataFile** field of the configured **BatchEstimator** resource. The contents of this file are described in the tables below.

Element	Description
CartesianStateNames	Names of all estimated parameters; spacecraft elements names are Cartesian
EstimationEpoch	BLS estimation epoch in UTCGregorian format
InitialState	The full initial (a priori) estimation state, in km and km/sec
KeplerianStateNames	Names of all estimated parameters; spacecraft elements names are Keplerian
Observations	A list of all observations included in the run; details are below
Iterations	A list of data for each iteration in the run, details are below

The **Observations** structure contains the tracking data observation measurement records. Contents of the **Observations** structure are described in the table below.

Element	Description
Epoch	The measurement epoch in UTCGregorian format
Participants	A comma-separated string containing the ID's of the GMAT objects in the measurement path

Element	Description
Type	The GMAT observation type name
Value	Observed measurements; for GPS_PosVec, each record has a list of X, Y, Z measurements. Units are as described in the <a href="#">tracking data types description</a> .

Contents of the **Iterations** list are described in the table below. There is one list element for each iteration performed by the estimator. Each iteration has the following elements.

Element	Description
CartesianCovariance	Cartesian covariance matrix at the end of the iteration; the order of the rows and columns is given by CartesianStateNames.
CartesianState	Spacecraft Cartesian elements and other estimated parameters at the end of the iteration; the order of elements is given by CartesianStateNames
ComputedMeasurements	An list of objects containing data for each computed measurement in the iteration; see below for details
KeplerianCovariance	Keplerian covariance matrix at the end of the iteration; the order of elements is given by KeplerianStateNames
KeplerianState	Spacecraft Keplerian elements and other estimated parameters at the end of the iteration; the order of elements is given by KeplerianStateNames

Fields of a ComputedMeasurements record are described below. The units for computed measurements and residuals are described in [tracking data types description](#).

Element	Description
EditFlag	The string observation edit flag; A value of <b>null</b> indicates unedited/accepted observations
Elevation	Measurement computed elevation in degrees
Epoch	Residual epoch in UTCGregorian format
Participants	A comma-separated string containing the ID's of the GMAT objects in the measurement path
Residual	Measurement residuals; for GPS_PosVec, each records holds a list of X, Y, Z residuals. The units are as described in <a href="#">tracking data types description</a> .
Type	The GMAT observation type name
Value	Computed measurements; for GPS_PosVec, each record holds a list of X, Y, Z computed measurements

### Data File Media Corrections for X/Y Angle Data

When formulating computed angle measurements, GMAT applies ionosphere and troposphere corrections as an elevation adjustment to the ground station to spacecraft

slant-range vector. All computed angle observables are then derived from the slant-range vector. This process yields the exact correction applied to the Elevation angle, but corrections to other angle measurement types are not directly computed and stored. To provide the user with an estimate of these corrections for X/Y angles, approximate X/Y angle corrections are computed from the elevation correction by an alternate method and stored in the data file. The user should be aware that the media corrections for X/Y data stored in the data file are not exactly consistent with the method used in formulation of the X/Y computed measurement. The differences are less than 1% for elevations greater than 5 degrees, but may be on the order of 100% for elevations below 5 degrees.

## Interactions

Resource	Description
<b>Tracking-</b> <b>FileSet re-</b> <b>source</b>	Must be created in order to tell the <b>BatchEstimator</b> resource which data will be processed
<b>Propaga-</b> <b>tor re-</b> <b>source</b>	Used by GMAT to generate the predicted orbit
<b>RunEsti-</b> <b>mator</b> <b>command</b>	Must use the <b>RunEstimator</b> command to actually process the data defined by the <b>BatchEstimator</b> resource

## Examples

Below is an example of a configured batch estimator instance. In this example, **estData** is an instance of a **TrackingFileSet** and **ODProp** is an instance of **Propagator**.

```
Create BatchEstimator bat;

bat.ShowProgress          = true;
bat.Measurements          = {estData};
bat.AbsoluteTol            = 0.000001;
bat.RelativeTol           = 0.001;
bat.MaximumIterations      = 10;
bat.MaxConsecutiveDivergences = 3;
bat.Propagator             = ODProp;
bat.ShowAllResiduals       = On;
bat.OLSEInitialRMSSigma    = 3000;
bat.OLSEMultiplicativeConstant = 3;
bat.OLSEAdditiveConstant   = 0;
bat.UseInnerLoopEditing    = True;
bat.ILSEMaximumIterations  = 15;
bat.ILSEMultiplicativeConstant = 3;
bat.InversionAlgorithm     = 'Internal';
bat.EstiminationEpochFormat = 'FromParticipants';
bat.EstiminationEpoch      = 'FromParticipants';
bat.ReportStyle             = 'Normal';
```

```
bat.ReportFile           = 'BatchEstimator_Report.txt';  
  
BeginMissionSequence;
```

The next example shows how to script multiple propagators on an estimator. This example illustrates the scripting for propagators only, and does not include other object settings. In this example, the TDRS spacecraft are propagated using an ephemeris based SPICE propagator. Any other spacecraft used in the simulator are propagated using the satprop propagator. This example illustrates using ephemeris propagators for the TDRS6 and TDRS10 orbits, but the BatchEstimator Propagator assignment syntax is identical when using independent numerical propagators with force models.

```
%Create and Configure Spacecraft  
Create Spacecraft SimSat;  
  
Create Spacecraft TDRS6;  
TDRS6.OrbitSpiceKernelName = {'TDRS6Ephem.bsp'};  
  
Create Spacecraft TDRS10;  
TDRS10.OrbitSpiceKernelName = {'TDRS10Ephem.bsp'};  
  
% Create and configure the Simulator object  
Create ForceModel FM1  
  
Create Propagator satprop;  
satprop.FM = FM1  
satprop.MinStep = 0  
  
Create Propagator tdrsprop;  
tdrsprop.Type = SPK  
tdrsprop.EpochFormat = 'A1ModJulian';  
tdrsprop.StartEpoch = 'FromSpacecraft';  
  
Create BatchEstimator bat;  
GMAT bat.Propagator      = satprop;  
GMAT bat.Propagator      = {tdrsprop, TDRS6, TDRS10};
```

For a comprehensive example of reading in measurements and running the estimator, see the [Orbit Estimation using DSN Range and Doppler Data](#) tutorial.

## ErrorModel

Used to specify measurement noise for simulation and estimation, and to apply or estimate measurement biases.

### Description

An **ErrorModel** is assigned on the **ErrorModels** field of an instance of **GroundStation** or a spacecraft-attached **Receiver** to model biases and noise, and optionally to estimate biases on each measurement type provided by the ground station or receiver. An error model must be specified for each data type employed by each tracking station or receiver, but a single instance of **ErrorModel** may be used by multiple ground stations or spacecraft receivers.

An error model is only assigned to a receiver if **GPS\_PosVec** data is employed. The **GPS\_PosVec** observation type models position estimates provided by an on-board GPS receiver. Since this type of data is not derived from ground station measurement modeling, the error model for **GPS\_PosVec** data is specified on the **ErrorModels** field of a **Receiver** resource instead. The receiver must be attached to the corresponding **Spacecraft** object. Error models for all other observation types should be specified on the **ErrorModels** field of the relevant ground station resources. Error models cannot be assigned on receivers attached to ground stations.

The **ErrorModel** is used by both the simulator and the estimator. For a data simulation run, the **ErrorModel** specifies the measurement type and noise employed when generating the simulated measurement. A bias may optionally be applied to the simulated observations.

For an estimation run, the **ErrorModel** specifies the observation type, presumed observation noise, and an optional bias to be applied to the observation. Observation biases may also be estimated by adding the **Bias** or **PassBiases** keyword to the **ErrorModel.SolveFors** list. See the remarks below for the difference between **Bias** and **PassBiases** estimation. If the **SolveFors** list is empty, no bias will be estimated. The **SolveFors** list is ignored by the simulator.



#### Note

In both simulation and estimation, the error model on the receiving station determines the measurement properties (bias and noise) and the transmit station error model properties are ignored.

The **ErrorModel** resource does not currently support application or estimation of biases for the **GPS\_PosVec** data type.

See Also [GroundStation](#), [Receiver](#), [Tracking Data Types for Orbit Determination](#)

## Fields

Field	Description												
<b>Bias</b>	<p>The constant bias associated with the measurement. For simulation, this bias is added to the measurement. As shown below, the units used depend upon measurement type, <b>ErrorModel.Type</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any Real number</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>0.0</b></td></tr> <tr> <td><b>Units</b></td><td>See Remarks section</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Any Real number	<b>Access</b>	set	<b>Default Value</b>	<b>0.0</b>	<b>Units</b>	See Remarks section	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Any Real number												
<b>Access</b>	set												
<b>Default Value</b>	<b>0.0</b>												
<b>Units</b>	See Remarks section												
<b>Interfaces</b>	script												
<b>BiasSigma</b>	<p>Standard deviation of <b>Bias</b>. This field is used to constrain the estimated value of <b>Bias</b>, and only has a function if both (1) <b>BatchEstimator.UselInitialCovariance = True</b> and (2) <b>Bias</b> is a solve-for parameter. As shown below, the units used depend upon measurement type, <b>ErrorModel.Type</b>. This parameter is not implemented for <b>GPS_PosVec</b> data.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real &gt; 0</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>1e+70</b></td></tr> <tr> <td><b>Units</b></td><td>See Remarks section</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real > 0	<b>Access</b>	set	<b>Default Value</b>	<b>1e+70</b>	<b>Units</b>	See Remarks section	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real > 0												
<b>Access</b>	set												
<b>Default Value</b>	<b>1e+70</b>												
<b>Units</b>	See Remarks section												
<b>Interfaces</b>	script												
<b>NoiseSigma</b>	<p>One sigma value of Gaussian noise. For simulation this noise is added to the measurements if <b>Sim.AddNoise = True</b>. For estimation, this value is used as part of the batch processing algorithms to calculate the measurement type weighting. As shown below, the units used depend upon measurement type, <b>ErrorModel.Type</b>.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real &gt; 0</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>103</b></td></tr> <tr> <td><b>Units</b></td><td>See Remarks section</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real > 0	<b>Access</b>	set	<b>Default Value</b>	<b>103</b>	<b>Units</b>	See Remarks section	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real > 0												
<b>Access</b>	set												
<b>Default Value</b>	<b>103</b>												
<b>Units</b>	See Remarks section												
<b>Interfaces</b>	script												

Field	Description													
<b>SolveFors</b>	<p>List of parameters to estimate. The user may estimate either a single bias across the entire arc for any station using the ErrorModel, or may estimate "pass-by-pass" biases. See the remarks below for more details on the PassBiases option. The <b>SolveFors</b> option is not implemented for <b>GPS_PosVec</b> data.</p> <table> <tr> <td><b>Data Type</b></td><td>StringArray</td></tr> <tr> <td><b>Allowed Values</b></td><td>{}, {Bias}, or {PassBiases}</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>{}</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>		<b>Data Type</b>	StringArray	<b>Allowed Values</b>	{}, {Bias}, or {PassBiases}	<b>Access</b>	set	<b>Default Value</b>	{}	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	StringArray													
<b>Allowed Values</b>	{}, {Bias}, or {PassBiases}													
<b>Access</b>	set													
<b>Default Value</b>	{}													
<b>Units</b>	N/A													
<b>Interfaces</b>	script													
<b>Type</b>	<p>Measurement data type.</p> <table> <tr> <td><b>Data Type</b></td><td>Enumeration</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any supported measurement type name. See <a href="#">Tracking Data Types for Orbit Determination</a></td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>DSN_SeqRange</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>		<b>Data Type</b>	Enumeration	<b>Allowed Values</b>	Any supported measurement type name. See <a href="#">Tracking Data Types for Orbit Determination</a>	<b>Access</b>	set	<b>Default Value</b>	<b>DSN_SeqRange</b>	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Enumeration													
<b>Allowed Values</b>	Any supported measurement type name. See <a href="#">Tracking Data Types for Orbit Determination</a>													
<b>Access</b>	set													
<b>Default Value</b>	<b>DSN_SeqRange</b>													
<b>Units</b>	N/A													
<b>Interfaces</b>	script													

## Remarks

### Units for Bias, BiasSigma, and NoiseSigma

The units to be used for **Bias**, **BiasSigma**, and **NoiseSigma** for each measurement data type that GMAT supports are listed in the table of measurement type descriptions in [Tracking Data Types for Orbit Determination](#).

### Pass-dependent Bias Estimation

GMAT provides two options for measurement bias estimation, set on the ErrorModel SolveFor parameter: **Bias** and **PassBiases**. Only one option may be chosen per ErrorModel instance, but an estimation run can simultaneously perform Bias and PassBiases estimation for different error models.

The **Bias** solve-for option instructs GMAT to estimate a single bias across the entire estimation arc for each station and spacecraft using the error model. Since the same instance of ErrorModel may be applied to multiple trackers, a separate single bias will be estimated for each tracker and spacecraft to which the error model applies.

The **PassBiases** solve-for option instructs GMAT to segment the measurement span into individual tracking passes, and to estimate an independent bias for each tracking pass. This option requires the user to also specify a **TimeGapForPassBreak** on the applicable **TrackingFileSet**. The value of TimeGapForPassBreak represents an interval between tracking measurements which indicates the start of a new pass. Measurements

separated in time by a span larger than the TimeGapForPassBreak are presumed to be from different passes. A typical appropriate value might be something like 30 minutes. In this case, batches of tracking measurements separated by 30 minutes or more are assumed to be independent tracking passes, and an individual bias will be estimated for each tracking pass. This process is only applied to those stations using the error model configured with PassBiases SolveFors. Other error models employing the Bias SolveFors option will still estimate only a single bias for the entire tracking span. GMAT will indicate the spans identified for each bias pass in both the estimation report file and GMAT log file. When employing PassBiases estimation, the user should review these files to confirm that passes were identified as intended by the user.

## Examples

This example shows how to create an error model for DSN Sequential Range observations and illustrates estimation of a range bias parameter.

```
% Create an ErrorModel
% Measurement noise is in Range Units

Create ErrorModel RangeModel;

RangeModel.Type      = 'DSN_SeqRange';
RangeModel.NoiseSigma = 11.;
RangeModel.Bias      = 0.;
RangeModel.SolveFors = {Bias};

% Assign it to a ground station

Create GroundStation DSN;

DSN.ErrorModels = {RangeModel};

BeginMissionSequence;
```

This example shows how to create an error model for on-board GPS observations.

```
% Create an ErrorModel
% Measurement noise is in kilometers. Bias estimation is not permitted.

Create ErrorModel PosVecModel;

PosVecModel.Type      = 'GPS_PosVec';
PosVecModel.NoiseSigma = 0.010;

% Assign the error model to a receiver and add that receiver to a spacecraft.

Create Antenna GpsAntenna;
Create Receiver GpsReceiver;

GpsReceiver.Id          = 800;
GpsReceiver.PrimaryAntenna = GpsAntenna;
GpsReceiver.ErrorModels   = {PosVecModel};

Create Spacecraft Sat;

Sat.AddHardware = {GpsReceiver, GpsAntenna};

BeginMissionSequence;
```

## EstimatedParameter

Used for modeling of dynamically estimated parameters in the Extended Kalman Filter.

### Description

The **EstimatedParameter** resource allows the user to model dynamic parameters such as coefficient of drag (Cd), coefficient of solar radiation pressure (Cr), as well as observation biases as random processes in the Kalman filter. This resource currently implements only a first-order Gauss-Markov process. A user-configured instance of **EstimatedParameter** resource is assigned to the **Spacecraft.SolveFors** list to enable estimation using the modeled process.

The only solve-fors currently supported are spacecraft coefficient of drag (Cd) and atmospheric density scale factor (AtmosDensityScaleFactor). The **EstimatedParameter** resource is for the Kalman filter only and may not be used with the BatchEstimator.

See Also [ExtendedKalmanFilter](#), [Spacecraft Ballistic/Mass Properties](#)

### Fields

Field	Description												
<b>HalfLife</b>	<p>The half-life in seconds for propagation of both the estimated parameter value and sigma (uncertainty). The model process noise is derived from the steady-state sigma and half-life. See the remarks below for more details.</p> <table> <tr> <td><b>Data Type</b></td><td>Real &gt; 0</td></tr> <tr> <td><b>Allowed Values</b></td><td>Any positive Real number</td></tr> <tr> <td><b>Access</b></td><td>Set</td></tr> <tr> <td><b>Default Value</b></td><td>7200</td></tr> <tr> <td><b>Units</b></td><td>Seconds</td></tr> <tr> <td><b>Interfaces</b></td><td>Script</td></tr> </table>	<b>Data Type</b>	Real > 0	<b>Allowed Values</b>	Any positive Real number	<b>Access</b>	Set	<b>Default Value</b>	7200	<b>Units</b>	Seconds	<b>Interfaces</b>	Script
<b>Data Type</b>	Real > 0												
<b>Allowed Values</b>	Any positive Real number												
<b>Access</b>	Set												
<b>Default Value</b>	7200												
<b>Units</b>	Seconds												
<b>Interfaces</b>	Script												
<b>Model</b>	<p>Name of the random process model.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>FirstOrderGaussMarkov</td></tr> <tr> <td><b>Access</b></td><td>Set</td></tr> <tr> <td><b>Default Value</b></td><td>FirstOrderGaussMarkov</td></tr> <tr> <td><b>Units</b></td><td>None</td></tr> <tr> <td><b>Interfaces</b></td><td>Script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	FirstOrderGaussMarkov	<b>Access</b>	Set	<b>Default Value</b>	FirstOrderGaussMarkov	<b>Units</b>	None	<b>Interfaces</b>	Script
<b>Data Type</b>	String												
<b>Allowed Values</b>	FirstOrderGaussMarkov												
<b>Access</b>	Set												
<b>Default Value</b>	FirstOrderGaussMarkov												
<b>Units</b>	None												
<b>Interfaces</b>	Script												
<b>SolveFor</b>	<p>Name of the parameter to which the random process applies.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Cd, AtmosDensityScaleFactor</td></tr> <tr> <td><b>Access</b></td><td>Set</td></tr> <tr> <td><b>Default Value</b></td><td>None</td></tr> <tr> <td><b>Units</b></td><td>None</td></tr> <tr> <td><b>Interfaces</b></td><td>Script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Cd, AtmosDensityScaleFactor	<b>Access</b>	Set	<b>Default Value</b>	None	<b>Units</b>	None	<b>Interfaces</b>	Script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Cd, AtmosDensityScaleFactor												
<b>Access</b>	Set												
<b>Default Value</b>	None												
<b>Units</b>	None												
<b>Interfaces</b>	Script												

Field	Description												
<b>SteadyStateSigma</b>	<p>The steady-state parameter uncertainty. In the absence of measurements, the parameter uncertainty will return to this value. The model process noise is derived from the steady-state sigma and half-life. See the remarks below for more details.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real &gt; 0</td></tr> <tr> <td><b>Access</b></td><td>Set</td></tr> <tr> <td><b>Default Value</b></td><td>0.1</td></tr> <tr> <td><b>Units</b></td><td>None</td></tr> <tr> <td><b>Interfaces</b></td><td>Script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real > 0	<b>Access</b>	Set	<b>Default Value</b>	0.1	<b>Units</b>	None	<b>Interfaces</b>	Script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real > 0												
<b>Access</b>	Set												
<b>Default Value</b>	0.1												
<b>Units</b>	None												
<b>Interfaces</b>	Script												
<b>SteadyStateValue</b>	<p>The steady-state parameter value. In the absence of measurements, the parameter value will return to this value. This value may be different from the initial value of the parameter, which will be taken from the value of the chosen solve-for as assigned on the Spacecraft object. See Remarks below for more details.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real <math>\geq 0</math></td></tr> <tr> <td><b>Access</b></td><td>Set</td></tr> <tr> <td><b>Default Value</b></td><td>1.0</td></tr> <tr> <td><b>Units</b></td><td>None</td></tr> <tr> <td><b>Interfaces</b></td><td>Script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real $\geq 0$	<b>Access</b>	Set	<b>Default Value</b>	1.0	<b>Units</b>	None	<b>Interfaces</b>	Script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real $\geq 0$												
<b>Access</b>	Set												
<b>Default Value</b>	1.0												
<b>Units</b>	None												
<b>Interfaces</b>	Script												

## Remarks



### Note

Creating an instance of **EstimatedParameter** that has the same name as a built-in solve for is not permitted. See **SolveFors** in [Spacecraft Navigation](#) for the list of built-in solve-for names.



### Note

When creating an instance of **EstimatedParameter**, the **Model** parameter must be assigned first, before any other parameters of the estimated parameter. See the example below for a demonstration.

Selection of spacecraft dynamic solve-fors is specified in the **Spacecraft** resource **SolveFors** list. As noted under [Spacecraft Navigation](#), there are specific keywords available to invoke estimation of dynamic parameters in both the batch estimator and filter. Using any of those predefined parameter names in the **SolveFors** list for a Kalman filter run invokes modeling of the parameter as a "random constant". In the random constant model, the estimated parameter and its uncertainty (sigma) both remain constant at their last estimated values during filter time updates. The random constant model does not

add any process noise during propagation of the parameter estimate, and using this model can cause problems in the filter over time.

To instead model the parameter as a first-order Gauss-Markov process, the user should configure an instance of **EstimatedParameter** for the desired dynamic solve-for, and assign the instance of **EstimatedParameter** in the **Spacecraft SolveFor**s list, instead of using one of the predefined parameter names. See the Examples section below for details.

When running the filter in cold-start mode, the nominal (a-priori) value and uncertainty of the selected estimated parameter are the values specified on the Spacecraft object. For example, if **EstimatedParameter.SolveFor = 'Cd'** is chosen, the initial value of Cd is the value assigned on the **Spacecraft.Cd** parameter and the initial uncertainty of Cd is assigned on the **Spacecraft.CdSigma** parameter. The parameter then propagates forward in time according to a first-order Gauss-Markov random process. When running the filter in warm-start mode (using a filter **InputWarmStartFile**), the initial parameter value and covariance are retrieved from the specified record in the warm start file.

## First-order Gauss-Markov Modeling

The variance of the parameter process noise is derived from the user-specified **SteadyStateSigma** and **HalfLife**. The variance of the Gauss-Markov process noise,  $\sigma_u^2$  is related to the **EstimatedParameter SteadyStateSigma** by the following equation:

$$\text{SteadyStateSigma} = \frac{\tau \sigma_u^2}{2}$$

where # is related to the **EstimatedParameter HalfLife** by

$$\tau = \frac{\text{HalfLife}}{\ln(2)}$$

## Examples

This example illustrates how to configure estimation of the spacecraft coefficient of drag as a first-order Gauss-Markov process.

```
% Configure estimation of spacecraft coefficient of drag (Cd)
% as a first-order Gauss-Markov process.

%
Create EstimatedParameter FogmCd

FogmCd.Model          = 'FirstOrderGaussMarkov'; % Must be assigned first, be
FogmCd.SolveFor        = 'Cd'
FogmCd.SteadyStateSigma = 0.1
FogmCd.HalfLife         = 7200
```

```
%  
% Use the configured instance of FogmCd in the spacecraft  
% SolveFors list, instead of the built-in 'Cd'  
  
Create Spacecraft EstSat;  
  
EstSat.DateFormat = UTCGregorian;  
EstSat.Epoch = '10 Jun 2010 00:00:00.000'  
EstSat.CoordinateSystem = EarthMJ2000Eq  
EstSat.DisplayStateType = Cartesian  
EstSat.X = 576.8  
EstSat.Y = -5701.1  
EstSat.Z = -4170.5  
EstSat.VX = -1.7645  
EstSat.VY = 4.1813  
EstSat.VZ = -5.9658  
EstSat.DryMass = 10  
EstSat.Cd = 1.75  
EstSat.CdSigma = 0.1  
EstSat.Cr = 1.8  
EstSat.DragArea = 100  
EstSat.SRPArea = 100  
EstSat.Id = 'LEOSat'  
EstSat.AddHardware = {GpsReceiver, GpsAntenna}  
EstSat.SolveFors = {CartesianState, FogmCd}  
EstSat.ProcessNoiseModel = SNC
```

## ExtendedKalmanFilter

An extended Kalman filter orbit determination estimator

### Description

A sequential estimator implementing an extended Kalman filter.

See Also: [BatchEstimator](#), [TrackingFileSet](#), [RunEstimator](#)

### Fields

Field	Description
<b>AddPredictToMatlabFile</b>	Set to True to include the data from the ExtendedKalmanFilter prediction span in the MATLAB file. Predicted data is only generated if <b>PredictTimeSpan</b> is non-zero. Setting this parameter to True will add the predicted states, covariance, process noise, and state transition matrix to the Filter MATLAB data file.  <b>Data Type</b> True/False <b>Allowed Values</b> True or False <b>Access</b> Set <b>Default Value</b> <b>False</b> <b>Units</b> N/A <b>Interfaces</b> Script
<b>DataFilters</b>	Defines data selection filters to be applied to the measurement pool. One or more filters of either type ( <b>AcceptFilter</b> , <b>RejectFilter</b> ) may be specified. Rules specified by data filters on an <b>ExtendedKalmanFilter</b> are applied to determine what measurements are accepted or rejected from the computation of the state update.  <b>Data Type</b> Resource array <b>Allowed Values</b> User defined instances of <b>AcceptFilter</b> and <b>RejectFilter</b> resources <b>Access</b> Set <b>Default Value</b> <b>None</b> <b>Units</b> N/A <b>Interfaces</b> Script

Field	Description
<b>DelayRectifyTimeSpan</b>	<p>Defines a period of time, beginning from warm start or initialization, for which the reference trajectory is generated from the a-priori or initial state. As always, any measurements are used to update the estimated state, but the measurements will not be applied to the reference trajectory used for linearization. After the delay rectify time span has elapsed, the a-priori state is discarded, and the current filter estimated state is used as the reference trajectory for linearization, in accordance with normal operation of an extended Kalman filter.</p>
	<p>This parameter can aid convergence when the initial state covariance is very large and the measurement noise is small. Delaying rectification until enough measurements have been processed to assure an improved state estimate can keep the filter from immediately diverging due to too-rapid collapse of the state covariance.</p>
	<p>Rectification will begin at the last measurement prior to expiration of the <b>DelayRectifyTimeSpan</b>. Warm start records will not be written to a specified <b>OutputWarmStartFile</b> while delayed rectification is in effect.</p>
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real >= 0
<b>Access</b>	Set
<b>Default Value</b>	0
<b>Units</b>	Seconds
<b>Interfaces</b>	Script
<b>InputWarmStartFile</b>	<p>CSV-format file containing records of states and covariances. This file should be the <b>OutputWarmStartFile</b> from a prior <b>ExtendedKalmanFilter</b> run. See <b>OutputWarmStartFile</b> and the remarks below for more details about this file. If an <b>InputWarmStartFile</b> is not specified, the <b>ExtendedKalmanFilter</b> begins processing in "cold start" or initialization mode, using the resource object settings.</p>
<b>Data Type</b>	String
<b>Allowed Values</b>	Empty, or the path to a valid warm start file
<b>Access</b>	Set
<b>Default Value</b>	None
<b>Units</b>	N/A
<b>Interfaces</b>	Script

Field	Description
<b>MatlabFile</b>	File name for the output MATLAB file. Leaving this parameter unset means that no MATLAB file will be generated. This file can only be generated if GMAT is properly connected to MATLAB. See remarks below for details on the contents of the estimator MATLAB file.
	<b>Data Type</b>
	String
	<b>Allowed Values</b>
	Any valid file name
	<b>Access</b>
	Set
	<b>Default Value</b>
	None
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	Script
<b>MeasDeweightingCoefficient</b>	Coefficient used for Measurement Underweighting. Using the default value, Measurement Underweighting is effectively turned off. As shown in the Remarks, we use Lear's Measurement Underweighting method described by Eq. (4.36) in Reference 1.
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	Real $\geq 0$ .
	<b>Access</b>
	Set
	<b>Default Value</b>
	0.0
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	Script
<b>MeasDeweightingSigmaThreshold</b>	1-sigma RSS position threshold used for Measurement Underweighting processing. Measurement Underweighting is only performed if the 1-sigma RSS position uncertainty, derived from the error covariance matrix, is greater than this threshold AND the <b>MeasDeweightingCoefficient</b> is greater than 0.
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	Real $\geq 0$ .
	<b>Access</b>
	Set
	<b>Default Value</b>
	1.0
	<b>Units</b>
	km
	<b>Interfaces</b>
	Script
<b>Measurements</b>	Specifies a list of <b>TrackingFileSets</b> identifying measurements used for estimation
	<b>Data Type</b>
	Resource array
	One or more valid <b>TrackingFileSet</b> instances
	<b>Access</b>
	Set
	<b>Default Value</b>
	Empty list
	<b>Units</b>
	N/A
	<b>Interfaces</b>
	Script

Field	Description
<b>OutputWarmStartFile</b>	File path and name of an output file to store warm start records. This file receives the full state and lower triangle of the square-root covariance matrix at all filter time and measurement updates during processing. This file may be later assigned as the <b>InputWarmStartFile</b> to force the filter to begin processing in warm start mode. It is recommended to use a ".csv" suffix for this file, but this is not required.
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> Empty, or any valid file name.</p> <p><b>Access</b> Set</p> <p><b>Default Value</b> <b>None</b></p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> Script</p>
<b>PredictTimeSpan</b>	Time span in seconds for filter ephemeris prediction after processing the last measurement.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Real <math>\geq 0</math>.</p> <p><b>Access</b> Set</p> <p><b>Default Value</b> <b>0</b></p> <p><b>Units</b> Seconds</p> <p><b>Interfaces</b> Script</p>
<b>Propagator</b>	Specifies the propagator resource instance used for estimation.
	<p><b>Data Type</b> Object</p> <p><b>Allowed Values</b> Valid <b>Propagator</b> object</p> <p><b>Access</b> Set</p> <p><b>Default Value</b> <b>None</b></p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> Script</p>
<b>ReportFile</b>	Specifies the name of the output estimation report file
	<p><b>Data Type</b> String</p> <p><b>Allowed Values</b> String containing a valid file name</p> <p><b>Access</b> Set</p> <p><b>Default Value</b> '<b>ExtendedKalmanFilter</b>' + <b>instancename</b> + '.data'</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> Script</p>

Field	Description
<b>ReportStyle</b>	<p>Specifies the type of estimation report. The <b>Normal</b> style excludes reporting of observation TAI, partials, and frequency information. Selection of <b>Verbose</b> mode requires the user to assign RUN_MODE = Testing in the GMAT startup file.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>ScaledResidualThreshold</b>	<p>Scaled residual editing criteria. The scaled residual is a unitless value representing the raw residual divided by the sum of state noise (appropriately transformed) and measurement noise. Schematically, Scaled Residual = Raw Residual / (HPH' + R). Any measurement will be edited out (and not used in the estimation) if the computed scaled residual is greater than the specified threshold.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>ShowAllResiduals</b>	Allows residuals plots to be shown in the GMAT GUI.
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>ShowProgress</b>	<p>Toggle generation of the estimator output report file and additional detailed output in the GUI console window.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>

Field	Description												
<b>WarmStartEpoch</b>	<p>Initial epoch from which to begin processing, when processing in warm start mode. GMAT will look for a record at this time in the <b>InputWarmStartFile</b>. If a record at the specified epoch does not exist in the <b>InputWarmStartFile</b>, the warm start record closest to, but earlier than, the specified epoch will be used. The default setting is 'FirstMeasurement', which means GMAT will automatically choose the closest input warm start record that is earlier than the first available measurement in the run. The user may also specify 'LastWarmStartRecord' to automatically use the last record in the input warm start file.</p> <table> <tr> <td><b>Data Type</b></td><td>String or Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Valid GMAT epoch string or value, 'FirstMeasurement', or 'LastWarmStartRecord'</td></tr> <tr> <td><b>Access</b></td><td>Set</td></tr> <tr> <td><b>Default Value</b></td><td><b>FirstMeasurement</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>Script</td></tr> </table>	<b>Data Type</b>	String or Real	<b>Allowed Values</b>	Valid GMAT epoch string or value, 'FirstMeasurement', or 'LastWarmStartRecord'	<b>Access</b>	Set	<b>Default Value</b>	<b>FirstMeasurement</b>	<b>Units</b>	N/A	<b>Interfaces</b>	Script
<b>Data Type</b>	String or Real												
<b>Allowed Values</b>	Valid GMAT epoch string or value, 'FirstMeasurement', or 'LastWarmStartRecord'												
<b>Access</b>	Set												
<b>Default Value</b>	<b>FirstMeasurement</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	Script												
<b>WarmStartEpochFormat</b>	<p>Specifies the format and time system of the warm start epoch.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>UTCGregorian, UTCModJulian, TAIGregorian, TAIModJulian, TTGregorian, TTModJulian A1Gregorian, A1ModJulian, TDBGregorian, TDBModJulian</td></tr> <tr> <td><b>Access</b></td><td>Set</td></tr> <tr> <td><b>Default Value</b></td><td><b>TAIModJulian</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>Script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	UTCGregorian, UTCModJulian, TAIGregorian, TAIModJulian, TTGregorian, TTModJulian A1Gregorian, A1ModJulian, TDBGregorian, TDBModJulian	<b>Access</b>	Set	<b>Default Value</b>	<b>TAIModJulian</b>	<b>Units</b>	N/A	<b>Interfaces</b>	Script
<b>Data Type</b>	String												
<b>Allowed Values</b>	UTCGregorian, UTCModJulian, TAIGregorian, TAIModJulian, TTGregorian, TTModJulian A1Gregorian, A1ModJulian, TDBGregorian, TDBModJulian												
<b>Access</b>	Set												
<b>Default Value</b>	<b>TAIModJulian</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	Script												

## Remarks

### Note



When configuring a numerical integrator for the Kalman filter, you must use the fixed-step option. The **ErrorControl** parameter of the **ForceModel** in use by the **ExtendedKalmanFilter** must be set to 'None.' Of course, when using fixed step control, the user must choose a step size, as given by the **Propagator InitialStepSize** field, that yields the desired accuracy for the chosen orbit regime and force profile.

## Filter Startup Modes

The **ExtendedKalmanFilter** may be run in either a first-time initialization (called here "cold start") mode, or as a continuation of a prior run, called here "warm start" mode.

In cold start mode, the states and covariances assigned on the resources configured in the script are used as the filter initial state and covariance. The spacecraft initial covariance is taken from the Spacecraft **OrbitErrorCovariance** parameter, and initial uncertainties for other estimated parameters are taken from each parameter's associated "sigma" value. For example the initial coefficient of drag is assigned on the Spacecraft **Cd** parameter and the initial uncertainty in Cd is assigned on the Spacecraft **CdSigma** parameter. The filter will run in cold start mode any time an **InputWarmStart** file is not specified on the ExtendedKalmanFilter resource.

In warm start mode, the filter full state and covariance from a prior run are used as the filter initial state and covariance. This mode allows the user to stop and start the filter in a manner that allows continuous operation of the filter in a fully converged state. To enable a warm start, the user should specify an **InputWarmStartFile** on the EKF resource. The user may optionally also specify a **WarmStartEpoch**, to identify the time at which the filter should begin processing. If a warm start epoch is given, the filter ignores all measurements prior to the warm start epoch. If a warm start epoch is not given, the filter will start up from the first measurement time, using the input warm start record closest to, but earlier than, the first measurement time. The warm start epoch must be within the time span of the input warm start file. The input warm start file should ideally be the output warm start file from a prior filter run.

### Generating an Ephemeris File from an Extended Kalman Filter Run

An ephemeris file can be created during the Kalman filter run. The ephemeris file is configured according to the usual methods (see [EphemerisFile](#)). This file will contain the Kalman filter estimated states at both the measurement and time update steps. The ephemeris file will also contain predicted states if the KalmanFilter **PredictTimeSpan** is non-zero. Measurement updates typically do not occur at constant time intervals and the estimated states at each measurement update are at least slightly discontinuous. For these reasons, only ephemeris formats supporting variable step sizes are permitted for use with the Kalman Filter. A Code500 ephemeris may not be generated during a Kalman filter run.



#### Note

When generating an STK ephemeris during a filter or smoother run, **IncludeEventBoundaries** should always be set to **True** on the STK ephemeris resource. The filter ephemeris is always at least slightly discontinuous at each measurement and including the event boundaries ensures that users of the STK ephemeris do not attempt to interpolate improperly across the discontinuities.

### Using a ReportFile Resource with the Kalman Filter

A **ReportFile** resource (see [ReportFile](#)) may be configured for use during a filter run. This allows the user to output data such as the spacecraft state, OrbitErrorCovariance, Cd, CdSigma, and other estimated parameters to a custom report file during the estimation run. The contents of the custom report file depend on the setting of the **ReportFile SolverIterations** parameter as follows:

- If **SolverIterations** is **None**, only the last state in the run is written. If there is a measurement at this time, the reported state is the measurement pre-update state.
- If **SolverIterations** is **Current** (the default), data is written at each measurement and time update. The reported state at each measurement update is the pre-update state.
- If **SolverIterations** is **All**, data is written at each measurement and time update. At each measurement update both the pre-update and post-update state are reported.

### Propagator Settings

The **ExtendedKalmanFilter** resource has a **Propagator** field containing the name of the **Propagator** resource that will be used during the estimation process. The minimum step size, **MinStep**, of your propagator should always be set to 0.

### Kalman filter report file

The Weighted RMS statistic reported for each data type in the Filter Measurement Statistics report is the weighted RMS of pre-update residuals.

### Kalman Filter MATLAB Data File

If MATLAB is installed and properly configured to interface with GMAT (see [MATLAB Interface](#)), the user may generate a mat-file containing useful analysis data from the **ExtendedKalmanFilter** run. This option is enabled by specifying a path and filename for the output file on the **MatlabFile** field of the configured **ExtendedKalmanFilter** resource. The file contains four top-level data structures - **EstimationConfig**, **Observed**, **Computed**, and **Filter**. Except as noted in the tables below, the units for data in the mat-file are the same as those in the Kalman filter output file; seconds, km, km/sec, DSN Range Units, Hz, and degrees.

**EstimationConfig** contains general information about the estimation run configuration. Contents of the **EstimationConfig** structure are described in the table below.

Variable	Description
InitialEpochUTC	A 1x2 column vector containing the filter starting epoch as a MATLAB datenum in the first row and GMAT TAI-ModJulian in the second row.
FinalEpochUTC	A 1x2 column vector containing the filter end epoch as a MATLAB datenum in the first row and GMAT TAIModJulian in the second row.
GravitationalParameter	The gravitational parameter of the primary central body of the run, in km^3/sec^2.
StateNames	Names of the run estimated parameters.

The **Observed** structure contains the tracking data observation measurement data. Contents of the **Observed** structure are described in the table below.

Variable	Description
DopplerCountInterval	For each Doppler-type measurement, the Doppler counting interval. Set to NaN for other data types.

Variable	Description
EpochTAI	The TAI epoch of each measurement. Each member is a column vector where the first row is the epoch as a MATLAB datenum and the second row is the epoch as a GMAT TAIModJulian date.
EpochUTC	The UTC epoch of each measurement. Each member is a column vector where the first row is the epoch as a MATLAB datenum and the second row is the epoch as a GMAT UTCModJulian date.
Frequency	Signal receive frequency in Hertz. Set to NaN for GPS_PosVec data.
Measurement	Observed measurements. For GPS_PosVec, each cell holds a 1x3 column vector of X, Y, Z measurements.
MeasurementNumber	Measurement record number.
MeasurementType	The GMAT observation type name.
MeasurementWeight	Measurement weights (1/noise^2). For GPS_PosVec, each cell holds a 1x3 column vector of X, Y, Z weights.
Participants	For each measurement, a cell array whose members are the ID's of the participants in the measurement path.
RangeModulo	For each DSN_SeqRange measurement, the range ambiguity interval in Range Units. Set to NaN for other data types.

The **Computed** structure stores information about filter measurement updates. Contents of the **Computed** structure are described in the table below. Some fields are not applicable to some measurement types (for example Elevation, Frequency, and FrequencyBand do not apply for GPS\_PosVec measurements) and are set to NaN or zero. The epoch of a record in the **Computed** structure can be determined by matching the computed **MeasurementNumber** to the same measurement number in the **Observed** structure.

Variable	Description
Elevation	Computed elevation in degrees at the measurement epoch. Does not apply (set to 0) for GPS_PosVec data.
IonosphericCorrection	The magnitude of the ionospheric measurement correction. Units are the same as the measurement. See note below regarding media corrections for X/Y angle measurements.
KalmanGain	The Kalman gain matrix.
Measurement	Computed measurements. For GPS_PosVec, each cell holds a 1x3 column vector of X, Y, Z computed measurements.
MeasurementEditFlag	The string observation edit flag. 'N' indicates unedited/accepted observations.

Variable	Description
MeasurementNumber	Measurement record number.
MeasurementPartials	A cell array of matrices. Each member is a matrix of the partial derivatives of the measurement with respect to each element of the state. The partials are taken with respect to the element type selected on the Spacecraft <b>SolveFor</b> s field. For example, if the user has chosen to estimate the KeplerianState, the partials are with respect to the Keplerian elements. The order of elements matches that given in the EstimationConfig state names. For GPS_PosVec data, each cell holds a 3xN matrix, where N is the number of estimated states. Each row contains the partials with respect to the X, Y, and Z GPS_PosVec measurement in order.
PreUpdateCovariance	Filter state covariance prior to measurement update.
PreUpdateCovarianceVNB	Filter state covariance prior to measurement update, in the VNB reference frame.
PreUpdateResidual	Filter state residual prior to measurement update.
PreUpdateState	Filter state prior to measurement update.
ScaledResidual	A unitless value representing the raw residual divided by the sum of state noise (appropriately transformed) and measurement noise. Schematically, Scaled Residual = Raw Residual / ( $H\Phi H'$ + R).
TroposphericCorrection	The magnitude of the tropospheric measurement correction. Units are the same as the measurement. See note below regarding media corrections for X/Y angle measurements.

The **Filter** structure stores information about processing that occurs at both measurement and time updates. Contents of the **Filter** structure are described in the table below.

Variable	Description
Covariance	The filter state covariance (Cartesian), after the measurement or time update.
CovarianceVNB	The filter state covariance (VNB coordinates), after the measurement or time update.
EpochTAI	The TAI epoch of each filter record. Each member is a column vector where the first row is the epoch as a MATLAB datenum and the second row is the epoch as a GMAT TAIModJulian date.
EpochUTC	The UTC epoch of each filter record. Each member is a column vector where the first row is the epoch as a MATLAB datenum and the second row is the epoch as a GMAT UTCModJulian date.

Variable	Description
MeasurementNumber	Measurement record number. Set to NaN for time update steps.
ProcessNoise	The filter process noise matrix.
State	Filter state after the measurement or time update.
StateTransitionMatrix	State transition matrix $\Phi_i$ from $t_{i-1}$ to $t_i$ , such that $\Phi_i = \Phi(t_{i-1}, t_i)$ .
UpdateType	Filter update mode (Initial, Time, or Measurement).

### MATLAB File Media Corrections for X/Y Angle Data

When formulating computed angle measurements, GMAT applies ionosphere and troposphere corrections as an elevation adjustment to the ground station to spacecraft slant-range vector. All computed angle observables are then derived from the slant-range vector. This process yields the exact correction applied to the Elevation angle, but corrections to other angle measurement types are not directly computed and stored. To provide the user with an estimate of these corrections for X/Y angles, approximate X/Y angle corrections are computed from the elevation correction by an alternate method and stored in the MATLAB file. The user should be aware that the media corrections for X/Y data stored in the MATLAB file are not exactly consistent with the method used in formulation of the X/Y computed measurement. The differences are less than 1% for elevations greater than 5 degrees, but may be on the order of 100% for elevations below 5 degrees.

### Measurement Underweighting

Measurement underweighting changes how the Extended Kalman Filter calculates the gain, K.

Let  $K_i = P_i^- H_i^T W_i^{-1}$  where  $W_i \equiv (1 + \text{MeasDeweightingCoefficient}) H_i P_i^- H_i^T + R_i$ . be the Kalman gain at some time,  $t_i$ . The use of a positive value for MeasDeweightingCoefficient makes the gain "smaller" and effectively makes the measurement at time  $t_i$  less important in calculating the estimated state at time  $t_i$ . Note that if MeasDeweightingCoefficient = 0, then  $K_i$  is the normal Kalman gain.

Let the 3x3 matrix,  $\tilde{P}_i^-$ , be the partition of the state estimation error covariance associated with the Cartesian position error states. If  $\sqrt{\text{trace}(\tilde{P}_i^-)} > \text{MeasDeweightingSigmaThreshold}$ , GMAT calculates the Kalman gain using the user input value for MeasDeweightingCoefficient. Otherwise, GMAT uses MeasDeweightingCoefficient = 0.

### Examples

Below is an example of a configured extended Kalman filter estimator instance. In this example, **EstData** is an instance of a **TrackingFileSet** and **Prop** is an instance of **Propagator**. Here, no input warm start file is specified, so the filter runs from a cold start (initialization), but generates an output warm start file which can be used in a subsequent run.

```
Create ExtendedKalmanFilter EKF;  
  
EKF.ShowProgress          = True;  
EKF.Measurements         = {EstData};  
EKF.Propagator           = Prop;  
EKF.ShowAllResiduals     = On;  
EKF.ScaledResidualThreshold = 3.;  
EKF.DataFilters          = {}  
EKF.PredictTimeSpan      = 86400.;  
EKF.ReportFile            = 'filter_report.txt';  
EKF.MatlabFile           = 'filter.mat';  
EKF.OutputWarmStartFile   = 'warm_start.csv';  
  
BeginMissionSequence;
```

## References

1. Carpenter, Russell and Chris D'Souza. *Navigation Filter Best Practices*. Technical Report TP-2018-219822, NASA, April 2018.

## ProcessNoiseModel

Used to specify process noise for estimation when using the `ExtendedKalmanFilter` estimator.

### Description

A **ProcessNoiseModel** is assigned on the **ProcessNoiseModel** field of an instance of **Spacecraft** to allow an **ExtendedKalmanFilter** to account for general errors in force modeling. This is additionally used to include noise calculations when propagating covariance using the **Propagate** command.

See also [ExtendedKalmanFilter](#), [Spacecraft Navigation](#)

### Fields

Field	Description	
<b>AccelNoiseSigma</b>	Three-axis process noise sigma. The root variance along each axis of an assumed Gaussian noise process.	
	<b>Data Type</b>	Array
	<b>Allowed Values</b>	Real > 0
	<b>Access</b>	set
	<b>Default Value</b>	[1.0e-8 1.0e-8 1.0e-8]
	<b>Units</b>	Depends on process noise model type; see remarks below
<b>CoordinateSystem</b>	<b>Interfaces</b>	script
	Reference coordinate system for the process noise acceleration sigma vector.	
	<b>Data Type</b>	String
	<b>Allowed Values</b>	Name of any built-in or user defined <b>CoordinateSystem</b> resource
	<b>Access</b>	set
	<b>Default Value</b>	<b>EarthMJ2000Eq</b>
<b>Type</b>	<b>Units</b>	N/A
	<b>Interfaces</b>	script
	Process noise modeling type. See remarks below for additional details.	
	<b>Data Type</b>	Enumeration
	<b>Allowed Values</b>	<b>StateNoiseCompensation</b>
	<b>Access</b>	set

Field	Description	
<b>UpdateTimeStep</b>	The time step at which to update the ProcessNoise and propagate the Covariance. If set to 0, then updates will occur at each integration step. When using multiple models for Covariance propagation in a <b>Propagate</b> command, this parameter must match on all models. See the remarks below for additional details.	
<b>Data Type</b>	Real	
<b>Allowed Values</b>	Real > 0	
<b>Access</b>	set	
<b>Default Value</b>	0	
<b>Units</b>	Seconds	
<b>Interfaces</b>	script	

## Remarks

### State Noise Compensation

The **StateNoiseCompensation** process noise type implements the process noise algorithm described in Tapley, Schutz, and Born, *Statistical Orbit Determination*, Section 4.9 and Appendix F. The process noise is assumed to be an additive Gaussian noise process applied to the total deterministic acceleration. For this scheme, the user provides the diagonal elements of the following matrix in a chosen reference frame.

$$\mathbf{Q} = \begin{bmatrix} q_1 & 0 & 0 \\ 0 & q_2 & 0 \\ 0 & 0 & q_3 \end{bmatrix}$$

where  $q_1$ ,  $q_2$ , and  $q_3$  are the squares of the elements of the specified **AccelNoiseSigma** in the selected **CoordinateSystem**. The process noise **S** is then given by the matrix

$$\mathbf{S} = \begin{bmatrix} \tilde{\mathbf{Q}} \frac{\Delta t^3}{3} & \tilde{\mathbf{Q}} \frac{\Delta t^2}{2} \\ \tilde{\mathbf{Q}} \frac{\Delta t^2}{2} & \tilde{\mathbf{Q}} \Delta t \end{bmatrix}$$

Where  $\Delta t$  is obtained from a time grid formed by the union of the input measurement times and the chosen **ProcessNoiseModel UpdateTimeStep**. When used in the context of covariance propagation using the **Propagate** command,  $\Delta t$  is the union of the each integration step and the UpdateTimeStep between the start and end of the of the propagation.  $\tilde{\mathbf{Q}}$  is the  $\mathbf{Q}$  matrix transformed into the coordinate system of integration. Process noise is added according to this formulation at each time update and measurement update during filtering and prediction.

Determination of appropriate values of  $q_1$ ,  $q_2$ , and  $q_3$  often involves experimentation via trial and error or a parametric analysis. References 1 and 2 indicate that an appropriate starting point for such tuning, in the case of near-circular orbits dominated by along-track error, can be derived from the following equation

$$q_{AT} = \frac{\sigma_{AT}^2}{3T^3}$$

Where  $\sigma_{AT}$  is the along-track error per orbit period (perhaps determined empirically), and  $T$  is the orbit period in seconds. Note that the square root of  $q_{AT}$  is specified when inputting the components of the **AccelNoiseSigma**. For State Noise Compensation, the units of **AccelNoiseSigma** are km/second<sup>3/2</sup>.

## Examples

This example shows how to create and assign a **ProcessNoiseModel**.

```
% Create a ProcessNoiseModel

Create ProcessNoiseModel SNC;

SNC.Type          = StateNoiseCompensation;
SNC.CoordinateSystem = EarthMJ2000Eq;
SNC.AccelNoiseSigma = [1e-8 1e-8 1e-8];
SNC.UpdateTimeStep = 120.

% Assign it to a Spacecraft

Create Spacecraft EstSat;

EstSat.ProcessNoiseModel = SNC;
```

## References

1. Carpenter, Russell and Chris D'Souza. *Navigation Filter Best Practices*. Technical Report TP-2018-219822, NASA, April 2018.
2. Geller, David. *Orbital Rendezvous: When is Autonomy Required?*. Journal of Guidance, Control, and Dynamics, Vol. 30, No.4. July-August 2007.

## Receiver

Hardware that receives an RF signal.

### Description

A **GroundStation** or **Spacecraft** may be configured with a **Receiver**. A **Receiver** is assigned on the **AddHardware** list of an instance of a **GroundStation** or **Spacecraft**.

A **GroundStation** resource, for example, needs to receive the RF signal from a tracked spacecraft. The receiver resource is also used as the host object for the GPS\_PosVec and inter-spacecraft measurement error models. When using GPS\_PosVec data for estimation or simulation, an **ErrorModel** instance specifying the **GPS\_PosVec** measurement type should be assigned on a **Receiver** object, and that receiver should be assigned to the associated **Spacecraft** object. For simulation or estimation of inter-spacecraft tracking, the "tracking" spacecraft must have a Receiver with the proper ErrorModels assigned and configured.

See Also: [GroundStation](#), [Antenna](#)

### Fields

Field	Description
<b>ErrorModels</b>	User-defined list of <b>ErrorModel</b> objects that describe the measurement error models used for this receiver. The error model types currently supported on the receiver object are GPS_PosVec, Range, and RangeRate. This parameter is needed when simulating or estimating using GPS_PosVec data to describe the measurement error model for the receiver. This parameter is also needed for simulation and estimation of inter-spacecraft tracking, currently implemented for measurement types Range, and RangeRate.  <b>Data Type</b> StringList <b>Allowed Values</b> An instance of <b>ErrorModel</b> using the GPS_PosVec, Range, or RangeRate observation type <b>Access</b> set <b>Default Value</b> <b>None</b> <b>Units</b> N/A <b>Interfaces</b> script

Field	Description	
<b>Id</b>	Integer identification number for this receiver. This should match the receiver ID specified for the GPS_PosVec data in the GMD file. This parameter is only needed when simulating or estimating using GPS_PosVec data.	
	<b>Data Type</b>	Integer
	<b>Allowed Values</b>	Integer >= 0
	<b>Access</b>	set
	<b>Default Value</b>	<b>800</b>
	<b>Units</b>	N/A
	<b>Interfaces</b>	script
<b>PrimaryAntenna</b>	Antenna resource used by <b>Receiver</b> or <b>Spacecraft</b> resource to receive a signal	
	<b>Data Type</b>	<b>Antenna</b> Object
	<b>Allowed Values</b>	Any valid <b>Antenna</b> object
	<b>Access</b>	set
	<b>Default Value</b>	<b>None</b>
	<b>Units</b>	N/A
	<b>Interfaces</b>	script

## Examples

Create and configure a **Receiver** object and attach it to a **GroundStation**.

```
Create Antenna DSNReceiverAntenna;
Create Receiver Receiver1;

Receiver1.PrimaryAntenna = DSNReceiverAntenna;

Create GroundStation DSN
DSN.AddHardware = {Receiver1};
BeginMissionSequence;
```

## RejectFilter

Allows selection of data subsets for processing by the batch least squares estimator.

### Description

The **RejectFilter** object is used to create criteria for the exclusion of subsets of the available data in the estimation process based on tracker, observed object, measurement type, or time. Instances of **RejectFilter** are specified for use on the **DataFilters** field of a **TrackingFileSet** or **BatchEstimator** object.

GMAT implements two levels of data editing for estimation. First-level editing criteria are specified on the **DataFilters** field of the **TrackingFileSet** instance. At this level, the user may choose what data is admitted into the overall pool of observations provided to the estimator. Any data excluded at the tracking file set level will be immediately discarded and not available to the estimation process.

Second-level data editing is specified on the **DataFilters** field of the **BatchEstimator** instance. At this level, the user may choose what data is used in the estimation state update. Residuals will be computed for any observations admitted through first-level editing, but any data excluded at the estimator level will be flagged as user edited, and will not affect the computation of the state correction. This allows the user to evaluate the quality of untrusted data against a solution computed using a trusted set of measurements.

A single reject filter may employ multiple selection criteria (for example simultaneous thinning by time and tracker). Multiple criteria on a single filter are considered in an AND sense. When multiple criteria are specified in a single filter, an observation must meet all specified criteria to be rejected. Multiple filters with different selection criteria may be specified on a single **TrackingFileSet** or **BatchEstimator**. When multiple filters are specified, these act in an OR sense. Data meeting criteria for any of the specified filters will be rejected.

See Also [AcceptFilter](#), [TrackingFileSet](#), [BatchEstimator](#)

### Fields

Field	Description	
<b>DataTypes</b>	List of data types	
	<b>Data Type</b>	String Array
	<b>Allowed Values</b>	A set of any supported GMAT measurement types, or 'All'
	<b>Access</b>	set
	<b>Default Value</b>	{All}
	<b>Units</b>	N/A
	<b>Interfaces</b>	script

Field	Description	
<b>EpochFormat</b>	Allows user to select format of the epoch	
	<b>Data Type</b>	String
	<b>Allowed Values</b>	UTCGregorian, UTCModJulian, TAIGregorian, TAIModJulian, TTGregorian, TTModJulian A1Gregorian, A1ModJulian, TDBGregorian, TDBModJulian
	<b>Access</b>	set
	<b>Default Value</b>	<b>TAIModJulian</b>
	<b>Units</b>	N/A
	<b>Interfaces</b>	script
<b>FileNames</b>	List of file names (a subset of the relevant <b>TrackingFileSet</b> 's <b>FileName</b> field) containing the tracking data, to be excluded from processing. This field is only applicable when the <b>RejectFilter</b> is used on a <b>TrackingFileSet</b> .	
	<b>Data Type</b>	StringArray
	<b>Allowed Values</b>	valid file name or 'All'
	<b>Access</b>	set
	<b>Default Value</b>	<b>{All}</b>
	<b>Units</b>	N/A
	<b>Interfaces</b>	script
<b>FinalEpoch</b>	Final epoch of desired data to process.	
	<b>Data Type</b>	String
	<b>Allowed Values</b>	any valid epoch
	<b>Access</b>	set
	<b>Default Value</b>	<b>latest day defined in GMAT</b>
	<b>Units</b>	N/A
	<b>Interfaces</b>	script
<b>InitialEpoch</b>	Initial epoch of desired data to process.	
	<b>Data Type</b>	String
	<b>Allowed Values</b>	any valid epoch
	<b>Access</b>	set
	<b>Default Value</b>	<b>earliest day defined in GMAT</b>
	<b>Units</b>	N/A
	<b>Interfaces</b>	script

Field	Description												
<b>ObservedObjects</b>	<p>List of user-created tracked objects (e.g., name of the <b>Spacecraft</b> resource being tracked).</p> <table> <tr> <td><b>Data Type</b></td><td>Object Array</td></tr> <tr> <td><b>Allowed Values</b></td><td>User defined observed object or 'All'</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>{All}</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Object Array	<b>Allowed Values</b>	User defined observed object or 'All'	<b>Access</b>	set	<b>Default Value</b>	{All}	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Object Array												
<b>Allowed Values</b>	User defined observed object or 'All'												
<b>Access</b>	set												
<b>Default Value</b>	{All}												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>RecordNumbers</b>	<p>A list of one or more single record numbers or spans of record numbers to reject. Observation record numbers are reported in the GMAT estimator output file. This field is only applicable when the <b>RejectFilter</b> is used on the estimator level.</p> <table> <tr> <td><b>Data Type</b></td><td>String array</td></tr> <tr> <td><b>Allowed Values</b></td><td>Integers or spans of integers (see examples)</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>{}</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String array	<b>Allowed Values</b>	Integers or spans of integers (see examples)	<b>Access</b>	set	<b>Default Value</b>	{}	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	String array												
<b>Allowed Values</b>	Integers or spans of integers (see examples)												
<b>Access</b>	set												
<b>Default Value</b>	{}												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>Trackers</b>	<p>List of user-created trackers (e.g., name of the <b>GroundStation</b> resource being used).</p> <table> <tr> <td><b>Data Type</b></td><td>Object Array</td></tr> <tr> <td><b>Allowed Values</b></td><td>any valid user-created Tracker object (e.g., <b>GroundStation</b>) or 'All'</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>{All}</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Object Array	<b>Allowed Values</b>	any valid user-created Tracker object (e.g., <b>GroundStation</b> ) or 'All'	<b>Access</b>	set	<b>Default Value</b>	{All}	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	Object Array												
<b>Allowed Values</b>	any valid user-created Tracker object (e.g., <b>GroundStation</b> ) or 'All'												
<b>Access</b>	set												
<b>Default Value</b>	{All}												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												

## Remarks

Some fields of **RejectFilter** are not applicable at either the first-level (tracking file set) or second-level (estimator) editing stages. The **RecordNumbers** field has no functionality when applied to a reject filter at the tracking file set level. The **FileNames** field has no functionality when applied to a reject filter at the estimator level.

Use of combinations of instances **AcceptFilter** and **RejectFilter** at both levels is permitted.

## Examples

### First-level (TrackingFileSet) Data Editing

The following examples illustrate use of a **RejectFilter** for first-level data editing. At this level, the **RejectFilter** instance should be assigned to the **DataFilters** field of a

**TrackingFileSet.** In these examples, data meeting the criteria specified by the reject filter will be immediately discarded. All other data is admitted.

This example shows how to create a **RejectFilter** to reject all observations from station **GDS**.

```
Create GroundStation GDS;
Create RejectFilter rf;

rf.Trackers = {'GDS'};

Create TrackingFileSet estData;

estData.DataFilters = {rf};

BeginMissionSequence;
```

The next example will reject all DSN Doppler (i.e., DSN\_TCP) tracking measurements from station **GDS**, and all tracking of any type from station **CAN**. All other tracking measurements will be accepted.

```
Create GroundStation GDS CAN;

Create RejectFilter rf1;
Create RejectFilter rf2;

rf1.Trackers = {'GDS'};
rf1.DataTypes = {'DSN_TCP'};
rf2.Trackers = {'CAN'};

Create TrackingFileSet estData;

estData.DataFilters = {rf1, rf2};

BeginMissionSequence;
```

### Second-level (estimator) Data Editing

The following examples illustrate use of a **RejectFilter** for second-level data editing. At this level, the **RejectFilter** instance should be assigned to the **DataFilters** field of a **BatchEstimator**. In these examples, data meeting the criteria specified by the reject filter will excluded from the estimation state update. Residuals will be computed for all available data (all data admitted at the first level), but data rejected at the estimator level will be flagged as user edited.

This example shows how to create a **RejectFilter** to reject specific observations by record number.

```
Create RejectFilter rf;
```

```
rf.RecordNumbers = {13, 25, 75-87};  
  
Create BatchEstimator bls;  
  
bls.DataFilters = {rf};  
  
BeginMissionSequence;
```

The next example shows how to simultaneously employ multiple reject filters. In this example:

- MAD range data over the span 10 Jun 2012 02:56 to 13:59 is rejected
- All CAN DSN\_TCP data is rejected
- All RangeRate data (from any station) is rejected

```
Create RejectFilter rf1 rf2 rf3;  
Create GroundStation MAD CAN;  
  
rf1.Trackers      = {'MAD'};  
rf1.DataTypes     = {'Range'};  
rf1.EpochFormat   = UTCGregorian;  
rf1.InitialEpoch  = '10 Jun 2012 02:56:00.000';  
rf1.FinalEpoch    = '10 Jun 2012 13:59:00.000';  
  
rf2.Trackers      = {'CAN'};  
rf2.DataTypes     = {'DSN_TCP'};  
  
rf3.DataTypes     = {'RangeRate'};  
  
Create BatchEstimator bls;  
  
bls.DataFilters = {rf1, rf2, rf3};  
  
BeginMissionSequence;
```

## Simulator

Configures the generation of simulated tracking data measurements.

### Description

A **Simulator** configures the generation of simulated tracking data measurements. These measurements can then be used by a **BatchEstimator** resource as part of an estimation run.

The **Simulator** object requires specification of one or more instances of a **TrackingFileSet** resource which identify the specific tracking data observation strands, data types, desired measurement corrections, and the output tracking data file name. Simulated data will be written in the GMAT Measurement Data (GMD) ASCII tracking data format. You must additionally specify a time span for the simulation run and a time interval between simulated observations. Simulated observations are only generated when a tracking strand meets the visibility constraints of all objects in the strand (for example, the observation must be above the ground station minimum elevation mask). Additionally, you must configure and specify an instance of a **Propagator** for the simulator. Finally, you can choose to add random Gaussian white noise to the generated measurements or to generate measurements without noise. If the **Simulator.AddNoise** option is set to On, noise with the standard deviation specified on each measurement strand's **GroundStation.ErrorModel**, is added to the measurements.

See Also: [TrackingFileSet](#), [RunEstimator](#)

### Fields

Field	Description
<b>AddData</b>	A list of one or more <b>TrackingFileSets</b> .  <b>Data Type</b> <b>TrackingFileSet</b> object <b>Allowed Values</b> Any valid <b>TrackingFileSet</b> object <b>Access</b> set <b>Default Value</b> <b>None</b> <b>Units</b> N/A <b>Interfaces</b> script
<b>AddNoise</b>	If true, adds noise to simulated observations.  <b>Data Type</b> Boolean <b>Allowed Values</b> true, false, on, off <b>Access</b> set <b>Default Value</b> <b>false</b> <b>Units</b> N/A <b>Interfaces</b> script

Field	Description														
<b>EpochFormat</b>	<p>Epoch format of both the initial and final epoch.</p> <table> <tr> <td><b>Data Type</b></td><td>STRING_TYPE</td></tr> <tr> <td><b>Allowed Values</b></td><td>A1ModJulian, TAIModJulian, UTCModJulian, TTModJulian, TDBModJulian, A1Gregorian, TAIGregorian, TTGregorian, UTCGregorian, TDBGregorian</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>TAIModJulian</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	STRING_TYPE	<b>Allowed Values</b>	A1ModJulian, TAIModJulian, UTCModJulian, TTModJulian, TDBModJulian, A1Gregorian, TAIGregorian, TTGregorian, UTCGregorian, TDBGregorian	<b>Access</b>	set	<b>Default Value</b>	TAIModJulian	<b>Units</b>	N/A	<b>Interfaces</b>	script		
<b>Data Type</b>	STRING_TYPE														
<b>Allowed Values</b>	A1ModJulian, TAIModJulian, UTCModJulian, TTModJulian, TDBModJulian, A1Gregorian, TAIGregorian, TTGregorian, UTCGregorian, TDBGregorian														
<b>Access</b>	set														
<b>Default Value</b>	TAIModJulian														
<b>Units</b>	N/A														
<b>Interfaces</b>	script														
<b>InitialEpoch</b>	<p>The initial (start) epoch of the data simulation span. In the GMAT script, the <b>EpochFormat</b> field needs to be set before this field is set.</p> <table> <tr> <td><b>Data Type</b></td><td>STRING_TYPE</td></tr> <tr> <td><b>Allowed Values</b></td><td>Gregorian: 04 Oct 1957 12:00:00.000 &lt;= Epoch &lt;= 28 Feb 2100 00:00:00.000</td></tr> <tr> <td></td><td>Modified Julian: 6116.0 &lt;= Epoch &lt;= 58127.5</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>'21545'</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	STRING_TYPE	<b>Allowed Values</b>	Gregorian: 04 Oct 1957 12:00:00.000 <= Epoch <= 28 Feb 2100 00:00:00.000		Modified Julian: 6116.0 <= Epoch <= 58127.5	<b>Access</b>	set	<b>Default Value</b>	'21545'	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	STRING_TYPE														
<b>Allowed Values</b>	Gregorian: 04 Oct 1957 12:00:00.000 <= Epoch <= 28 Feb 2100 00:00:00.000														
	Modified Julian: 6116.0 <= Epoch <= 58127.5														
<b>Access</b>	set														
<b>Default Value</b>	'21545'														
<b>Units</b>	N/A														
<b>Interfaces</b>	script														
<b>FinalEpoch</b>	<p>The final (ending) epoch of the data simulation span. In the GMAT script, the <b>EpochFormat</b> field needs to be set before this field is set.</p> <table> <tr> <td><b>Data Type</b></td><td>STRING_TYPE</td></tr> <tr> <td><b>Allowed Values</b></td><td>Gregorian: 04 Oct 1957 12:00:00.000 &lt;= Epoch &lt;= 28 Feb 2100 00:00:00.000</td></tr> <tr> <td></td><td>Modified Julian: 6116.0 &lt;= Epoch &lt;= 58127.5</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>'21545'</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	STRING_TYPE	<b>Allowed Values</b>	Gregorian: 04 Oct 1957 12:00:00.000 <= Epoch <= 28 Feb 2100 00:00:00.000		Modified Julian: 6116.0 <= Epoch <= 58127.5	<b>Access</b>	set	<b>Default Value</b>	'21545'	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	STRING_TYPE														
<b>Allowed Values</b>	Gregorian: 04 Oct 1957 12:00:00.000 <= Epoch <= 28 Feb 2100 00:00:00.000														
	Modified Julian: 6116.0 <= Epoch <= 58127.5														
<b>Access</b>	set														
<b>Default Value</b>	'21545'														
<b>Units</b>	N/A														
<b>Interfaces</b>	script														

Field	Description	
<b>Measurement-TimeStep</b>	Specifies time step in seconds between two consecutive simulated observations.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real > 0
	<b>Access</b>	set
	<b>Default Value</b>	60
	<b>Units</b>	seconds
	<b>Interfaces</b>	script
<b>Propagator</b>	Name of <b>Propagator</b> object used to advance a spacecraft through time. Optionally, a separate <b>Propagator</b> field can be used to identify the propagator for specific spacecraft in the simulator's configuration, as described below.	
	<b>Data Type</b>	Valid <b>Propagator</b> object optionally followed by a set of valid <b>Spacecraft</b> objects.
	<b>Allowed Values</b>	Any valid <b>Propagator</b> object optionally followed by one or more <b>Spacecraft</b> objects
	<b>Access</b>	<i>Propagator, or {Propagator, Spacecraft[, Spacecraft2, Spacecraft3, etc.]}</i>
	<b>Default Value</b>	set
	<b>Units</b>	<b>None</b>
	<b>Interfaces</b>	N/A
		script

## Remarks



### Note

When configuring a numerical integrator for the simulator, you must use the fixed-step option. The **ErrorControl** parameter specified for the **Force-Model** resource associated with the **Simulator Propagator** must be set to 'None.' Of course, when using fixed step control, the user must choose a step size, as given by the **Propagator InitialStepSize** field, for the chosen orbit regime and force profile, that yields the desired accuracy.

## Propagator Settings

The **Simulator** resource has a **Propagator** field containing the name of the **Propagator** resource that will be used during the simulation process. The minimum step size, **MinStep**, of your propagator should always be set to 0.

If the simulator includes tracking configurations referencing multiple spacecraft, the **Simulator** uses the first **Propagator** identified as the default propagator for spacecraft that are simulated. You can specify a different **Propagator** for specific spacecraft using an

optional list of spacecraft assigned to other propagator components. An example of this usage is shown below.

### Central Bodies Other Than Earth

The GMAT simulator will account for central body occultations for spacecraft orbiting bodies other than the Earth. For example, for a Moon-centered spacecraft, simulated measurements will exclude any times when the line of sight between the spacecraft and the ground station is blocked by the Moon. Note however, that GMAT currently uses a spherical shape model for this occultation check. GMAT will use the polar radius of the central body when performing the occultation check and any body oblateness is ignored.

### Interactions

Resource	Description
<b>Tracking-FileSet</b>	Must be created in order to tell the <b>Simulator</b> resource, via the <b>AddData</b> field, which data types will be simulated and to specify the name of the output tracking data file (via <b>FileName</b> )
<b>Propagator resource</b>	Used by GMAT to generate the simulated orbit
<b>RunSimulator com-mand</b>	Must use the <b>RunSimulator</b> command to actually create the data defined by the <b>Simulator</b> resource

### Examples

The example below illustrates using the simulator to generate DSN range measurements. This example is more detailed than usual as it can actually be run to produce a file, `simData.gmd`, that contains a single range measurement for a fictional DSN ground station. For a more comprehensive example of simulating measurements, see the [Simulate DSN Range and Doppler Data](#) tutorial.

```
%Create and Configure Spacecraft
Create Spacecraft SimSat

SimSat.DateFormat = UTCGregorian
SimSat.Epoch      = '19 Aug 2015 00:00:00.000'
SimSat.X          = -126544963
SimSat.Y          = 61978518
SimSat.Z          = 24133225
SimSat.VX         = -13.789
SimSat.VY         = -24.673
SimSat.VZ         = -10.662
SimSat.AddHardware = {SatTransponder, SatTranponderAntenna}

%Create and configure RF hardware
Create Antenna SatTranponderAntenna DSNReceiverAntenna DSNTtransmitterAntenna

Create Transponder SatTransponder
SatTransponder.PrimaryAntenna = SatTranponderAntenna

Create Transmitter DSNTtransmitter
DSNTtransmitter.PrimaryAntenna = DSNTtransmitterAntenna
```

```

DSNTransmitter.Frequency      = 7200

Create Receiver DSNReceiver
DSNReceiver.PrimaryAntenna = DSNReceiverAntenna

%Create and configure ground station and related error model
Create GroundStation DSN
DSN.AddHardware = ...
    {DSNTransmitter, DSNReceiver, DSNTransmitterAntenna, DSNReceiverAntenna}
DSN.ErrorModels = {DSNrange}

Create ErrorModel DSNrange
DSNrange.Type      = 'DSN_SeqRange'
DSNrange.NoiseSigma = 10

%Define data types
Create TrackingFileSet simData
simData.AddTrackingConfig = {{DSN,SimSat,DSN}, DSN_SeqRange}
simData.FileName         = {'simData.gmd'}

% Create and configure the Simulator object
Create ForceModel FM1
FM1.ErrorControl = None    %Fixed step integration required for Navigation

Create Propagator prop
prop.FM      = FM1
prop.MinStep = 0           %For Navigation, allow propagator to take arbitrarily small steps

Create Simulator Sim
Sim.AddData          = {simData}
Sim.Propagator       = prop
Sim.EpochFormat     = UTCGregorian
Sim.InitialEpoch    = '19 Aug 2015 08:00:00.000'
Sim.FinalEpoch      = '19 Aug 2015 08:00:01.000'
Sim.MeasurementTimeStep = 60
Sim.AddNoise        = On

% Mission Sequence - run the simulator.

BeginMissionSequence

RunSimulator sim

```

The next example shows how to script multiple propagators on a simulator. This example illustrates the scripting for propagators only, and does not include other object settings. In this example, the TDRS spacecraft are propagated using an ephemeris-based SPICE propagator. Any other spacecraft used in the simulator are propagated using the SatProp propagator.

```

% Create and Configure Spacecraft
Create Spacecraft SimSat

% This example assumes these BSP files exist in the GMAT output directory
Create Spacecraft TDRS6
TDRS6.OrbitSpiceKernelName = {'TDRS6Ephem.bsp'}

Create Spacecraft TDRS10
TDRS10.OrbitSpiceKernelName = {'TDRS10Ephem.bsp'}

% Create and configure the Simulator object

```

```
Create ForceModel FM

Create Propagator SatProp
SatProp.FM      = FM
SatProp.MinStep = 0

Create Propagator TdrsProp
TdrsProp.Type   = SPK

Create Simulator Sim

Sim.Propagator = SatProp
Sim.Propagator = {TdrsProp, TDRS6, TDRS10}
```

## Smoother

A backwards filter yielding an improved estimate of states through weighted combination of forward and reverse sequential estimation.

### Description

A fixed-interval backward-running sequential estimator utilizing the Fraser-Potter algorithm for fusion of forward and reverse estimated states.

See Also: [ExtendedKalmanFilter](#), [RunSmoother](#)

### Fields

Field	Description												
<b>AddPredictToMatlabFile</b>	<p>Set to True to include the data from the Smoother prediction span in the MATLAB file. Predicted data is only generated if <b>PredictTimeSpan</b> is non-zero. Setting this parameter to True will add the predicted states, covariance, process noise, and state transition matrix to the Smoother MATLAB data file.</p> <table> <tr> <td><b>Data Type</b></td><td>True/False</td></tr> <tr> <td><b>Allowed Values</b></td><td>True or False</td></tr> <tr> <td><b>Access</b></td><td>Set</td></tr> <tr> <td><b>Default Value</b></td><td><b>False</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>Script</td></tr> </table>	<b>Data Type</b>	True/False	<b>Allowed Values</b>	True or False	<b>Access</b>	Set	<b>Default Value</b>	<b>False</b>	<b>Units</b>	N/A	<b>Interfaces</b>	Script
<b>Data Type</b>	True/False												
<b>Allowed Values</b>	True or False												
<b>Access</b>	Set												
<b>Default Value</b>	<b>False</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	Script												
<b>DelayRectifyTimeSpan</b>	<p>Defines a period of time, beginning from warm start or initialization, for which the reference trajectory is generated from the a-priori or initial state. As always, any measurements are used to update the estimated state, but the measurements will not be applied to the reference trajectory used for linearization. After the delay rectify time span has elapsed, the a-priori state is discarded, and the current filter estimated state is used as the reference trajectory for linearization, in accordance with normal operation of an extended Kalman filter.</p> <p>This parameter applies to the backward filter when using the Fraser-Potter smoothing algorithm. A similar parameter exists for the forward filter on the <b>ExtendedKalmanFilter</b> resource. See the Remarks below for further notes on this parameter.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real <math>\geq 0</math></td></tr> <tr> <td><b>Access</b></td><td>Set</td></tr> <tr> <td><b>Default Value</b></td><td><b>0</b></td></tr> <tr> <td><b>Units</b></td><td>Seconds</td></tr> <tr> <td><b>Interfaces</b></td><td>Script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real $\geq 0$	<b>Access</b>	Set	<b>Default Value</b>	<b>0</b>	<b>Units</b>	Seconds	<b>Interfaces</b>	Script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real $\geq 0$												
<b>Access</b>	Set												
<b>Default Value</b>	<b>0</b>												
<b>Units</b>	Seconds												
<b>Interfaces</b>	Script												

Field	Description	
<b>Filter</b>	The forward-run <b>Filter</b> instance containing the states and covariances to process in the smoother.	
	<b>Data Type</b>	Resource
	<b>Allowed Values</b>	User defined instance of an <b>Extended-KalmanFilter</b> resource
	<b>Access</b>	Set
	<b>Default Value</b>	<b>None</b>
	<b>Units</b>	N/A
	<b>Interfaces</b>	Script
<b>MatlabFile</b>	File name for the output MATLAB data file. Leaving this parameter unset means that no MATLAB file will be generated.	
	<b>Data Type</b>	String
	<b>Allowed Values</b>	String containing a valid file name.
	<b>Access</b>	Set
	<b>Default Value</b>	<b>None</b>
	<b>Units</b>	N/A
	<b>Interfaces</b>	Script
<b>MeasDeweighting-Coefficient</b>	Coefficient used for Measurement Underweighting for the backward propagating EKF used by the smoother. Using the default value, Measurement Underweighting is effectively turned off. We use Lear's Measurement Underweighting method described by Eq. (4.36) in Reference 1. See the Remarks for the <b>Extended-KalmanFilter</b> resource for additional details.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real $\geq 0$ .
	<b>Access</b>	Set
	<b>Default Value</b>	<b>0.0</b>
	<b>Units</b>	N/A
	<b>Interfaces</b>	Script
<b>MeasDeweightingSigmaThreshold</b>	1-sigma RSS position threshold used for Measurement Underweighting processing. Measurement Underweighting is only performed if the 1-sigma RSS position threshold, derived from the error covariance matrix, is greater than this threshold AND the <b>MeasDeweightingCoefficient</b> is greater than 0.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real $\geq 0$ .
	<b>Access</b>	Set
	<b>Default Value</b>	<b>1.0</b>
	<b>Units</b>	km
	<b>Interfaces</b>	Script

Field	Description	
<b>PredictTimeSpan</b>	Time span in seconds for the smoother ephemeris prediction after processing the last measurement.	
	<b>Data Type</b>	Real
	<b>Allowed Values</b>	Real $\geq 0$
	<b>Access</b>	Set
	<b>Default Value</b>	0
	<b>Units</b>	Seconds
	<b>Interfaces</b>	Script
<b>ReportFile</b>	Smoothen output report file name.	
	<b>Data Type</b>	String
	<b>Allowed Values</b>	String containing a valid file name
	<b>Access</b>	Set
	<b>Default Value</b>	'Smoothen' + instancename + '.data'
	<b>Units</b>	N/A
	<b>Interfaces</b>	Script
<b>ReportStyle</b>	Specifies the level of report output from the smoother. If Normal mode is selected, only the smoother report file is generated. If Verbose mode is selected, an additional output report file will be generated from the smoother backward filter run. Selection of Verbose mode requires the user to assign RUN_MODE = Testing in the GMAT startup file.	
	<b>Data Type</b>	String
	<b>Allowed Values</b>	Normal, Verbose
	<b>Access</b>	Set
	<b>Default Value</b>	Normal
	<b>Units</b>	N/A
	<b>Interfaces</b>	Script

## Remarks

### Fraser-Potter Smoother

The **Smoothen** resource implements a Fraser-Potter (FP) fixed-interval smoother as described in Reference 1 and Reference 2. The FP smoother first runs a filter backward (from the latest to earliest measurement) over the same span as the filter "forward" run. The backward filter initial state is set to the forward filter final state. The backward filter initial covariance is set to the diagonal elements of the forward filter end covariance, with the position and velocity variances multiplied by a scale factor of 1e+10 and other estimated parameter variances multiplied by a factor of 1e+4. The off-diagonal elements of the backward filter initial covariance are zeroed out. The smoother estimate at each time or measurement update is formulated as a weighted linear combination of the forward filter and backward smoother estimates. See the references for further mathematical details.

The inflation of the backwards filter initial covariance makes it susceptible to divergence and other numerical errors during its convergence span. If the smoother fails, it is strongly recommended to attempt another smoother run with **DelayRectifyTimeSpan** set to a time span that would normally allow the filter to converge. In Normal mode, the smoother output report file does not include the results of the backward filter pass, but you can set the Smoother **ReportStyle** to **Verbose** (requires setting RUN\_MODE = TESTING in gmat\_startup\_file.txt) to produce a report of the backward filter run to assist troubleshooting.

### Navigation Requires Use of Fixed Step Numerical Integration

GMAT navigation requires use of fixed stepped propagation. The **ExtendedKalmanFilter** resource has a **Propagator** field containing the name of the **Propagator** resource that will be used during the estimation process. As shown in the **Note** below, there are some hard restrictions on the choice of error control specified for the **ForceModel** resource associated with your propagator.



#### Note

The **ErrorControl** parameter specified for the **ForceModel** resource associated with the **ExtendedKalmanFilter Propagator** must be set to 'None.' Of course, when using fixed step control, the user must choose a step size, as given by the **Propagator InitialStepSize** field, for the chosen orbit regime and force profile, that yields the desired accuracy.

### Smoother MATLAB Data File

If MATLAB is installed and properly configured to interface with GMAT (see [MATLAB Interface](#)), the user may generate a mat-file containing useful analysis data from the **Smoother** run. This option is enabled by specifying a path and filename for the output file on the **MatlabFile** field of the configured **Smoother** resource. Except as noted in the tables below, the units for data in the mat-file are the same as those in the Smoother output file; seconds, km, km/sec, DSN Range Units, Hz, and degrees.

The Smoother MATLAB file **EstimationConfig**, and **Observed** structures are identical to those from the Filter resource and are described in the Filter resource documentation (see [the section called "Kalman Filter MATLAB Data File"](#)). The output from the smoother backward filter run is stored in the **BackwardComputed** and **BackwardFilter** structures of the smoother output file. These have the same structure and contents as the **Computed** and **Filter** structures in the forward filter MATLAB file, and again are described in the Filter resource documentation.

The smoother MATLAB file **Computed** structure differs slightly from its Filter counterpart. Contents of the smoother **Computed** structure are described in the table below.

Variable	Description
Elevation	Computed elevation in degrees at the measurement epoch. Does not apply (set to 0) for GPS_PosVec data.

Variable	Description
IonosphericCorrection	The magnitude of the ionospheric measurement correction. Units are the same as the measurement. See note below regarding media corrections for X/Y angle measurements.
Measurement	Computed measurements. For GPS_PosVec, each cell holds a 1x3 column vector of X, Y, Z computed measurements.
MeasurementEditFlag	The string observation edit flag. 'N' indicates unedited/accepted observations.
MeasurementNumber	Measurement record number.
MeasurementPartials	A cell array of matrices. Each member is a matrix of the partial derivatives of the measurement with respect to each element of the state. The partials are taken with respect to the element type selected on the Spacecraft <b>SolveFor</b> s field. For example, if the user has chosen to estimate the KeplerianState, the partials are with respect to the Keplerian elements. The order of elements matches that given in the EstimationConfig state names. For GPS_PosVec data, each cell holds a 3xN matrix, where N is the number of estimated states. Each row contains the partials with respect to the X, Y, and Z GPS_PosVec measurement in order.
PreUpdateCovariance	Smoother state covariance prior to measurement update.
PreUpdateCovarianceVNB	Smoother state covariance prior to measurement update, in the VNB reference frame.
Residual	Smoother state residual prior to measurement update.
PreUpdateState	Smoother state prior to measurement update.
ScaledResidual	A unitless value representing the raw residual divided by the sum of state noise (appropriately transformed) and measurement noise. Schematically, Scaled Residual = Raw Residual / ( $HPH'$ + R).
TroposphericCorrection	The magnitude of the tropospheric measurement correction. Units are the same as the measurement. See note below regarding media corrections for X/Y angle measurements.

Contents of the **Smoother** structure are described in the table below.

Variable	Description
Covariance	The smoother state covariance (Cartesian), after the measurement or time update.

Variable	Description
CovarianceVNB	The smoother state covariance (VNB coordinates), after the measurement or time update.
EpochTAI	The TAI epoch of each smoother record. Each member is a column vector where the first row is the epoch as a MATLAB datenum and the second row is the epoch as a GMAT TAIModJulian date.
EpochUTC	The UTC epoch of each smoother record. Each member is a column vector where the first row is the epoch as a MATLAB datenum and the second row is the epoch as a GMAT UTCModJulian date.
MeasurementNumber	Measurement record number. Set to NaN for initial or time update steps.
State	Smoother state after the measurement or time update.
UpdateType	Filter update mode (Initial, Time, or Measurement).

## Examples

Below is an example of a configured **Smoother** instance. In this example, **EKF** is an instance of an **ExtendedKalmanFilter**.

```
Create Smoother SMO;
SMO.Filter      = EKF;
SMO.PredictTimeSpan = 86400.;
SMO.ReportFile   = 'smoother_run.txt';
SMO.MatlabFile   = 'smoother_run.mat';

BeginMissionSequence;

RunSmoother SMO;
```

## References

1. Carpenter, Russell and Chris D'Souza. *Navigation Filter Best Practices*. Technical Report TP-2018-219822, NASA, April 2018.
2. D. C. Fraser and J. E. Potter, "The Optimum Linear Smoother as a Combination of Two Optimum Linear Filters", *IEEE Trans. Automat. Contr.*, vol. AC-14, no. 4, pp. 387-390, Aug. 1969.

## Spacecraft Navigation

There are a number of **Spacecraft** fields that are used exclusively to support GMAT's navigation (orbit determination) capability.

### Description

When using GMAT's navigation (orbit determination) capabilities, certain Spacecraft parameters can be estimated or "solved-for." As discussed in the [Spacecraft Ballistic/Mass Properties](#) section, the **Spacecraft** ballistic and mass properties include the coefficient of reflectivity, **Cr**, and the coefficient of drag, **Cd**. As part of GMAT's navigation capability, GMAT can ingest measurements and estimate ("solve-for") either the **CartesianState**, or **KeplerianState**, as well as any of a set of associated force modeling parameters. See the **SolveFors** parameter below for a full list of estimated parameters.

See Also: [BatchEstimator](#)

### Fields

Field	Description
<b>AddHardware</b>	<p>List of <b>Antenna</b>, <b>Transmitter</b>, <b>Receiver</b>, and <b>Transponder</b> objects attached to a <b>Spacecraft</b></p> <p><b>Data Type</b>      Antenna, Transmitter, Receiver, or Transponder object <b>Allowed Values</b>    Any user defined Antenna, Transmitter, Receiver, or Transponder object <b>Access</b>            set <b>Default Value</b>     None <b>Units</b>             N/A <b>Interfaces</b>        script</p>
<b>AtmosDensityScaleFactorSigma</b>	<p>Standard deviation of the atmospheric density scale factor, <b>AtmosDensityScaleFactor</b>. For the batch estimator, this field is only used if the <b>UseInitialCovariance</b> field of the <b>BatchEstimator</b> resource is set to True and <b>AtmosDensityScaleFactor</b> is estimated.</p> <p><b>Data Type</b>      Real <b>Allowed Values</b>   Real &gt; 0 <b>Access</b>            set <b>Default Value</b>    1.0E+70 <b>Units</b>             dimensionless <b>Interfaces</b>        script</p>

Field	Description
<b>CdSigma</b>	<p>Standard deviation of the coefficient of drag, <b>Cd</b>. For the batch estimator, this field is only used if the <b>UseInitialCovariance</b> field of the <b>BatchEstimator</b> resource is set to True and <b>Cd</b> is estimated.</p>
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	Real > 0
	<b>Access</b>
	set
	<b>Default Value</b>
	1.0E+70
	<b>Units</b>
	dimensionless
	<b>Interfaces</b>
	script
<b>CrSigma</b>	<p>Standard deviation of the coefficient of reflectivity, <b>Cr</b>. For the batch estimator, this field is only used if the <b>UseInitialCovariance</b> field of the <b>BatchEstimator</b> resource is set to True and <b>Cr</b> is estimated.</p>
	<b>Data Type</b>
	Real
	<b>Allowed Values</b>
	Real > 0
	<b>Access</b>
	set
	<b>Default Value</b>
	1.0E+70
	<b>Units</b>
	dimensionless
	<b>Interfaces</b>
<b>Id</b>	<p>The spacecraft Id used in GMD tracking data files. This value must match the spacecraft ID appearing in the GMD tracking data records. In general any value is allowed, but see the remarks below for important rules regarding TDRS spacecraft IDs.</p>
	<b>Data Type</b>
	String
	<b>Allowed Values</b>
	String
	<b>Access</b>
	set
	<b>Default Value</b>
	SatId
	<b>Units</b>
	N/A
	<b>Interfaces</b>

Field	Description
<b>OrbitErrorCovariance</b>	<p>State 6x6 error covariance matrix. If <b>CartesianState</b> is estimated, this must be a Cartesian covariance. If <b>KeplerianState</b> is estimated, this must be a Keplerian covariance. Regardless of choice of spacecraft coordinate system, the covariance must be specified in the EarthMJ2000Eq coordinate system.</p> <p>For the batch estimator, this field is only used if the <b>UseInitialCovariance</b> of the <b>BatchEstimator</b> resource is set to True.</p> <p>For the extended Kalman filter, this field sets the spacecraft initial covariance in cold-start mode. This field is ignored by the extended Kalman filter when running in warm-start mode.</p> <p>For the Propagate command, the covariance may be specified in any coordinate system defined with MJ2000Eq axes. This will contain the propagated Cartesian covariance. The Covariance may be output in user defined coordinate systems, including non-MJ2000Eq systems, using the syntax <b>Spacecraft.CoordinateSystem.OrbitErrorCovariance</b></p>
<b>Data Type</b>	Real Matrix
<b>Allowed Values</b>	6x6 positive definite symmetric <b>Array</b>
<b>Access</b>	set, get
<b>Default Value</b>	6x6 diagonal matrix with 1e70 in all diagonal entries.
<b>Units</b>	For Cartesian elements: covariance matrix where position is specified in km and velocity in km/s. (Thus, first three diagonal elements have units km^2 and last three diagonal elements have units (km/s)^2)
	For Keplerian elements: covariance matrix in km and degrees (For example, the SMA element of the matrix has units km^2 and the INC element has units deg^2). The order of Keplerian elements is (SMA, ECC, INC, RAAN, AOP, MA). See the Remarks section for additional notes.
<b>Interfaces</b>	script

Field	Description
<b>ProcessNoiseMod-el</b>	<p>An instance of <b>ProcessNoiseModel</b>. This is used by an <b>ExtendedKalmanFilter</b> and the Covariance option of the <b>Propagate</b> command to account for general force modeling errors.</p>
	<p><b>Data Type</b> Resource  <b>Allowed Values</b> Any user defined <b>ProcessNoiseModel</b> resource  <b>Access</b> set  <b>Default Value</b> None  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>SolveFor</b>	<p>List of fields to be solved for. This list must at least include either <b>CartesianState</b> or <b>KeplerianState</b> (but not both). For example, <b>Cr</b> cannot be the only parameter solved for.</p> <p>When using the batch estimator, it is not possible to simultaneously estimate both <b>Cd</b> and <b>AtmosDensityScaleFactor</b> since they are linearly-dependent parameters. They may be simultaneously estimated in the extended Kalman filter, by configuring them as separate <b>EstimatedParameter</b> resources.</p> <p>Estimation of KeplerianElements is not currently supported for the ExtendedKalmanFilter estimator.</p>
	<p><b>Data Type</b> StringArray  <b>Allowed Values</b> CartesianState, KeplerianState (BatchEstimator only), Cr, Cd, SPADDragScaleFactor, SPADSRPSScaleFactor, AtmosDensityScaleFactor  <b>Access</b> set  <b>Default Value</b> None  <b>Units</b> N/A  <b>Interfaces</b> script</p>
<b>SPADDragScale-FactorSigma</b>	<p>Standard deviation of the SPAD drag scale factor. For the batch estimator, this field is only used if the <b>UseInitialCovariance</b> field of the <b>BatchEstimator</b> resource is set to True and <b>SPADDragScaleFactor</b> is estimated.</p>
	<p><b>Data Type</b> Real  <b>Allowed Values</b> Real &gt; 0  <b>Access</b> set  <b>Default Value</b> 1.0E+70  <b>Units</b> dimensionless  <b>Interfaces</b> Script</p>

Field	Description												
<b>SPADSRPScaleFactorSigma</b>	<p>Standard deviation of the SPAD SRP scale factor. For the batch estimator, this field is only used if the <b>UseInitialCovariance</b> field of the <b>BatchEstimator</b> resource is set to True and <b>SPADSRPScaleFactor</b> is estimated.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real &gt; 0</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>1.0E+70</td></tr> <tr> <td><b>Units</b></td><td>dimensionless</td></tr> <tr> <td><b>Interfaces</b></td><td>Script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real > 0	<b>Access</b>	set	<b>Default Value</b>	1.0E+70	<b>Units</b>	dimensionless	<b>Interfaces</b>	Script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real > 0												
<b>Access</b>	set												
<b>Default Value</b>	1.0E+70												
<b>Units</b>	dimensionless												
<b>Interfaces</b>	Script												

## Remarks

When estimating **CartesianState**, the input **OrbitErrorCovariance** matrix must represent a Cartesian covariance, and when estimating **KeplerianState** the **OrbitErrorCovariance** must represent a Keplerian covariance. Note that Keplerian covariance input employs Mean Anomaly (MA) instead of True Anomaly. The current release of GMAT only supports input of Keplerian orbit elements using TA and does not permit explicitly setting an initial MA. After estimation completes, **OrbitErrorCovariance** is updated to the value of the estimated covariance matrix.

For more details, see the section called “[UseInitialCovariance Restrictions](#)” in the Batch Estimator resource.

## Rules for Tracking and Data Relay Satellite System (TDRSS) Spacecraft Ids

Certain constants in the TDRSS measurement model depend on the user service (SA1, SA2, or MA) and TDRS spacecraft ID. The user service is explicitly indicated in the GMD file tracking data records. GMAT will attempt to determine the TDRS spacecraft ID from the **Spacecraft** resource **Id** parameter. For TDRS measurements to function properly in all cases, the user must observe one of the following conventions when assigning the **Spacecraft.Id** parameter for a TDRS spacecraft.

- The user may specify the TDRS SIC as the TDRS spacecraft Id. GMAT will infer the TDRS ID from the proper TDRS spacecraft SIC.
- Optionally, the user may specify the TDRS **Spacecraft.Id** in the format "<string><nn>", where <nn> is a one- or two-digit number indicating the TDRS ID. The <string> portion of the ID may be any string. For example, setting the spacecraft **Id** parameter to "TDRS09", "TD09", or "TDRS9" all properly identify the spacecraft as TDRS-9 (TDRS ID = 9).

Failing to follow one of these conventions may result in some Doppler measurements being computed incorrectly. GMAT will issue a warning message in the log file if it is unable to determine the TDRS ID from the spacecraft **Id** parameter.

## Examples

Solve for Cr and the spacecraft Cartesian state.

```
Create Spacecraft Sat
Create BatchEstimator bat
Sat.SolveFors = {CartesianState, Cr}
%User must create a TrackingFileSet
%and set up bat appropriately

BeginMissionSequence
RunEstimator bat
```

Solve for Cd and the spacecraft Cartesian state assuming that the *a priori* information is included in the estimation state vector.

```
Create Spacecraft Sat
Sat.SolveFors = {CartesianState, Cd}

Create BatchEstimator bat
bat.UseInitialCovariance= True
%User must create a TrackingFileSet
%and set up bat appropriately

Create Array Initial_6x6_covariance[6,6]

BeginMissionSequence
Initial_6x6_covariance = ...
    diag([1e-6 1e70 1e70 1e70 1e70 1e70]) %X pos known very well
Sat.OrbitErrorCovariance = Initial_6x6_covariance
Sat.CrSigma = 1e-6 %Cr known very well

RunEstimator bat
```

## TrackingFileSet

Manages the observation data contained in one or more external tracking data files.

### Description

A **TrackingFileSet** is required for both simulator and estimator runs. For a data simulation run, the user must specify the desired tracking strings for the simulated data (via **AddTrackingConfig**) and provide an output file name for the simulated tracking observations (via **FileName**). In simulation mode, the user may specify a range modulo constant, Doppler count interval, and other parameters, depending on the type of tracking data being simulated. See the remarks below for more details. For both the simulator and estimator, measurement and media corrections may optionally be applied.

When running the estimator, the **FileName** parameter specifies the path to a pregenerated external tracking data file. It is not necessary to explicitly specify tracking configurations when running the estimator; GMAT will examine the specified external tracking data file and attempt to determine the tracking configurations automatically. GMAT will throw an error message if it is unable to uniquely identify all objects found in the tracking data file.

When running the estimator, one or more **AcceptFilters** and/or **RejectFilters** may be employed to select from all available observations a smaller subset for use in the estimation process.

See Also: [Simulator](#), [BatchEstimator](#), [AcceptFilter](#), [RejectFilter](#), [Tracking Data Types for Orbit Determination](#)

### Fields

Field	Description
<b>AberrationCorrection</b>	Apply an aberration correction to angle measurements. This correction applies only to the angle measurement types.  The Diurnal correction accounts for the velocity of the observer due to rotation of the central body only. The Annual correction accounts for the velocity of the observer due to central body orbital motion only. The AnnualAndDiurnal correction accounts for both effects.

<b>Data Type</b>	String
<b>Allowed Values</b>	None, Annual, Diurnal, AnnualAndDiurnal
<b>Access</b>	set
<b>Default Value</b>	None
<b>Units</b>	N/A
<b>Interfaces</b>	script

Field	Description
<b>AddTrackingConfig</b>	One or more signal paths and measurement types for simulation or estimation. See the Remarks section below for details on the Tracking Strand specification.
<b>Data Type</b>	String
<b>Allowed Values</b>	<code> {{Tracking Strand}, MeasurementType1[, MeasurementType2, ...]}</code>
<b>Access</b>	set
<b>Default Value</b>	<b>None</b>
<b>Units</b>	N/A
<b>Interfaces</b>	script
<b>DataFilters</b>	Defines filters to be applied to the data. One or more filters of either type ( <b>AcceptFilter</b> , <b>RejectFilter</b> ) may be specified. Rules specified by data filters on a <b>TrackingFileSet</b> are applied to determine what data is admitted or rejected as input to the estimation process.
<b>Data Type</b>	Resource array
<b>Allowed Values</b>	User defined instances of <b>AcceptFilter</b> and <b>RejectFilter</b> resources
<b>Access</b>	set
<b>Default Value</b>	<b>None</b>
<b>Units</b>	N/A
<b>Interfaces</b>	script
<b>FileName</b>	For simulation, specifies an output file for the simulated measurement data. For estimation, specifies one or more preexisting tracking data input files in GMD-format.
<b>Data Type</b>	String
<b>Allowed Values</b>	Valid file path
<b>Access</b>	set
<b>Default Value</b>	<b>None</b>
<b>Units</b>	N/A
<b>Interfaces</b>	script

Field	Description
<b>MaxCentralAngleOfRayPath</b>	<p>For space-to-space tracking only. Specifies an angle, with apex at the center of the central body, between the tracking and target satellite. If the participants in a space-to-space tracking measurement (like TDRS tracking) are within this angle of separation, the measurement will be accepted regardless of the computed height of ray path. If the participants are separated by an angle greater than this value, the <b>MinHeightOfRayPath</b> criteria is applied to determine acceptance. This parameter is typically used in conjunction with <b>MinHeightOfRayPath</b> to specify criteria for rejection of space-to-space tracking signals that may experience excessive atmospheric refraction.</p>
<b>Data Type</b>	Real
<b>Allowed Values</b>	0 <= MaxCentralAngleOfRayPath <= 180
<b>Access</b>	set
<b>Default Value</b>	<b>70 degrees, for Earth-centered orbits</b>
	This constraint is ignored by default for orbits around bodies other than the Earth, see Remarks below.
<b>Units</b>	Degrees
<b>Interfaces</b>	script
<b>MinHeightOfRayPath</b>	<p>For space-to-space tracking only. Specifies a minimum altitude of the space-to-space tracking signal path above the surface of the Earth (assuming a spherical model using the equatorial radius) for which the measurement will be accepted. This parameter is only tested if the computed central angle of ray path exceeds <b>MaxCentralAngleOfRayPath</b>. Any measurements rejected due to this criteria are flagged with the HОРР editing indicator in the estimator output report.</p>
<b>Data Type</b>	Real
<b>Allowed Values</b>	Real >= 0.
<b>Access</b>	set
<b>Default Value</b>	<b>500 km, for Earth-centered orbits</b>
	This constraint is ignored by default for orbits around bodies other than the Earth, see Remarks below.
<b>Units</b>	Kilometers
<b>Interfaces</b>	script

Field	Description												
<b>RampTable</b>	<p>Specifies a transmit frequency ramp table to be used when computing measurements for both simulation and estimation.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>Valid file path</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>None</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	Valid file path	<b>Access</b>	set	<b>Default Value</b>	<b>None</b>	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	String												
<b>Allowed Values</b>	Valid file path												
<b>Access</b>	set												
<b>Default Value</b>	<b>None</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>SimDopplerCountInterval</b>	<p>Specifies the Doppler count interval used for simulating Doppler and range-rate measurements. This parameter is not used when running estimation. In estimation, the Doppler count interval should already be specified in the GMD file.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real &gt; 0</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>1.0</b></td></tr> <tr> <td><b>Units</b></td><td>Seconds</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real > 0	<b>Access</b>	set	<b>Default Value</b>	<b>1.0</b>	<b>Units</b>	Seconds	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real > 0												
<b>Access</b>	set												
<b>Default Value</b>	<b>1.0</b>												
<b>Units</b>	Seconds												
<b>Interfaces</b>	script												
<b>SimRangeModuloConstant</b>	<p>Specifies the value of the DSN range ambiguity interval for simulation. This parameter is not used when running estimation. In estimation, the range modulo, when needed, should already be specified in the GMD file.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Allowed Values</b></td><td>Real &gt; 0</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>1.00E+18</b></td></tr> <tr> <td><b>Units</b></td><td>Range Units (RU)</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	Real	<b>Allowed Values</b>	Real > 0	<b>Access</b>	set	<b>Default Value</b>	<b>1.00E+18</b>	<b>Units</b>	Range Units (RU)	<b>Interfaces</b>	script
<b>Data Type</b>	Real												
<b>Allowed Values</b>	Real > 0												
<b>Access</b>	set												
<b>Default Value</b>	<b>1.00E+18</b>												
<b>Units</b>	Range Units (RU)												
<b>Interfaces</b>	script												
<b>SimTDRSServiceAccessList</b>	<p>TDRS service access list for simulation. A service will be chosen randomly from the services provided in the list. This parameter is not used when running estimation. In estimation, the TDRS service ID should already be specified in the GMD file.</p> <table> <tr> <td><b>Data Type</b></td><td>String list</td></tr> <tr> <td><b>Allowed Values</b></td><td>'SA1', 'SA2', or 'MA'</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>{SA1}</b></td></tr> <tr> <td><b>Units</b></td><td>None</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String list	<b>Allowed Values</b>	'SA1', 'SA2', or 'MA'	<b>Access</b>	set	<b>Default Value</b>	<b>{SA1}</b>	<b>Units</b>	None	<b>Interfaces</b>	script
<b>Data Type</b>	String list												
<b>Allowed Values</b>	'SA1', 'SA2', or 'MA'												
<b>Access</b>	set												
<b>Default Value</b>	<b>{SA1}</b>												
<b>Units</b>	None												
<b>Interfaces</b>	script												

Field	Description
<b>SimTDRSSmarId</b>	S-Band Multiple Access Return (SMAR) downlink frequency ID for simulation. This parameter is not used when running estimation. In estimation, the SMAR ID should already be specified in the GMD file.
	<p><b>Data Type</b> Integer</p> <p><b>Allowed Values</b> Integer between 1 and 30 inclusive</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 1</p> <p><b>Units</b> None</p> <p><b>Interfaces</b> script</p>
<b>SimTDRSTracker-Type</b>	Tracker type indicator for simulating TDRS MA services. This parameter is not used when running estimation. In estimation, the TDRS tracker type should already be specified in the GMD file.
	<p><b>Data Type</b> Integer</p> <p><b>Allowed Values</b> 0 = STGT/legacy, 1 = TDRS-K.</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 0</p> <p><b>Units</b> None</p> <p><b>Interfaces</b> script</p>
<b>TimeGapForPass-Break</b>	Time gap in seconds between measurements to indicate the start of a new tracking pass. Consecutive measurements separated by greater than this time span are assumed to come from different tracking passes. This is used in conjunction with the ErrorModel PassBiases solve-fors option. See the <a href="#">remarks</a> section of the ErrorModel resource for more details.
	<p><b>Data Type</b> Real</p> <p><b>Allowed Values</b> Real &gt; 0</p> <p><b>Access</b> set</p> <p><b>Default Value</b> 1e70</p> <p><b>Units</b> Seconds</p> <p><b>Interfaces</b> script</p>

Field	Description
<b>UseETminusTAI</b>	<p>Flag specifying if general relativistic time corrections should be made to the measurements. If this flag is set, GMAT will apply the adjustment from TAI to Ephemeris Time when solving the light time equations for the computed measurement.</p> <p>We strongly recommend that this be set to True for any tracking file set that includes tracking strands with different transmit and receive nodes, regardless of the total light time or distance from the Sun of the measurement path. See Remarks below for more details.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>UseLightTime</b>	<p>Flag specifying whether light time corrections should be applied to computed measurements.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>
<b>UseRelativityCorrection</b>	<p>Flag specifying if General Relativistic corrections should be made to the computed measurements. If this flag is set, GMAT will adjust the computed light time to include the effects due to the coordinate velocity of light and bending of the signal path. See Remarks below for more details.</p>
	<b>Data Type</b>
	<b>Allowed Values</b>
	<b>Access</b>
	<b>Default Value</b>
	<b>Units</b>
	<b>Interfaces</b>

## Remarks

See [Tracking Data Types for Orbit Determination](#) for a detailed listing of all tracking data types and tracking data file formats supported by GMAT for orbit determination.

Setting **UseETminusTAI** to True corresponds to inclusion in the computed round-trip light time of the ET-TAI uplink and downlink terms in Eq. 11-7 of Moyer, *Formulation of Observed and Computed Values of Deep Space Network Data Types for Navigation*, JPL Publication 00-7, October 2000. When choosing to formulate light-time in the Solar

System Barycentric frame, as GMAT does, the ET-TAI correction mostly cancels out for measurement paths having the same transmit and receive station. However, if the transmit and receive stations differ, even for short light times, the ET-TAI correction may be significant and should be included for highest-accuracy measurement processing.

Setting **UseRelativityCorrection** to True corresponds to inclusion of the RLT uplink and downlink terms in Eq. 11-7 of Moyer.

The **SimRangeModuloConstant** field is used only in the simulation of DSN range tracking data. The user may specify a value to be used for this field or may omit it, in which case the default value is used. This field is not applicable to estimation. In estimation, this value is provided in the input tracking data file.

The **SimDopplerCountInterval** is used in the simulation of DSN\_TCP and RangeRate tracking data. The user may specify a value to be used for this field or may omit it, in which case default value of 1 second is used. This field is not applicable to estimation. In estimation, this value is provided in the input tracking data file.

### Ray Path Editing Criteria

The default values of the constraints pertaining to Height of Ray Path (HORP) measurement editing, **MinHeightOfRayPath** and **MaxCentralAngleOfRayPath**, apply for Earth-centered orbits only. By default, no HORP constraints are applied for space-to-space tracking involving spacecraft orbiting bodies other than the Earth. The user can apply HORP constraints for non-Earth centered orbits by specifying explicit values for the constraints in their script. To disable use of the HORP constraint for Earth orbits, set **MinHeightOfRayPath** to 0 km.

The ray path editing criteria described above are applied identically for both simulation and estimation. In the case of simulation, the criteria determine whether a simulated measurement will be written to the tracking data file or ignored. In the case of estimation, the criteria determine whether a measurement will be accepted or rejected from the state update in either the batch estimator or Kalman filter.

### Tracking Strand Specification

When simulating tracking data, at least one tracking strand must be specified using the **AddTrackingConfig** parameter. The tracking strand must be enclosed within curly braces. The format of the tracking strand depends on the measurement data type being generated. Use the following table as a guide. It is not necessary to specify tracking strands when estimating using real tracking data. In this case, GMAT will examine the input tracking data file and automatically determine the tracking strands present in the file.



#### Note

In both simulation and estimation, the error model on the receiving station determines the measurement properties (bias and noise) and the transmit station error model properties are ignored.

Measurement Type Name	Tracking Strand Specification Format
All angle types, Range_Skin, DSN_SeqRange, DSN_PNRange, DSN_TCP	{XmitGroundStation, Spacecraft, RecvGroundStation}
Range, RangeRate (ground to space)	{XmitGroundStation, Spacecraft, RecvGroundStation}
Range, RangeRate (space to space)	{XmitSpacecraft, Spacecraft, RecvSpacecraft}
BRTS_Doppler, BRTS_Range	{XmitGroundStation, ForwardTDRS, BRTSGroundStation, ReturnTDRS, RecvGroundStation}
GPS_PosVec	{Spacecraft.Receiver}
SN_Doppler, SN_Range	{XmitGroundStation, ForwardTDRS, SNUUserSpacecraft, ReturnTDRS, RecvGroundStation}
SN_Doppler_Rtn	{SNUUserSpacecraft, ReturnTDRS, RecvGroundStation}
SN_DOWD	{SNUUserSpacecraft, ReturnTDRS1, RecvGroundStation1, ReturnTDRS2, RecvGroundStation2}

## Measurement Corrections

The **TrackingFileSet** object is used to specify various corrections GMAT may apply when deriving a computed measurement. Some corrections are not applicable to some measurement types. The aberration correction is only applicable to angle measurement types, and no corrections are applicable to GPS\_PosVec. Selecting an inapplicable correction will not result in an error, but no correction will be applied.

## Examples

This example illustrates use of the **TrackingFileSet** object for simulation of DSN tracking data. Specification of the tracking configurations (**AddTrackingConfig**) is optional when running the estimator. If omitted, GMAT will attempt to automatically detect the tracking configurations present in the tracking data file.

In this example, the frequency ramp table file dsn.ramp must be a preexisting ramp table. GMAT will not simulate ramp table records. Alternatively, the user may omit specification of a ramp table when simulating data. If the ramp table is omitted, the simulator will use the frequency specified on the **Transmitter** object attached to each **GroundStation**.

```
Create TrackingFileSet dsn0bs;

%Create objects referenced by dsn0bs
Create GroundStation GDS CAN MAD;
Create Spacecraft EstSat;
Create AcceptFilter af;

dsn0bs.AddTrackingConfig      = {{GDS, EstSat, GDS}, 'DSN_TCP'};
dsn0bs.AddTrackingConfig      = {{CAN, EstSat, CAN}, 'DSN_TCP'};
dsn0bs.AddTrackingConfig      = {{MAD, EstSat, MAD}, 'DSN_TCP', 'DSN_SeqRange'};
dsn0bs.FileName               = {'dsn.gmd'};
```

```
dsnObs.RampTable          = {'dsn.ramp'};
dsnObs.UseLightTime       = True;
dsnObs.UseRelativityCorrection = False;
dsnObs.UseETminusTAI      = False;
dsnObs.SimRangeModuloConstant = 67108864;
dsnObs.SimDopplerCountInterval = 10.;
dsnObs.DataFilters        = {af};

BeginMissionSequence;
```

This example illustrates use of the **TrackingFileSet** object for simulation of GPS\_PosVec tracking data. This example assumes that GpsReceiver is a previously created instance of **Receiver** and has been attached to SimSat using the **AddHardware** method.

```
Create TrackingFileSet PosVecObs;

PosVecObs.FileName         = {'posvec_obs.gmd'};
PosVecObs.AddTrackingConfig = {{SimSat.GpsReceiver}, 'GPS_PosVec'};
SimMeas.DataFilters        = {};

BeginMissionSequence;
```

## Transmitter

Defines the electronics hardware, attached to a **GroundStation** or **Spacecraft** resource, that transmits an RF signal.

### Description

A ground station needs a **Transmitter** to transmit the RF signal to both user spacecraft and to navigation spacecraft such as TDRS. A **Transmitter** is assigned on the **AddHardware** list of an instance of a **GroundStation**. A **Transmitter** may also be assigned on a TDRS user spacecraft to specify or estimate properties of the user-to-TDRS transmit frequency.

See Also [GroundStation](#), [Antenna](#)

### Fields

Field	Description
<b>EpochFormat</b>	This field allows you to set the type of the epoch that you choose to enter for the <b>ReferenceEpoch</b> . This field cannot be modified in the Mission Sequence.  <b>Data Type</b> Enumeration <b>Allowed Values</b> Any of the following epoch formats: <b>UTC-Gregorian</b> , <b>UTCModJulian</b> , <b>TAIGregorian</b> , <b>TAIModJulian</b> , <b>TTGregorian</b> , <b>TTModJulian</b> , <b>A1Gregorian</b> , <b>A1ModJulian</b> <b>Access</b> Set <b>Default Value</b> <b>UTCGregorian</b> <b>Units</b> N/A <b>Interfaces</b> GUI, script
<b>Frequency</b>	Transmit frequency  <b>Data Type</b> Real <b>Allowed Values</b> Real $\geq 0$ <b>Access</b> set <b>Default Value</b> <b>2000</b> <b>Units</b> MHz <b>Interfaces</b> script

Field	Description												
<b>FrequencyBand</b>	<p>Transmit frequency band. This parameter is only used for measurement simulation. The frequency band for estimation (when applicable) is specified in the GMD tracking data file.</p>												
	<p>This parameter is ignored when simulating DSN data types. For simulation of DSN data, the frequency band is inferred from the <b>Frequency</b> parameter according to DSN specifications for frequency ranges. If set to <b>None</b>, GMAT will attempt to infer the frequency band based on the Transmitter <b>Frequency</b>.</p>												
<b>Data Type</b>	String												
<b>Allowed Values</b>	'None', 'C', 'S', 'X', 'K'												
<b>Access</b>	set												
<b>Default Value</b>	<b>None</b>												
<b>Units</b>	NA												
<b>Interfaces</b>	script												
<b>FrequencyBias</b>	<p>Coefficients of the transmitter frequency bias model. The coefficients in the <b>FrequencyBias</b> list specify a polynomial frequency bias <math>f_{bias}(t)</math> such that <math>f_{bias}(t) = C0 + C1*(t - t0) + C2*(t - t0)^2 + \dots</math> where <math>t0</math> is the ReferenceEpoch and <math>t</math> is the measurement or integration time. The number of coefficients in this list specifies the order of the polynomial.</p>												
	<p>The instantaneous transmitter frequency is given by <math>f(t) = F + f_{bias}(t)</math>, where <math>F</math> is the value of the Transmitter <b>Frequency</b> parameter.</p>												
<b>Data Type</b>	Real array												
<b>Allowed Values</b>	Any real number												
<b>Access</b>	set												
<b>Default Value</b>	[ 0.0 ]												
<b>Units</b>	Hz, Hz/sec, Hz/sec^2 , ...												
<b>Interfaces</b>	script												
<b>PrimaryAntenna</b>	<p>Antenna resource used by <b>GroundStation</b> resource to transmit a signal</p>												
	<table border="1"> <tr> <td data-bbox="649 1512 796 1543"><b>Data Type</b></td><td data-bbox="926 1512 1139 1543"><b>Antenna</b> Object</td></tr> <tr> <td data-bbox="649 1543 866 1575"><b>Allowed Values</b></td><td data-bbox="926 1543 1192 1575">Any <b>Antenna</b> object</td></tr> <tr> <td data-bbox="649 1575 747 1607"><b>Access</b></td><td data-bbox="926 1575 967 1607">set</td></tr> <tr> <td data-bbox="649 1607 838 1638"><b>Default Value</b></td><td data-bbox="926 1607 1002 1638"><b>None</b></td></tr> <tr> <td data-bbox="649 1638 731 1670"><b>Units</b></td><td data-bbox="926 1638 967 1670">N/A</td></tr> <tr> <td data-bbox="649 1670 796 1702"><b>Interfaces</b></td><td data-bbox="926 1670 1002 1702">script</td></tr> </table>	<b>Data Type</b>	<b>Antenna</b> Object	<b>Allowed Values</b>	Any <b>Antenna</b> object	<b>Access</b>	set	<b>Default Value</b>	<b>None</b>	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	<b>Antenna</b> Object												
<b>Allowed Values</b>	Any <b>Antenna</b> object												
<b>Access</b>	set												
<b>Default Value</b>	<b>None</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												

Field	Description												
<b>ReferenceEpoch</b>	<p>Anchor epoch for the <b>FrequencyBias</b> polynomial. The coefficients in the <b>FrequencyBias</b> list specify a polynomial frequency bias <math>f\_bias(t)</math> such that <math>f\_bias(t) = C0 + C1*(t - t0) + C2*(t - t0)^2 + \dots</math> where <math>t0</math> is the ReferenceEpoch and <math>t</math> is the measurement or integration time. The default value of <b>FromSpacecraft</b> assigns <b>ReferenceEpoch</b> the value of the spacecraft initial epoch.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>User-defined epoch or default value</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td><b>FromSpacecraft</b></td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	User-defined epoch or default value	<b>Access</b>	set	<b>Default Value</b>	<b>FromSpacecraft</b>	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	String												
<b>Allowed Values</b>	User-defined epoch or default value												
<b>Access</b>	set												
<b>Default Value</b>	<b>FromSpacecraft</b>												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												
<b>SolveFors</b>	<p>List of parameters to estimate. If estimation of FrequencyBias is specified, GMAT will estimate the frequency bias coefficients to the order determined by the size of the FrequencyBias array.</p> <table> <tr> <td><b>Data Type</b></td><td>String</td></tr> <tr> <td><b>Allowed Values</b></td><td>{ } or FrequencyBias</td></tr> <tr> <td><b>Access</b></td><td>set</td></tr> <tr> <td><b>Default Value</b></td><td>{ }</td></tr> <tr> <td><b>Units</b></td><td>N/A</td></tr> <tr> <td><b>Interfaces</b></td><td>script</td></tr> </table>	<b>Data Type</b>	String	<b>Allowed Values</b>	{ } or FrequencyBias	<b>Access</b>	set	<b>Default Value</b>	{ }	<b>Units</b>	N/A	<b>Interfaces</b>	script
<b>Data Type</b>	String												
<b>Allowed Values</b>	{ } or FrequencyBias												
<b>Access</b>	set												
<b>Default Value</b>	{ }												
<b>Units</b>	N/A												
<b>Interfaces</b>	script												

## Remarks

### Transmitter Frequency use in Simulation and Estimation

A transmitter may be attached to a **GroundStation** or **Spacecraft** resource. As discussed in the **RunSimulator** help, for the case where a ramp table is not used, the transmit frequency is used directly to calculate the DSN range and Doppler measurements. For both simulation and estimation, if a ramp table is specified on the relevant **TrackingFileSet**, the frequency profile specified in the ramp table is used and the Transmitter **Frequency** and **FrequencyBand** are ignored.

For simulation of TDRS measurements, a Transmitter may be attached to the TDRS user spacecraft to specify the user-to-TDRS transmit frequency for measurement simulation. If no Transmitter is attached to the TDRS user, a default frequency of 2000 MHz is used. When estimating, the user-to-TDRS transmit frequency is obtained from the GMD tracking data file, and the Transmitter **Frequency** and **FrequencyBand** are ignored.

## Examples

Create and configure a **Transmitter** object

```
Create Antenna DSNAntenna;
Create Transmitter Transmitter1;
```

```
Transmitter1.PrimaryAntenna = DSNAntenna;
Transmitter1.Frequency = 7186.3;

Create GroundStation DSN
DSN.AddHardware = {Transmitter1};

BeginMissionSequence;
```

Create and configure a **Transmitter** for estimation of a linear frequency bias. The **FrequencyBias** array has two elements, indicating that the frequency bias polynomial has only a constant C0 and linear C1 term. In this case (estimation) the nominal value of the frequency is obtained from the GMD file (not shown here). For simulation, you should specify the nominal frequency on the Transmitter using the **Frequency** parameter.

```
Create Spacecraft Sat
Create Antenna HGA;
Create Transmitter Transmitter1;

Transmitter1.PrimaryAntenna = HGA
Transmitter1.FrequencyBand = 'S'
Transmitter1.EpochFormat = 'UTCGregorian'
Transmitter1.ReferenceEpoch = '15 Nov 2018 12:00:00.000'
Transmitter1.FrequencyBias = [0.0, 0.0]
Transmitter1.SolveFor = {FrequencyBias}

Sat.AddHardware = {Transmitter1, HGA}

BeginMissionSequence;
```

## Transponder

Defines the electronics hardware, typically attached to a spacecraft, that receives and automatically re-transmits an incoming signal.

### Description

The spacecraft **Transponder** model is required for modeling two-way coherent range and Doppler data types. The **Transponder** object includes modeling of a retransmission delay due to the spacecraft transponder electronics. You can also specify a turn around ratio which is a multiplicative ratio describing how the frequency of the retransmitted signal differs from the received frequency. The incoming and outgoing frequencies are designed to be different so as to avoid RF interference between the signal transmitted by the ground station to the spacecraft and the return signal from the spacecraft to the ground station.

See Also: [GroundStation](#), [Antenna](#)

### Fields

Field	Description
<b>HardwareDelay</b>	Transponder electronics delay between receiving time and transmitting time at the transponder. It is applied for both simulation and estimation, with or without ramp table use.  <b>Data Type</b> Real <b>Allowed Values</b> Real $\geq 0$ <b>Access</b> set <b>Default Value</b> 0 <b>Units</b> seconds <b>Interfaces</b> script
<b>PrimaryAntenna</b>	Antenna resource used by the <b>Transponder</b> resource  <b>Data Type</b> Antenna Object <b>Allowed Values</b> Any valid <b>Antenna</b> object <b>Access</b> set <b>Default Value</b> None <b>Units</b> N/A <b>Interfaces</b> script

Field	Description
<b>TurnAroundRatio</b>	Transponder turn around ratio which is used in both simulation and estimation. For the DSN Doppler data type where an input ramp table is not used, changing the transponder turn around ratio appreciably changes the measurement. For all DSN data types, changing the turn around ratio affects the media correction calculations which will typically result in a small change in the measurement. See the <b>RunSimulator</b> and <b>RunEstimator</b> help for additional details.
<b>Data Type</b>	STRING_TYPE
<b>Allowed Values</b>	A string in form of 'a/b' where a and b are real numbers
<b>Access</b>	set
<b>Default Value</b>	'240/221'
<b>Units</b>	N/A
<b>Interfaces</b>	script

## Remarks

### Turn around ratio affects media correction calculations

Suppose you are given a signal with multiple 'n' legs. In order to calculate the media (ionosphere) corrections for a given leg, we need to know the associated frequency for that leg. The turn-around ratio is used to calculate the frequency for legs 2 through n. If media corrections are modeled, then, for both DSN range and Doppler measurements, the value of the turn-around ratio, as set in the **Transponder** resource, will have an effect on the measurements and thus both simulation and estimation processes will be affected.

### Independent of media corrections, how does the turn around ratio, as set in the Transponder resource, affect DSN measurements?

Assume that media corrections are turned off so that we can ignore any, typically small, changes to the DSN measurements caused by media corrections. We make the following observations.

1. The value of **Transponder.TurnAroundRatio** has no effect on DSN range measurements.
2. If a ramp table is provided, then the value of **Transponder.TurnAroundRatio** has no effect on DSN Doppler measurements. In this case, the multiplicative turn around ratio used to calculate the computed measurement is based upon the Uplink Band given in the ramp table. (240/221 for S-band and 880/749 for X band)
3. If a ramp table is not provided, then the value of **Transponder.TurnAroundRatio** has a proportional effect on DSN Doppler measurements. For example, if the turn around ratio is doubled, then so is the DSN Doppler measurement in Hz.

For additional discussion on how the **Transponder.TurnAroundRatio** field affects the DSN measurements, see the **RunSimulator** and **RunEstimator** help.

### Custom turn-around ratios for DSN Doppler data

As mentioned above, the DSN Doppler (TRK-2-34 Type 17) data type observation value depends upon the transponder turn-around ratio. As shown in the tables in the **RunSimulator** and **RunEstimator** help, for ramped Doppler data, GMAT only allows for the use of the standard S-band (240/221) and X-band (880/749) turn-around ratios. For Doppler data where a ramp table is not used, setting the **Transponder** turn-around ratio will correctly model the **Doppler** data. GMAT cannot currently accommodate custom turn-around ratios for ramped Doppler data.

### Examples

```
% Create and configure a Transponder object

Create Spacecraft Sat1;
Create Antenna HGA;
Create Transponder Transponder1;

Transponder1.PrimaryAntenna = HGA;
Transponder1.HardwareDelay = 0.0;
Transponder1.TurnAroundRatio = '240/221';

Sat1.AddHardware = {HGA, Transponder1};
BeginMissionSequence;
```

### Commands

## RunEstimator

Ingests navigation measurements and generates an estimated state vector

### Script Syntax

```
RunEstimator BatchEstimator_InstanceName [{SolveMode = value}]
RunEstimator ExtendedKalmanFilter_InstanceName
```

### Description

The **RunEstimator** command ingests navigation measurements and generates an estimated state vector according to the specifications of the input **BatchEstimator** or **ExtendedKalmanFilter** resource.

See Also: [BatchEstimator](#), [ExtendedKalmanFilter](#)

### Options

Option	Description
<b>SolveMode</b>	Specifies how the <b>BatchEstimator</b> behaves during mission execution. When <b>SolveMode</b> is set to <b>RunInitialGuess</b> , the batch estimator will perform an "observed-minus-computed" run. GMAT will compute and report residuals with respect to the initial state or orbit, but will not attempt a differential correction, and the run will terminate at the end of iteration 0. When <b>SolveMode</b> is set to <b>Solve</b> , the <b>BatchEstimator</b> will perform differential corrections and will iterate until the estimator stopping conditions are met.  The <b>ExtendedKalmanFilter</b> estimator ignores this parameter.
<b>Accepted Data Types</b>	Reference Array
<b>Allowed Values</b>	<b>Solve</b> , <b>RunInitialGuess</b>
<b>Default Value</b>	<b>Solve</b>
<b>Required</b>	no
<b>Interfaces</b>	GUI, script

### Remarks

#### How GMAT generates “Computed (C)” DSN data

As part of the estimation process, GMAT must calculate the so-called observation residual, “O-C,” where “C” is the “Computed” measurement. As discussed in the [RunSimulator](#) help, GMAT calculates the DSN range “C” measurement as

$$C \int_{t_1}^{t_3} f_T(t) dt, \text{ mod M} \quad (\text{RU})$$

where

$t_1, t_3$  = Transmission and Reception epoch, respectively

$f_T$  = Ground Station transmit frequency

$C$  = transmitter dependent constant (221/1498 for X-band and 1/2 for S-Band)

$M$  = length of the ranging code in RU

and GMAT calculates the DSN Doppler measurement as

$$C = -\frac{M_2}{(t_{3e} - t_{3s})} \int_{t_{1s}}^{t_{1e}} f_T(t_1) dt_1 = -\frac{M_2(t_{1e} - t_{1s})}{DCI} \bar{f}_T \text{ (Hz)}$$

where

$t_{1s}, t_{1e}$  = start and end of transmission interval, respectively

$f_T$  = transmit frequency

$M_2$  = Transponder turn around ratio (typically, 240/221 for S-band and 880/749 for X-band)

$DCI = (t_{3e} - t_{3s})$  = Doppler Count Interval

$$\bar{f}_T \equiv \frac{\int_{t_{1s}}^{t_{1e}} f_T(t_1) dt_1}{(t_{1e} - t_{1s})} = \text{average transmit frequency}$$

The value of C and M2 used to calculate the computed range or Doppler measurement depends upon the data type and whether the data being ingested is ramped or non-ramped according to the table below. The value of the transmit frequency used to calculate the computed measurement depends upon whether or not the data being ingested is ramped or non-ramped.

Data Type	Value of C (Range) or M2 (Doppler) used to calculate “Computed” measurement	Value of transmit frequency used to calculate “Computed” measurement
<b>Estimate Range without ramp table</b>	<ul style="list-style-type: none"> <li>Set based upon Uplink Band in input Range measurement GMD file. C=½ for S-band and 221/1498 for X-band.</li> </ul>	<ul style="list-style-type: none"> <li>Use frequency in input range GMD file</li> <li>Ground Station transmit frequency set via Transmitter.Frequency is not used</li> </ul>
<b>Estimate Range with ramp table</b>	<ul style="list-style-type: none"> <li>Set based upon Uplink Band in input ramp table. C=½ for S-band and 221/1498 for X-band.</li> <li>Value of Uplink Band in input Range measurement file has no effect.</li> </ul>	<ul style="list-style-type: none"> <li>Use frequency in ramp table</li> <li>Frequency in input GMD file is not used</li> <li>Ground Station transmit frequency set via Transmitter.Frequency is not used</li> </ul>

Data Type	Value of C (Range) or M2 (Doppler) used to calculate “Computed” measurement	Value of transmit frequency used to calculate “Computed” measurement
<b>Estimate Doppler without ramp table</b>	<ul style="list-style-type: none"> <li>• M2=Transponder.TurnAroundRatio</li> <li>• Value of Uplink Band in input Range measurement file has no effect.</li> </ul>	<ul style="list-style-type: none"> <li>• Use Ground Station transmit frequency set via Transmitter.Frequency (Note that for Doppler data, there is no frequency data in the GMD file)</li> </ul>
<b>Estimate Doppler with ramp table</b>	<ul style="list-style-type: none"> <li>• Set based upon Uplink Band in input ramp table. M2=240/221 for S-band and 880/749 for X band.</li> <li>• Value of Uplink Bank in input Doppler GMD measurement file has no effect.</li> </ul>	<ul style="list-style-type: none"> <li>• Use frequency in ramp table. (Note that for Doppler data, there is no frequency data in the GMD file)</li> <li>• Ground Station transmit frequency set via Transmitter.Frequency is not used</li> </ul>

### Earth Nutation Update Interval

If you want the estimator to calculate a Doppler or range rate type of measurement (e.g., DSN\_TCP and RangeRate) residual precisely, you will need to set the Earth nutation update interval to 0 as shown below.

```
Earth.NutationUpdateInterval = 0
```

It is good general practice to set the Earth nutation update interval to zero for all measurement types.

### Examples

Run batch estimator.

```
Create BatchEstimator myBatchEstimator
BeginMissionSequence
RunEstimator myBatchEstimator
```

For a comprehensive example of reading in measurements and running the estimator, see the [Orbit Estimation using DSN Range and Doppler Data](#) tutorial.

## RunSimulator

Generates simulated navigation measurements

### Script Syntax

```
RunSimulator Simulator_InstanceId
```

### Description

The **RunSimulator** command generates the simulated measurements specified in the user-provided **Simulator** resource. An output file, with name specified in the **Simulator** resource is created.

See Also: [Simulator](#)

### Remarks

#### Content of the Output File for DSN data

After the **RunSimulator** command has finished execution, one or more output files, as defined in the specified **Simulator** object, will be created. Each row of data in an output file contains information about one specific measurement at a given time. The format for a given row of data is described fully in the [TrackingFileSet](#) resource help.

When you simulate DSN range or Doppler, you can choose whether or not the frequency from the transmitting **Ground Station** is non-ramped or ramped. If you wish to model ramped data, you must supply an input ramp table. The format of the input ramp table is discussed in the [the section called “Transmit Frequency Ramp Records”](#) resource help.

The table below shows how the values of uplink band, C, M2, and transmit frequency are calculated. The second column shows how the uplink band, which is included in the output file for both range and Doppler measurements, is calculated. For S-band, a “1” is output and for X-band, a “2” is output.

The output GMAT Measurement Data (GMD) file contains the observable value which is calculated using the equations shown in [Tracking Data Types for Orbit Determination](#). The third column shows how the value of C or M2, which is used to calculate the observation value shown in the GMD file, is calculated. Finally, the fourth column shows how the transmit frequency, which shows up directly in the GMD file (for DSN range but not DSN Doppler) and is also used to calculate the observation value given in the GMD file, is calculated.

Mea-sure-ment Type	Uplink Band	Value of C (Range) or M2 (Doppler) used to calculate Observation	Transmit freq used to calculate Observation
Sim-u-late Range without ramp table	<ul style="list-style-type: none"> <li>Set based upon transmitter frequency set by user on the Transmitter.Frequency field. If freq is in [2000-4000] MHz, then Uplink Band is S-band. If freq is in [7000-8000] MHz, then Uplink Band is X-band.</li> </ul>	<ul style="list-style-type: none"> <li>Set based upon Uplink Band result shown in previous column. C=½ for S-band and 221/1498 for X-band.</li> <li>Value of Transponder.TurnAroundRatio has no effect on C</li> </ul>	<ul style="list-style-type: none"> <li><math>f_T</math>=Transmitter.frequency (This frequency will be written to the GMD range file)</li> </ul>
Sim-u-late Range with ramp table	<ul style="list-style-type: none"> <li>Uplink Band in ramp table takes precedence over both transmitter frequency set by user and transmit frequency in ramp table.</li> </ul>	<ul style="list-style-type: none"> <li>Set based upon Uplink Band result shown in previous column. C=½ for S-band and 221/1498 for X-band.</li> <li>Value of Transponder.TurnAroundRatio has no effect on C</li> </ul>	<ul style="list-style-type: none"> <li><math>f_T</math>=Ramp Table frequency (This frequency will be written to the GMD range file)</li> </ul>
Sim-u-late Doppler without ramp table	<ul style="list-style-type: none"> <li>Set based upon transmitter frequency set by user on the Transmitter.Frequency field. If freq is in [2000-4000] MHz, then Uplink Band is S-band. If freq is in [7000-8000] MHz, then Uplink Band is X-band.</li> </ul>	<ul style="list-style-type: none"> <li>M2=Transponder.TurnAroundRatio</li> </ul>	<ul style="list-style-type: none"> <li><math>f_T</math>=Transmitter.frequency</li> </ul>
Sim-u-late Doppler with ramp table	<ul style="list-style-type: none"> <li>Uplink Band in ramp table takes precedence over both transmitter frequency set by user and transmit frequency in ramp table.</li> </ul>	<ul style="list-style-type: none"> <li>Set based upon Uplink Band result shown in previous column. M2=240/221 for S-band and 880/749 for X band.</li> <li>Value of Transponder.TurnAroundRatio has no effect on M2</li> </ul>	<ul style="list-style-type: none"> <li><math>f_T</math>=Ramp Table frequency</li> </ul>

As discussed in the [Transponder Help](#), for both ramped and non-ramped data, the turn-around ratio set on the **Transponder** object, **Transponder.TurnAroundRatio**, will be used to calculate the media corrections needed to determine the value of the simulated range and Doppler measurements.

## Earth Nutation Update Interval

For the best consistency between the simulation and estimation processes you should set the Earth nutation update interval to 0 as shown below. It is good general practice to set the Earth nutation update interval to zero for all measurement types.

```
Earth.NutationUpdateInterval = 0
```

## Examples

Run simulation.

```
%Perform a simulation  
  
Create Simulator mySim  
  
BeginMissionSequence  
RunSimulator mySim
```

For a comprehensive example of running a simulation, see the [Simulate DSN Range and Doppler Data](#) tutorial.

## RunSmoother

Runs a sequential smoother estimator.

### Script Syntax

```
RunSmoother Smoother_InstanceId
```

### Description

The **RunSmoother** command ingests navigation measurements and generates an estimated state vector according to the specifications of the input **Smoother** resource.

See Also: [ExtendedKalmanFilter](#), [Smoother](#)

### Remarks

GMAT currently implements only one type of smoother, using the Fraser-Potter algorithm. This algorithm runs a backwards filter starting from the last measurement processed by the forward **ExtendedKalmanFilter** estimator and then generates an improved state estimate by weighted average of the forward and reverse sequential filters.

You must run an **ExtendedKalmanFilter** estimator (using the **RunEstimator** command) prior to running the smoother.

### Examples

Run a filter and smoother estimator.

```
Create ExtendedKalmanFilter myEKF
Create Smoother myFPSmooth

BeginMissionSequence

RunEstimator myEKF
RunSmoother myFPSmooth
```

## System

## Tracking Data Types for Orbit Determination

This section describes tracking data types and file formats for orbit determination.

### Measurement Types Supported

GMAT supports the following measurement types for orbit determination.

GMAT Measurement Type Name	Measurement Description	Measurement Units
Azimuth, Elevation	Antenna pointing angles, for antennas using Az/EI mounts. The geometry for Azimuth and Elevation angles is depicted in Figure 9-3 of Reference 1. Azimuth is defined to vary from 0 to 360 degrees. Azimuth is 0 along the North axis and increases in the East direction. Elevation is defined to vary from -90 to 90 degrees. Elevation is zero in the North/East plane and increases in the Zenith direction.	Degrees
BRTS_Doppler	Two-way coherent Doppler tracking from the NASA Tracking and Data Relay Satellite System Bilateral Ranging Transponder System (BRTS).	Hertz
BRTS_Range	Two-way coherent range tracking from the NASA Tracking and Data Relay Satellite System Bilateral Ranging Transponder System (BRTS).	Kilometers
DSN_PNRange	DSN pseudo-noise ranging (TRK-2-34 data type 14).	Range Units
DSN_SeqRange	DSN sequential ranging (TRK-2-34 data type 7).	Range Units
DSN_TCP	DSN total count phase (TRK-2-34 data type 17) measurements, implemented as a derived "Doppler" type measurement using successive phase measurements. This measurement type is used for both two-way and three-way tracking. See the notes below for details.	Hertz
GPS_PosVec	Earth-fixed position vectors from a spacecraft on-board GPS receiver.	Kilometers
Range	Two-way transponder range. A round-trip range measurement that includes the Spacecraft <b>Transponder.HardwareDelay</b> . This measurement type may be used for ground-to-space and inter-spacecraft (also called crosslink) tracking. See the notes below for details.	Kilometers
Range_Skin	Two-way non-transponder range. A round-trip range measurement that does not include the Spacecraft <b>Transponder.HardwareDelay</b> . This measurement type is appropriate for radar and other skin-tracking measurements.	Kilometers

GMAT Measurement Type Name	Measurement Description	Measurement Units
RangeRate	Two-way coherent transponder range-rate. This is modeled as the difference between range measurements at the end and start of the Doppler count interval, divided by the length of the count interval. The measurement is time-tagged at the end of the interval. This measurement type may be used for ground-to-space and inter-spacecraft (space-to-space, also called crosslink) tracking. This measurement type is used for both two-way and three-way tracking. See the notes below for details.	Kilometers/sec
SN_Doppler	Two-way coherent user (on-orbit) Doppler tracking from the NASA Tracking and Data Relay Satellite (Space Network) System.	Hertz
SN_Doppler_Rtn	One-way non-coherent user return link Doppler tracking from the NASA Tracking and Data Relay Satellite (Space Network/Space Relay) System. SN_Doppler_Rtn is a space-to-ground Doppler measurement that originates at a user spacecraft, is received by a TDRS spacecraft, and relayed by the TDRS to a TDRS ground station.	Hertz
SN_DOWD	Differenced one-way return Doppler tracking from the NASA Tracking and Data Relay Satellite (Space Network/Space Relay) System. SN_DOWD measurements are formulated by differencing (subtracting) simultaneous TDRS one-way return Doppler measurements	Hertz
SN_Range	Two-way coherent user (on-orbit) range tracking from the NASA Tracking and Data Relay Satellite (Space Network) System.	Kilometers
XEast, YNorth	Antenna pointing angles, for antennas using an X/Y mount with the X rotation axis (the axis we rotate by angle XEast) oriented to the North. The geometry for XEast and YNorth angles is depicted in Figure 9-4 of Reference 1. Both angles are zero when the antenna is pointed to the zenith. XEast is defined to vary from -180 to +180 degrees. YNorth is defined to vary from -90 to +90 degrees.	Degrees

GMAT Measurement Type Name	Measurement Description	Measurement Units
XSouth, YEast	Antenna pointing angles, for antennas using an X/Y mount with the X rotation axis (the axis we rotate by angle XSouth) oriented to the East. The geometry for XSouth and YEast angles is depicted in Figure 9-5 of Reference 1. Both angles are zero when the antenna is pointed to the zenith. XSouth is defined to vary from -180 to +180 degrees. YEast is defined to vary from -90 to +90 degrees.	Degrees

The GMAT measurement type names listed are the string names to be used in instances of **ErrorModel**, **AcceptFilter**, **RejectFilter**, and **TrackingFileSet**, and in the GMAT GMD-format tracking data file to identify each measurement type to GMAT.

### Inter-spacecraft Tracking Measurements

GMAT supports simulation and estimation of inter-spacecraft (also called "crosslink") tracking for some measurement types. These measurements are tracking observations consisting of range or Doppler/range-rate tracking between two spacecraft orbiting the same or different gravitational bodies. Inter-spacecraft tracking is currently supported for the Range and RangeRate measurement types. The formatting of GMAT tracking data files for inter-spacecraft tracking is identical to the associated ground-to-space measurement, with the exception that inter-spacecraft measurements use different observation type index numbers, as indicated below for each supported measurement type.

To configure two spacecraft for inter-spacecraft tracking, the "tracking" spacecraft must be assigned **Transmitter** and **Receiver** objects. The tracking spacecraft Receiver is then configured with the proper **ErrorModels** for the inter-spacecraft tracking. The measurement time tag for each inter-spacecraft measurement is the TAIModJulian measurement receive time at the tracking spacecraft.

See also [Simulate and Estimate Inter-Spacecraft Tracking](#) for a tutorial on simulating and estimating an orbit using inter-spacecraft tracking. Since the spacecraft participating in inter-spacecraft tracking may be in significantly different orbit regimes and each may require unique force modeling, GMAT supports specification of individual force models and propagators for each participant. See the **Propagator** fields of the **Simulator**, **BatchEstimator**, and **ExtendedKalmanFilter** resources for details on configuring multiple propagators.

### GMAT Tracking Data File Formats

GMAT uses a native ASCII tracking data file format called a "GMAT Measurement Data File", or GMD file. Each GMD file consists of a series of space-delimited ASCII records. Details of the GMD file format for each observation type are provided in the following sections. A single GMD file may contain one or more of the record types described below, but ramp records must be in a separate file.

For further details on the TRK-2-34 raw data formats referenced below, please consult Reference 2.

### Angle Measurements

All angle measurement types (Azimuth, Elevation, XEast, YNorth, XSouth, and YEast) share the same GMD file format. The generic angle observation is measured in degrees and represents rotation angles in the topocentric reference frame depicted in Figure 9-2 of Reference 1. The GMD record format for angle observation data is shown in the table below.

Field	Description
1	Observation receive time in TAIModJulian
2	Observation type name - Azimuth, Elevation, XEast, YNorth, XSouth, or YEast
3	Observation type index number: <ul style="list-style-type: none"> <li>• 9016 = Azimuth, 9017 = Elevation</li> <li>• 9018 = XEast, 9019 = YNorth</li> <li>• 9020 = XSouth, 9021 = YEast</li> </ul>
4	Downlink Ground station pad ID
5	Spacecraft ID
6	Angle measurement in degrees

A sample of GMD data records for Azimuth and Elevation data is shown below.

%	- 1 -	- 2 -	3	4	5	- 6 -
26088.5524768518518518444200	Azimuth	9016	MAD	LEOSat	4.8265973546050333e+001	
26088.5524768518518518444200	Elevation	9017	MAD	LEOSat	1.2679724467383584e+001	
26088.5531712962962962888639	Azimuth	9016	MAD	LEOSat	5.9562253624641066e+001	
26088.5531712962962962888639	Elevation	9017	MAD	LEOSat	1.6962633728400046e+001	
26088.5538657407407407333080	Azimuth	9016	MAD	LEOSat	7.4485459451069659e+001	
26088.5538657407407407333080	Elevation	9017	MAD	LEOSat	2.0586055229649272e+001	
26088.5545601851851851777532	Azimuth	9016	MAD	LEOSat	9.2442509281488796e+001	
26088.5545601851851851777532	Elevation	9017	MAD	LEOSat	2.2241223403621646e+001	

### Bilateration Ranging Transponder System (BRTS) Measurements

The Bilateration Ranging Transponder System (BRTS) consists of a collection of transponders fixed to the surface of the Earth at various locations. TDRS satellites track the BRTS transponders as if they were on-orbit spacecraft. Given the known location of the BRTS transponder, the resulting range and Doppler measurements can be used to determine the TDRS orbit. BRTS measurements are effectively the same as SN User measurements (see below) in that the BRTS on the ground acts identically to an SN user in space.

Please see the [note below](#) regarding rules for assigning TDRS spacecraft IDs.

The measurement path for BRTS\_Range and BRTS\_Doppler originates at a TDRSS ground terminal, proceeds along an uplink leg to a TDRSS spacecraft, and is relayed by

the TDRS along the forward leg to a BRTS antenna on the ground. The BRTS transponder receives and retransmits the signal along a return path to (usually the same) TDRSS spacecraft, which then relays the signal along the downlink path to a TDRSS ground terminal (usually the same as the transmit ground station).

## BRTS Doppler Measurements

The GMD record format for BRTS\_Doppler observation data is shown in the table below.

Field	Description
1	Observation receive time in TAIModJulian
2	Observation type name - BRTS_Doppler
3	Observation type index number - 9025 = BRTS_Doppler
4	Measurement path. The format of the measurement path is { Xmit-GroundStation ForwardTDRS BRTSGroundStation ReturnTDRS Recv-GroundStation }
5	Nominal BRTS transmit frequency in Hertz
6	BRTS transmit frequency band indicator - 0 = unknown, 1 = S-band, 2 = X-band, 3 = Ka-band, 4 = Ku-band, 5 = L-band
7	TDRS Service ID - 'SA1', 'SA2', or 'MA'
8	Tracker type for MA services (0 = legacy, 1 = TDRS-K)
9	S-Band Multiple Access Return (SMAR) downlink frequency ID
10	Doppler count interval in seconds
11	Doppler observation in Hertz

A sample of GMD data records for BRTS Doppler data is shown below.

```
% - 1 -      - 2 -      3      - 4 -      - 5 -      6      7      8      9      - 10 -      - 11 -
23585.508370370 BRTS_Doppler 9825 { 48 TDRS12 148 TDRS12 48 } 3.00000000000000e+09 1 SA1 0 0 10.000000 -1.3677498921896984e+10
23585.508370370 BRTS_Doppler 9825 { 48 TDRS12 152 TDRS12 48 } 3.00000000000000e+09 1 SA1 0 0 10.000000 -1.3677499155046673e+10
23585.507314814 BRTS_Doppler 9825 { 48 TDRS12 148 TDRS12 48 } 3.00000000000000e+09 1 SA1 0 0 10.000000 -1.3677498755754671e+10
23585.507314814 BRTS_Doppler 9825 { 48 TDRS12 152 TDRS12 48 } 3.00000000000000e+09 1 SA1 0 0 10.000000 -1.3677499026034889e+10
```

## BRTS Range Measurements

The GMD record format for BRTS Range observation data is shown in the table below.

Field	Description
1	Observation receive time in TAIModJulian
2	Observation type name - BRTS_Range
3	Observation type index number - 9027 = BRTS_Range
4	Measurement path. The format of the measurement path is { Xmit-GroundStation ForwardTDRS BRTSGroundStation ReturnTDRS Recv-GroundStation }
5	Total round-trip range measurement in kilometers

A sample of GMD data records for BRTS Range data is shown below.

```
%      - 1 -      - 2 -      3      - 4 -      - 5 -
29002.7362152777777777 BRTS_Range 9027 {47 TDRS11 1311 TDRS11 47} +1.625344877538e+05
29002.736226851851851 BRTS_Range 9027 {47 TDRS11 1311 TDRS11 47} +1.625345659996e+05
29002.736238425925925 BRTS_Range 9027 {47 TDRS11 1311 TDRS11 47} +1.625346436459e+05
29002.736250000000000 BRTS_Range 9027 {47 TDRS11 1311 TDRS11 47} +1.625347218917e+05
29002.736261574074074 BRTS_Range 9027 {47 TDRS11 1311 TDRS11 47} +1.625348010369e+05
```

## DSN Pseudo-Noise Range

DSN TRK-2-34 pseudo-noise ranging employs the **DSN\_PNRange** measurement type. DSN\_PNRange is an ambiguous range observation measured in range units. Computation of the unambiguous round-trip range is performed by GMAT internally using the predicted spacecraft state and the range modulo value supplied in the GMD file. Note that if the initial spacecraft state is very poor, it is possible that an incorrect number of range intervals may be computed, resulting in computation of an incorrect measured round-trip range. This can generally be remedied by supplying a more accurate initial state, if one is available. The GMD record format for DSN\_PNRange tracking data is shown in the table below.

Field	Description
1	Observation receive time in TAIModJulian
2	Observation type name - DSN TRK-2-34 type 14 Pseudo-Noise Range = DSN_PNRange
3	Observation type index number - 9033 = DSN_PNRange
4	Tracking measurement path. The format is { XmitGroundStation Spacecraft RecvGroundStation }
5	Range observable in range units ( <i>meas_rng</i> value from the TRK-2-34 PN range tracking CHDO)
6	Transmit delay in seconds. This is the sum <i>ul_stn_cal</i> + <i>ul_zheight_corr</i> , where <i>ul_stn_cal</i> is obtained from the PN range tracking CHDO and <i>ul_zheight_corr</i> is obtained from CHDO 134. The value of <i>ul_stn_cal</i> should be converted from range units to seconds according to the method shown below.
7	Receive delay in seconds. This is the sum <i>dl_stn_cal</i> + <i>dl_zheight_corr</i> , where <i>dl_stn_cal</i> is obtained from the PN range tracking CHDO and <i>dl_zheight_corr</i> is obtained from CHDO 134. The value of <i>dl_stn_cal</i> should be converted from range units to seconds according to the method shown below.
8	Uplink frequency band indicator - 0 = unknown, 1 = S-band, 2 = X-band, 3 = Ka-band, 4 = Ku-band, 5 = L-band. This is the <i>ul_band</i> value from CHDO 134.
9	Downlink frequency band indicator - 0 = unknown, 1 = S-band, 2 = X-band, 3 = Ka-band, 4 = Ku-band, 5 = L-band. This is the <i>vld_dl_band</i> value from CHDO 134.
10	Transmit frequency in Hz. See notes below.
11	Range modulo value ( <i>rng_modulo</i> from TRK-2-34 PN range tracking CHDO)

The uplink (*ul\_stn\_cal*) and downlink (*dl\_stn\_cal*) station calibration values must be converted to seconds and added to the respective z-height corrections (already in seconds). The conversion of station calibration values from range units to seconds requires the

transmit frequency at the time of the observation. This is found by identifying the nearest ramp record prior to the observation time and using the transmit frequency and frequency rate from that record to determine the transmit frequency at the observation time. The conversion to from range units to seconds is then given by the equation shown below, where  $k = 1/2$  for S-band and  $k = 221/1498$  for X-Band.

$$\text{seconds} = \text{Range Units} \div (F(t_{OBS}) * k)$$

The transmit frequency specified in the TRK-2-34 range data GMD file is only used if a frequency ramp table is not available. If a transmit frequency ramp record file is provided on the **TrackingFileSet.RampTable** field, the transmit frequency will be determined from the ramp table and the frequency specified in the range data GMD file will be ignored. A sample of GMD data records for TRK-2-34 Pseudo-Noise Range data is shown below.

```
% - 1 -      - 2 -      3      - 4 -      - 5 -      - 6 -      - 7 -      8      9      - 10 -      - 11 -
29899_9861921296287619043142 DSN_PNRange 9033 { 26 23 26 } 3.5177653473651981e+08 8.1677625136844035e-05 8.8413709125097467e-04 1 1 2.0410472153173406e+09 5.1684864000000000000e+
29899_9863078703710925765336 DSN_PNRange 9033 { 26 23 26 } 3.5198542211253548e+08 8.1677625439244134e-05 8.8413709453168197e-04 1 1 2.0410472077438405e+09 5.1684864000000000000e+
29899_9864236111097852699459 DSN_PNRange 9033 { 26 23 26 } 3.5219423880677605e+08 8.1677625741644234e-05 8.8413709781238916e-04 1 1 2.0410472001783405e+09 5.1684864000000000000e+
29899_9865393518521159421653 DSN_PNRange 9033 { 26 23 26 } 3.5240297588308334e+08 8.1677626044044334e-05 8.8413710109309625e-04 1 1 2.0410471925968406e+09 5.1684864000000000000e+
```

## Formulation of the Computed PN Range Value

GMAT determines a computed PN range value by the following process:

1. The GMD record measurement observation time represents the time the signal reached the receiver electronics. The time the signal arrived at the antenna is obtained by subtracting the GMD record receive delay from the GMD record observation receive time.
2. The transmit time and total round-trip light time are obtained by solving the light-time equation starting from the adjusted receive time. The light time solution yields the time the signal left the antenna at transmission.
3. The time the signal left the antenna at transmission is adjusted by subtracting the transmit delay to obtain the time the signal left the transmitting antenna electronics.
4. The frequency is integrated, using the ramp table if applicable, between the electronics transmit and receive times. This yields the total round-trip signal path in range units.

## DSN Sequential Range

DSN TRK-2-34 sequential ranging employs the **DSN\_SeqRange** measurement type. DSN\_SeqRange is an ambiguous range observation measured in range units. Computation of the unambiguous round-trip range is performed by GMAT internally using the computed spacecraft state and the range modulo value supplied in the GMD file. Note that if the initial spacecraft state is very poor, it is possible that an incorrect number of range intervals may be computed, resulting in computation of an incorrect measured round-trip range. This can generally be remedied by supplying a more accurate initial state, if one is available. The GMD record format for DSN\_SeqRange tracking data is shown in the table below.

Field	Description
1	Observation receive time in TAIModJulian

Field	Description
2	Observation type name - DSN TRK-2-34 Type 7 Sequential Range = DSN_SeqRange
3	Observation type index number - 9004 = DSN_SeqRange
4	Downlink Ground station pad ID or tracking spacecraft ID
5	Spacecraft ID
6	Range observable ( <i>meas_rng</i> or <i>rng_obs</i> from TRK-2-34 Sequential Range CHDO, with appropriate corrections applied)
7	Uplink frequency band indicator - 0 = unknown, 1 = S-band, 2 = X-band, 3 = Ka-band, 4 = Ku-band, 5 = L-band
8	Uplink frequency in Hz
9	Range modulo value ( <i>rng_modulo</i> from TRK-2-34 Sequential Range CHDO)

The transmit frequency specified in the TRK-2-34 range data GMD file is only used if a frequency ramp table is not available. If a transmit frequency ramp record file is provided on the **TrackingFileSet.RampTable** field, the transmit frequency will be determined from the ramp table and the frequency specified in the range data GMD file will be ignored. A sample of GMD data records for TRK-2-34 Sequential Range data is shown below.

```
% - 1 - - 2 - 3 4 5 - 6 - 7 - 8 - - 9 -
27236.157789352 DSN_SeqRange 9004 45 59 +9.810325186004e+005 1 +2.091414432000e+009 +1.048576000000e+006
27236.158240741 DSN_SeqRange 9004 45 59 +5.813243487947e+005 1 +2.091414432000e+009 +1.048576000000e+006
27236.158692130 DSN_SeqRange 9004 45 59 +1.863046908683e+005 1 +2.091414432000e+009 +1.048576000000e+006
27236.159143519 DSN_SeqRange 9004 45 59 +8.450116485521e+005 1 +2.091414432000e+009 +1.048576000000e+006
```

### Formulation of the Computed Sequential Range Value

GMAT determines a computed PN range value by the following process:

$$\text{computed range} = C \int_{t_1}^{t_3} f_T(t) dt, \text{ mod M} \quad (\text{RU})$$

where

$t_1, t_3$  = Transmission and Reception epoch, respectively

$f_T$  = Ground Station transmit frequency

$C$  = transmitter dependent constant (221/1498 for X-band and 1/2 for S-Band)

M = length of the ranging code in RU

### DSN Total Count Phase

DSN TRK-2-34 total count phase employs the **DSN\_TCP** measurement type. This measurement type is used for both two-way and three-way tracking. As shown below, the GMAT Doppler measurement type, measured in Hz, is derived from successive total count phase (TCP) observations.

$$\text{Derived "Doppler" Observation} = -\frac{[\phi(t_{3e}) - \phi(t_{3s})]}{t_{3e} - t_{3s}} = -\frac{[\phi(t_{3e}) - \phi(t_{3s})]}{\text{DCI}} \text{ (Hz)}$$

where

$t_{3s}, t_{3e}$  = start and end of reception interval  
 DCI = Doppler Count Interval in seconds  
 $\phi$  = Total Count Phase (from type 17 TRK-2-34 record)

The GMD record format for DSN\_TCP tracking data is shown in the table below.

Field	Description
1	Observation receive time in TAIModJulian
2	Observation type name - DSN TRK-2-34 Type 17 Total Count Phase = DSN_TCP
3	Observation type index number - 9006 = DSN_TCP
4	Tracking measurement path. The format is { XmitGroundStation Spacecraft RecvGroundStation }. For three-way tracking, the transmit and receive ground stations are different.
5	Uplink frequency band indicator - 0 = unknown, 1 = S-band, 2 = X-band, 3 = Ka-band, 4 = Ku-band, 5 = L-band
6	Doppler count interval in seconds
7	Observation value - Doppler observable derived from Total Count Phase (TCP) TRK-2-34 Type 17 measurements



### Note

Please note the new format for representing the tracking measurement path. The old format RecvGroundStation Spacecraft will continue to work but is deprecated and may be removed in a future release.

A sample of GMD data records for TRK-2-34 total count phase derived Doppler data is shown below.

%	- 1 -	- 2 -	3	- 4 -	5	6	- 7 -
27226.011944444	DSN_TCP	9006	{ 15 6241 15 }	1	10	-2.2445668331979342e+09	
27226.012060185	DSN_TCP	9006	{ 15 6241 15 }	1	10	-2.2445668330920730e+09	
27226.012175926	DSN_TCP	9006	{ 15 6241 15 }	1	10	-2.2445668329843016e+09	
27226.012291667	DSN_TCP	9006	{ 15 6241 15 }	1	10	-2.2445668328729177e+09	

### Formulation of the Computed TCP Doppler Value

GMAT determines a computed TCP Doppler value by the following process:

$$C = -\frac{M_2}{(t_{3e} - t_{3s})} \int_{t_{1s}}^{t_{1e}} f_T(t_1) dt_1 = -\frac{M_2(t_{1e} - t_{1s})}{DCI} \bar{f}_T \text{ (Hz)}$$

where

$$t_{1s}, t_{1e} = \text{start and end of transmission interval}$$

$$f_T = \text{transmit frequency}$$

$M_2$  = Transponder turn around ratio (typically, 240/221 for S-band and 880/749 for X-band)

$$\text{DCI} = (t_{3e} - t_{3s}) = \text{Doppler Count Interval}$$

$$\int_{t_{1s}}^{t_{1e}} f_T(t_1) dt_1$$

$$\bar{f}_T \equiv \frac{\int_{t_{1s}}^{t_{1e}} f_T(t_1) dt_1}{(t_{1e} - t_{1s})} = \text{average transmit frequency}$$

Note that ( $t_{3e} - t_{3s}$ ) is known as the Doppler Count Interval. This value is read from the GMD file record (for estimation) and is an input field, **SimDopplerCountInterval** on the **TrackingFileSet** resource for simulation.

### Transmit Frequency Ramp Records

GMAT supports DSN tracking utilizing both constant and ramped transmit frequencies. If the transmit frequency is constant, GMAT will use the transmit frequency specified on the DSN\_SeqRange or DSN\_PNRange measurement records for the computation of the range observation and a ramp table file is not required. If the transmit frequency is ramped, the user must generate a GMD file of ramp records from TRK-2-34 Type 9 raw data, and provide the GMD ramp table on the **TrackingFileSet.RampTable** object field. If a ramp table is provided, GMAT ignores the frequency specified on the range records and instead computes the transmit frequency from the ramp records.

The record format for ground-based range-rate tracking data is shown in the table below.

Field	Description
1	Ramp record epoch in TAIModJulian
2	Ground station pad ID
3	Spacecraft ID
4	Uplink frequency band indicator - 0 = unknown, 1 = S-band, 2 = X-band, 3 = Ka-band, 4 = Ku-band, 5 = L-band. (This is the <i>ul_band</i> value from CHDO 132).
5	Ramp type - 0 = snap, 1 = start of new ramp, 2 = medial report, 3 = periodic report, 4 = end of ramps, 5 = ramping terminated by operator, 6 = invalid/unknown ( <i>ramp_type</i> from the TRK-2-34 ramp tracking CHDO)
6	Ramp frequency in Hz ( <i>ramp_freq</i> from the TRK-2-34 ramp tracking CHDO)
7	Ramp rate in Hz/sec ( <i>ramp_rate</i> from the TRK-2-34 ramp tracking CHDO)

A sample GMD ramp file is shown below.

```
%      - 1 -      2 3   4   5           - 6 -           - 7 -
27238.640625000 34 234   2   1 +7.186571173393e+09 +6.010599999990e-01
```

27238.654513889	34	234	2	1	+7.186571894665e+09	+5.822699999990e-01
27238.659664352	34	234	2	3	+7.186572153775e+09	+5.822699999990e-01
27238.668402778	34	234	2	1	+7.186572593389e+09	+5.590199999990e-01
27238.682291667	34	234	2	1	+7.186573264213e+09	+5.315100000000e-01

### Earth-fixed Position Vectors from a Spacecraft On-board GPS Receiver

GPS-derived Earth-fixed position vectors employ the **GPS\_PosVec** measurement type. The fixed frame assumed for the vector components is GMAT's EarthFixed reference frame (see [CoordinateSystem](#)). The record format for GPS\_PosVec tracking data is shown in the table below.

Field	Description
1	Observation receive time in TAIModJulian
2	Observation type name - GPS_PosVec
3	Observation type index number - 9014 = GPS_PosVec
4	GPS receiver ID
5	Earth-fixed position X component (km)
6	Earth-fixed position Y component (km)
7	Earth-fixed position Z component (km)

The GMAT user should be aware that the GPS\_PosVec measurement is currently treated as a vector quantity. The vector components are not treated as independent observations. If any component of a vector observation (X, Y, or Z) is edited from the solution by the user or by autonomous sigma editing, the other components associated with that observation will also be edited out, regardless of their quality.

A sample GMD GPS\_PosVec file is shown below.

%	- 1 -	- 2 -	3 4	- 5 -	- 6 -	- 7 -
26112.586516203704	GPS_PosVec	9014	800	-3575.594419	-5758.828897	1440.891615
26112.587210648147	GPS_PosVec	9014	800	-3257.134099	-5984.428574	1265.579859
26112.587905892594	GPS_PosVec	9014	800	-2926.558570	-6187.149174	1084.793371
26112.588599537037	GPS_PosVec	9014	800	-2585.076391	-6366.230816	899.311591
26112.589293981480	GPS_PosVec	9014	800	-2233.950454	-6520.997704	709.941434

### Two-Way Transponder Range

Two-way range measurements that pass through a Spacecraft transponder use the **Range** measurement type. **Range** is an unambiguous round-trip range observation measured in kilometers. The measurement model in GMAT will include the Spacecraft **Transponder.HardwareDelay**, but the HardwareDelay may be set to zero. The GMD record format for Range data is shown in the table below.

Field	Description
1	Observation receive time in TAIModJulian
2	Observation type name - Range

Field	Description
3	Observation type index number <ul style="list-style-type: none"> <li>• 9002 = Ground-to-space Range</li> <li>• 9029 = Inter-spacecraft (crosslink) Range</li> </ul>
4	Downlink ground station pad ID or tracking spacecraft ID
5	Spacecraft ID
6	Two-way (round-trip) range observation in kilometers

A sample of GMD data records for Range data is shown below.

```
% - 1 - - 2 - 3 4 5 - 6 -
27182.022395833334 Range 9002 117 322 +7.447171160686e+04
27182.022511574076 Range 9002 117 322 +7.447456623065e+04
27182.022627314815 Range 9002 117 322 +7.447742325277e+04
27182.022743055557 Range 9002 117 322 +7.448028087448e+04
```

### Two-Way Non-Transponder Range

Two-way range measurements that do not pass through a Spacecraft transponder use the **Range\_Skin** measurement type. Range\_Skin is an unambiguous round-trip range observation measured in kilometers. Users of tracking data in raw 46-character or NO-RAD B3 format should be aware that these formats encode a one-way range value, so the reported range measurement must be converted to a two-way value (by multiplying the observed range by 2) when formatting this data into a GMD file. The GMD record format for Range\_Skin data is shown in the table below.

Field	Description
1	Observation receive time in TAIModJulian
2	Observation type name - Range_Skin
3	Observation type index number - 9024 = Range_Skin
4	Receive ground station pad ID
5	Spacecraft ID
6	Two-way (round-trip) range observation in kilometers

A sample of GMD data records for Range\_Skin data is shown below.

```
% - 1 - - 2 - 3 4 5 - 6 -
27182.022395833334 Range_Skin 9024 117 322 +7.447171160686e+04
27182.022511574076 Range_Skin 9024 117 322 +7.447456623065e+04
27182.022627314815 Range_Skin 9024 117 322 +7.447742325277e+04
27182.022743055557 Range_Skin 9024 117 322 +7.448028087448e+04
```

### Two-Way Range-Rate

Two-way coherent range-rate tracking uses the **RangeRate** measurement type. RangeRate is the difference of the range observation at the end of the averaging interval

and the start of the averaging interval, divided by the averaging interval duration. The time tag is at the end of the averaging interval. The GMD record format for RangeRate data is shown in the table below.

Field	Description
1	Observation receive time in TAIModJulian
2	Observation type name - RangeRate
3	Observation type index number <ul style="list-style-type: none"> <li>• 9012 = Ground-to-space RangeRate</li> <li>• 9030 = Inter-spacecraft (crosslink) RangeRate</li> </ul>
4	Tracking measurement path. The format is { XmitGroundStation Spacecraft RecvGroundStation }. For three-way tracking, the transmit and receive stations are different.
5	Uplink frequency band indicator - 0 = unknown, 1 = S-band, 2 = X-band, 3 = Ka-band, 4 = Ku-band, 5 = L-band
6	Doppler averaging interval in seconds
7	Range-rate observation in kilometers/second



### Note

Please note the new format for representing the tracking measurement path. The old format RecvGroundStation Spacecraft will continue to work but is deprecated and may be removed in a future release.

A sample of GMD data records for RangeRate data is shown below.

```
% - - 1 - - 2 - 3 - 4 - 5 6 - 7 -
21544.500370370370 RangeRate 9012 { CAN SAT USPS } 1 10 -3.8108162251433930e-02
21544.501064814814 RangeRate 9012 { CAN SAT USPS } 1 10 -3.7958430795696073e-02
21544.501759259259 RangeRate 9012 { CAN SAT USPS } 1 10 -3.7805598218522536e-02
21544.502453703703 RangeRate 9012 { CAN SAT USPS } 1 10 -3.7655205945919069e-02
```

### Space Network (Tracking and Data Relay Satellite System) Measurements

The Tracking and Data Relay Satellite System (TDRSS) consists of a constellation of spacecraft in geosynchronous orbit that provides near-continuous coverage of low-earth orbit. The TDRSS spacecraft are used to relay data from low-earth orbiting spacecraft to the ground. TDRSS spacecraft are also used to track low-earth spacecraft, and the TDRSS provides a number of measurement types that are supported for OD in GMAT.



### Note

Certain constants in the TDRSS measurement model depend on the user service (SA1, SA2, or MA) and TDRS spacecraft ID. The user service is explicitly indicated in the GMD file tracking data records. GMAT will attempt to determine the TDRS spacecraft ID from the **Spacecraft** resource **Id** parameter. For TDRS measurements to function properly in all cases, the user must observe one of the following conventions when assigning the **Spacecraft.Id** parameter for a TDRS spacecraft.

- The user may specify the TDRS SIC as the TDRS spacecraft Id. GMAT will infer the TDRS ID from the proper TDRS spacecraft SIC.
- Optionally, the user may specify the TDRS **Spacecraft.Id** in the format "*<string><nn>*", where *<nn>* is a one- or two-digit number indicating the TDRS ID. The *<string>* portion of the ID may be any string. For example, setting the **spacecraft.Id** parameter to "TDRS09", "TD09", or "TDRS9" all properly identify the spacecraft as TDRS-9 (TDRS ID = 9).

Failing to follow one of these conventions may result in some Doppler measurements being computed incorrectly. GMAT will issue a warning message in the log file if it is unable to determine the TDRS ID from the spacecraft **Id** parameter.

For all TDRS measurement types, media (ionosphere and troposphere) corrections are only applied on the TDRS to ground tracking leg. No media corrections are computed on user to TDRS (space to space) tracking legs.

### Space Network (TDRSS) Two-way Doppler

TDRSS coherent two-way Doppler tracking uses the **SN\_Doppler** measurement type. The measurement path for SN\_Doppler originates at a TDRSS ground terminal, proceeds along an uplink leg to a TDRSS spacecraft, and is relayed by the TDRS along the forward leg to the user spacecraft. The user spacecraft receives and retransmits the signal along a return path to (usually the same) TDRSS spacecraft, which then relays the signal along the downlink path to a TDRSS ground terminal (usually the same as the transmit ground station). The GMD record format for SN\_Doppler data is shown in the table below.

Field	Description
1	Observation receive time in TAIModJulian
2	Observation type name - SN_Doppler
3	Observation type index number - 9013 = SN_Doppler
4	Measurement path; the format is { XmitGroundStation ForwardTDRS UserSpacecraft ReturnTDRS RecvGroundStation }.
5	Nominal user transmit frequency in Hertz
6	User transmit frequency band indicator - 0 = unspecified, 1 = S-band, 3 = K-band

Field	Description
7	TDRS service identifier; SA1, SA2, or MA.
8	Tracker type for MA services (0 = legacy, 1 = TDRS-K)
9	S-Band Multiple Access Return (SMAR) downlink frequency ID
10	Doppler count interval in seconds
11	Doppler measurement in Hertz

A sample of GMD data records for SN\_Doppler data is shown below.

```
%      - 1 -      - 2 -      - 3 -      - 4 -      - 5 -      - 6 -      - 7 -      - 8 -      - 9 -      - 10 -      - 11 -
27235.503981481481481 SN_Doppler 9013 { 47 TDRS10 1874 TDRS10 47 } 2.28750896e0000e+09 1 SA2 1 0 1.000000 81582.008000
27235.503993855555555 SN_Doppler 9013 { 47 TDRS10 1874 TDRS10 47 } 2.28750896e0000e+09 1 SA2 1 0 1.000000 81491.748000
27235.504004629629629 SN_Doppler 9013 { 47 TDRS10 1874 TDRS10 47 } 2.28750896e0000e+09 1 SA2 1 0 1.000000 81401.316000
27235.504016203703703 SN_Doppler 9013 { 47 TDRS10 1874 TDRS10 47 } 2.28750896e0000e+09 1 SA2 1 0 1.000000 81318.708000
27235.504027777777777 SN_Doppler 9013 { 47 TDRS10 1874 TDRS10 47 } 2.28750896e0000e+09 1 SA2 1 0 1.000000 81219.995000
```

### Space Network (TDRSS) One-way Return Doppler

TDRSS non-coherent one-way user return Doppler tracking uses the **SN\_Doppler\_Rtn** measurement type. The measurement path for SN\_Doppler\_Rtn originates at an on-orbit user spacecraft, proceeds along a return leg to a TDRSS spacecraft, and is relayed by the TDRS along the downlink leg to TDRSS ground terminal.

This measurement is formulated as a combination of the one-way average range-rate from the user spacecraft to the TDRS to the ground, and the two-way average range-rate from the ground to TDRS to ground. Please note that GMAT formulates the light-time solution in the Solar System Barycentric (SSB) frame and this requires modeling of the ET-TAI correction on the one-way user to TDRS to ground leg. GMAT will automatically apply ET-TAI on that leg regardless of the setting of the **TrackingFileSet UseETminusTAI** flag. This flag will apply as set by the user (True or False) to the two-way range-rate component of the measurement.

The GMD record format for SN\_Doppler\_Rtn data is shown in the table below.

Field	Description
1	Observation receive time in TAIModJulian
2	Observation type name - SN_Doppler_Rtn
3	Observation type index number - 9026
4	Measurement path; the format is { UserSpacecraft, ReturnTDRS, RecvGroundStation }
5	Nominal user transmit frequency in Hertz
6	User transmit frequency band indicator - 0 = unspecified, 1 = S-band, 3 = K-band
7	TDRS service identifier; 'SA1', 'SA2', or 'MA'.
8	Tracker type for MA services (0 = legacy, 1 = TDRS-K)
9	S-Band Multiple Access Return (SMAR) downlink frequency ID
10	Doppler count interval in seconds
11	Doppler measurement in Hertz

A sample of GMD data records for SN\_Doppler\_Rtn data is shown below.

```
% - 1 -           - 2 -           3           - 4 -           - 5 -           6   7   8   9   - 10 -           - 11 -
23585.5184259259259259259262 SN_Doppler_Rtn 9826 { 1874 1411 48 } 3.00000000000000e+09 1  SA1 0 0 10.000000 -1.3677461877950760e+10
23585.5198148148148148142 SN_Doppler_Rtn 9826 { 1874 1411 48 } 3.00000000000000e+09 1  SA1 0 0 10.000000 -1.3677458521391161e+10
23585.5212637037037037037036 SN_Doppler_Rtn 9826 { 1874 1411 48 } 3.00000000000000e+09 1  SA1 0 0 10.000000 -1.3677455761216986e+10
23585.5225925925925925925927 SN_Doppler_Rtn 9826 { 1874 1411 48 } 3.00000000000000e+09 1  SA1 0 0 10.000000 -1.3677453673831347e+10
23585.5239814814814914814820 SN_Doppler_Rtn 9826 { 1874 1411 48 } 3.00000000000000e+09 1  SA1 0 0 10.000000 -1.3677452330975290e+10
```

## Space Network (TDRSS) Differenced One-way Return Doppler

TDRSS differenced one-way return Doppler tracking uses the **SN\_DOWD** measurement type. SN\_DOWD is formulated by differencing simultaneous SN one-way return Doppler measurements. Formulation of SN\_DOWD requires two simultaneous SN one-way return tracking passes that have at least some coincident time tags. GMAT models each individual one-way return Doppler strand using the SN\_Doppler\_Rtn measurement model and then computes the arithmetic difference of the modeled one-way Doppler measurements to obtain the computed DOWD measurement.

The GMD record format for SN\_DOWD data is shown in the table below. Note that the differencing of simultaneous one-way measurements must be performed external to GMAT during formulation of the GMD records.

Field	Description
1	Observation receive time in TAIModJulian
2	Observation type name - SN_DOWD
3	Observation type index number - 9028
4	Measurement path; the format is { UserSpacecraft, ReturnTDRS1, RecvGroundStation1, ReturnTDRS2, RecvGroundStation2 }
5	ReturnTDRS1 path nominal user transmit frequency in Hertz
6	ReturnTDRS1 path user transmit frequency band indicator - 0 = unspecified, 1 = S-band, 3 = K-band
7	ReturnTDRS1 path TDRS service identifier; 'SA1', 'SA2', or 'MA'.
8	ReturnTDRS1 path tracker type for MA services (0 = legacy, 1 = TDRS-K)
9	ReturnTDRS1 path S-Band Multiple Access Return (SMAR) downlink frequency ID
10	ReturnTDRS1 path Doppler count interval in seconds
11	ReturnTDRS2 path nominal user transmit frequency in Hertz
12	ReturnTDRS2 path user transmit frequency band indicator - 0 = unspecified, 1 = S-band, 3 = K-band
13	ReturnTDRS2 path TDRS service identifier; 'SA1', 'SA2', or 'MA'.
14	ReturnTDRS2 path tracker type for MA services (0 = legacy, 1 = TDRS-K)
15	ReturnTDRS2 path S-Band Multiple Access Return (SMAR) downlink frequency ID
16	ReturnTDRS2 path Doppler count interval in seconds
17	DOWD measurement in Hertz

A sample of GMD data records for SN\_DOWD data is shown below.

%	- 1 -	- 2 -	3	- 4 -	- 5 -	6	7	8	9	- 10 -	- 11 -	12	13	14	15	- 16 -	- 17 -
29222.84246527779411	SN_DWD	9028	{ 7369 1411 49 1306 94 }	2.282300000000e+09	1	SA2	0	0	1.000000	2.282300000000e+09	1	SA1	0	0	1.000000	-7.6810850000E+03	
29222.8424768518F2E52	SN_DWD	9028	{ 7369 1411 49 1306 94 }	2.282300000000e+09	1	SA2	0	0	1.000000	2.282300000000e+09	1	SA1	0	0	1.000000	-7.7030230000E+03	
29222.842488425925694	SN_DWD	9028	{ 7369 1411 49 1306 94 }	2.282300000000e+09	1	SA2	0	0	1.000000	2.282300000000e+09	1	SA1	0	0	1.000000	-7.7249500000E+03	
29222.842499999998836	SN_DWD	9028	{ 7369 1411 49 1306 94 }	2.282300000000e+09	1	SA2	0	0	1.000000	2.282300000000e+09	1	SA1	0	0	1.000000	-7.7467780000E+03	
29222.842511574075615	SN_DWD	9028	{ 7369 1411 49 1306 94 }	2.282300000000e+09	1	SA2	0	0	1.000000	2.282300000000e+09	1	SA1	0	0	1.000000	-7.7686560000E+03	

## Space Network (TDRSS) Two-way Range

TDRSS coherent two-way range tracking uses the **SN\_Range** measurement type. The measurement path for SN\_Range originates at a TDRSS ground terminal, proceeds along an uplink leg to a TDRSS spacecraft, and is relayed by the TDRS along the forward leg to the user spacecraft. The user spacecraft receives and retransmits the signal along a return path to (usually the same) TDRSS spacecraft, which then relays the signal along the downlink path to a TDRSS ground terminal (usually the same as the transmit ground station). The GMD record format for SN\_Range data is shown in the table below.

Field	Description
1	Observation receive time in TAIModJulian
2	Observation type name - SN_Range
3	Observation type index number - 9000 = SN_Range
4	Measurement path; the format is { XmitGroundStation, ForwardTDRS, UserSpacecraft, ReturnTDRS, RecvGroundStation }
5	Total round-trip range measurement in kilometers

A sample of GMD data records for SN\_Range data is shown below.

%	- 1 -	- 2 -	3	- 4 -	- 5 -
27235.503958333333333	SN_Range	9000	{47 TDRS10 1874 TDRS10 47}	+1.551416168318e+05	
27235.503969907407407	SN_Range	9000	{47 TDRS10 1874 TDRS10 47}	+1.551309765979e+05	
27235.503981481481481	SN_Range	9000	{47 TDRS10 1874 TDRS10 47}	+1.551203453578e+05	
27235.503993055555555	SN_Range	9000	{47 TDRS10 1874 TDRS10 47}	+1.551097282079e+05	
27235.504004629629629	SN_Range	9000	{47 TDRS10 1874 TDRS10 47}	+1.550991239491e+05	

## References

1. Moyer, Theodore D., *Formulation for Observed and Computed Values of Deep Space Network Data Types for Navigation*, (JPL Publication 00-7), Jet Propulsion Laboratory, California Institute of Technology, October 2000.
2. Shin, Dong., *DSN Tracking System Data Archival Format*, DSN Document 820-013, Module TRK-2-34, Rev. P, 2017.

## Configuration of Propagators for Orbit Determination

This section describes some special considerations for configuration of numerical and ephemeris propagators for GMAT's estimators.

### Use of Propagators in Estimation

As noted elsewhere in this documentation, all estimators (**BatchEstimator**, **Extended-KalmanFilter**, and **Smoother**) currently require fixed-step integration. The **ErrorControl** parameter of the force model used by the estimator must be set to 'None'. Step size for fixed-step integration is configured on the propagator **InitialStepSize** and **MaxStep** fields. The smaller of the two values assigned to these parameters will be the integration step size. It is usually convenient to set both to the same value, to avoid confusion.

In the most common case, running estimation for a single spacecraft, the user will configure a single numerical integrator according to the description and examples provided in the documentation for the [Numerical Propagator](#) resource. The configured propagator is then assigned on the estimator **Propagator** field. GMAT does permit some unusual configurations that deserve further explanation:

- Simultaneous estimation of multiple spacecraft, or estimation using inter-spacecraft tracking, with each spacecraft requiring a unique force model and propagator,
- Use of ephemeris propagators in estimation.

These options are discussed in the next sections.



#### Note

Ephemeris propagators use interpolation methods to obtain states at times in between those states present on the ephemeris file. These interpolation methods are usually less accurate near the beginning and end of ephemeris files, and near segment boundaries in ephemeris files. For best accuracy, the user should ensure there is ample ephemeris data surrounding the data processing interval to avoid inaccuracy near ephemeris end points or segment boundaries.

## Configuring Propagators for Simultaneous Estimation of Multiple Spacecraft



#### Note

Simultaneous propagation of multiple spacecraft is only available with the **BatchEstimator** and **Simulator** and is currently disallowed for the **ExtendedKalmanFilter**.

GMAT now supports simultaneous estimation of multiple spacecraft, with or without inter-spacecraft (or crosslink) tracking. An example of this scenario might be a spacecraft

in Earth geosynchronous orbit which performs tracking on a spacecraft in low-Earth orbit. In this instance, the low-Earth spacecraft requires drag modeling and a moderately small integration step size, while the geosynchronous spacecraft does not require drag modeling and can use a larger integration step size.

To configure this in GMAT, the user should create individual force models and propagators for each spacecraft. The syntax for assigning propagators on estimator objects has been modified to accommodate assigning the individual propagators to each spacecraft. The following syntax may now be used in the case where more than one propagator is required in the estimation process (this example illustrates application to the **BatchEstimator** resource, but the syntax is the same for the **Simulator**):

```
Create Spacecraft EstLEO, EstGEO1, EstGEO2, EstGEO3

%
%   ForceModels and Propagators
%

Create ForceModel LeoFM;

LeoFM.CentralBody          = Earth;
LeoFM.PrimaryBodies         = {Earth}
LeoFM.GravityField.Earth.Degree = 30;
LeoFM.GravityField.Earth.Order = 30;
LeoFM.GravityField.Earth.PotentialFile = 'JGM2.cof';
LeoFM.SRP                   = On;
LeoFM.SRP.Flux              = 1370.052;
LeoFM.Drag.AtmosphereModel = 'JacchiaRoberts';
LeoFM.Drag.HistoricWeatherSource = 'CSSISpaceWeatherFile';
LeoFM.ErrorControl          = None;

Create Propagator LeoProp;

LeoProp.FM                  = LeoFM;
LeoProp.Type                = RungeKutta89;
LeoProp.InitialStepSize     = 60;
LeoProp.Accuracy            = 1e-13;
LeoProp.MinStep              = 0;
LeoProp.MaxStep              = 60;
LeoProp.MaxStepAttempts     = 50;

Create ForceModel GeoFM;

GeoFM.CentralBody          = Earth;
GeoFM.PrimaryBodies         = {Earth}
GeoFM.PointMasses          = {Luna, Sun}
GeoFM.GravityField.Earth.Degree = 8;
GeoFM.GravityField.Earth.Order = 8;
GeoFM.GravityField.Earth.PotentialFile = 'JGM2.cof';
```

```

GeoFM.Drag = None;
GeoFM.SRP = On;
GeoFM.ErrorControl = None;

Create Propagator GeoProp;

GeoProp.FM = GeoFM;
GeoProp.Type = RungeKutta89;
GeoProp.InitialStepSize = 300;
GeoProp.Accuracy = 1e-13;
GeoProp.MinStep = 0;
GeoProp.MaxStep = 300;
GeoProp.MaxStepAttempts = 50;

%
% Estimator
%

Create BatchEstimator BLS

BLS.ShowProgress = true;
BLS.Measurements = {estData}
BLS.AbsoluteTol = 0.005;
BLS.RelativeTol = 0.001;
BLS.MaximumIterations = 10;
BLS.MaxConsecutiveDivergences = 5;
BLS.Propagator = {LeoProp, EstLEO};
BLS.Propagator = {GeoProp, EstGEO1, EstGEO2, EstGEO3};
BLS.ShowAllResiduals = On;
BLS.OLSEInitialRMSSigma = 1000;
BLS.OLSEMultiplicativeConstant = 3;
BLS.OLSEUseRMSP = False;
BLS.UseInitialCovariance = False
BLS.ReportFile = 'bls_report.txt';

%
% Mission Sequence
%

BeginMissionSequence

```

In the above example, take specific note of the **BLS.Propagator** assignments.

```

BLS.Propagator = {LeoProp, EstLEO};
BLS.Propagator = {GeoProp, EstGEO1, EstGEO2, EstGEO3};

```

This syntax assigns the LeoProp propagator to the EstLEO spacecraft and assigns the GeoProp propagator to Spacecraft EstGEO1, EstGEO2, and EstGEO3. This enables the estimator to use appropriate force modeling and propagation controls for each individual spacecraft when performing estimation.

Note that the old syntax for single spacecraft propagation may still be used for multi-spacecraft estimation scenarios, as shown below.

```
BLS.Propagator = LeoProp;
```

However, be aware that this syntax, when used in a multi-spacecraft estimation run, will cause the LeoProp force model and propagator to be used for all spacecraft in the run.

### Interaction with Propagator MaxStepAttempts

When using multiple propagators with different step sizes, it is necessary to pay attention to each propagator's **MaxStepAttempts** parameter. During propagation, GMAT first takes a propagation step at the size of the largest step-sized propagator. Then it looks to the other propagators and steps each as many times as needed to reach the step of the larger, using the **MaxStepAttempts** parameter for guidance of how many steps it is allowed to try. For example, if one propagator was configured to use a 300-second step size, and another to use a 5-second step size, the propagator stepping at 5-seconds steps would require 60 steps to match each step of the 300-second step propagator. With a **MaxStepAttempts** parameter of 50 (the default value), the 5-second propagator will not reach the target step of 300 seconds before exceeding the **MaxStepAttempts**, and GMAT will issue a failure message. In this case, the 5-second propagator should have **MaxStepAttempts** set to 60 or larger.

### Use of Ephemeris Propagators in Estimation



#### Note

GMAT currently supports use of SPK/SPICE, STK, and CCSDS OEM ephemeris files as ephemeris propagators for estimation. The Code500 ephemeris format is not supported as an ephemeris propagator for use with estimators. Use of ephemeris propagators during estimation is only allowed in the **Simulator** and **BatchEstimator**. The user cannot estimate any orbit parameters for a spacecraft utilizing an ephemeris propagator.

An ephemeris propagator may be used in place of a numerical propagator for any spacecraft participating in an estimation or simulation run. An example use case for this scenario is estimation of one or more spacecraft using tracking from the Tracking and Data Relay Satellite System (TDRSS), or other relay or space-to-space tracking, where the analyst possesses an ephemeris for the tracking spacecraft orbit and desires to estimate the orbit of the target or user spacecraft. GMAT also allows the possibility of simultaneously estimating both the TDRS and user orbit, or estimating the TDRS orbit from a given user or target spacecraft orbit. Note that it is not possible to estimate the orbit of any spacecraft for which an ephemeris propagator is in use.

An ephemeris propagator for estimation can be configured for SPICE/SPK, STK, or CCSDS OEM format ephemeris files as described in the [Propagator](#) resource. In the example shown above, any of the spacecraft may be assigned to an ephemeris propagator using the same syntax shown for multiple spacecraft propagation on the estimator **Propagator** parameter.

### BatchEstimator "Observed Minus Computed" Run Using an Ephemeris File

The user can configure the **BatchEstimator** to perform an "observed minus computed" (OMC) run using an ephemeris propagator. An example of this use would be an instance where a user has a predicted ephemeris modeling a maneuver, and wants to evaluate how the maneuver performed by examining incoming pre- and post-maneuver tracking data residuals against the ephemeris maneuver prediction. (Note that the same run could be configured using a state vector, numerical propagator, and **ThrustHistoryFile** which models the maneuver.) Similarly, a user could desire just to compute the residuals of tracking data versus a free-flight, non-maneuver ephemeris.

In either of these cases, the user should configure an ephemeris propagator as described in the [Propagator](#) resource, and assign the ephemeris propagator on the **BatchEstimator Propagator** parameter. When running the batch estimator with an ephemeris propagator, state estimation is not possible and the user should also set the estimator **SolveMode** to **RunInitialGuess** when calling **RunEstimator**. See [RunEstimator](#) for more details. This feature is not currently available for the [ExtendedKalmanFilter](#).

## Initial Orbit Determination

A set of python functions to support early orbit operations

### Description

A collection of functions to allow the user to perform initial orbit determination (IOD). This includes implementations of the Gibbs and the Herrick-Gibbs methods, by which the user may determine the velocity of an object from set of three sequential position vectors. Additionally, top level functions are included which may determine which method to use based on the inputs provided by the user.

The initial orbit determination functions are accessed through the Python user interface using GMAT's CallPythonFunction command and require the Numpy library to be installed to Python. For details on the Python user interface, see the [Python Interface](#) reference. For details on calling a Python function and passing data, see the [CallPython-Function](#) reference. Instructions for installing the Numpy package may be found at their website, <https://numpy.org/>

### Functions

Field	Description	
<b>CalculateIODGibbs</b>	Implementation of the Gibbs method. Calculates the velocity corresponding to the second position vector input.	
<b>Inputs</b>	r1 - [x,y,z] position vector at the first observation (km)  r2 - [x,y,z] position vector at the second observation. This is the position for which the velocity will be solved. (km)  r3 - [x,y,z] position vector at the third observation (km)  mu - Gravitational parameter of the central body. Default to Earth (3.986004415e5 km^3/s^2)	
<b>Outputs</b>	<b>If Verbose == False</b> v2 - [vx,vy,vz] Velocity vector at the second observation. (km/s)  <b>If Verbose == True</b> v2 - [vx,vy,vz] Velocity vector at the second observation. (km/s)  log - String that contains any information logged as part of the calculation.	

Field	Description
<b>CalculateODHerrickGibbs</b>	Implementation of the Herrick-Gibbs method. Calculates the velocity corresponding to the second position vector input.
<b>Inputs</b>	<p>r1 - [x,y,z] position vector at the first observation (km)</p> <p>r2 - [x,y,z] position vector at the second observation. This is the position for which the velocity will be solved. (km)</p> <p>r3 - [x,y,z] position vector at the third observation (km)</p> <p>t1 - Time of first measurement in Julian Date format (Can also be Modified Julian Date, or Seconds/86400)</p> <p>t2 - Time of second measurement in Julian Date format (Can also be Modified Julian Date, or Seconds/86400)</p> <p>t3 - Time of third measurement in Julian Date format (Can also be Modified Julian Date, or Seconds/86400)</p> <p>mu - Gravitational parameter of the central body. Default to Earth (3.986004415e5 km^3/s^2)</p> <p>verbose - True or false flag if logging information. Default to false.</p>
<b>Outputs</b>	<p><b>If Verbose == False</b></p> <p>v2 - [vx,vy,vz] Velocity vector at the second observation. (Units in km/s)</p> <p><b>If Verbose == True</b></p> <p>v2 - [vx,vy,vz] Velocity vector at the second observation. (Units in km/s)</p> <p>log - String that contains any information logged as part of the calculation.</p>

Field	Description
<b>ThreePositionIOD</b>	Top level function to perform IOD, selecting Gibbs or Herrick-Gibbs based on the separation angle between the observations.
<b>Inputs</b>	<p>r1 - [x,y,z] position vector at the first observation (km)</p> <p>r2 - [x,y,z] position vector at the second observation. This is the position for which the velocity will be solved. (km)</p> <p>r3 - [x,y,z] position vector at the third observation (km)</p> <p>t1 - Time of first measurement in Julian Date format (Can also be Modified Julian Date, or Seconds/86400)</p> <p>t2 - Time of second measurement in Julian Date format (Can also be Modified Julian Date, or Seconds/86400)</p> <p>t3 - Time of third measurement in Julian Date format (Can also be Modified Julian Date, or Seconds/86400)</p> <p>mu - Gravitational parameter of the central body. Default to Earth (3.986004415e5 km^3/s^2)</p> <p>IODType - Optional string that may set to "Gibbs" or "HerrickGibbs" to override the sorting logic and force the specified IOD method</p>
<b>Outputs</b>	<p>v2 - [vx,vy,vz] Velocity vector at the second observation. (Units in km/s)</p> <p>log - String that contains any information logged as part of the calculation, as well as logging which method of IOD was performed.</p>

Field	Description
Inputs	<p>Top level function to perform IOD, selecting Gibbs or Herrick-Gibbs based on the separation angle between the observations. Version does not return a log parameter.</p> <p><b>Inputs</b></p> <ul style="list-style-type: none"> <li>r1 - [x,y,z] position vector at the first observation (km)</li> <li>r2 - [x,y,z] position vector at the second observation. This is the position for which the velocity will be solved. (km)</li> <li>r3 - [x,y,z] position vector at the third observation (km)</li> <li>t1 - Time of first measurement in Julian Date format (Can also be Modified Julian Date, or Seconds/86400)</li> <li>t2 - Time of second measurement in Julian Date format (Can also be Modified Julian Date, or Seconds/86400)</li> <li>t3 - Time of third measurement in Julian Date format (Can also be Modified Julian Date, or Seconds/86400)</li> <li>mu - Gravitational parameter of the central body. Default to Earth (3.986004415e5 km^3/s^2)</li> <li>IODType - Optional string that may set to "Gibbs" or "HerrickGibbs" to override the sorting logic and force the specified IOD method</li> </ul>
Outputs	v2 - [vx,vy,vz] Velocity vector at the second observation. (Units in km/s)

## Remarks

There are certain scenarios in which the user has limited information on the body for which they wish to perform orbit determination. In such a circumstance, the user would have only a number of position measurements (or measurements from which position could be derived, such as Azimuth, Elevation and Range) from which to predict the future state of the spacecraft. For this particular problem, the Gibbs and the Herrick-Gibbs methods are well suited. These methods each take in three position vectors in an inertial frame from which they return the velocity of the craft at the second position. Each approach has circumstances for which they are better suited as a by-product of the approach they take to solve the problem, and both share a common set of assumptions. Both methods provide solutions for a two-body problem, so scenarios in which there are significant outside perturbations are not appropriate for this feature. Additionally, both methods assume that the three position vectors are time-ordered sequentially and are coplanar. To allow for variance in real data, some flexibility is allowed on the coplanar requirement, such that the observations must be within 3 degrees of being copla-

nar. Since the Gibbs method is finding a solution geometrically, it is better suited for observations with large angles of separation. In contrast, the Herrick-Gibbs approach, which essentially performs a Taylor-Series expansion about the second observation, is superior for closely packed measurements, but degrades as the separation angles between observations grow. The exact cross-over point where one algorithm is superior to the other is an area of active research, and can vary from 6 degrees to 16 degrees depending on the properties of the orbit. For the top level functions, GMAT uses the more conservative 6 degrees as the value for sorting, selecting Gibbs if either separation angle exceeds this value and selecting Herrick-Gibbs if both are equal to or fall under the value. For more information about the Gibbs and Herrick-Gibbs methods as well as algorithms to implement them, please consult the first reference. For more information on the separation angle selection criteria, consult the second reference.

## Examples

Solve for the velocity from three closely-spaced observations and write out the result and the log.

```
Create Array R1[1,3] R2[1,3] R3[1,3] V2[1,3];
Create Variable T1 T2 T3;
Create String Log;

BeginMissionSequence;
%Observation 1
T1 = 0.0;
R1(1) = -6775.105759552147;
R1(2) = -2396.512640028521;
R1(3) = 3.17775066150299;

%Observation 2
T2 = 1.0/86400;
R2(1) = -6775.468602539761;
R2(2) = -2395.440370930451;
R2(3) = 10.54007909680081;

%Observation 3
T3 = 2.0/86400;
R3(1) = -6775.824159536231;
R3(2) = -2394.365525912181;
R3(3) = 17.90239606811341;

[V2,Log] = Python.IODFunctions.ThreePositionIOD(R1,R2,R3,T1,T2,T3);
Write V2
Write Log
```

Solve for the velocity from three widely-spaced observations and write out the result and the log. These observations occur with 8 minutes between measurements.

```
Create Array R1[1,3] R2[1,3] R3[1,3] V2[1,3];
Create Variable T1 T2 T3;
```

```
Create String Log;

BeginMissionSequence;
%Observation 1
T1 = 0.0;
R1(1) = -6775.105759552147;
R1(2) = -2396.512640028521;
R1(3) = 3.17775066150299;

%Observation 2
T2 = 480.0/86400;
R2(1) = -6121.441100575906;
R2(2) = -1612.515594798989;
R2(3) = 3392.148414170606;

%Observation 3
T3 = 960.0/86400;
R3(1) = -3981.62429448081;
R3(2) = -437.0235397882232;
R3(3) = 5955.582570970698;

[V2,Log] = Python.IODFunctions.ThreePositionIOD(R1,R2,R3,T1,T2,T3);
Write V2
Write Log
```

## References

1. Vallado, David A., and Wayne D. McClain. Fundamentals of Astrodynamics and Applications, Fourth Edition. Microcosm Press, 2013.
2. Kaushik, Arvind Shankar, *A Statistical Comparison Between Gibbs and Herrick-Gibbs Orbit Determination Methods*. Master's thesis, Texas A & M University, 2016.



# Programming

This chapter contains documentation for Resources and Commands related to script programming and customization functionality.

## Resources

## Array

A user-defined one- or two-dimensional array variable

### Description

The **Array** resource is used to store a one- or two-dimensional set of numeric values, such as a vector or a matrix. Individual elements of an array can be used in place of a literal numeric value in most commands.

Arrays must be dimensioned at the time of creation, using the following syntax:

```
Create Array anArray[rows, columns]
```

If only one dimension is specified, a row vector is created.

Array values are initialized to zero at creation. Values can be assigned individually using literal numeric values or (in the Mission Sequence) **Variable** resources, **Array** resource elements, resource parameters of numeric type, or **Equation** commands that evaluate to scalar numeric values.

```
anArray(row, column) = value
```

If only one dimension is specified during assignment, *row* is assumed to be 1.

An **Array** can also be assigned as a whole in the Mission Sequence using another **Array** resource or an **Equation** that evaluates to an array. Both sides of the assignment must be identically-sized.

```
anArray = array expression
```

See Also: [String](#), [Variable](#)

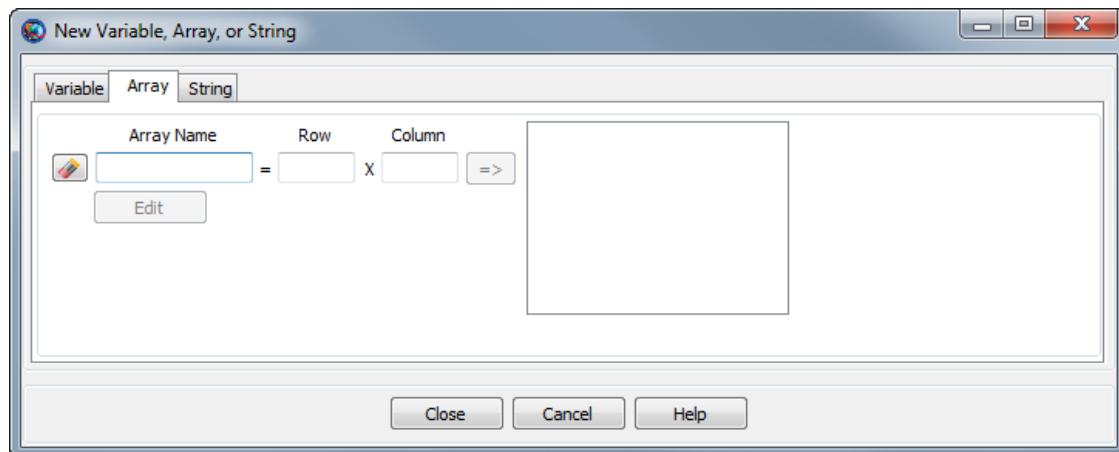
### Fields

The **Array** resource has no fields; instead, the resource elements themselves are set to the desired values.

Field	Description
<i>rows</i>	The number of rows (during creation), or the row being addressed. The total size of the array is <i>rows</i> × <i>columns</i> . This field is required.  <b>Data Type</b> Integer <b>Allowed Values</b> Integer >= 1 <b>Access</b> set <b>Default Value</b> 1 <b>Units</b> N/A <b>Interfaces</b> GUI, script

Field	Description
<code>columns</code>	The number of columns (during creation), or the column being addressed. The total size of the array is <code>rows × columns</code> . This field is required.
	<p><b>Data Type</b> Integer</p> <p><b>Allowed Values</b> Integer <math>\geq 1</math></p> <p><b>Access</b> set</p> <p><b>Default Value</b> 1</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>
<code>value</code>	The value of the array element being addressed.
	<p><b>Data Type</b> Real number</p> <p><b>Allowed Values</b> <math>-\# &lt; \text{Real} &lt; \#</math></p> <p><b>Access</b> set, get</p> <p><b>Default Value</b> 0.0</p> <p><b>Units</b> N/A</p> <p><b>Interfaces</b> GUI, script</p>

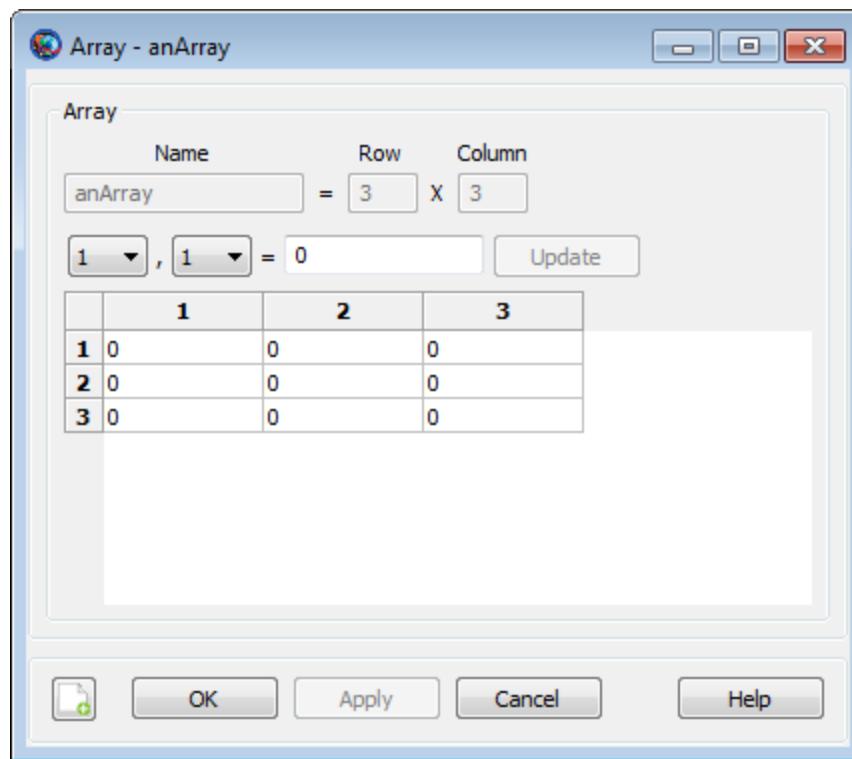
## GUI



The GMAT GUI lets you create multiple **Array** resources at once without leaving the window. To create an **Array**:

1. In the **Array Name** box, type the desired name of the array.
2. In the **Row** and **Column** boxes, type the desired number of rows and columns, respectively. To create a one-dimensional array, set **Row** to 1.
3. Click the **=>** button to create the array and add it to the list on the right.
4. Click the **Edit** button to edit the array element values.

You can create multiple **Array** resources this way. To edit an existing array in this window, click it in the list on the right. Click **Edit** to change the element values, or edit the **Row** and **Column** values. You must click the **=>** button again to save changes to the size of the array.



You can edit the elements of an **Array** by either clicking **Edit** while creating an array, or by double-clicking the array in the resources tree in the main GMAT window. The edit window allows you to change array elements individually using the row and column lists and clicking **Update**, or by directly entering data in the table in the lower portion of the window. The data table recognizes a few different mouse and keyboard controls:

- Click a cell once to select it
- Click a selected cell again, double-click an unselected cell, or press F2 to edit the value
- Use the arrow keys to select adjacent cells
- Click the corner header cell to select the entire table
- Drag the column and row separators to adjust the row height or column width
- Double-click the row or column separators in the heading to auto-size the row height or column width

## Remarks

GMAT **Array** resources store an arbitrary number of numeric values organized into one or two dimensions. Internally, the elements are stored as double-precision real numbers, regardless of whether or not fractional portions are present. **Array** resources can be created and assigned using one or two dimension specifiers. This example shows the behavior in each case:

```
% a is a row vector with 3 elements
Create Array a[3]
a(1) = 1    % same as a(1, 1) = 1
a(2) = 2    % same as a(1, 2) = 2
```

```
a(3) = 3      % same as a(1, 3) = 3

% b is a matrix with 5 rows and 3 columns
Create Array b[5, 3]
b(1) = 1      % same as b(1, 1) = 1
b(2) = 2      % same as b(1, 2) = 2
b(3) = 3      % same as b(1, 3) = 3
b(4) = 4      % error: b(1, 4) does not exist
b(4, 3) = 4 % row 4, column 3
```

## Examples

Creating and reporting an array:

```
Create ReportFile aReport
Create Variable i idx1 idx2
Create Array fib[9]

BeginMissionSequence

fib(1) = 0
fib(2) = 1
For i=3:9
    idx1 = i-1
    idx2 = i-2
    fib(i) = fib(idx1) + fib(idx2)
EndFor
Report aReport fib
```

## GMATFunction

Declaration of a GMAT function

### Description

The **GmatFunction** resource declares a new GMAT function or can be used to load-in a pre-existing GMAT function. This function can be called in the Mission Sequence through GMAT's **CallGmatFunction** command. See the **CallGmatFunction** reference for details.

Through this GMAT function, data can be passed in the function as input and received as output. Data that is passed into the function as input or received from the function as output can also be declared as global. See the **Global** reference for more details. See also the **Remarks** and **Examples** sections for detailed discussion on GMAT functions and how to use them.

See Also: [CallGmatFunction](#), [Global](#)

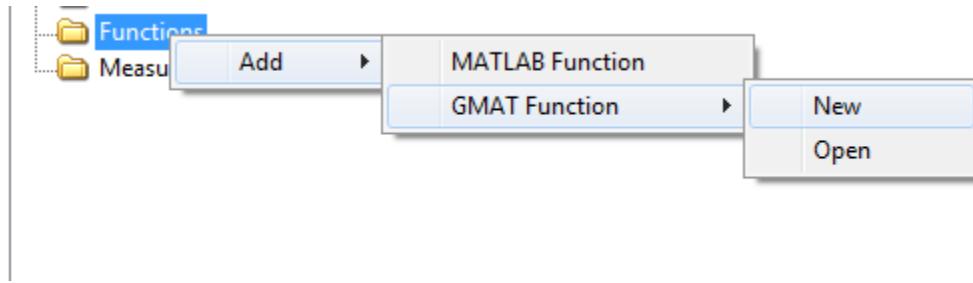
### Fields

Field	Description
<b>Function-Path</b>	Allows the user to define a valid function path. In the GUI, the <b>Function-Path</b> field is activated after editing the function and then clicking on the function's Save As button. The path of the function can be defined as either absolute or relative.
<b>Data Type</b>	String
<b>Allowed Values</b>	Valid file path. The path can be either absolute or relative. In the Script mode, if this field is not used at all, then default location of functions is GMAT's ...\\user-functions\\gmat\\ directory
<b>Access</b>	set
<b>Default Value</b>	User-defined
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

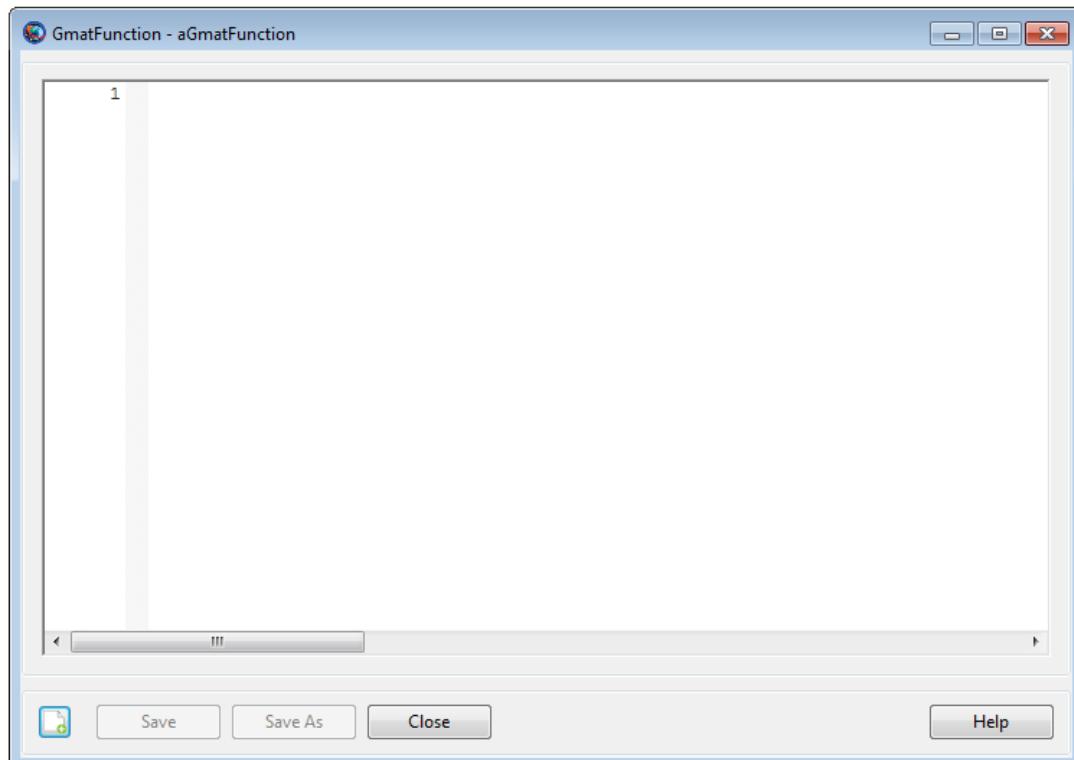
### GUI

In the GUI, a new **GmatFunction** resource is created as follows:

1. In the **Resources Tree**, right click on the **Functions** folder, select **Add -> GMAT Function -> New**
2. In the **New GMAT function** dialog box, type the desired name of your function.



The **GmatFunction** resource's GUI window is very simple. When a new GMAT function is created through the GUI, the **FunctionPath** field is defined by first editing the function and then clicking on the **Save As** button. This lets you graphically define the path.



## Remarks

### Input and Output Arguments

Arguments can be passed into a GMAT function as input and returned from a GMAT function as output. You can pass GMAT objects as input to a function and receive entire objects as output from the function. If a given GMAT object is not declared as global in both the main script and in the function, then all objects that are passed into or received as output from the function are considered to be local to that function and the main script.

In GMAT, you can use **CallGmatFunction** command to pass GMAT objects as input arguments and receive objects as output from the function. In general, any objects in GMAT's **Resources** tree can be passed as input to the function. Most common objects that a user is likely to pass as input to the function are objects that are related to prop-

agating a spacecraft, performing differential correction (DC) in a targeter, implementing optimization in an optimizer loop, user-defined variables/arrays/strings or subscribers that are used to draw or report parameters. Note that similar to most coding languages, if a resource of the same name of an input is created within the function, that object is freshly initialized and the input object's parameters are ignored. Most common objects that are likely to be passed as output arguments from the function maybe a **Spacecraft** resource or user-defined objects such as **Variables, Arrays or Strings**.

Below is a list of allowed objects that can be passed as input and output to and from the function. Also see [Examples](#) section that show two distinct methods in two separate examples of how to pass local objects as inputs to the function, perform an operation inside the function, then receive local objects as outputs from the function.

The input arguments can be any of the following types:

- Any resource objects (e.g. **Spacecraft**, **Propagator**, **DC**, **Optimizers**, **Impulsive or FiniteBurns**)
- resource parameter of real number type (e.g. **Spacecraft.X**)
- resource parameter of string type (e.g. **Spacecraft.UTCGregorian**)
- **Array**, **String**, or **Variable** resource

The output arguments can be any of the following types:

- Resource object like **Spacecraft**
- resource parameter of real number type (e.g. **Spacecraft.X**)
- resource parameter of string type (e.g. **Spacecraft.UTCGregorian**)
- **Array**, **String**, or **Variable** resource

## Global Spacecraft, Subscribers and Other Objects

In GMAT, objects can be declared as global by using the **Global** command in the **Mission** tree. All default objects present in GMAT's Resources tree or any new user-defined resources can be declared as global. Currently any default or new user-defined coordinate systems, **SolarSystemBarycenter**, **SolarSystem**, default or new user-defined propagators are automatic global objects and not needed to be specifically declared as global via the **Global** command.

Often times, there will be cases when you will propagate a spacecraft both in the main script and from inside the GMAT function. Additionally users may want to report and/or plot spacecraft's trajectory, parameters, variables, arrays and strings to same subscribers both from the main script and/or solely from inside the function. If you want to report and plot continuous set of data to any of the five subscribers (i.e. **OrbitView**, **GroundTrackPlot**, **XYPlot**, **ReportFile**, **EphemerisFile**), then always declare your **Spacecraft** object and subscriber objects as global both in the main script and inside the function. Abiding by this rule draws plots, reports and ephemeris files correctly and flow of data will be reported continuously to all the subscribers.

In general, a good scripting practice is that objects that have been declared global don't need to be sent as input or output arguments to and from the function. For example, if **Spacecraft**, all subscriber objects or objects that are used to perform propagation,

targeting or optimization have already been declared global, then you don't have to be redundant and send those global objects again as input or receive them as output from the function. Having said that, GMAT does allow globally declared objects such as **Spacecraft**, global variables/arrays/strings to be passed as input/output argument to and from the function. Globally declared objects such as spacecraft, variables/arrays/strings can be plotted or reported interchangeably both from the main script and inside the function to globally declared subscribers.

See [Examples](#) section that shows three examples of how to declare spacecraft, all five subscribers and variables/arrays as global in both the main script and inside the function. As you run the examples, notice that the flow of data reported to all five subscribers is continuous.

### Using GMAT Functions in an Assignment Command

GMAT allows you to use simple GMAT functions in the main script in an assignment command mode. Below example snippet shows how to use simple GMAT functions in mathematical statements. Note that in the below snippet, function path to GMAT function's **FunctionPath** field was not specifically defined. Whenever the **FunctionPath** field is not defined in the script mode, then preferred default path of these functions is in the following directory where GMAT was installed: ..\GMAT\userfunctions\gmat\

```
%%Using a GMAT function in a mathematical statement

Create ReportFile rf

Create GmatFunction Math_GmatPi Math_GmatSin
Create GmatFunction Math_GmatAtan2 Math_GmatInv

Create Variable x y z pi in
Create Array A[2,2] B[2,2]

BeginMissionSequence

A(1,1) = 1
A(1,2) = 3
A(2,1) = 4
A(2,2) = 2

% no inputs into the function
pi = Math_GmatPi * 2
Report rf pi

% one input into the function
[pi] = Math_GmatPi
in = pi/4
x = Math_GmatSin(in) - 15
Report rf x

% two inputs:
```

```
in = 0.5
y = Math_GmatAtan2(in, x)^2
Report rf y

% array input/output:
B = Math_GmatInv(A)'
Report rf B

%%%% Math_GmatPi Function begins below:

function [pi] = Math_GmatPi
Create Variable pi
BeginMissionSequence
pi = acos(-1)

%%%% Math_GmatSin Function begins below:

function [y] = Math_GmatSin(x)
Create Variable y
BeginMissionSequence
y = sin(x)

%%%% Math_GmatAtan2 Function begins below:

function [z] = Math_GmatAtan2(y, x)
Create Variable z
BeginMissionSequence
z = atan2(y, x)

%%%% Math_GmatInv Function begins below:

function [B] = Math_GmatInv(A)
Create Array B[2,2]
BeginMissionSequence
B = inv(A)
```

## Examples

Method 1 of how to pass local objects into the function and receiving local objects as the output from the function. Pass local spacecraft, other local objects into the function, perform hohmann targeting inside the function, receive updated local spacecraft, local variables as output and finally report them to local subscribers in the main script. Since the spacecraft and all five subscribers were only local objects (i.e. not declared as global), hence notice that all subscribers begin to draw and report data once the updated spacecraft is returned back and propagated in the main script.

```
Create Spacecraft aSat

Create ForceModel aFM
aFM.CentralBody = Earth
aFM.PointMasses = {Earth}

Create Propagator aProp
aProp.FM = aFM

Create ImpulsiveBurn TOI
Create ImpulsiveBurn GOI

Create DifferentialCorrector DC

Create OrbitView anOrbitView
anOrbitView.SolverIterations = Current
anOrbitView.Add = {aSat, Earth}

Create GroundTrackPlot GroundTrackPlot1
GroundTrackPlot1.Add = {aSat}
GroundTrackPlot1.CentralBody = Earth

Create XYPlot XYPlot1
XYPlot1.XVariable = aSat.ElapsedDays
XYPlot1.YVariables = {aSat.EarthMJ2000Eq.X}

Create ReportFile rf
rf.Add = {aSat.UTCGregorian, aSat.EarthMJ2000Eq.X, ...
aSat.EarthMJ2000Eq.Y, aSat.EarthMJ2000Eq.Z, ...
aSat.EarthMJ2000Eq.VX, aSat.EarthMJ2000Eq.VY, aSat.EarthMJ2000Eq.VZ}

Create ReportFile rf2
rf2.WriteHeaders = false

Create EphemerisFile anEphemerisFile
GMAT anEphemerisFile.Spacecraft = aSat

Create GmatFunction Targeter_Inside_Function
Targeter_Inside_Function.FunctionPath = ...
'C:\Users\rqureshi\Desktop\Targeter_Inside_Function.gmf'

Create Variable DV1 DV2

BeginMissionSequence;

% Pass local S/C, local objects into function and receive back
% updated local S/C and local variables:
'Hohmann Transfer'[DV1, DV2, aSat] ...
= Targeter_Inside_Function(aSat, aProp, TOI, GOI, DC)
```

```

TOI.Element1 = DV1
GOI.Element1 = DV2

% Report updated S/C:
Report rf2 aSat.UTCModJulian aSat.UTCGregorian aSat.X aSat.Y aSat.Z ...
aSat.VX aSat.VY aSat.VZ TOI.Element1 GOI.Element1

Propagate 'Prop one day' aProp(aSat) {aSat.ElapsedDays = 1.0}

Report rf2 aSat.UTCModJulian aSat.UTCGregorian aSat.X aSat.Y aSat.Z ...
aSat.VX aSat.VY aSat.VZ

%%%%%%% Function begins below:

function [dv1, dv2, aSat] = Targeter_Inside_Function(aSat, aProp, TOI, GOI, DC)

% Create local variables:
Create Variable dv1 dv2

BeginMissionSequence

Propagate 'Propagate to Periapsis' aProp(aSat) {aSat.Earth.Periapsis}

Target 'Hohmann Transfer' DC {SolveMode = Solve, ExitMode = SaveAndContinue}
    Vary 'Vary TOI' DC(TOI.Element1 = 1.0, {Perturbation = 0.0001, ...
    Lower = 0.0, Upper = 3.14159, MaxStep = 0.5})
        Maneuver 'Perform TOI' TOI(aSat)
        Propagate 'Prop to Apoapsis' aProp(aSat) {aSat.Earth.Apoapsis}
        Achieve 'Achieve RMAG = 42165' DC(aSat.Earth.RMAG = 42165)
        Vary 'Vary GOI' DC(GOI.Element1 = 1.0, {Perturbation = 0.0001, ...
        Lower = 0.0, Upper = 3.14159, MaxStep = 0.2})
            Maneuver 'Perform GOI' GOI(aSat)
            Achieve 'Achieve ECC = 0.005' DC(aSat.Earth.ECC = 0.005)
EndTarget

dv1 = TOI.Element1
dv2 = GOI.Element1

```

Method 2 of how to pass local objects into the function and receiving local objects as the output from the function. In this method, notice that we now only pass local spacecraft as input to the function. Instead of passing additional local objects into the function, we now create those required local objects inside the function itself. Similar to method 1, we perform hohmann targeting inside the function, then send updated spacecraft and variables back to the main script as output from the function. Finally updated spacecraft is propagated for one day in main script and reported by all subscribers. Since the spacecraft and all five subscribers were only local objects (i.e. not declared as global), hence

notice that all subscribers begin to draw and report data once the updated spacecraft begins propagation in the main script.

```
Create Spacecraft aSat

Create ForceModel aFM
aFM.CentralBody = Earth
aFM.PointMasses = {Earth}

Create Propagator aProp
aProp.FM = aFM

Create ImpulsiveBurn TOI
Create ImpulsiveBurn GOI

Create DifferentialCorrector DC

Create OrbitView anOrbitView
anOrbitView.SolverIterations = Current
anOrbitView.Add = {aSat, Earth}

Create GroundTrackPlot GroundTrackPlot1
GroundTrackPlot1.Add = {aSat}
GroundTrackPlot1.CentralBody = Earth

Create XYPlot XYPlot1
XYPlot1.XVariable = aSat.ElapsedDays
XYPlot1.YVariables = {aSat.EarthMJ2000Eq.X}

Create ReportFile rf
rf.Add = {aSat.UTCGregorian, aSat.EarthMJ2000Eq.X, ...
aSat.EarthMJ2000Eq.Y, aSat.EarthMJ2000Eq.Z, ...
aSat.EarthMJ2000Eq.VX, aSat.EarthMJ2000Eq.VY, aSat.EarthMJ2000Eq.VZ}

Create ReportFile rf2
rf2.WriteHeaders = false

Create EphemerisFile anEphemerisFile
GMAT anEphemerisFile.Spacecraft = aSat

Create GmatFunction Targeter_Inside_Function
Targeter_Inside_Function.FunctionPath = ...
'C:\Users\rqureshi\Desktop\Targeter_Inside_Function.gmf'

Create Variable DV1 DV2

BeginMissionSequence;

% Pass only local S/C into the function and receive back
```

```
% updated local S/C and local variables:  
'Hohmann Transfer'[DV1, DV2, aSat] ...  
= Targeter_Inside_Function(aSat)  
  
TOI.Element1 = DV1  
GOI.Element1 = DV2  
  
% Report updated S/C:  
Report rf2 aSat.UTCModJulian aSat.UTCGregorian aSat.X aSat.Y aSat.Z ...  
aSat.VX aSat.VY aSat.VZ TOI.Element1 GOI.Element1  
  
Propagate 'Prop one day' aProp(aSat) {aSat.ElapsedDays = 1.0}  
  
Report rf2 aSat.UTCModJulian aSat.UTCGregorian aSat.X aSat.Y aSat.Z ...  
aSat.VX aSat.VY aSat.VZ  
  
%%%%%%% Function begins below:  
  
function [dv1, dv2, aSat] = Targeter_Inside_Function(aSat)  
  
% Create local objects that are used to do targeting:  
Create ForceModel aFM  
aFM.CentralBody = Earth  
aFM.PointMasses = {Earth}  
  
Create Propagator aProp  
aProp.FM = aFM  
  
Create ImpulsiveBurn TOI  
Create ImpulsiveBurn GOI  
  
Create DifferentialCorrector DC  
  
% Create local variables:  
Create Variable dv1 dv2  
  
BeginMissionSequence  
  
Propagate 'Propagate to Periapsis' aProp(aSat) {aSat.Earth.Periapsis}  
  
Target 'Hohmann Transfer' DC {SolveMode = Solve, ExitMode = SaveAndContinue}  
    Vary 'Vary TOI' DC(TOI.Element1 = 1.0, {Perturbation = 0.0001, ...  
    Lower = 0.0, Upper = 3.14159, MaxStep = 0.5})  
        Maneuver 'Perform TOI' TOI(aSat)  
        Propagate 'Prop to Apoapsis' aProp(aSat) {aSat.Earth.Apoapsis}  
        Achieve 'Achieve RMAG = 42165' DC(aSat.Earth.RMAG = 42165)  
        Vary 'Vary GOI' DC(GOI.Element1 = 1.0, {Perturbation = 0.0001, ...  
        Lower = 0.0, Upper = 3.14159, MaxStep = 0.2})
```

```
Maneuver 'Perform GOI' GOI(aSat)
Achieve 'Achieve ECC = 0.005' DC(aSat.Earth.ECC = 0.005)
EndTarget

dv1 = TOI.Element1
dv2 = GOI.Element1
```

In this example, we declare spacecraft, all subscribers and other objects as global in both main script and in function. Propagate inside the function, perform targeting inside function, and report local variables, global spacecraft state and global variable (DV1, DV2) to global reportfile. Next, we continue to propagate in the main script and continue to report spacecraft state to global reportfile in the main script. After running this example, pay special attention to all subscribers. Note that spacecraft trajectory is plotted continuously on three plotting subscribers and data is reported continuously as well to both reportfiles and ephemerisfile.

```
Create Spacecraft aSat

Create ForceModel aFM
aFM.CentralBody = Earth
aFM.PointMasses = {Earth}

Create Propagator aProp
aProp.FM = aFM

Create ImpulsiveBurn TOI
Create ImpulsiveBurn GOI

Create DifferentialCorrector DC

Create OrbitView anOrbitView
anOrbitView.SolverIterations = Current
anOrbitView.Add = {aSat, Earth}

Create GroundTrackPlot GroundTrackPlot1
GroundTrackPlot1.Add = {aSat}
GroundTrackPlot1.CentralBody = Earth

Create XYPlot XYPlot1
XYPlot1.XVariable = aSat.ElapsedDays
XYPlot1.YVariables = {aSat.EarthMJ2000Eq.X}

Create ReportFile rf
rf.Add = {aSat.UTCGregorian, aSat.EarthMJ2000Eq.X, ...
          aSat.EarthMJ2000Eq.Y, aSat.EarthMJ2000Eq.Z, ...
          aSat.EarthMJ2000Eq.VX, aSat.EarthMJ2000Eq.VY, aSat.EarthMJ2000Eq.VZ}

Create ReportFile rf2
rf2.WriteHeaders = false
```

```
Create EphemerisFile anEphemerisFile
GMAT anEphemerisFile.Spacecraft = aSat

Create GmatFunction Global_Subscribers
Global_Subscribers.FunctionPath = ...
'C:\Users\rqureshi\Desktop\Global_Subscribers.gmf'

Create Variable DV1 DV2

BeginMissionSequence;

% Declare aSat, Subscribers and other objects as Global:
Global aSat
Global aFM TOI GOI DC %aProp is global by default.
Global anOrbitView GroundTrackPlot1 XYPlot1 rf rf2 anEphemerisFile
Global DV1 DV2

Report rf2 aSat.UTCGregorian aSat.UTCModJulian aSat.X aSat.Y aSat.Z ...
aSat.VX aSat.VY aSat.VZ

% Call function:
Global_Subscribers()

% Report updated Global S/C, TOI and GOI:
Report rf2 aSat.UTCGregorian aSat.UTCModJulian aSat.X aSat.Y aSat.Z ...
aSat.VX aSat.VY aSat.VZ TOI.Element1 GOI.Element1

Propagate 'Prop one more day' aProp(aSat) {aSat.ElapsedDays = 1.0}

Report rf2 aSat.UTCGregorian aSat.UTCModJulian aSat.X aSat.Y aSat.Z ...
aSat.VX aSat.VY aSat.VZ

% Report Global DV1 and DV2 to global 'rf2' in main script:
Report rf2 DV1 DV2

%%%%%%% Function begins below:

function Global_Subscribers()

% Create Local variables, string:
Create Variable sc_epoch x y z vx vy vz dv1 dv2;
Create String utc_epoch

Global aSat
Global aFM TOI GOI DC
Global anOrbitView GroundTrackPlot1 XYPlot1 rf rf2 anEphemerisFile
Global DV1 DV2
```

```

BeginMissionSequence

Propagate 'Propagate to Periapsis' aProp(aSat) {aSat.Earth.Periapsis}

Target 'Hohmann Transfer' DC {SolveMode = Solve, ExitMode = SaveAndContinue}
    Vary 'Vary TOI' DC(TOI.Element1 = 1.0, {Perturbation = 0.0001, ...
    Lower = 0.0, Upper = 3.14159, MaxStep = 0.5})
        Maneuver 'Perform TOI' TOI(aSat)
        Propagate 'Prop to Apoapsis' aProp(aSat) {aSat.Earth.Apoapsis}
        Achieve 'Achieve RMAG = 42165' DC(aSat.Earth.RMAG = 42165)
        Vary 'Vary GOI' DC(GOI.Element1 = 1.0, {Perturbation = 0.0001, ...
        Lower = 0.0, Upper = 3.14159, MaxStep = 0.2})
            Maneuver 'Perform GOI' GOI(aSat)
            Achieve 'Achieve ECC = 0.005' DC(aSat.Earth.ECC = 0.005)
EndTarget

sc_epoch = aSat.UTCModJulian
utc_epoch = aSat.UTCGregorian
x = aSat.X
y = aSat.Y
z = aSat.Z
vx = aSat.VX
vy = aSat.VY
vz = aSat.VZ
dv1 = TOI.Element1
dv2 = GOI.Element1

% Report local variables/strings to Global reportfile 'rf2':
Report rf2 utc_epoch sc_epoch x y z vx vy vz dv1 dv2

Propagate 'Prop one Day Inside Function' aProp(aSat) {aSat.ElapsedDays = 1.0}

% Report Global aSat state to global 'rf2':
Report rf2 aSat.UTCGregorian aSat.UTCModJulian aSat.X aSat.Y aSat.Z aSat.VX ...
aSat.VY aSat.VZ TOI.Element1 GOI.Element1

% Report Global variables DV1 and DV2 to global 'rf2' in main script:
DV1 = TOI.Element1
DV2 = TOI.Element1

```

Just as previous example, we declare spacecraft, all subscribers and other objects as global in both main script and in function. This time GMAT function is nested inside control logic statements like While and If-EndIf. LEO station-keeping is performed inside the function. As the example will be running, pay special attention to all subscribers. Note that spacecraft trajectory is plotted continuously on three plotting subscribers and data is reported continuously as well to both reportfiles and ephemerisfile.

```
Create Spacecraft LEOsat
LEOsat.DisplayStateType = Keplerian
LEOsat.SMA = 6733.989999999996
LEOsat.ECC = 0.000432999999984123
LEOsat.INC = 34.98399999999998
LEOsat.RAAN = 274.742
LEOsat.AOP = 287.8049999999732
LEOsat.TA = 294.0690000000269

Create ForceModel LEOprop_ForceModel
LEOprop_ForceModel.CentralBody = Earth
LEOprop_ForceModel.PrimaryBodies = {Earth}
LEOprop_ForceModel.PointMasses = {Luna, Sun}
LEOprop_ForceModel.SRP = On
LEOprop_ForceModel.GravityField.Earth.Degree = 4
LEOprop_ForceModel.GravityField.Earth.Order = 4
LEOprop_ForceModel.GravityField.Earth.PotentialFile = 'JGM2.cof'
LEOprop_ForceModel.Drag.AtmosphereModel = JacchiaRoberts
LEOprop_ForceModel.Drag.F107 = 150
LEOprop_ForceModel.Drag.F107A = 150

Create Propagator LEOprop
GMAT LEOprop.FM = LEOprop_ForceModel

Create ImpulsiveBurn TCM1
Create ImpulsiveBurn TCM2

Create DifferentialCorrector DC

Create OrbitView DefaultOrbitView
DefaultOrbitView.Add = {LEOsat, Earth}

Create XYPlot XYPlot1
GMAT XYPlot1.XVariable = LEOsat.A1ModJulian
GMAT XYPlot1.YVariables = {LEOsat.Earth.Altitude}

Create GroundTrackPlot GroundTrackPlot1
GroundTrackPlot1.Add = {LEOsat}

Create ReportFile rf

Create ReportFile rf2
rf2.Add = {LEOsat.UTCModJulian, LEOsat.Earth.Altitude, ...
LEOsat.Earth.RMAG, LEOsat.Earth.ECC}

Create EphemerisFile anEphemerisFile
GMAT anEphemerisFile.Spacecraft = LEOsat

Create GmatFunction TargetLEOSTationKeeping
```

```
TargetLEOStationKeeping.FunctionPath = ...
'C:\Users\rqureshi\Desktop\TargetLEOStationKeeping.gmf'

Create Variable desiredRMAG desiredECC X Y Z

BeginMissionSequence

desiredRMAG = 6737
desiredECC = 0.00005

% Declare LEOsat, Subscribers and other objects as Global:
Global LEOsat
Global DC TCM1 TCM2 LEOProp_ForceModel
Global DefaultOrbitView XYPlot1 GroundTrackPlot1
Global rf rf2 anEphemerisFile

While 'While ElapsedDays < 10' LEOsat.ElapsedDays < 10.0

Propagate 'Prop One Step' LEOProp(LEOsat)

If 'If Alt < Threshold' LEOsat.Earth.Altitude < 342

Propagate 'Prop To Periapsis' LEOProp(LEOsat) {LEOsat.Periapsis}

% Call function to implement SK. Pass local variables as input:
TargetLEOStationKeeping(desiredRMAG,desiredECC)

EndIf

EndWhile

Report rf LEOsat.UTCGregorian LEOsat.UTCModJulian LEOsat.X ...
LEOsat.Y LEOsat.Z LEOsat.Earth.Altitude LEOsat.Earth.ECC

%%%%%%% Function begins below:

function TargetLEOStationKeeping(desiredRMAG,desiredECC)

BeginMissionSequence

Global LEOsat
Global DC TCM1 TCM2 LEOProp_ForceModel
Global DefaultOrbitView XYPlot1 GroundTrackPlot1
Global rf rf2 anEphemerisFile

Target 'Raise Orbit' DC {SolveMode = Solve, ExitMode = DiscardAndContinue}
Vary 'Vary TCM1.V' DC(TCM1.Element1 = 0.002, {Perturbation = 0.0001, ...
Lower = -9.999999e300, Upper = 9.999999e300, MaxStep = 0.05})
```

```

Maneuver 'Apply TCM1' TCM1(LEOsat);
Propagate 'Prop to Apoapsis' LE0prop(LEOsat) {LEOsat.Apoapsis}
Achieve 'Achieve RMAG' DC(LEOsat.RMAG = desiredRMAG, {Tolerance = 0.1})
Vary 'Vary TCM2.V' DC(TCM2.Element1 = 1e-005, {Perturbation = 0.00005, ...
Lower = -9.999999e300, Upper = 9.999999e300, MaxStep = 0.05})
Maneuver 'Apply TCM2' TCM2(LEOsat);
Achieve 'Achieve ECC' DC(LEOsat.Earth.ECC = desiredECC)
EndTarget

```

In this example, all arrays, string and a single subscriber are declared global both in main script and inside function. Note that global arrays are passed into the function, cross products are computed and computed global arrays (v5, v6) are sent back to the main script. Also note that global arrays, string are reported to global report file in both main script and inside the function.

```

Create ReportFile rf
rf.WriteHeader = false

Create GmatFunction cross3by1;
GMAT cross3by1.FunctionPath = ...
'C:\Users\rqureshi\Desktop\cross3by1.gmf'

Create Array v1[3,1] v2[3,1] v3[3,1] ...
v4[3,1] v5[3,1] v6[3,1]
Create String tempstring

BeginMissionSequence

% Declare Arrays, string and subscriber as global:
Global v1 v2 v3 v4 v5 v6 tempstring rf

v1(1,1) = 1
v1(2,1) = 2
v1(3,1) = 3
v2(1,1) = 4
v2(2,1) = 5
v2(3,1) = 6
v3(1,1) = 8
v3(2,1) = 9
v3(3,1) = 10
v4(1,1) = 10
v4(2,1) = 11
v4(3,1) = 12

% Report global arrays/string to global 'rf':
Report rf v1 v2 v3 v4
tempstring = '-----'
Report rf tempstring

```

```
% Call function. Pass in Global arrays
% Receive global arrays in return:
GMAT [v5, v6] = cross3by1(v1, v2, v3, v4)

% Report global output to global 'rf':
Report rf v5 v6

tempstring = '-----'
Report rf tempstring

%%%%%%% Function begins below:

function [v5, v6] = cross3by1(vector1,vector2, vector3, vector4)

BeginMissionSequence

Global v1 v2 v3 v4 v5 v6 tempstring rf

v5(1,1) = vector1(2,1)*vector2(3,1) - vector1(3,1)*vector2(2,1)
v5(2,1) = -(vector1(1,1)*vector2(3,1) - vector1(3,1)*vector2(1,1))
v5(3,1) = vector1(1,1)*vector2(2,1) - vector1(2,1)*vector2(1,1)

v6(1,1) = vector3(2,1)*vector4(3,1) - vector3(3,1)*vector4(2,1)
v6(2,1) = -(vector3(1,1)*vector4(3,1) - vector3(3,1)*vector4(1,1))
v6(3,1) = vector3(1,1)*vector4(2,1) - vector3(2,1)*vector4(1,1)

v1 = v1 + 1
v2 = v2*2
v3 = v3/2
v4 = v4 + v4

% Continue to report global arrays/string to global 'rf':
Report rf v1 v2 v3 v4
tempstring = '-----'
Report rf tempstring
```

## MatlabFunction

Declaration of an external MATLAB function

### Description

The **MatlabFunction** resource declares to GMAT that the name given refers to an existing external function in the MATLAB language. This function can be called in the Mission Sequence like a built-in function, with some limitations. See the [CallMatlabFunction](#) reference for details. Both user-created functions and built-in functions (like cos or path) are supported.

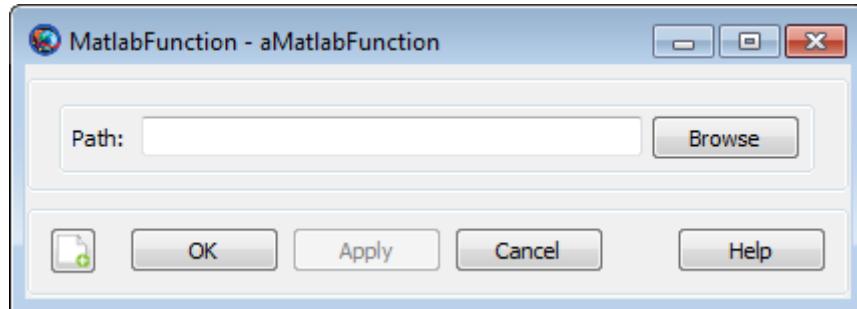
GMAT supports passing data to and from MATLAB through the function. It requires that a supported and properly configured version of MATLAB exist on the system. See the [MATLAB Interface](#) documentation for general details on the interface.

See Also: [CallMatlabFunction](#), [MATLAB Interface](#)

### Fields

Field	Description
<b>Function-Path</b>	Paths to add to the MATLAB search path when the associated function is called. Separate multiple paths with semicolons (on Windows) or colons (on other platforms).
<b>Data Type</b>	String
<b>Allowed Values</b>	Valid file path(s)
<b>Access</b>	set, get
<b>Default Value</b>	MATLAB_FUNCTION_PATH properties in the startup file
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

### GUI



The **MatlabFunction** GUI window is very simple; it has a single file input box for the function path, and a Browse button that lets you graphically select the path.

## Remarks

### Search Path

When a function declared as a **MatlabFunction** is called, GMAT starts MATLAB in the background with a custom, configurable search path. MATLAB then searches for the named function in this search path. The search is case-sensitive, so the name of the function name and the **MatlabFunction** resource must be identical.

The search path consists of the following components, in order:

1. **FunctionPath** field of the associated **MatlabFunction** resource (default: empty)
2. MATLAB\_FUNCTION\_PATH entries in the GMAT startup file (default: GMAT\userfunctions\matlab)
3. MATLAB search path (returned by the MATLAB path() function)

If multiple MATLAB functions are called within a run, the **FunctionPath** fields for each are prepended to the search path at the time of the function call.

Multiple paths can be combined in the **FunctionPath** field by separating the paths with a semicolon (on Windows) or a colon (on macOS and Linux).

### Working Directory

When MATLAB starts in the background, its working directory is set to the GMAT bin directory.

## Examples

Call a simple built-in MATLAB function:

```
Create MatlabFunction sinh  
Create Variable x y  
  
BeginMissionSequence  
  
x = 1  
[y] = sinh(x)
```

Call an external custom MATLAB function:

```
Create Spacecraft aSat  
Create ImpulsiveBurn aBurn  
Create Propagator aProp  
  
Create MatlabFunction CalcHohmann  
CalcHohmann.FunctionPath = 'C:\path\to\functions'  
  
Create Variable a_target mu dv1 dv2  
mu = 398600.4415
```

```
BeginMissionSequence

% calculate burns for circular Hohmann transfer (example)
[dv1, dv2] = CalcHohmann(aSat.SMA, a_target, mu)

% perform first maneuver
aBurn.Element1 = dv1
Maneuver aBurn(aSat)

% propagate to apoapsis
Propagate aProp(aSat) {aSat.Apoapsis}

% perform second burn
aBurn.Element1 = dv2
Maneuver aBurn(aSat)
```

Return the MATLAB search path and working directory:

```
Create MatlabFunction path pwd
Create String pathStr pwdStr
Create ReportFile aReport

BeginMissionSequence

[pathStr] = path
[pwdStr] = pwd

Report aReport pathStr
Report aReport pwdStr
```

## String

A user-defined string variable

### Description

The **String** resource is used to store a string value for use by commands in the Mission Sequence.

In the script environment, **String** resources are initialized to the string '`STRING_PARAMETER_UNDEFINED`' on creation. In the GUI environment, they're initialized to the empty string (''). String resources can be assigned using string literals or (in the Mission Sequence) other **String** resources, numeric **Variable** resources, or resource parameters that have string types.

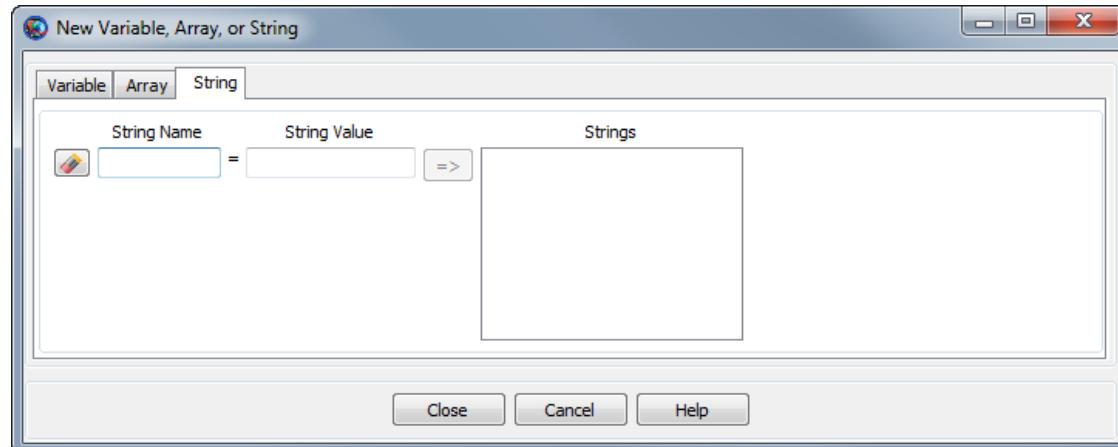
See Also: [Array](#), [Variable](#)

### Fields

The **String** resource has no fields; instead, the resource itself is set to the desired value.

Field	Description
<code>value</code>	The value of the string variable.
<b>Data Type</b>	String
<b>Allowed Values</b>	N/A
<b>Access</b>	set, get
<b>Default Value</b>	'' (empty) (GUI)
<b>Units</b>	' <code>STRING_PARAMETER_UNDEFINED</code> ' (script)
<b>Interfaces</b>	N/A GUI, script

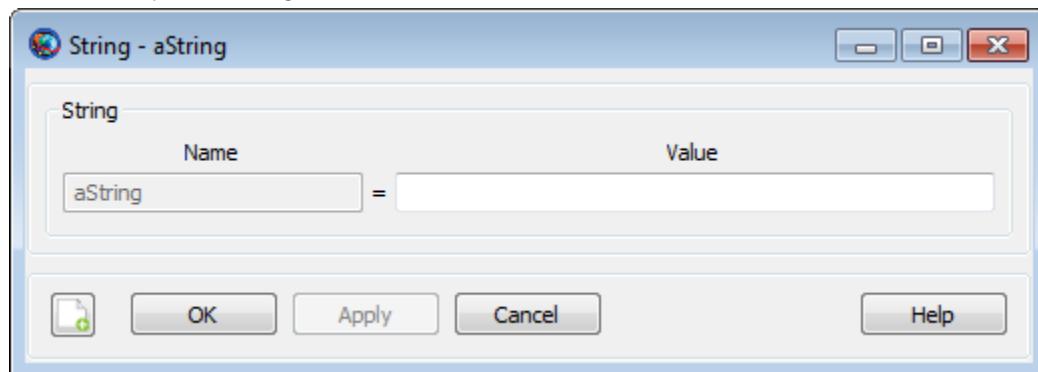
### GUI



The GMAT GUI lets you create multiple **String** resources at once without leaving the window. To create a **String**:

1. In the **String Name** box, type the desired name of the string.
2. In the **String Value** box, type the initial value of the string. This is required and must be a literal string value. Quotes are not necessary when setting the value.
3. Click the => button to create the string and add it to the list on the right.

You can create multiple **String** resources this way. To edit an existing string in this window, click it in the list on the right and edit the value. You must click the => button again to save your changes.



You can also double-click an existing **String** in the resources tree in the main GMAT window. This opens the string properties box above that allows you to edit the value of that individual string.

## Remarks

**String** resources can (in the Mission Sequence) be set using numeric **Variable** resources. The numeric value of the **Variable** is converted to a string during the assignment. The numeric value is converted to a string representation in either floating-point or scientific notation (whichever is more appropriate) with a maximum of 16 significant figures.

## Examples

Creating a string and assigning it a literal value:

```
Create ReportFile aReport  
  
Create String aStr  
aStr = 'MyString'  
  
BeginMissionSequence  
  
Report aReport aStr
```

## Variable

A user-defined numeric variable

### Description

The **Variable** resource is used to store a single numeric value for use by commands in the Mission Sequence. It can be used in place of a literal numeric value in most commands. **Variable** resources are initialized to zero on creation, and can be assigned using literal numeric values or (in the Mission Sequence) **Variable** resources, **Array** resource elements, resource parameters of numeric type, or **Equation** commands that evaluate to scalar numeric values.

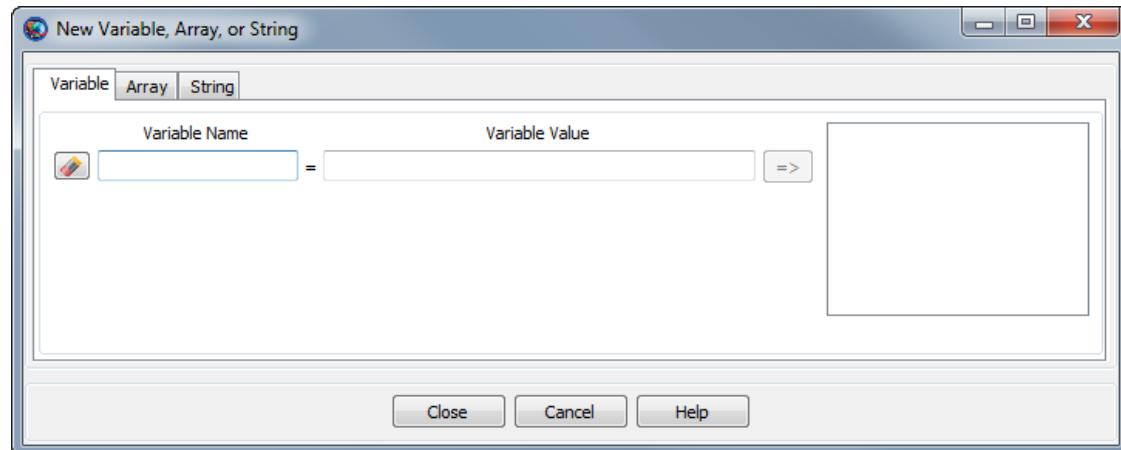
See Also: [Array](#), [String](#)

### Fields

The **Variable** resource has no fields; instead, the resource itself is set to the desired value.

Field	Description
<i>value</i>	The value of the variable.
<b>Data Type</b>	Real number
<b>Allowed Values</b>	$-\# < \text{value} < \#$
<b>Access</b>	set, get
<b>Default Value</b>	0.0
<b>Units</b>	N/A
<b>Interfaces</b>	GUI, script

### GUI

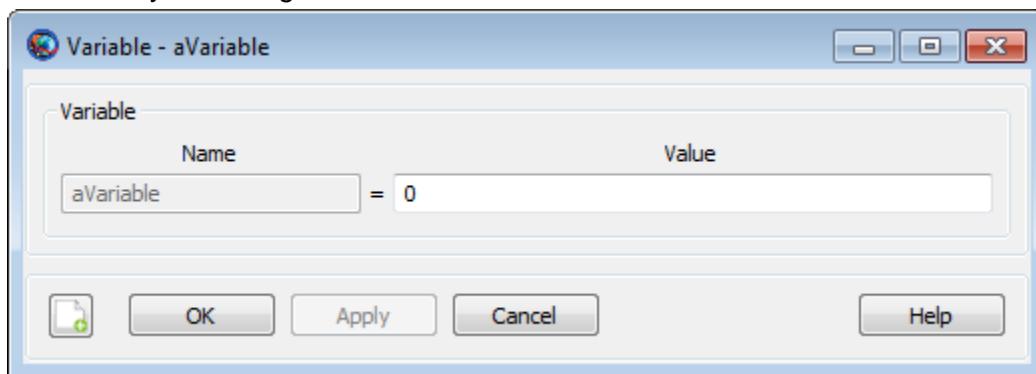


The GMAT GUI lets you create multiple **Variable** resources at once without leaving the window. To create a **Variable**:

1. In the **Variable Name** box, type the desired name of the variable.

2. In the **Variable Value** box, type the initial value of the variable. This is required and must be a literal numeric value.
3. Click the => button to create the variable and add it to the list on the right.

You can create multiple **Variable** resources this way. To edit an existing variable in this window, click it in the list on the right and edit the value. You must click the => button again to save your changes.



You can also double-click an existing variable in the resources tree in the main GMAT window. This opens the **Variable** properties box above that allows you to edit the value of that individual variable.

### Remarks

GMAT **Variable** resources store a single numeric value. Internally, the value is stored as a double-precision real number, regardless of whether or not a fractional portion is present.

### Examples

Creating a variable and assigning it a literal value:

```
Create ReportFile aReport  
  
Create Variable aVar  
aVar = 12  
  
BeginMissionSequence  
  
Report aReport aVar
```

Using variables in Mission Sequence commands:

```
Create Spacecraft aSat  
Create ForceModel anFM  
Create ReportFile aReport  
  
Create Propagator aProp  
aProp.FM = anFM
```

```
Create Variable i step totalDuration nSteps

BeginMissionSequence

step = 60
totalDuration = 24*60^2      % one day
nSteps = totalDuration / step

% Report Keplerian elements every 60 seconds for one day
For i=1:nSteps
    Propagate aProp(aSat) {aSat.ElapsedSecs = step}
    Report aReport aSat.TAIModJulian aSat.SMA aSat.ECC aSat.INC ...
        aSat.RAAN aSat.AOP aSat.TA
EndFor
```

## Commands

## Assignment (=)

Set a variable or resource field to a value, possibly using mathematical expressions

### Script Syntax

```
settable_item = expression
```

### Description

The assignment command (in the GUI, the **Equation** command) allows you to set a resource field or parameter to a value, possibly using mathematical expressions. GMAT uses the assignment operator ('=') to indicate an assignment command. The assignment operator uses the following syntax, where LHS denotes the left-hand side of the operator, and RHS denotes the right-hand side of the operator:

```
LHS = RHS
```

In this expression, the left-hand side (*LHS*) is being set to the value of the right-hand side (*RHS*). The syntax of the *LHS* and *RHS* expressions vary, but both must evaluate to compatible data types for the command to succeed.

### Left-hand side

The left-hand side of the assignment command must be a single item of any of the following types:

- allowed resource (e.g. **Spacecraft**, **Variable**, **Array**)
- resource field for allowed resources (e.g. **Spacecraft.Epoch**, **Spacecraft.DateFormat**)
- settable resource parameter (e.g. **Spacecraft.X**, **ReportFile.Precision**)
- **Array** or **Array** element

See the documentation for a particular resource to determine which fields and parameters can be set.

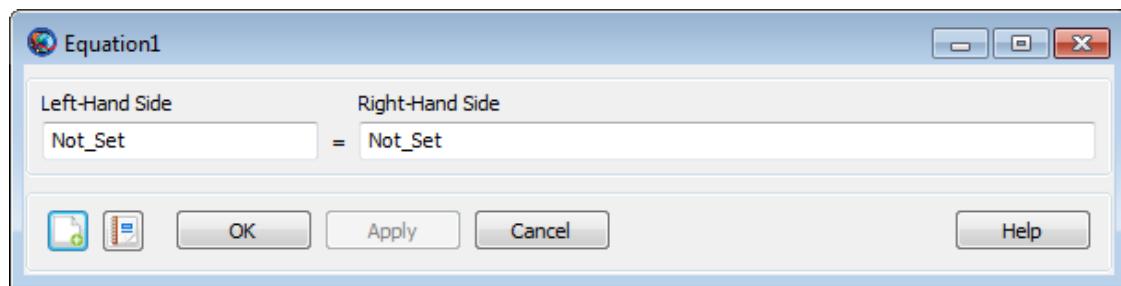
### Right-hand side

The right-hand side of the assignment command can consist of any of the following:

- literal value
- resource (e.g. **Spacecraft**, **Variable**, **Array**)
- resource field (e.g. **Spacecraft.Epoch**, **Spacecraft.DateFormat**)
- resource parameter (e.g. **Spacecraft.X**, **ChemicalThruster.K1**)
- **Array** or **Array** element
- mathematical expression (see below)

MATLAB function calls are considered distinct from the assignment command. See the reference pages for more information.

## GUI



The assignment command in the script language corresponds to the **Equation** command in the GUI. The **Equation** properties box allows you to input both sides of the expression into free-form text boxes. The default values on each side are “Not\_Set”; these are placeholders only, and are not valid during the mission run. You can type into each box the same syntax described above for the script language. When you click **OK** or **Apply**, GMAT validates each side of the expression and provides feedback for any warnings or errors.

## Remarks

### Data type compatibility

In general, the data types of the left-hand side and the right-hand side must match after all expressions are evaluated. This means that a **Spacecraft** resource can only be set to another **Spacecraft** resource, numeric parameters can only be set to numeric values, and **String** resources can only be set to string values. Additionally, the dimension of **Array** instances must match for the command to succeed. For numeric quantities, the assignment command does not distinguish between integers and floating-point values.

### Parameters

Parameters can be used on either side of an assignment command, but there may be certain restrictions.

On the right-hand side of the command, any parameter can be used. If a parameter accepts a dependency (such as **Spacecraft.CoordinateSystem.X**) and the dependency is omitted, a default dependency value will be used. For coordinate-system-dependent parameters, the default is **EarthMJ2000Eq**. For central-body-dependent parameters, the default is **Earth**.

On the left-hand side, only settable (writable) parameters can be used. Furthermore, no dependency can be specified, except in the special case that the dependencies on both sides of the assignment command are equivalent. On the left-hand side, the default values of omitted dependencies are automatically taken to be the current values of the **CoordinateSystem** field of the referenced **Spacecraft** and its origin.

These examples show valid and invalid usage of parameters:

```
Create Spacecraft aSat1 aSat2
```

```

aSat2.CoordinateSystem = 'EarthFixed'
Create Variable x
BeginMissionSequence
x = aSat1.EarthFixed.X      % Valid: Parameter with dependency on RHS
x = aSat1.EarthMJ2000Eq.X  % Valid: This and next statement are equiv.
x = aSat1.X                % Valid: Default dep. value is EarthMJ2000Eq.

x = aSat1.Mars.Altitude    % Valid: Parameter with dependency on RHS
x = aSat1.Earth.Altitude   % Valid: This and next statement are equiv.
x = aSat1.Altitude         % Valid: Default dependency value is Earth.

aSat2.X = 1e5               % Valid: Default parameter value is EarthFixed.
aSat2.EarthMJ2000Eq.X = 1e5 % INVALID: Dependencies not allowed on LHS.
aSat2.EarthFixed.X = 1e5    % Valid: Special case because value = default.

aSat2.EarthMJ2000Eq.X = aSat1.EarthFixed.X  % INVALID: Dependency on LHS
aSat2.EarthMJ2000Eq.X = aSat1.EarthMJ2000Eq.X % INVALID: Dependency on LHS
aSat2.EarthFixed.X = aSat1.EarthFixed.X       % Valid: Special case

% DANGEROUS! Valid, but sets EarthMJ2000Eq RHS values to EarthFixed LHS param.
aSat2.X = aSat1.EarthMJ2000Eq.X

% DANGEROUS! RHS default is EarthMJ2000Eq, LHS default is current setting on
% aSat2 (EarthFixed in this case).
aSat2.X = aSat1.X

```

## Mathematical Expressions

The assignment command supports the use of inline mathematical expressions on the right-hand side of the command. These expressions follow the general syntax rules of MATLAB expressions, and can use a variety of operators and built-in functions.

## Parsing

Mathematical expressions are recognized by the presence of any of the operators or built-in functions described below. Before execution, all white space (e.g. spaces and tabs) is removed from the expression.

## Data Types

Mathematical expressions operate on numeric values (integers or floating-point numbers). This includes the following:

- literal values
- numeric resources (**Variable**, **Array**)
- gettable resource parameters (e.g. **Spacecraft.X**, **ChemicalThruster.K1**)
- **Array** elements
- calculation parameters (e.g. **Spacecraft.OrbitPeriod**)
- nested mathematical expressions

Several of GMAT's operators and functions are vectorized, so they operate on full **Array** resources as well as scalar numeric values.

## Operators

---

<b>Vector- ized op- erators</b>	<ul style="list-style-type: none"> <li>+ Addition or unary plus. <math>X+Y</math> adds X and Y. X and Y must have the same dimensions unless either is a scalar.</li> <li>- Subtraction or unary minus. <math>-X</math> is the negative of X, where X can be any size. <math>X-Y</math> subtracts Y from X. X and Y must have the same dimensions unless either is a scalar.</li> <li>* Multiplication. <math>X*Y</math> is the product of X and Y. If both X and Y are scalars, this is the simple algebraic product. If X is a matrix or vector and Y is a scalar, all elements of X are multiplied by Y (and vice versa). If both X and Y are non-scalar, <math>X*Y</math> performs matrix multiplication and the number of columns in X must equal the number of rows in Y.</li> <li>' Transpose. <math>X'</math> is the transpose of X. If X is a scalar, <math>X'</math> is equal to X.</li> </ul>
<b>Scalar op- / erators</b>	<ul style="list-style-type: none"> <li>/ Division. <math>X/Y</math> divides X by Y. If both X and Y are scalars, this is the simple algebraic quotient. If X is a matrix or vector, each element is divided by Y. Y must be a non-zero scalar quantity.</li> <li>^ Power. <math>X^Y</math> raises X to the Y power. X and Y must be scalar quantities. A special case is <math>X^{(-1)}</math>, which when applied to a square matrix X, returns the inverse of X.</li> </ul>

---

When multiple expressions are combined, GMAT uses the following order of operations. Operations begin with those operators at the top of the list and continue downwards. Within each level, operations proceed left-to-right.

1. parentheses ()
2. transpose ('), power (^)
3. unary plus (+), unary minus (-)
4. multiplication (\*), division (/)
5. addition (+), subtraction (-)

## Built-in Functions

GMAT supports the following built-in functions in mathematical expressions. Supported functions include common scalar functions, meaning they accept a single value only, such as sin and cos, matrix functions that operate on an entire matrix or vector, and string functions.

---

<b>Scalar Math Functions</b>	<b>sin</b>	Sine. In $Y = \sin(X)$ , Y is the sine of the angle X. X must be in radians. Y will be in the range [-1, 1].
	<b>cos</b>	Cosine. In $Y = \cos(X)$ , Y is the cosine of the angle X. X must be in radians. Y will be in the range [-1, 1].
	<b>tan</b>	Tangent. In $Y = \tan(X)$ , Y is the tangent of the angle X. X must be in radians. The tangent function is undefined at angles that normalize to $\pi/2$ or $-\pi/2$ .
	<b>asin</b>	Arcsine. In $Y = \text{asin}(X)$ , Y is the arcsine of X. X must be in the range [-1, 1], and Y will be in the range $[-\pi/2, \pi/2]$ .
	<b>acos</b>	Arccosine. In $Y = \text{acos}(X)$ , Y is the arccosine of X. X must be in the range [-1, 1], and Y will be in the range $[0, \pi]$ .
	<b>atan</b>	Arctangent. In $Y = \text{atan}(X)$ , Y is the arctangent of X. Y will be in the range $(-\pi/2, \pi/2)$ .
	<b>atan2</b>	Four-quadrant arctangent. In $A = \text{atan2}(Y, X)$ , A is the arctangent of $Y/X$ . A will be in the range $(-\pi, \pi]$ . $\text{atan2}(Y, X)$ is equivalent to $\text{atan}(Y/X)$ except for the expanded range.
	<b>log</b>	Natural logarithm. In $Y = \text{log}(X)$ , Y is the natural logarithm of X. X must be non-zero positive.
	<b>log10</b>	Common logarithm. In $Y = \text{log10}(X)$ , Y is the common (base-10) logarithm of X. X must be non-zero positive.
	<b>exp</b>	Exponential. In $Y = \text{exp}(X)$ , Y is exponential of X ( $e^X$ ).
	<b>DegToRad</b>	Radian conversion. In $Y = \text{DegToRad}(X)$ , Y is the angle X in units of radians. X must be an angle in degrees.
	<b>RadToDeg</b>	Degree conversion. In $Y = \text{RadToDeg}(X)$ , Y is the angle X in units of degrees. X must be an angle in radians.
	<b>abs</b>	Absolute value. In $Y = \text{abs}(X)$ , Y is the absolute value of X.
	<b>sqrt</b>	Square root. In $Y = \text{sqrt}(X)$ , Y is the square root of X. X must be non-negative.

---

<b>Numeric Manipulation Functions</b>	<b>mod</b>	Modulus after division. $\text{mod}(x,y)$ returns $x - n*y$ , where $n = \text{floor}(x/y)$ if $y \neq 0$ . By convention, $\text{mod}(x,x)$ is x.
	<b>ceil</b>	Round towards plus infinity. $\text{ceil}(X)$ rounds X to the nearest integer towards plus infinity.
	<b>floor</b>	Round towards minus infinity. $\text{floor}(X)$ rounds X to the nearest integer towards minus infinity.
	<b>fix</b>	Round towards zero. $\text{fix}(X)$ rounds X to the nearest integer towards zero.

---

---

<b>Random Number Functions</b>	<b>randn</b>	Normally distributed pseudorandom numbers. $R = \text{randn}(N)$ returns an N-by-N matrix containing pseudorandom values drawn from the standard normal distribution. $R = \text{randn}()$ returns a single random number.
	<b>rand</b>	Uniformly distributed pseudorandom numbers. $R = \text{rand}(N)$ returns an N-by-N matrix containing pseudorandom values drawn from the standard uniform distribution on the open interval $(0,1)$ . $R = \text{rand}()$ returns a single random number.
	<b>SetSeed</b>	Set seed for random number generation. $\text{SetSeed}(X)$ sets the seed for the random number generator where X must be a positive real number. Note: SetSeed calls through to the C++ 11 random number generator seed algorithm that requires an unsigned integer. Since the GMAT script language only supports real numbers, casting is performed by the compiler which rounds the real number down to the nearest integer. We recommend passing in real numbers with zero mantissa (i.e "1.0" or "198.0").
<b>Matrix Functions</b>	<b>norm</b>	2-norm. In $Y = \text{norm}(X)$ , Y is the 2-norm of X, where X must be a vector (i.e. one dimension must be 1). If X is a scalar, Y is equal to X.
	<b>det</b>	Determinant. In $Y = \text{det}(X)$ , Y is the cross product of the vectors A and B. If X is a matrix, the number of rows must equal the number of columns. If X is a scalar, Y is equal to X. For efficiency, GMAT's implementation of the determinant is currently limited to matrices 9x9 or smaller.
	<b>cross</b>	Vector cross product. In $C = \text{cross}(A,B)$ , C is the vector cross product of A and B . A and B must be 3 element arrays.
	<b>inv</b>	Inverse. In $Y = \text{inv}(X)$ , Y is the inverse of X. X must be a matrix or a scalar. If X is a matrix, the number of rows must equal the number of columns. $X^{-1}$ is an alternate syntax.

---

---

<b>String Manipulation Functions</b>	
<b>strcat</b>	String concatenation. STROUT = strcat(S1, S2, ..., SN) concatenates strings. Inputs can be combinations of string variables and string literals.
<b>strfind</b>	String find. INDEX = strfind(TEXT, PATTERN) returns the starting index of the first instance of PATTERN in TEXT. If PATTERN is not found, INDEX = -1.
<b>strrep</b>	String replace. NEWSTR = strrep(OLDSTR, OLDSUBSTR, NEWSUBSTR) replaces all occurrences of the string OLDSUBSTR within string OLDSTR with the string NEWSUBSTR.
<b>strcmp</b>	String compare. FLAG = strcmp(S1, S2) compares the strings S1 and S2 and returns logical 1 (true) if they are identical, and returns logical 0 (false) otherwise.
<b>strlen</b>	String length. LENGTH = strlen(S1) returns the length of the string s1.
<b>substr</b>	Substring. S2 = substr(S1, START, END = strlen(s1)) creates a substring from the string S1 starting at the index START and ending at the index END (zero-indexed). END is an optional variable. If END is excluded, END will be treated as the string length and the created substring will end at the end of the original string.
<b>sprintf</b>	Write formatted data to a string. STRING = sprintf(FORMATSPEC, A, ...) formats data in A, ... according to FORMATSPEC which is a C-style format spec.

---

Note: The GMAT sprintf function calls through to the sprintf function in the c-library iostream. Additionally, the GMAT script language does not support an integer data type, only doubles.

A format spec follows this prototype:

```
%[flags][width]
[.precision][length]specifier
```

---

---

<b>Specifiers</b>	a	Hexadecimal floating point, lowercase.
	A	Hexadecimal floating point, uppercase
	e	Scientific notation (mantissa/exponent), lowercase
	E	Scientific notation (mantissa/exponent), uppercase
	f	Decimal floating point, lowercase
	F	Decimal floating point, uppercase
	g	Use the shortest representation: %e or %f
	G	Use the shortest representation: %E or %F
	o	Unsigned octal
	x	Unsigned hexadecimal integer, lowercase
	X	Unsigned hexadecimal integer, uppercase

---

<b>Flags</b>	+	Forces to precede the result with a plus or minus sign (+ or -) even for positive numbers. By default, only negative numbers are preceded with a - sign.
	-	Left-justify within the given field width; Right justification is the default (see width sub-specifier).
	#	Used with o, x or X specifiers the value is preceded with 0, 0x or 0X respectively for values different than zero. Used with a, A, e, E, f, F, g or G it forces the written output to contain a decimal point even if no more digits follow. By default, if no digits follow, no decimal point is written.
	0	Left-pads the number with zeroes (0) instead of spaces when padding is specified (see width sub-specifier).
	(space)	If no sign is going to be written, a blank space is inserted before the value.
<b>Width</b>		Minimum number of characters to be printed. If the value to be printed is shorter than this number, the result is padded with blank spaces. The value is not truncated even if the result is larger.
<b>Precision</b>		For a, A, e, E, f and F specifiers: this is the number of digits to be printed after the decimal point (by default, this is 6).  For g and G specifiers: This is the maximum number of significant digits to be printed.  For s: this is the maximum number of characters to be printed. By default all characters are printed until the ending null character is encountered. If the period is specified without an explicit value for precision, 0 is assumed.  Integer specifiers are not supported as GMAT does not have an integer data type in the script language.

---

---

<b>Time Manipulation Pause Functions</b>	Pause. Pause(T) pauses the GMAT application. Input is an real number representing the time to pause in seconds. The Pause time is truncated to millisecond accuracy.
<b>ConvertTime</b>	Convert Time. ConvertTime(SF, EF, T) takes a time value T in a predefined GMAT format SF and returns that time in the GMAT format EF. T must be a GMAT time string. SF and EF must be strings with one of the following values: "A1ModJulian", "TAIModJulian", "UTCModJulian", "TDBModJulian", "TTModJulian", "A1Gregorian", "TAIGregorian", "UTCGregorian", "TDBGregorian", "TTGregorian".
<b>SystemTime</b>	System Time. SystemTime(F) generates the current time of the system that called it, in the format F. F must be a string with one of the following values: "A1ModJulian", "TAIModJulian", "UTCModJulian", "TDBModJulian", "TTModJulian", "A1Gregorian", "TAIGregorian", "UTCGregorian", "TDBGregorian", "TTGregorian".  Note: SystemTime may behave differently between Windows and Unix-based systems, like Linux and Mac.

---

---

<b>Other Functions</b>	<b>Sign</b>	Sign. Sign(N) takes any real number N and returns 1.0 if it is positive, 0.0 if it is zero, and -1.0 if it is negative.
	<b>Str2num</b>	String to number. Str2num(S) takes a string value S and converts it into a real number, stored in a GMAT Variable. The input string S must be a string representation of a valid real number.
	<b>Num2str</b>	Number to String. Num2str(N) takes a numeric value N and converts it into a GMAT String.
	<b>RotationMatrix</b>	RotationMatrix(CS, E, EF) generates the last rotation matrix and rotation dot matrix for a coordinate system at a specific epoch. CS must be a fully constructed CoordinateSystem object. E must be a string containing an epoch. EF is the format of the epoch string, and must be one of the following values: "A1ModJulian", "TAI-ModJulian", "UTCModJulian", "TDBModJulian", "TTModJulian", "A1Gregorian", "TAIGregorian", "UTCGregorian", "TDBGregorian", "TTGregorian".
	<b>Angle</b>	Angle(V, E1, E2) generates the angle between 3 SpacePoint objects. The first argument passed must be the vertex of the angle, and the 2nd and 3rd arguments must be the endpoints. At least one of the SpacePoint objects must be a Spacecraft.

---

## Examples

Evaluate a basic algebraic equation:

```
Create Variable A B C x y
x = 1
Create ReportFile aReport

BeginMissionSequence

A = 10
B = 20
C = 2

y = A*x^2 + B*x + C
Report aReport y
```

Matrix manipulation:

```
Create Array A[2,2] B[2,2] C[2,2] x[2,1] y[2,1]
Create ReportFile aReport

A(1,1) = 10
A(2,1) = 5
A(1,2) = .10
A(2,2) = 1

x(1,1) = 2
x(2,1) = 3

BeginMissionSequence

B = inv(A)
C = B'
y = C*x
Report aReport A B C x y
```

Cloning a resource:

```
Create Spacecraft Sat1 Sat2
Sat1.Cd = 1.87
Sat1.DryMass = 123.456

Create ReportFile aReport

BeginMissionSequence

Sat2 = Sat1
Report aReport Sat2.Cd Sat2.DryMass
```

Using built-in functions:

```
Create Variable pi x y1 y2 y3
Create Array A[3,3]
Create Spacecraft aSat
Create ReportFile aReport

BeginMissionSequence

pi = acos(-1)

aSat.TA = pi/4
x = pi/4
A(1,1) = pi/4

y1 = sin(x)
y2 = sin(aSat.TA)
y3 = sin(A(1,1))
```

```
Report aReport y1 y2 y3
```

## BeginMissionSequence

Begin the mission sequence portion of a script

### Script Syntax

```
BeginMissionSequence
```

### Description

The **BeginMissionSequence** command indicates the end of resource initialization and the beginning of the mission sequence portion of a GMAT script. It must appear once as the first command in the script, and must follow all resource creation lines.

*See Also:* [Script Language](#)

### GUI

The **BeginMissionSequence** command is managed automatically when building mission sequences using the GUI mission tree. However, when editing the GMAT script directly, either with the GMAT script editor or with an external editor, you must insert the **BeginMissionSequence** command manually.

### Remarks

The **BeginMissionSequence** is a script-only command that is not needed when working from the GUI. It indicates to GMAT that the portion of the script above the command consists of static resource initialization that can be performed in any order, and that the portion below the command consists of mission sequence commands that must be executed sequentially. This and other rules of the scripting language are discussed in detail in the [script language reference](#).

### Examples

A minimal GMAT script that propagates a spacecraft:

```
Create Spacecraft aSat
Create Propagator aProp

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

## BeginScript

Execute free-form script commands

### Script Syntax

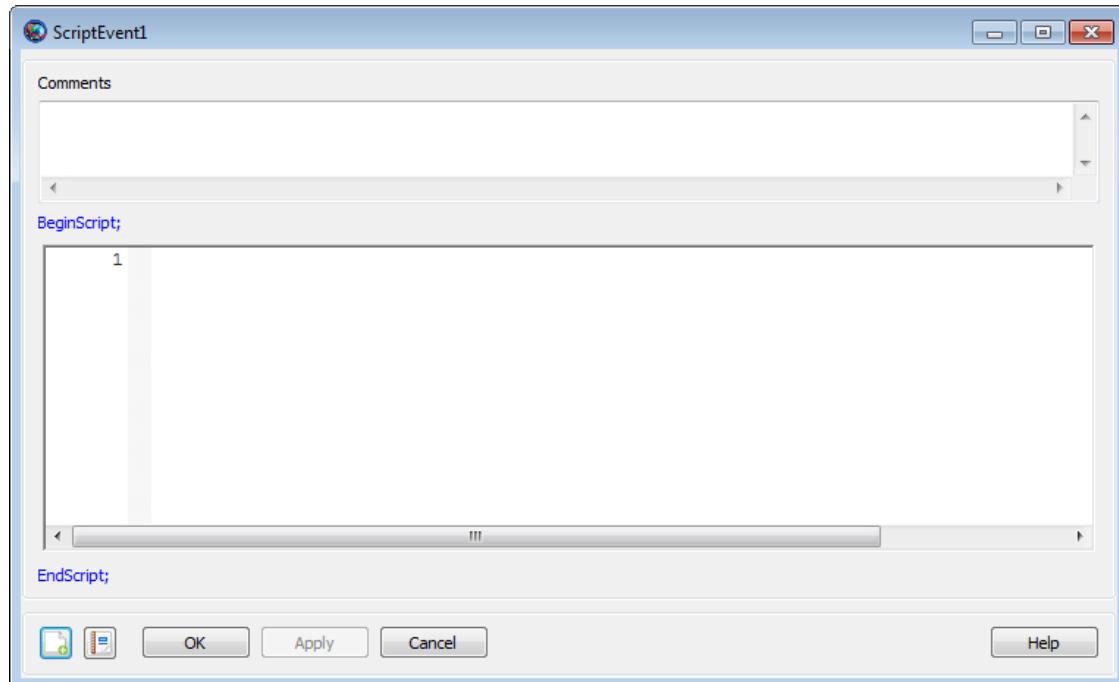
```
BeginScript  
  [script statements]  
  ...  
EndScript
```

### Description

The **BeginScript** and **EndScript** commands (**ScriptEvent** in the GUI) allow you to write free-form script statements in the mission sequence without the statements being shown as individual commands in the GMAT GUI. This is useful as a way to group and label a complex sequence of statements as one unit, or to write small sequences of script statements when otherwise using the GUI to create the mission sequence. Within the script itself, there is no difference in the execution of statements within a **BeginScript**/**EndScript** block and those outside of it.

See Also: [the section called “Script Editor”](#)

### GUI



The **ScriptEvent** GUI window divides the command into three parts: an initial comment, fixed **BeginScript** and **EndScript** commands, and the content of the block itself. The scripting window is a miniature version of the main script editor, and features line numbers, syntax highlighting, code folding, and all of the editing tools available in the full

editor. See the [the section called “Script Editor”](#) documentation for more information. The **ScriptEvent** window performs script syntax validation when changes are applied. Nested **BeginScript/EndScript** blocks in the script language are collapsed into a single **ScriptEvent** when loaded into the GUI, and are saved to a single **BeginScript/EndScript** block when saved to a script.

## Examples

Perform a calculation inside a **BeginScript/EndScript** block. When loaded into the GUI, the calculations within the **BeginScript/EndScript** block will be contained within a single **ScriptEvent** command.

```
Create Spacecraft aSat
Create Propagator aProp
Create ImpulsiveBurn aBurn
Create Variable a_init v_init
Create Variable a_transfer v_transfer_1 v_transfer_2
Create Variable a_target v_final mu
Create Variable dv_1 dv_2
mu = 398600.4415
a_target = 42164

BeginMissionSequence

% calculate Hohmann burns
BeginScript
    a_init = aSat.SMA
    v_init = aSat.VMAG
    a_transfer = (a_init + a_target) / 2
    v_transfer_1 = sqrt(2*mu/a_init - mu/a_transfer)
    v_transfer_2 = sqrt(2*mu/a_target - mu/a_transfer)
    v_final = sqrt(mu/a_target)
    dv_1 = v_transfer_1 - v_init
    dv_2 = v_final - v_transfer_2
EndScript

% perform burn 1
aBurn.Element1 = dv_1
Maneuver aBurn(aSat)

Propagate aProp(aSat) {aSat.Apoapsis}

% perform burn 2
aBurn.Element1 = dv_2
Maneuver aBurn(aSat)

Propagate aProp(aSat) {aSat.ElapsedSecs = aSat.OrbitPeriod}
```

## Breakpoint

Pause a run and let the user examine the state of objects.

### Description

The Breakpoint command causes GMAT to pause the current run at a set point in the mission sequence. When the command triggers, the GMAT GUI opens an object inspection window. The user can examine the current state of any object in the run from that window. The run can then be stepped forward command by command and the objects examined to see the effect of the command that was executed. The user can also resume execution of the run or terminate the run from the object inspector window.

## CallGmatFunction

Call a GMAT function

### Script Syntax

```
GmatFunction()  
GmatFunction(input_argument[, input_argument]...)  
[output_argument[, output_argument]...] = GmatFunction  
[output_argument[, output_argument]...] = ...  
GmatFunction(input_argument[, input_argument]...)
```

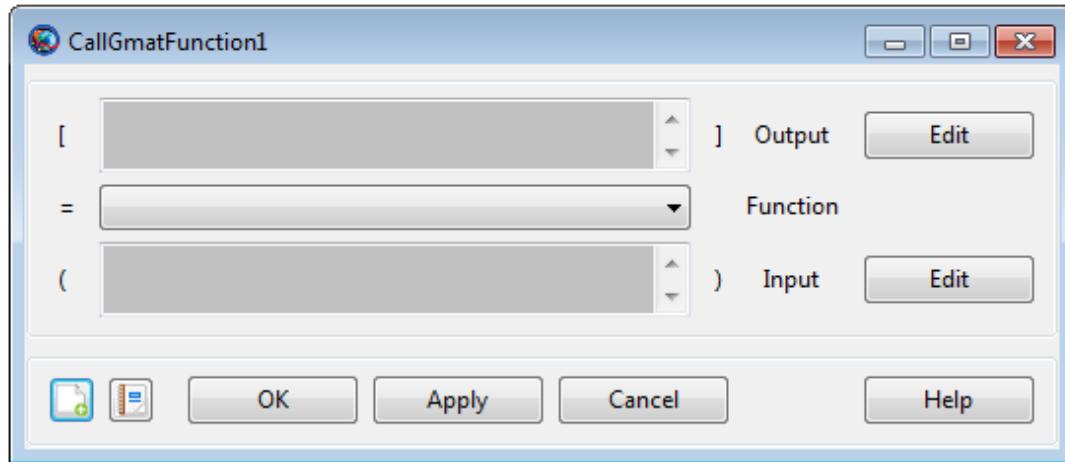
### Description

GMAT provides a special command that allows you to call a GMAT function which is written via GMAT's **GmatFunction** resource. In the GUI, the GMAT function is called through the **CallGmatFunction** command.

In the syntax description, **GmatFunction** is a **GmatFunction** resource that must be declared during initialization. Arguments can be passed into the function as inputs and returned from the function as outputs. See [Remarks](#) for details. Furthermore, data that is passed into the function as input or received from the function as output can also be declared as global by using GMAT's **Global** command. See the [Global](#) reference for more details.

See Also: [GMATFunction](#), [Global](#)

### GUI



The **CallGmatFunction** GUI provides two input boxes for input and output arguments and a list to select a GMAT function to call.

The **Output** box lists all configured output argument parameters. These must be selected by clicking **Edit**, which displays a **ParameterSelectDialog** window. See the [Calculation Parameters](#) reference for details on how to select a parameter.

The **Input** box is identical in behavior to **Output**, but lists all configured input arguments to the function. Arguments must be selected by clicking **Edit**. The **Function** list displays all functions that have been declared as **GmatFunction** resources in the **Resources** tree. Select a function from the list to call it.

When the changes are accepted, GMAT does not perform any validation of input or output arguments. This validation is performed when the mission is actually run.

## Remarks

GMAT objects can be passed into the GMAT function as input and can also be returned from the function as output. If a given GMAT object is not declared as global in both the main script and inside the GMAT function, then all objects that are passed into or received as output from the function are considered to be local to that function and the main script.

Below is a list of allowed arguments that can be passed as input to the function and received as output from the function. Also see **GmatFunction** resource's [Remarks](#) and [Examples](#) sections for more details and distinct examples that show how to pass objects as inputs to the function, perform an operation inside the function, then receive objects as outputs from the function. Note, a GMAT function file must contain one and only one function definition.

The input arguments (*input\_argument* values in the syntax description) can be any of the following types:

- Any resource objects (e.g. **Spacecraft**, **Propagator**, **DC**, **Optimizers**, **Impulsive** or **FiniteBurns**)
- resource parameter of real number type (e.g. **Spacecraft.X**)
- resource parameter of string type (e.g. **Spacecraft.UTCGregorian**)
- **Array**, **String**, or **Variable** resource

The output arguments can be any of the following types:

- Resource object like **Spacecraft**
- resource parameter of real number type (e.g. **Spacecraft.X**)
- resource parameter of string type (e.g. **Spacecraft.UTCGregorian**)
- **Array**, **String**, or **Variable** resource

## Examples

Call two different functions. One function performs a simple cross product and the second function performs a dot product.

```
Create ReportFile rf
rf.WriteHeader = false

Create GmatFunction cross_product
cross_product.FunctionPath = ...
'C:\Users\rqureshi\Desktop\cross_product.gmf'

Create GmatFunction dot_product
```

```
dot_product.FunctionPath = ...
'C:\Users\rqureshi\Desktop\dot_product.gmf'

Create Array v1[3,1] v2[3,1] v3[3,1] ...
v4[3,1] v5[3,1]

Create Variable v6
Create String tempstring

BeginMissionSequence

v1(1,1) = 1
v1(2,1) = 2
v1(3,1) = 3
v2(1,1) = 4
v2(2,1) = 5
v2(3,1) = 6
v4(1,1) = 1
v4(2,1) = 2
v4(3,1) = 3
v5(1,1) = 4
v5(2,1) = -5
v5(3,1) = 6

% Call function. Pass local arrays as input:
% Receive local array as output
[v3] = cross_product(v1, v2)

Report rf v3

% Call function. Pass local arrays as input:
% Receive local variable as output
GMAT [v6] = dot_product(v4, v5)

tempstring = '-----'
Report rf tempstring
Report rf v6

%%%%% cross_product Function begins below:

function [cross] = cross_product(vec1,vec2)

Create Array cross[3,1]

BeginMissionSequence

cross(1,1) = vec1(2,1)*vec2(3,1) - vec1(3,1)*vec2(2,1)
```

```
cross(2,1) = -(vec1(1,1)*vec2(3,1) - vec1(3,1)*vec2(1,1))
cross(3,1) = vec1(1,1)*vec2(2,1) - vec1(2,1)*vec2(1,1)
```

```
%%%%%% dot_product Function begins below:
```

```
function [c] = dot_product(a1,b1)

Create Variable c

BeginMissionSequence

c = a1(1,1)*b1(1,1) + a1(2,1)*b1(2,1) + a1(3,1)*b1(3,1)
```

Call GMAT function and pass local spacecraft as input, perform simple operation inside the function, then send out updated, local spacecraft to the main script. Finally report spacecraft old and updated position vector to the local report file subscriber:

```
Create Spacecraft aSat
aSat.DateFormat = UTCGregorian;
aSat.Epoch = '01 Jan 2000 11:59:28.000'
aSat.CoordinateSystem = EarthMJ2000Eq
aSat.DisplayStateType = Cartesian
aSat.X = 7100
aSat.Y = 0
aSat.Z = 1300

Create ReportFile rf
rf.WriteHeaders = false

Create GmatFunction Spacecraft_In_Out
Spacecraft_In_Out.FunctionPath = ...
'C:\Users\rqureshi\Desktop\Spacecraft_In_Out.gmf'

BeginMissionSequence

% Report initial S/C Position to local 'rf':
Report rf aSat.X aSat.Y aSat.Z

% Call function. Pass local S/C as input:
% Receive updated local S/C:
[aSat] = Spacecraft_In_Out(aSat)

% Report updated S/C Position to local 'rf':
Report rf aSat.X aSat.Y aSat.Z
```

```
%%%%%% Function begins below:  
  
function [aSat] = Spacecraft_In_Out(aSat)  
  
BeginMissionSequence  
  
% Update the S/C Position vector:  
% Send updated S/C back to main script:  
aSat.X = aSat.X + 1000  
aSat.Y = aSat.Y + 2000  
aSat.Z = aSat.Z + 3000
```

## CallMatlabFunction

Call a MATLAB function

### Script Syntax

```
MatLabFunction()  
MatLabFunction(input_argument[, input_argument]...)  
[output_argument[, output_argument]...] = MatLabFunction  
[output_argument[, output_argument]...] = ...  
MatLabFunction(input_argument[, input_argument]...)
```

### Description

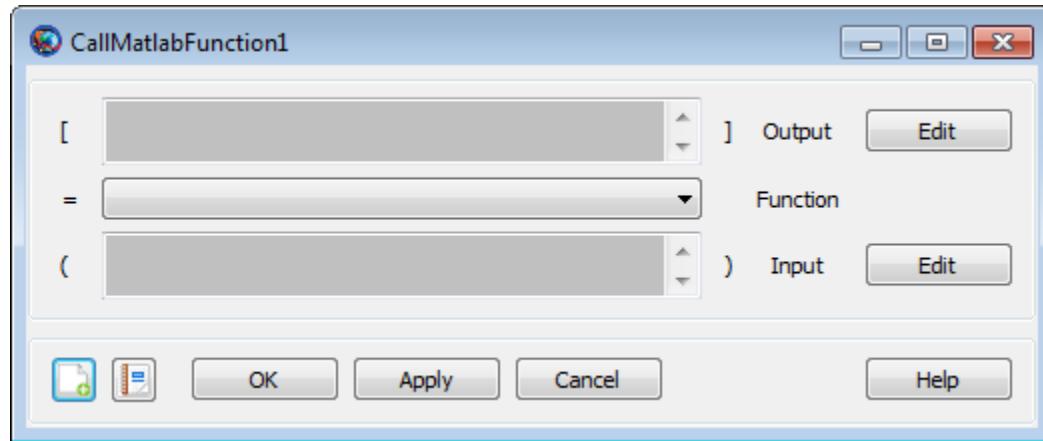
GMAT provides a special command that allows you to call a function written in the MATLAB language or provided with the MATLAB software. In the GUI, this is the **CallMatlabFunction** command.

In the syntax description, **MatlabFunction** is a **MatlabFunction** resource that must be declared during initialization. Arguments can be passed into and returned from the function, though some data-type limitations apply. See [Remarks](#) for details.

When a MATLAB function is called, GMAT opens a MATLAB command-line window in the background. This functionality requires that MATLAB be properly installed and configured on your system.

See Also: [MatlabFunction](#), [MATLAB Interface](#)

### GUI



The **CallMatlabFunction** GUI provides two input boxes for input and output arguments and a list to select a function to call.

The **Output** box lists all configured output argument parameters. These must be selected by clicking **Edit**, which displays a parameter selection window. See the [Calculation Parameters](#) reference for details on how to select a parameter.

The **Input** box is identical in behavior to **Output**, but lists all configured input arguments to the function. Arguments must be selected by clicking **Edit**. The **Function** list displays all functions that have been declared as **MatlabFunction** resources in the Resources tree. Select a function from the list to call it.

When the changes are accepted, GMAT does not perform any validation of input or output arguments. This validation is performed when the mission is run, when MATLAB has been started.

## Remarks

The input arguments (*input\_argument* values in the syntax description) can be any of the following types:

- resource parameter of real number type (e.g. **Spacecraft.X**)
- resource parameter of string type (e.g. **Spacecraft.UTCGregorian**)
- **Array**, **String**, or **Variable** resource
- **Array** resource element

The output arguments (*output\_argument* values in the syntax description) can be any of the following types:

- resource parameter of real number type (e.g. **Spacecraft.X**)
- resource parameter of string type (e.g. **Spacecraft.UTCGregorian**)
- **Array**, **String**, or **Variable** resource
- **Array** resource element

Data type conversion is performed for the following data types when values are passed between MATLAB and GMAT. When data is passed from GMAT to MATLAB as input arguments, the following conversions occur.

GMAT	MATLAB
real number (e.g. <b>Spacecraft.X</b> , <b>Variable</b> , double <b>Array</b> element)	
string (e.g. <b>Spacecraft.UTCGregorian</b> , char array <b>String</b> resource)	
<b>Array</b> resource	double array

When data is passed from MATLAB to GMAT as output arguments, the following conversions occur.

MATLAB	GMAT
char array	string
double	real number
double array	Array resource

## Examples

Call a simple built-in MATLAB function:

```
Create MatlabFunction sinh  
Create Variable x y  
  
BeginMissionSequence  
  
x = 1  
[y] = sinh(x)
```

Call an external custom MATLAB function:

```
Create Spacecraft aSat  
Create ImpulsiveBurn aBurn  
Create Propagator aProp  
  
Create MatlabFunction CalcHohmann  
CalcHohmann.FunctionPath = 'C:\path\to\functions'  
  
Create Variable a_target mu dv1 dv2  
mu = 398600.4415  
  
BeginMissionSequence  
  
% calculate burns for circular Hohmann transfer (example)  
[dv1, dv2] = CalcHohmann(aSat.SMA, a_target, mu)  
  
% perform first maneuver  
aBurn.Element1 = dv1  
Maneuver aBurn(aSat)  
  
% propagate to apoapsis  
Propagate aProp(aSat) {aSat.Apoapsis}  
  
% perform second burn  
aBurn.Element1 = dv2  
Maneuver aBurn(aSat)
```

Return the MATLAB search path and working directory:

```
Create MatlabFunction path pwd  
Create String pathStr pwdStr  
Create ReportFile aReport  
  
BeginMissionSequence  
  
[pathStr] = path  
[pwdStr] = pwd
```

```
Report aReport pathStr  
Report aReport pwdStr
```

## CallPythonFunction

Call a Python function

### Script Syntax

```
Python.PythonModule.PythonFunction()  
Python.PythonModule.PythonFunction(input_argument[, input_argument]...)  
[output_argument[, output_argument]...] = Python.PythonModule.PythonFunction  
[output_argument[, output_argument]...] = Python.PythonModule.PythonFunction(ir
```

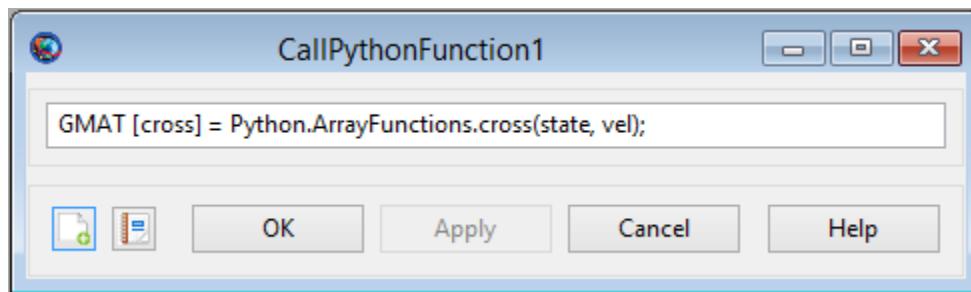
### Description

GMAT provides a special command that allows you to call a function written in the Python language. In the GUI, this is the **CallPythonFunction** command.

In the syntax description, the preface **Python** is a keyword used to tell GMAT that the scripting is calling into the Python system. The **PythonModule** identifies a Python file, with the name PythonModule.py, containing the function that is to be called. **Python-Function** is the function that is called inside of that file. Arguments can be passed into and returned from the function, following the guidelines described below. See [Remarks](#) for details.

When a Python function is called, GMAT loads the Python engine in the background. This functionality requires that a compatible installation of Python be properly installed and configured on your system. Once GMAT has loaded the engine, it remains in memory until GMAT is closed.

### GUI



The **CallPythonFunction** GUI provides a single text entry field used to enter the Python function as a line of script.

The syntax for the CallPythonFunction is as described in the Script Syntax section above. GMAT's Python interface accepts Variables, Strings, numerical object parameters, and one dimensional arrays as input parameters. It returns Variables, Arrays, and Strings, either as a single value or as a collection of values. The interface calls into Python scripts, identified by the PythonModule field, that define the function to be accessed. The receiving function is responsible for validating the inputs, based on the type conversions described in the Remarks below.

When the user accepts the entries on the panel, GMAT does not perform any validation of input or output arguments. This validation is performed when the mission is run, after Python has been started.

## Remarks

The input arguments (*input\_argument* values in the syntax description) can be any of the following types:

- resource parameter of real number type (e.g. ***Spacecraft.X***)
- resource parameter of string type (e.g. ***Spacecraft.UTCGregorian***)
- One dimensional **Array**, **String**, or **Variable** resource
- **Array** resource element

The output arguments (*output\_argument* values in the syntax description) can be any of the following types:

- **Array**, **String**, or **Variable** resource

Data type conversion is performed for the following data types when values are passed between Python and GMAT. When data is passed from GMAT to Python as input arguments, the following conversions occur.

GMAT	Python
real num- float ber (e.g. <b>Spacecraft.X</b> , <b>Variable</b> , <b>Array</b> ele- ment)	
string (e.g. str <b>Spacecraft.UTCGregorian</b> , <b>String</b> re- source)	
<b>Array</b> re- memoryview source	

When data is passed from Python to GMAT as output arguments, the following conversions occur.

Python	GMAT
str	String
float	real number
float array	Array resource

## Examples

Call a simple Python function:

```
Create Variable x y  
  
BeginMissionSequence  
  
x = 1  
y = Python.MyMath.sinh(x)
```

Call a multiple input and output Python function:

```
Create Spacecraft aSat  
Create ImpulsiveBurn aBurn  
Create Propagator aProp  
  
Create Variable a_target mu dv1 dv2  
mu = 398600.4415  
  
BeginMissionSequence  
  
% calculate burns for circular Hohmann transfer (example)  
[dv1, dv2] = Python.MyOrbitFunctions.CalcHohmann(aSat.SMA, a_target, mu)  
  
% perform first maneuver  
aBurn.Element1 = dv1  
Maneuver aBurn(aSat)  
  
% propagate to apoapsis  
Propagate aProp(aSat) {aSat.Apoapsis}  
  
% perform second burn  
aBurn.Element1 = dv2  
Maneuver aBurn(aSat)
```

## CommandEcho

Toggle the use of the **Echo** command

### Script Syntax

**CommandEcho** *EchoSetting*

### Description

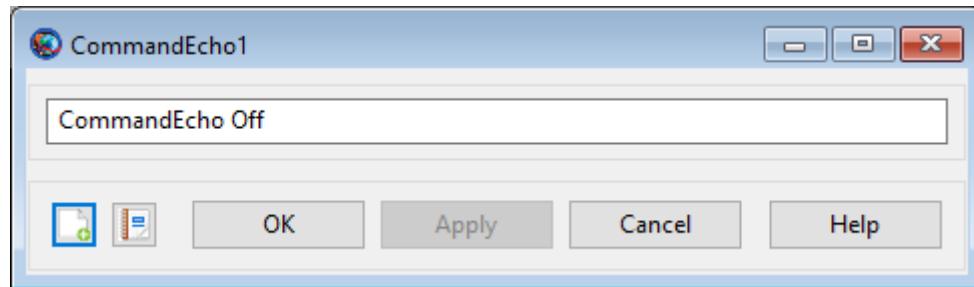
The **EchoCommand** command is used to toggle the use of the **Echo** on and off throughout a mission sequence. This allows for specific parts of a mission sequence to be displayed to the message window and the generated log file. This command is a part of the **ScriptTools** plugin.

### Options

Option	Description		
<b>EchoSetting</b>	Specifies whether the current <b>EchoSetting</b> of the <b>Echo</b> command should be on or off.		
	<b>Accepted Data Types</b>	String	
	<b>Allowed Values</b>	On, Off	
	<b>Default Value</b>	Off	
	<b>Required</b>	yes	
	<b>Interfaces</b>	GUI, script	

### GUI

The **CommandEcho** command to toggle the **Echo** on or off at any point in a mission sequence. Any number of this command can be placed throughout a mission sequence. The message box shown below will appear when setting the **EchoSetting** through the GUI. To set the command on, simply replace Off with On in the text. Note that if the command is renamed, the new name will appear in this GUI display with quotation marks surrounding it.



## For

Execute a series of commands a specified number of times

### Script Syntax

```
For Index = Start:[Increment:]End  
    [script statement]  
    ...  
EndFor
```

### Description

The **For** command is a control logic statement that executes a series of commands a specified number of times. The command argument must have one of the following forms:

*Index* = *Start*:*End*

This syntax increments **Index** from **Start** to **End** in steps of 1, repeating the script statements until **Index** is greater than **End**. If **Start** is greater than **End**, then the script statements do not execute.

*Index* = *Start*:*Increment*:*End*

This syntax increments **Index** from **Start** to **End** in steps of **Increment**, repeating the script statements until **Index** is greater than **End** if **Increment** is positive and less than **End** if **Increment** is negative. If **Start** is less than **End** and **Increment** is negative, or if **Start** is greater than **End** and **Increment** is positive, then the script statements do not execute.

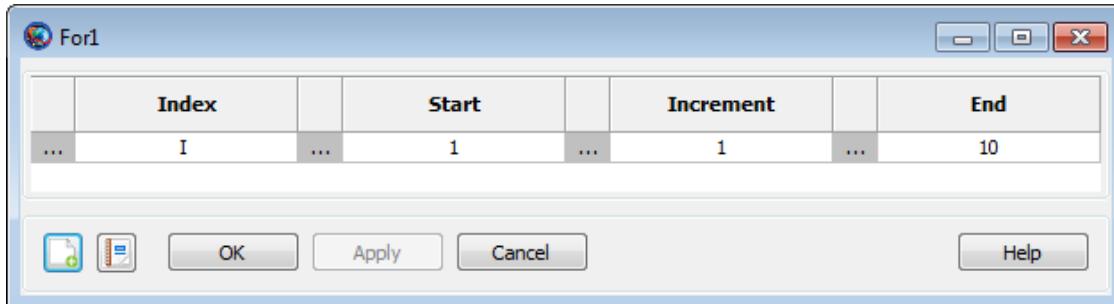
See Also: [If](#), [While](#)

### Options

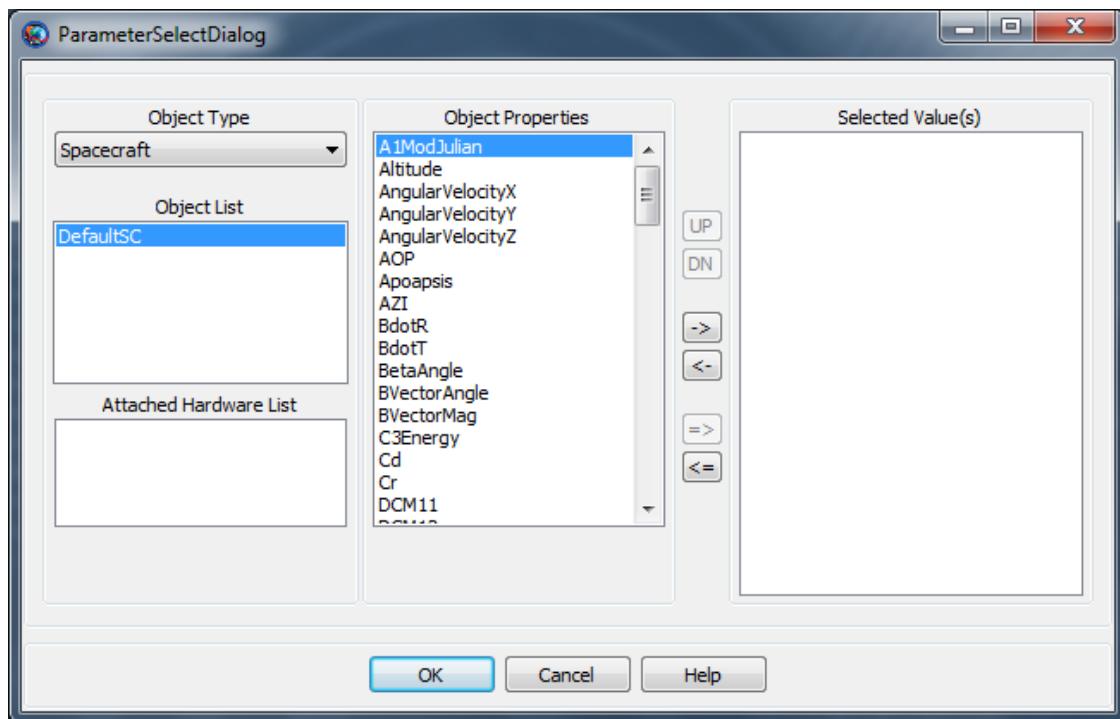
Option	Description
<b>Index</b>	Independent variable in a for loop. <b>Index</b> is computed according to the arithmetic progression defined by the values for <b>Start</b> , <b>Increment</b> , and <b>End</b> .
<b>Accepted Data Types</b>	<b>Variable</b>
<b>Allowed Values</b>	$-\# < \text{Index} < \#$
<b>Default Value</b>	<b>Variable</b> named <b>I</b>
<b>Required</b>	yes
<b>Interfaces</b>	GUI, script

Option	Description
<b>Start</b>	Initial value for the <b>Index</b> parameter
<b>Accepted Data Types</b>	parameter
<b>Allowed Values</b>	-# < Start < #
<b>Default Value</b>	1
<b>Required</b>	yes
<b>Interfaces</b>	GUI, script
<b>Increment</b>	The <b>Increment</b> parameter is used to compute the arithmetic progression of the loop Index such that pass i through the loop is <b>Start</b> + $i^*$ <b>Increment</b> if the resulting value satisfies the constraint defined by <b>End</b> .
<b>Accepted Data Types</b>	parameter
<b>Allowed Values</b>	-# < Increment < #
<b>Default Value</b>	1
<b>Required</b>	no
<b>Interfaces</b>	GUI
<b>End</b>	The <b>End</b> parameter is the upper (or lower if <b>Increment</b> is negative) bound for the <b>Index</b> .
<b>Accepted Data Types</b>	parameter
<b>Allowed Values</b>	-# < End < #
<b>Default Value</b>	10
<b>Required</b>	yes
<b>Interfaces</b>	GUI, script

## GUI



The **For** command GUI panel contains fields for all of its parameters: **Index**, **Start**, **Increment**, and **End**. To edit the values, click the field value you wish to change and type the new value (e.g. 5, `anArray(1,5)`, or `Spacecraft.X`). Alternately, you can either right-click the field value or click the ellipses (...) button to the left of the field. This displays the **ParameterSelectDialog** window, which allows you to choose a parameter from a list.



## Remarks

The values of the **Index**, **Start**, **Increment**, and **End** parameters can be any of the following types:

- Literal numeric value (e.g. 1, 15.2, -6)
- **Variable** resource
- **Array** resource element
- Resource parameter of numeric type (e.g. **Spacecraft.X**, **ChemicalThruster.K1**)

with the extra requirement that if a Resource parameter is used for **Index**, the parameter must be settable.

The index specification cannot contain mathematical operators or parentheses. After execution of the **For** loop, the value of **Index** retains its value from the last loop iteration. If the loop does not execute, the value of **Index** remains equal to its value before the loop was encountered.

Changes made to the index variable inside of a **For** loop are overwritten by the **For** loop statement. For example, the output from the following snippet:

```
For I = 1:1:3
  I = 100
  Report aReport I
EndFor
```

is:

```
100  
100
```

Changes made to the the **Start**, **Increment**, and **End** parameters made inside of a loop do not affect the behavior of the loop. For example, the output from the following snippet:

```
J = 2  
K = 2  
L = 8  
For I = J:K:L  
    J = 1  
    K = 5  
    L = 100  
    Report aReport I  
EndFor
```

is:

```
2  
4  
6  
8
```

## Examples

Propagate a spacecraft to apogee 3 times:

```
Create Spacecraft aSat  
Create Propagator aPropagator  
Create Variable I  
  
BeginMissionSequence  
  
For I = 1:1:3  
    Propagate aPropagator(aSat, {aSat.Apoapsis})  
EndFor
```

Index into an array:

```
Create Variable I J  
Create Array anArray[10,5]  
BeginMissionSequence  
  
For I = 1:10  
    For J = 1:5  
        anArray(I,J) = I*J  
    EndFor  
EndFor
```

## Global

Declare Objects as global

### Script Syntax

```
Global ObjectList
```

```
ObjectList
```

```
ObjectList List all GMAT objects that you want to declare as global.
```

### Description

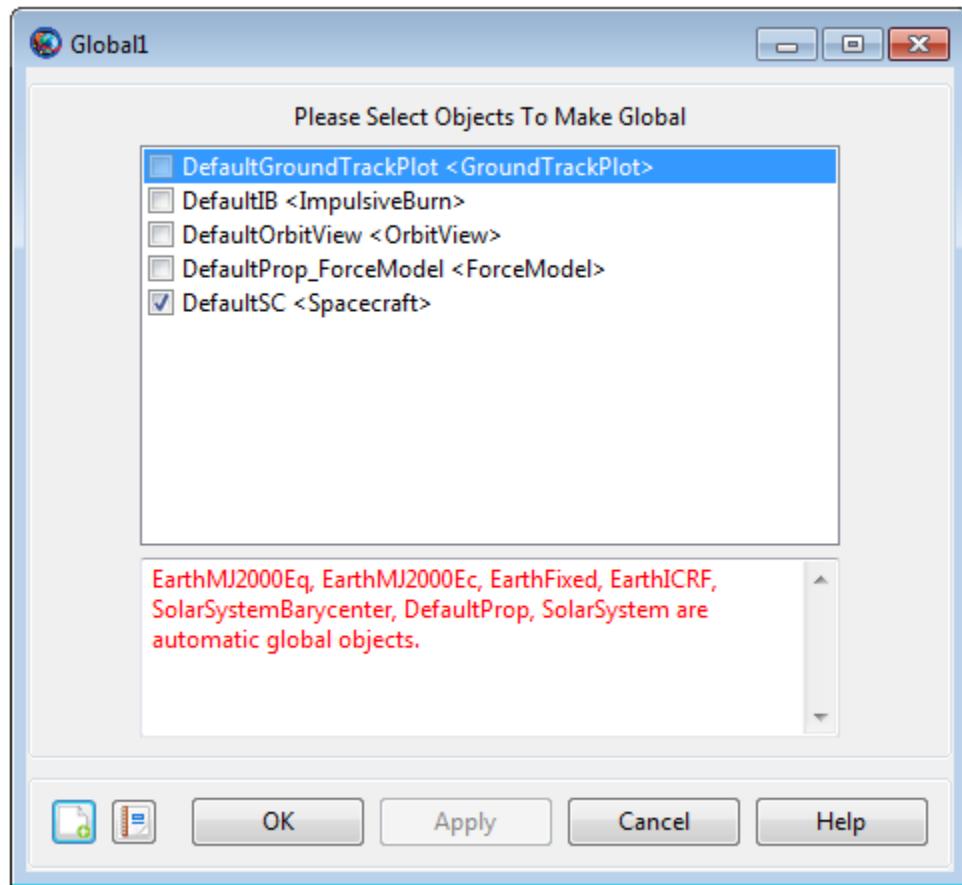
In GMAT you can use a special command that allows you to declare GMAT objects as global. By using the **Global** command, you can declare GMAT's objects as global either through the GUI or the script mode.

The syntax for declaring objects as global is very simple. After using the **Global** command, simply list the name of the objects that needs global declaration. Once the **GmatFunction** resource has been declared during initialization, arguments can be passed to and from the function as input/output by using GMAT's **CallGmatFunction** command. Data that is passed into the function as input or received from the function as output can be declared as global by using the **Global** command. See the **Remarks** section for more details on the **Global** command.

See Also: [GMATFunction](#), [CallGmatFunction](#)

### GUI

Figure below shows default settings of the **Global** command. By default, only **Spacecraft** object is checked and declared as global. As more objects are created by the user in GMAT's **Resources** tree, the list of objects that are available to be declared as global increases.



Notice in the above figure that GMAT by default already considers objects such as the default coordinate systems, **SolarSystemBarycenter**, **DefaultProp** and **SolarSystem** as automatic global objects. Furthermore whenever new coordinate systems or propagators are created in the **Resources** tree, GMAT automatically declares the newly created coordinate systems and propagators as global objects. Since GMAT always declares default or newly created coordinate systems and propagators as global, hence you do not need to use **Global** command on coordinate system and propagator objects.

## Remarks

### Declaration of Global Objects

GMAT objects can be passed into the GMAT function as input and can also be returned from the function as output. Refer to both **GmatFunction** resource and **CallGmatFunction** command's Remarks sections to learn more about list of allowed objects that can be passed as input and output to and from the function. By default, in GMAT any objects that are created inside the main script are considered local to the main script. Similarly any objects that may be created inside the GMAT function are considered local to that function. In GMAT, in order to declare objects as global, you must declare the objects as global in both your main script and inside the function. It is a good practice to declare objects as global right after the **BeginMissionSequence** line in both the main script and inside the function.

If a given GMAT object is not declared as global in both the main script and in the function, then all objects that are passed into the function as input and/or received as output from the function are considered to be local to that function and the main script.

Often times, you will propagate a spacecraft, perform differential correction (DC) or optimization routines interchangeably from both the main script and inside the function. Whenever you want to plot continuous set of spacecraft trajectory data and report parameters to same subscribers interchangeably from both inside the main script and the function, then always declare your **Spacecraft** object and subscriber objects (i.e. **OrbitView**, **GroundTrackPlot**, **XYPlot**, **ReportFile**, **EphemerisFile**) as global both in the main script and inside the function. Abiding by this rule draws plots, reports and ephemeris files correctly and flow of data will be reported continuously to all the subscribers.

GMAT allows globally declared objects such as **Spacecraft**, global variables/arrays/strings to be passed as input/output argument to and from the function. Globally declared objects such as **Spacecraft**, variables/arrays/strings can be plotted or reported interchangeably both from the main script and inside the function as long as all subscribers are also declared global.

Refer to **GmatFunction** resource's [Examples](#) section that shows three more examples of how to declare spacecraft, five subscribers, arrays/variables/strings as global in both the main script and inside the function.

## Examples

Declare spacecraft, all subscribers and variables as global. Global variables are passed as input and received as global output from the function. As you run the example, notice that data is reported continuously to all 5 subscribers.

```
Create Spacecraft aSat

Create ForceModel aFM
aFM.CentralBody = Earth
aFM.PointMasses = {Earth}

Create Propagator aProp
aProp.FM = aFM

Create ImpulsiveBurn TOI
Create ImpulsiveBurn GOI

Create DifferentialCorrector DC

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth}

Create GroundTrackPlot GroundTrackPlot1
GroundTrackPlot1.Add = {aSat}
GroundTrackPlot1.CentralBody = Earth
```

```
Create XYPlot XYPlot1
XYPlot1.XVariable = aSat.ElapsedDays
XYPlot1.YVariables = {aSat.EarthMJ2000Eq.X}

Create ReportFile rf
rf.Add = {aSat.UTCGregorian, aSat.EarthMJ2000Eq.X, ...
aSat.EarthMJ2000Eq.Y, aSat.EarthMJ2000Eq.Z, ...
aSat.EarthMJ2000Eq.VX, aSat.EarthMJ2000Eq.VY, aSat.EarthMJ2000Eq.VZ}

Create ReportFile rf2
rf2.WriteHeaders = false

Create EphemerisFile anEphemerisFile
GMAT anEphemerisFile.Spacecraft = aSat

Create GmatFunction Global_Objects
Global_Objects.FunctionPath = ...
'C:\Users\rqureshi\Desktop\Global_Objects.gmf'

Create Variable T X Y Z VX VY VZ

BeginMissionSequence

Global aSat
Global aFM TOI GOI DC
Global anOrbitView GroundTrackPlot1 XYPlot1 rf rf2 anEphemerisFile
Global T X Y Z VX VY VZ

% Report initial state to Global 'rf2':
Report rf2 aSat.UTCGregorian aSat.X aSat.Y aSat.Z ...
aSat.VX aSat.VY aSat.VZ

Propagate aProp(aSat) {aSat.ElapsedDays = 1.0}

T = aSat.UTCModJulian
X = aSat.X
Y = aSat.Y
Z = aSat.Z
VX = aSat.VX
VY = aSat.VY
VZ = aSat.VZ

% Call function. Pass Global Variables as input:
% Receive updated global S/C state via global variables:
[T,X,Y,Z,VX,VY,VZ] = Global_Objects(T,X,Y,Z,VX,VY,VZ)

% Report global variables to global 'rf2':
```

```
Report rf2 T X Y Z VX VY VZ

% Re-report global S/C state:
Report rf2 aSat.UTCGregorian aSat.X aSat.Y aSat.Z ...
aSat.VX aSat.VY aSat.VZ

%%%%%%% Function begins below:

function [T,X,Y,Z,VX,VY,VZ] = Global_Objects(T,X,Y,Z,VX,VY,VZ)

BeginMissionSequence

Global aSat
Global aFM TOI GOI DC
Global anOrbitView GroundTrackPlot1 XYPlot1 rf rf2 anEphemerisFile
Global T X Y Z VX VY VZ

% Report global variables to global 'rf2':
Report rf2 T X Y Z VX VY VZ

While aSat.ElapsedDays < 5
    Propagate aProp(aSat) {aSat.ElapsedDays = 0.5}
EndWhile

% Send global variables back to main script:
T = aSat.UTCModJulian
X = aSat.X
Y = aSat.Y
Z = aSat.Z
VX = aSat.VX
VY = aSat.VY
VZ = aSat.VZ
```

## If

Conditionally execute a series of commands

### Script Syntax

```
If logical expression
    [script statement]
    ...
EndIf
```

```
If logical expression
    [script statement]
    ...
Else
    [script statement]
    ...
EndIf
```

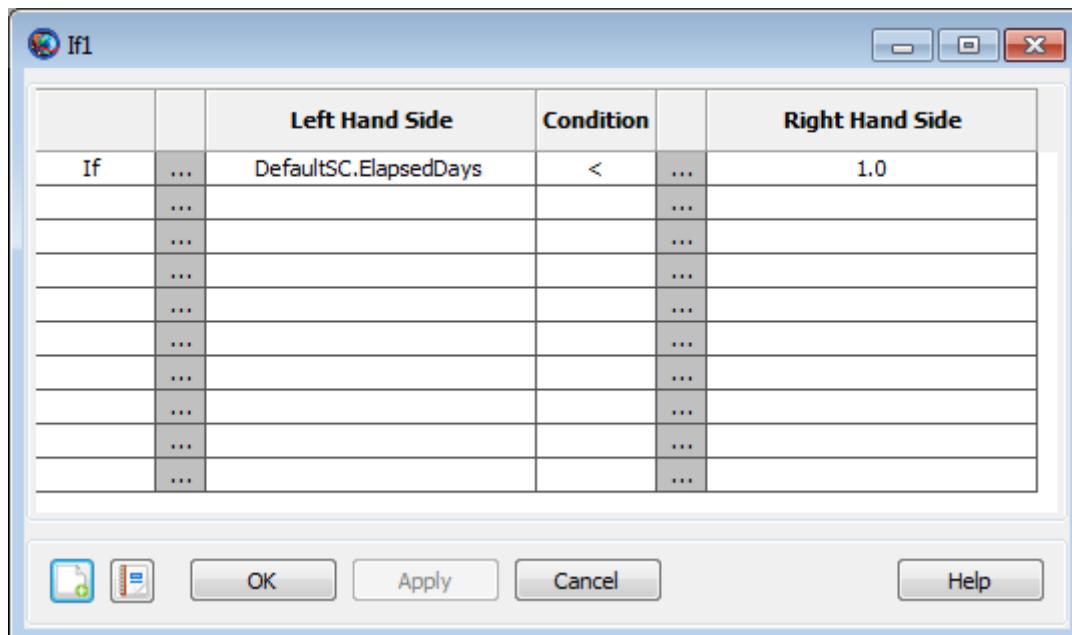
### Description

The **If** command is a control logic statement that executes a series of commands if the value of the provided logical expression is true. The syntax of the logical expression is described in the [script language reference](#).

The **If** command can optionally contain an **Else** clause that defines a series of commands to execute if the associated logical expression is false.

See Also: [Script Language](#), [For](#), [While](#)

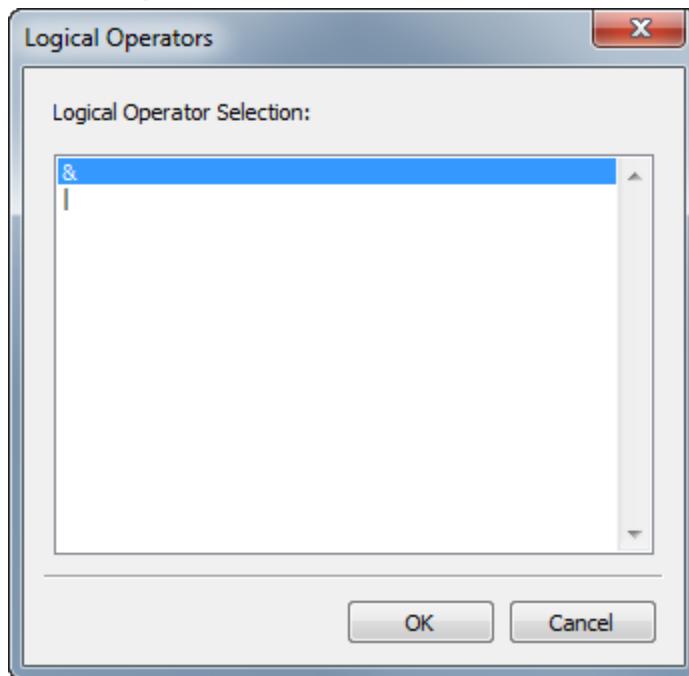
### GUI



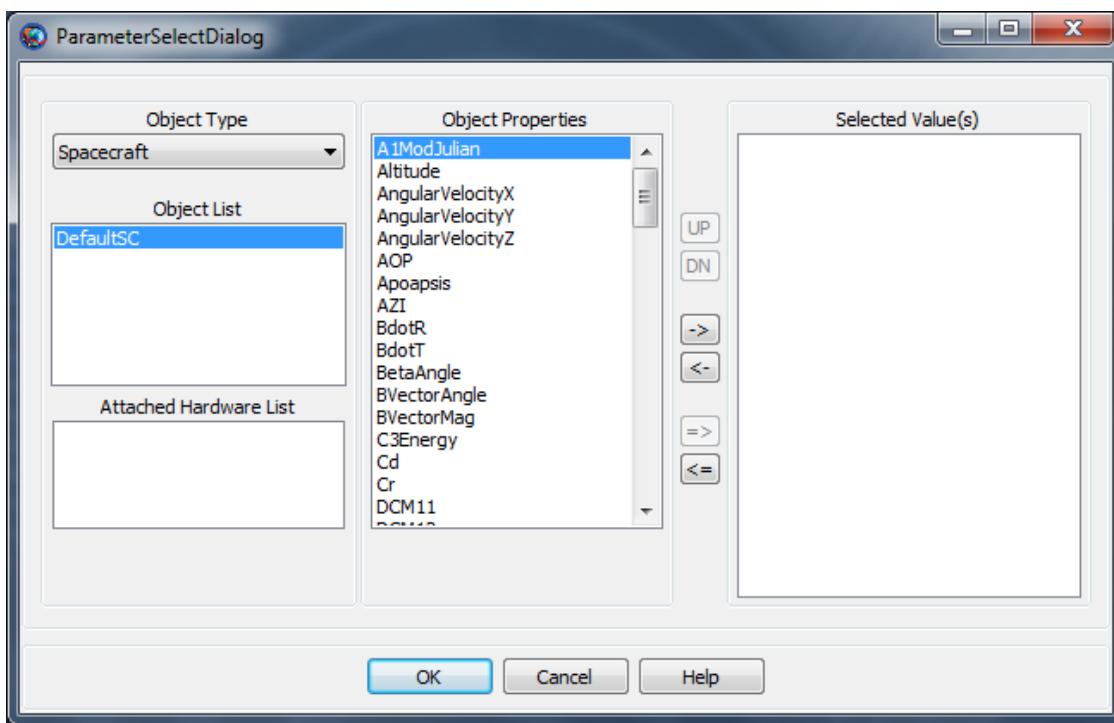
The **If** command GUI panel features a table in which you can build a complex logical expression. The rows of the table correspond to individual relational expressions in a compound logical expression (up to 10), and the columns correspond to individual elements of those expressions. The first line automatically contains a default statement:

```
If DefaultSC.ElapsedDays < 1.0
```

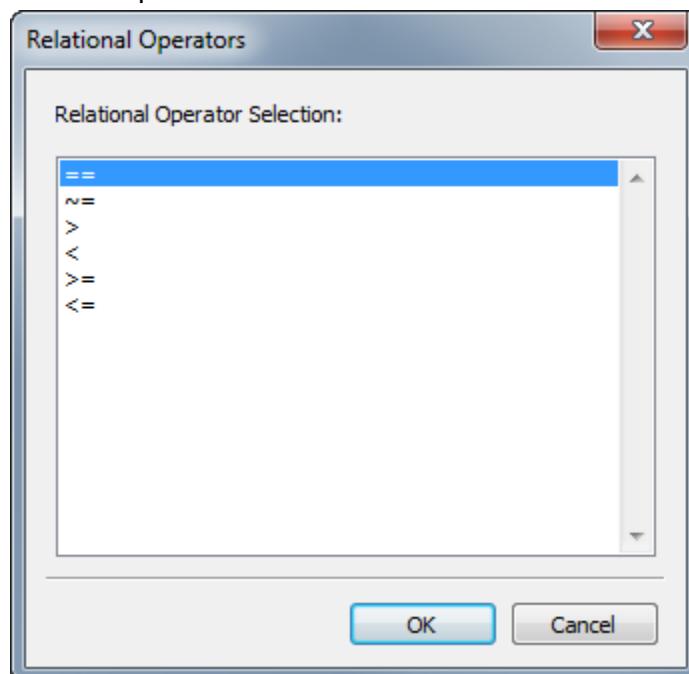
The first column of the first row contains a placeholder for the **If** command name. This cannot be changed. The first column of each additional row contains the logical operator (&, |) that joins the expression in that row with the one above it. To select a logical operator, double-click or right-click in the appropriate box in the table to display a selection window. Click the correct operator and click **OK** to select it.



The **Left Hand Side** column contains the left-hand side of each individual expression. Double-click the cell to type a parameter name. To set this value from a parameter selection list instead, either click “...” to the left of the cell you want to set, or right-click the cell itself. A **ParameterSelectDialog** window will appear that allows you to choose a parameter.



The **Condition** column contains the conditional operator ( $==$ ,  $\sim=$ ,  $<$ , etc.) that joins the left-hand and right-hand sides of the expression. To select a relational operator, double-click or right-click in the appropriate box in the table, and a selection window will appear. Click the correct operator and click **OK** to select it.



Finally, the **Right Hand Side** column contains the right-hand side of the expression. This value can be modified the same way as the **Left Hand Side** column.

When you are finished, click **Apply** to save your changes, or click **OK** to save your changes and close the window. The command will be validated when either button is clicked.

## Examples

A simple **If** statement:

```
Create Spacecraft aSat
Create ForceModel aForceModel

Create Propagator aProp
aProp.FM = aForceModel

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1, aSat.Altitude = 300}
If aSat.Altitude < 301 & aSat.Altitude > 299
    % propagation stopped on altitude constraint
Else
    % propagation continued for 1 day
EndIf
```

## Stop

Stop mission execution

### Description

The **Stop** command stops execution of the current mission at the point that the command is encountered and returns control to the GMAT interface. The effect is similar to that of the **Stop** button on the GUI toolbar.

### GUI

The **Stop** command can be inserted into and deleted from Mission tree, but the command has no GUI panel of its own.

### Remarks

The **Stop** command stops execution of the current mission, not the GMAT application. All data displayed to the point, at which the script was stopped (e.g. **OrbitView** windows, **GroundTrackPlot** windows), remain available for manipulation. Using the **Stop** command within a loop or solver structure will stop execution at the first iteration during which the command is encountered.

### Examples

Stopping the execution of a script between commands:

```
Create Spacecraft aSat
Create ForceModel aForceModel
Create Propagator aProp
aProp.FM = aForceModel

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 30};
Stop
Propagate aProp(aSat) {aSat.ElapsedDays = 30};
```

Stopping the execution of a solver structure for further investigation:

```
Create ChemicalTank aTank
Create ForceModel aForceModel
Create DifferentialCorrector aDC

Create Spacecraft aSat
aSat.Tanks = {aTank}

Create Propagator aProp
aProp.FM = aForceModel
```

```
Create ImpulsiveBurn anIB
anIB.DecrementMass = true
anIB.Tanks = {aTank}

BeginMissionSequence

Target aDC
Vary aDC(anIB.Element1 = 0.5)
Maneuver anIB(aSat)
Propagate aProp(aSat) {aSat.Periapsis}
If aSat.aTank.FuelMass < 10
Stop
EndIf
Achieve aDC(aSat.Altitude = 1000)
```

## While

Execute a series of commands repeatedly while a condition is met

### Script Syntax

```
While logical expression
    [script statement]
    ...
EndWhile
```

### Description

The **While** command is a control logic statement that executes a series of commands repeatedly as long as the value of the provided logical expression is true. The logical expression is evaluated before every iteration of the loop. If the expression is initially false, the loop is never executed. If the while loop is empty, it is skipped and a warning message is posted to the user. The syntax of the expression is described in the [script language reference](#).

See Also: [Script Language](#), [For](#), [If](#)

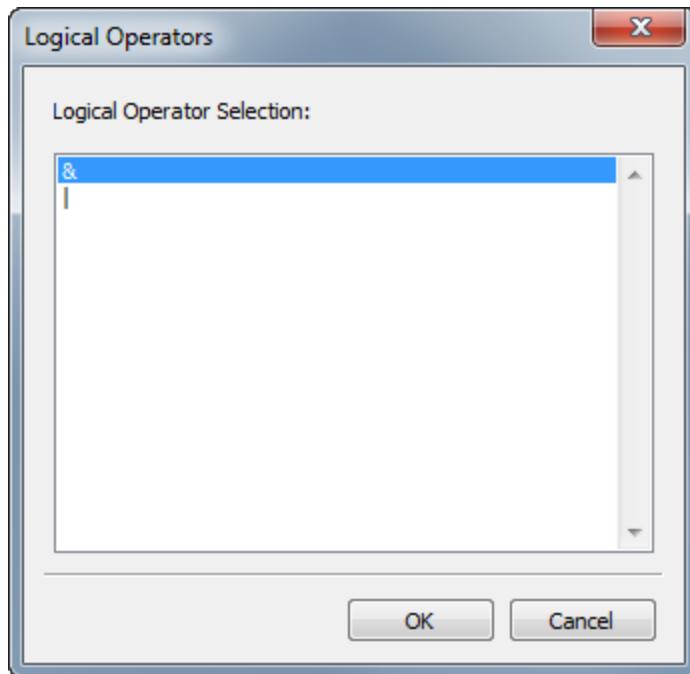
### GUI



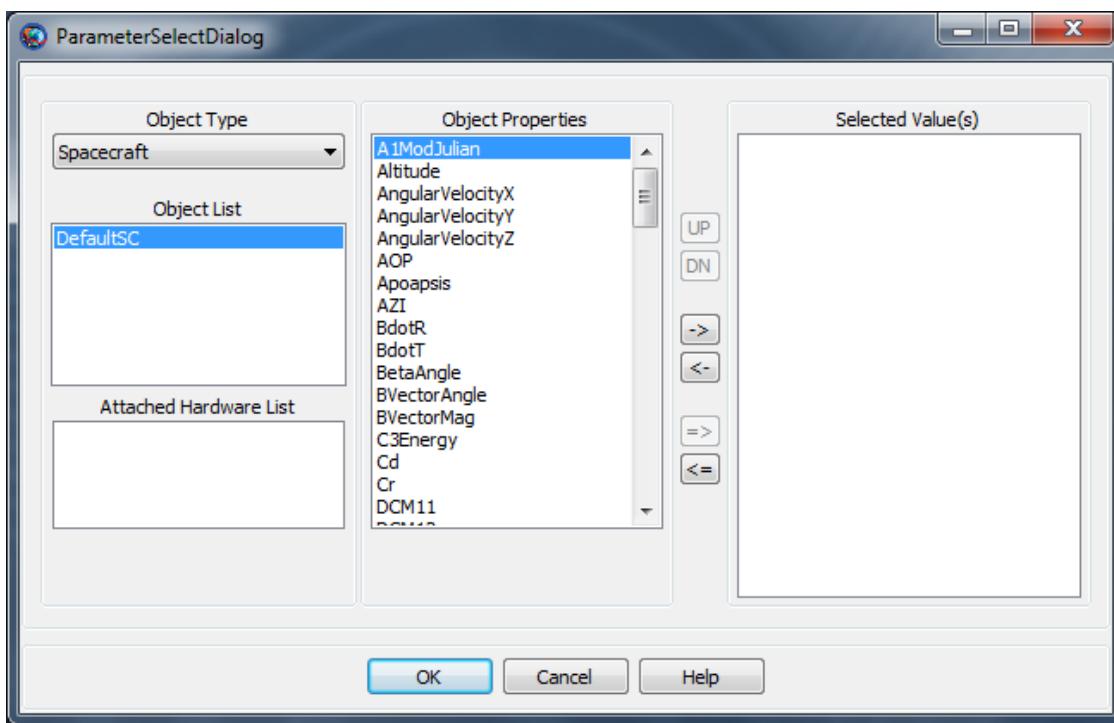
The **While** command GUI panel features a table in which you can build a complex logical expression. The rows of the table correspond to individual relational expressions in a compound logical expression, and the columns correspond to individual elements of those expressions. The first line automatically contains a default statement:

```
While DefaultSC.ElapsedDays < 1.0
```

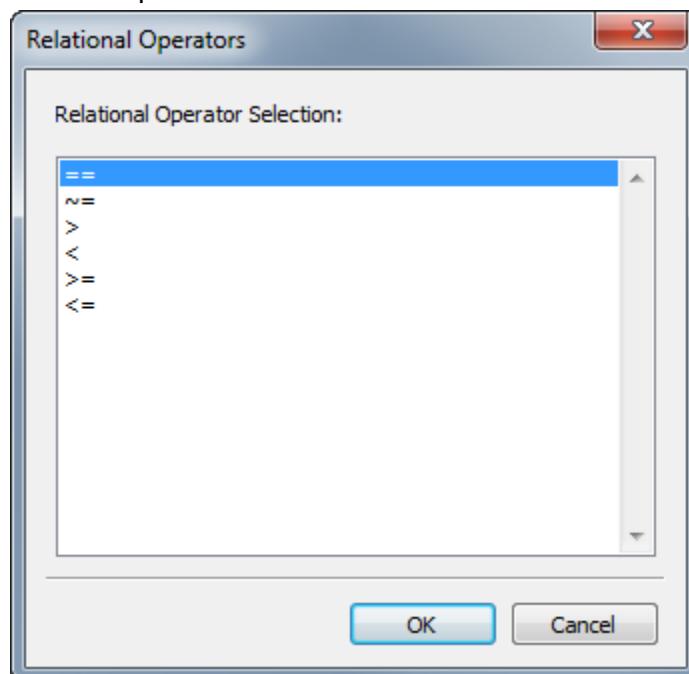
The first column of the first row contains a placeholder for the **While** command name. This cannot be changed. The first column of each additional row contains the logical operator (**&**, **|**) that joins the expression in that row with the one above it. To select a logical operator, double-click or right-click in the appropriate box in the table, and a selection window will appear. Click the correct operator and click **OK** to select it.



The **Left Hand Side** column contains the left-hand side of each individual relational expression. Double-click the cell to type a parameter name. To set this value from a parameter selection list instead, either click "..." to the left of the cell you want to set, or right-click the cell itself. A **ParameterSelectDialog** window will appear that allows you to choose a parameter.



The **Condition** column contains the conditional operator ( $==$ ,  $\sim=$ ,  $<$ , etc.) that joins the left-hand and right-hand sides of the expression. To select a relational operator, double-click or right-click in the appropriate box in the table, and a selection window will appear. Click the correct operator and click **OK** to select it.



Finally, the **Right Hand Side** column contains the right-hand side of the expression. This value can be modified the same way as the **Left Hand Side** column.

When you are finished, click **Apply** to save your changes, or click **OK** to save your changes and close the window. The command will be validated when either button is clicked.

## Examples

Propagate a spacecraft until it reaches a predefined altitude, reporting data at each periapsis crossing:

```
Create Spacecraft aSat
aSat.SMA = 6800
aSat.ECC = 0

Create ForceModel aForceModel
aForceModel.Drag.AtmosphereModel = MSISE90

Create Propagator aProp
aProp.FM = aForceModel

Create ReportFile aReport

BeginMissionSequence

While aSat.Altitude > 300
    Propagate aProp(aSat) {aSat.Periapsis}
    Report aReport aSat.TAIGregorian aSat.Altitude
EndWhile
```

## System

## #Include Macro

Load or import a script snippet

### Script Syntax

```
#Include './Define_Path_to_Script_Snippet_File_In_SingleQuotes.txt'
```

```
#Include UserStringVariable
```

### Description

Using the **#Include** macro, GMAT now allows you to load GMAT resources and script snippets from external files during the script initialization and mission execution. This is a powerful feature that allows you to reuse configurations across multiple users and/or scripts. This feature can be used to simplify automation for operations and Monte-Carlo and parametric scanning that have use cases with a lot of common data but some data that changes from one execution to the next.

The script snippet external files that you can now load using the **#Include** macro can be defined with any file extensions, although most common file extensions are (\*.script) or (\*.txt). The **#Include** macro can be used to load snippets from external files either before or after the **BeginMissionSequence** script command. The **#Include** macro can only be used through the script mode and its usage is not allowed via the GUI.

### GUI

There are two rules in regards to how GMAT's GUI behaves whenever we use the **#Include** macro:

1. If any **#Include** macro is used before **BeginMissionSequence**, then GMAT's GUI is editable, runnable but you cannot save GMAT scripts from the GUI's Save button. You can of course make changes to your script in the Script mode and save your changes from the script mode.
2. If there are no **#Include** macros before **BeginMissionSequence** and there are any number of **#Include** macros after **BeginMissionSequence**, then GMAT's GUI is editable, runnable and savable (i.e. you can make changes to objects in the GUI and then save those changes to the script from the GUI's Save button).

Whenever you load and run GMAT scripts that may use an **#Include** macro before **BeginMissionSequence** command, (i.e. Rule # 1 defined above), then GMAT's **Resources**, **Mission** and **Output** trees will change color to a light olive green and a Non-Savable GUI Mode message will show up in red color at the top center of the main GMAT screen. This light olive green color change and Non-Savable GUI Mode message is simply telling you that GMAT's GUI is editable, runnable but you cannot save changes to your GMAT script via GMAT GUI's Save button.

If your GMAT script only contains **#Include** macro(s) after **BeginMissionSequence** (i.e. Rule # 2 defined above), then no color changes occur in GMAT's **Resources**, **Mission**

and **Output** trees and you can save changes to your scripts either from GUI or script mode.

## Remarks

In GMAT, the default method of defining the file path of the external file(s) that you want to load using the **#Include** macro is: './My\_Script\_Snippet.txt'. This is the easiest and most convenient method of defining the path of your script snippet files as it simply requires that both your main script and script snippet file be in the same directory. You can also define both relative ('..\My\_Script\_Snippet.txt') and absolute paths to your external script snippet files.

You may also use a created [String](#) variable's value as the path for **#Include**. For example, setting your variable as UserString = './My\_Script\_Snippet.txt', the scripting #Include UserString would include your listed file.

The [Examples](#) section shows you simple yet powerful examples of how to use the **#Include** macro in simplifying your main GMAT scripts.

## Examples

Initialize S/C from an external script snippet file called 'Initialize\_Spacecraft.txt'. Run this example by creating a .txt file and paste contents of 'Initialize\_Spacecraft.txt' and put this snippet script in same directory as the main GMAT script.

```
Create Spacecraft aSat

%Initialize aSat from external file:
#include './Initialize_Spacecraft.txt'

Create Propagator aProp

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 0.5}

%%%%% Contents of 'Initialize_Spacecraft.txt' snippet file begins below:

aSat.DateFormat = UTCGregorian
aSat.Epoch = '02 Jan 2000 11:59:28.000'
aSat.CoordinateSystem = EarthMJ2000Eq
aSat.DisplayStateType = Cartesian
aSat.X = 8000
aSat.Y = 2000
aSat.Z = 4000
aSat.VX = 0.5
```

```

aSat.VY = 7.5
aSat.VZ = 1.5
aSat.DryMass = 1000
aSat.Cd = 2.2
aSat.Cr = 1.8
aSat.DragArea = 20
aSat.SRPArea = 1
aSat.NAIFId = -10009001
aSat.NAIFIdReferenceFrame = -9009001
aSat.OrbitColor = Yellow
aSat.TargetColor = Teal
aSat.Id = 'SatId'
aSat.Attitude = CoordinateSystemFixed
aSat.SPADSRPScaleFactor = 1
aSat.ModelFile = 'aura.3ds'
aSat.ModelOffsetX = 0
aSat.ModelOffsetY = 0
aSat.ModelOffsetZ = 0
aSat.ModelRotationX = 0
aSat.ModelRotationY = 0
aSat.ModelRotationZ = 0
aSat.ModelScale = 1
aSat.AttitudeDisplayStateType = 'Quaternion'
aSat.AttitudeRateDisplayStateType = 'AngularVelocity'
aSat.AttitudeCoordinateSystem = EarthMJ2000Eq
aSat.EulerAngleSequence = '321'
```

In this example, we call an external file through **#Include** macro which is used only after the **BeginMissionSequence** command. Perform a finite burn from an external script snippet file called 'Perform\_FiniteBurn.txt'. Run this example by creating a .txt file and paste contents of 'Perform\_FiniteBurn.txt' and put this snippet script in same directory as the main GMAT script.

```

Create Spacecraft aSat

Create ChemicalTank aFuelTank

Create ChemicalThruster aThruster
aThruster.DecrementMass = true
aThruster.Tank = {aFuelTank}
aThruster.C1 = 1000 % Constant Thrust
aThruster.K1 = 300 % Constant Isp

aSat.Thrusters = {aThruster}
aSat.Tanks = {aFuelTank}

Create ForceModel aFM
aFM.CentralBody = Earth
aFM.PointMasses = {Earth}
```

```

Create Propagator aProp
aProp.FM = aFM

Create FiniteBurn aFB
aFB.Thrusters = {aThruster}

Create ReportFile rf
rf.Add = {aSat.UTCGregorian, aFB.TotalAcceleration1, ...
aFB.TotalAcceleration2, aFB.TotalAcceleration3, ...
aFB.TotalMassFlowRate, aFB.TotalThrust1, ...
aFB.TotalThrust2, aFB.TotalThrust3, ...
aSat.aThruster.MassFlowRate, ...
aSat.aThruster.ThrustMagnitude, aSat.aThruster.Isp}

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedSecs = 1000}

%Perform a FiniteBurn from an external file:
#include './Perform_FiniteBurn.txt'

Propagate aProp(aSat) {aSat.ElapsedSecs = 1000}

%%%%% Contents of 'Perform_FiniteBurn.txt' snippet file begins below:

% Do a Finite-Burn for 1800 Secs

BeginFiniteBurn aFB(aSat)
Propagate aProp(aSat) {aSat.ElapsedSecs = 1800, OrbitColor = Yellow}
EndFiniteBurn aFB(aSat)

```

In this example, we call external files through **#Include** macros which are used both before and after the **BeginMissionSequence**. Note that all objects in the Resources tree are imported and initialized from an external script snippet file called 'Entire\_Resources\_Tree.txt'. Similarly, all commands in the Mission tree are loaded from an external snippet file called 'Entire\_Mission\_Tree.txt'. Run this example by creating a .txt file and paste contents of 'Entire\_Resources\_Tree.txt'. Next create another .txt file and paste contents of 'Entire\_Mission\_Tree.txt'. Put both of these snippet scripts in same directory as the main GMAT script and then run the main GMAT script.

```

% Initialize all Resources tree objects
% from an external file:
#include './Entire_Resources_Tree.txt'

```

```
BeginMissionSequence

% Execute all Mission tree commands
% from an external file:
#include './Entire_Mission_Tree.txt'

%%%%% Contents of 'Entire_Resources_Tree.txt' snippet file begins below:

Create Spacecraft aSat

Create Propagator aProp

Create ImpulsiveBurn TOI

Create DifferentialCorrector aDC

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth}
anOrbitView.SolverIterations = All

%%%%% Contents of 'Entire_Mission_Tree.txt' snippet file begins below:

Propagate aProp(aSat) {aSat.Earth.Periapsis}

Target aDC
Vary aDC(TOI.Element1 = 0.24, {Perturbation = 0.001, ...
Lower = 0.0, Upper = 3.14159, MaxStep = 0.5})
Maneuver TOI(aSat)
Propagate aProp(aSat) {aSat.Earth.Apoapsis}
Achieve aDC(aSat.Earth.RMAG = 42165)
EndTarget
```

## MATLAB Interface

Interface to MATLAB system

### Description

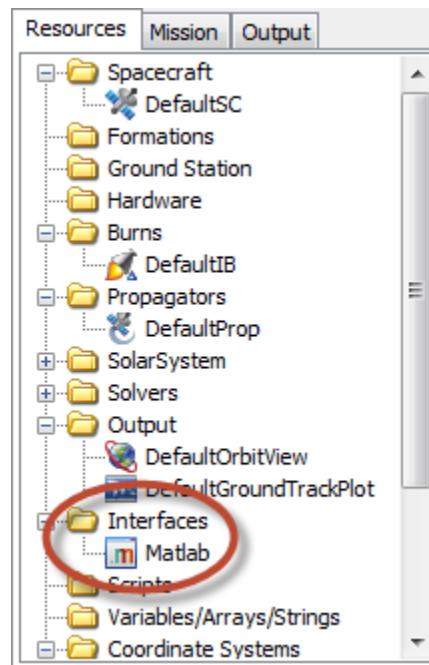
The MATLAB interface provides a link to the Mathworks MATLAB environment, allowing GMAT to run MATLAB functions as if they were native functions in the GMAT script language.

The interface cannot be controlled directly through the script language, though it can be in the GMAT GUI. Instead, GMAT starts the interface automatically when it calls a MATLAB function.

There are two GMAT components that provide user access to the interface. For details on declaring a MATLAB function, see the [MatlabFunction](#) reference. For details on calling a function and passing data, see the [CallMatlabFunction](#) reference.

See Also: [CallMatlabFunction](#), [MatlabFunction](#)

### GUI



The MATLAB interface provides an icon in the **Interfaces** folder in the Resources tree that can be used to control the interface. Right-clicking the icon shows two options: **Open** and **Close**.

The **Open** menu item causes GMAT to open a connection to the MATLAB Engine, which in turns displays a MATLAB command window in the background. This connection is then used for all communication between GMAT and MATLAB until the connection is closed. Only one connection can be open at a time.

The **Close** menu item causes GMAT to close any open connection to the MATLAB Engine. If no connection is open, it has no effect.

## Remarks

### Interface Setup

The following conditions must be true for GMAT to successfully initiate communication with MATLAB. All conditions must be true for the same instance of MATLAB.

- Install a compatible, licensed version of MATLAB on the same machine on which GMAT is running. GMAT is tested with the latest version of MATLAB at the time of release, though versions R2006b and newer have been known to work.
- The architecture (32-bit or 64-bit) of GMAT and the installed version of MATLAB must match. For example, the 32-bit version of GMAT is compatible only with the 32-bit version of MATLAB.
- On Windows:
  1. Add the following path (where *MATLAB* is the path to the installed version of MATLAB) to your Path environment variable (either your user variable, or the system variable). If you continue to have trouble, try putting this path at the very beginning of your system path.

*MATLAB\bin\win32* (or *win64* for use with 64-bit versions of GMAT)

2. Register MATLAB for use as a COM server by running:

```
matlab -regserver
```

This is done automatically by the MATLAB installer. To do it manually, open an elevated command window and run the command above. Make sure to run the command in the folder containing the executable you wish to use (i.e. *MATLAB\bin\win32* or *MATLAB\bin\win64*.)

- On macOS:
  1. Open the MacConfigure.txt in the bin directory and edit the MATLAB\_APP\_PATH field to point to the location of your MATLAB application bundle.
  2. If the Matlab interface does not work with the GmatConsole command line application, you may need to set up your Terminal so that the system can load the Matlab libraries and start up MATLAB. For example, if you are using a .bashrc, you may need to add something like this:

```
export MATLAB = <path/to/MATLAB/app/location/>
```

```
export DYLD_LIBRARY_PATH=$MATLAB/bin/maci64:$DYLD_LIBRARY_PATH
```

```
export PATH=$PATH:$MATLAB/bin
```



### Note

64-bit GMAT must be used to interface with MATLAB after version R2010a.

- On Linux:
  - The MATLAB interface on Linux requires that the C shell, csh, be installed. This is a requirement from the MathWorks for startup of the MATLAB engine, used for the interface. If your system does not have csh installed, the package manager for your Linux installation should include csh as an installation option.

The MATLAB interface needs to be able to locate the MATLAB shared libraries libeng.so (and related libraries) and libMatlabEngine.so. For MATLAB R2019a, the former is in the MATLAB bin/glnxa64 folder and the latter in MATLAB's extern/bin/glnxa64 folder. One way to start GMAT and apply the library path settings is to launch the application with a library path. From the Linux terminal, the command (for MATLAB installed in the default /usr/local/MATLAB/R2019a folder)

```
LD_LIBRARY_PATH=/usr/local/MATLAB/R2019a/extern/bin/glnxa64:/usr/local/MATLAB/R2019a/bin/glnxa64 ./GMAT
```

accomplishes this task, starting the GMAT GUI with the settings needed to run the MATLAB interface.



### Note

Common troubleshooting tips on Windows:

- If you are using the officially-released 32-bit version of GMAT, make sure you have the 32-bit version of MATLAB installed.
- If the path above exists in your system Path variable, try place it at the front.
- Make sure the same instance of MATLAB is referenced both in the Path variable and when running `matlab -regserver`.

## MATLAB Engine Connection



### Warning

Caution: GMAT does not close the MATLAB Command Window it creates after a run has completed. This allows manual inspection of the MATLAB workspace, but it can lead to confusing behavior if MATLAB functions or paths are changed and rerun in the same window.

We recommend closing the MATLAB Command Window by right-clicking Matlab in the Resources tree and clicking Close between each run if you are actively editing the script.

When GMAT runs a mission that contains a MATLAB function call, it opens a connection to the MATLAB engine before it makes the function call. It then reuses this connection for the rest of the GMAT session.

The MATLAB Engine can be controlled manually through the **Open** and **Close** options available by right-clicking the **Matlab** item in the Resources tree.

## Examples

See the [MatlabFunction](#) reference for common examples.

## Python Interface

Interface to the Python programming language

### Description

The Python interface provides a link to the Python programming language, allowing GMAT to run Python functions as if they were native functions in the GMAT script language.

The interface does not have any parameters that can be controlled directly through the GMAT script language. Instead, GMAT starts the Python interface automatically when it calls a Python function.

The Python interface is accessed using GMAT's `CallPythonFunction` command. For details on calling a function and passing data, see the [CallPythonFunction](#) reference.

*See Also:* [CallPythonFunction](#)

### GUI

The Python interface in GMAT is launched and driven internally. Users do not have direct access to the interface from the GMAT graphical user interface.

### Remarks

#### Interface Setup

The following conditions must all be true for GMAT to successfully call into a compatible instance of Python.

- The GMAT startup file must specify a version of the Python interface that matches the installed version of Python (see compatibility table below). Only one version of the Python interface can be loaded at a time. Note that untested Python interface versions are provided purely for convenience.

Python Version	Python Interface Plugin	Status
<b>3.6 (64-bit)</b>	<code>libPythonInterface_py36</code>	Linux and Windows only, untested
<b>3.7 (64-bit)</b>	<code>libPythonInterface_py37</code>	Linux and Windows only, untested
<b>3.8 (64-bit)</b>	<code>libPythonInterface_py38</code>	Untested
<b>3.9 (64-bit)</b>	<code>libPythonInterface_py39</code>	Tested
<b>3.10 (64-bit)</b>	<code>libPythonInterface_py310</code>	Tested
<b>3.11 (64-bit)</b>	<code>libPythonInterface_py311</code>	Tested
<b>3.12 (64-bit)</b>	<code>libPythonInterface_py312</code>	Tested

- GMAT no longer supports 32-bit Python.
- The Python interface accesses Python modules on the user's machine. This functionality is configured, including path information used by Python, on a per-OS basis as shown below.

- On Windows:
  - The following path entries (where *Python* is the full path to the installed version of Python) must be present in the Path environment variable.

*Python*

*Python\Scripts*

- The following path (where *Python* is the path to the installed version of Python) must be present in the PYTHONPATH environment variable.

*Python\Lib\site-packages*

- The PYTHONHOME environment variable must be set to the directory containing *python3X.dll*, where 3X denotes the python version, for example **python39.dll**. This directory is normally the root directory of your python installation or Anaconda environment.

If you are using Anaconda Python, these paths may be set to point to directories within the Anaconda environment you want GMAT to use.

- On macOS:

- On macOS, the Python interface only works with Python.org distributions of Python. These installations must be in the following specific directory (default for Python.org): /Library/Frameworks/Python.framework/Versions/3.X

The Python interface has not been tested with Anaconda Python on macOS.

- The following entry (where *Python* is the full path to the installed version of Python 3.X) must be present in the GMAT startup file. This allows the Python Interface to access Python packages such as Numpy.

PYTHON\_MODULE\_PATH = *Python/lib/python3.X/site-packages*

Note that multiple PYTHON\_MODULE\_PATH entries are allowed in the startup file, and they can be placed anywhere in the file.

- Python versions 3.6 and 3.7 are not supported for the Mac platform.
- On Linux:
  - The Python release used in the GMAT build must be the default Python package (e.g. Python 3.6) accessed from the terminal.

Users that enable the MATLAB interface may find that the Python interface does not load because of a library conflict. If the Python interface reports the issue

**undefined symbol: XML\_SetHashSalt**

there is a conflict between the expat library that is included with MATLAB and the library required for the distribution's Python 3 installation. This issue can be corrected by loading the system expat library before GMAT starts using the LD\_PRELOAD command. The command

loads the expat library and then launches GMAT, resolving the issue for systems like Ubuntu 18.04.



### Note

Common troubleshooting tips on Windows:

- If you are using the officially-released 32-bit version of GMAT, make sure you have the 32-bit version of Python installed.
- If the path above exists in your system Path variable, try placing it at the front of the path specification.

## Python Engine Connection



### Warning

GMAT does not close the Python interface after a run has completed. This feature prevents anomalous behavior that can occur when loading some Python modules repeatedly during a run, but it can lead to confusing behavior if Python files are changed and rerun in the same GMAT session.

We recommend restarting GMAT after editing Python functions in order to guarantee that your edits take effect when you rerun your script.

When GMAT runs a mission that contains a Python function call, it loads Python into memory as an embedded system in GMAT before it makes the function call. It then reuses this system for the rest of the GMAT session.

## Examples

See the [CallPythonFunction](#) reference for common examples.



# Optimal Control

## User Guide



### Note

The user guide for the optimal control components including CSALT and GMAT optimal control are written in Sphinx and located in the GMAT distribution here: [gmat/docs/GMAT\\_OptimalControl\\_Specification.pdf](#)



# System

This chapter contains documentation for Resources and Commands related to the system and for system setup and execution.

## System Level Components

## Calculation Parameters

Resource properties available for use by commands and output

### Description

Parameters are named resource properties that can be used to obtain data for use by Mission Sequence commands or by output resources. Some parameters, such as the **Altitude** parameter of **Spacecraft**, are calculated values that can only be used to retrieve data. They cannot be set directly. Others, such as the **Element1** parameter of **ImpulsiveBurn**, share the same name as a resource field and can be used both to set data and retrieve it. Parameters are distinguished from resource fields by their extra functionality: fields are static resource properties that are usually set in initialization (or in the GUI Resources tree), while parameters can be calculated on the fly and used in plots, reports, and mathematical expressions.

Parameters are classified as one of four types: central-body-dependent parameters, coordinate-system-dependent parameters, attached-hardware parameters, and stand-alone parameters. Standalone parameters are the simplest type, as they have no dependencies. The **ElapsedSecs** parameter of **Spacecraft** is an example of this; it is simply referenced as *Spacecraft*.**ElapsedSecs**.

Central-body-dependent parameters, as the name suggests, have a value that is dependent on the chosen celestial body. The **Altitude** parameter of **Spacecraft** is an example of this. To reference this parameter, you must specify a central body, such as *Spacecraft*.**Mars**.**Altitude**. Any built-in central body or user-defined **Asteroid**, **Comet**, **Moon**, or **Planet** is valid as a dependency.

Likewise, coordinate-system-dependent parameters have a value that is dependent on the chosen coordinate system. The **DEC** parameter of **Spacecraft** is an example of this. To reference this parameter, you must specify the name of a **CoordinateSystem** resource, such as *Spacecraft*.**EarthFixed**.**DEC**. Any default or user-defined **CoordinateSystem** resource is valid as a dependency.

If a dependency is used when retrieving the value of the parameter, as in the following line, the value of **Altitude** is calculated at Mars before setting it to the variable *x*. If the dependency is omitted, **Earth** and **EarthMJ2000Eq** are assumed unless noted otherwise.

```
x = DefaultSC.Mars.Altitude
```

If a dependency is used when setting the value of a parameter, the value of the parameter is first converted based on the value of the dependency, then the value is set. For example, in the following line, the value of **SMA** is first calculated at Mars, then it is set to the value **10000** in that context. If the dependency is omitted when setting the value, the default is assumed to be the central body or coordinate system of the parent resource (in this case, **DefaultSC**).

```
DefaultSC.Mars.SMA = 10000
```

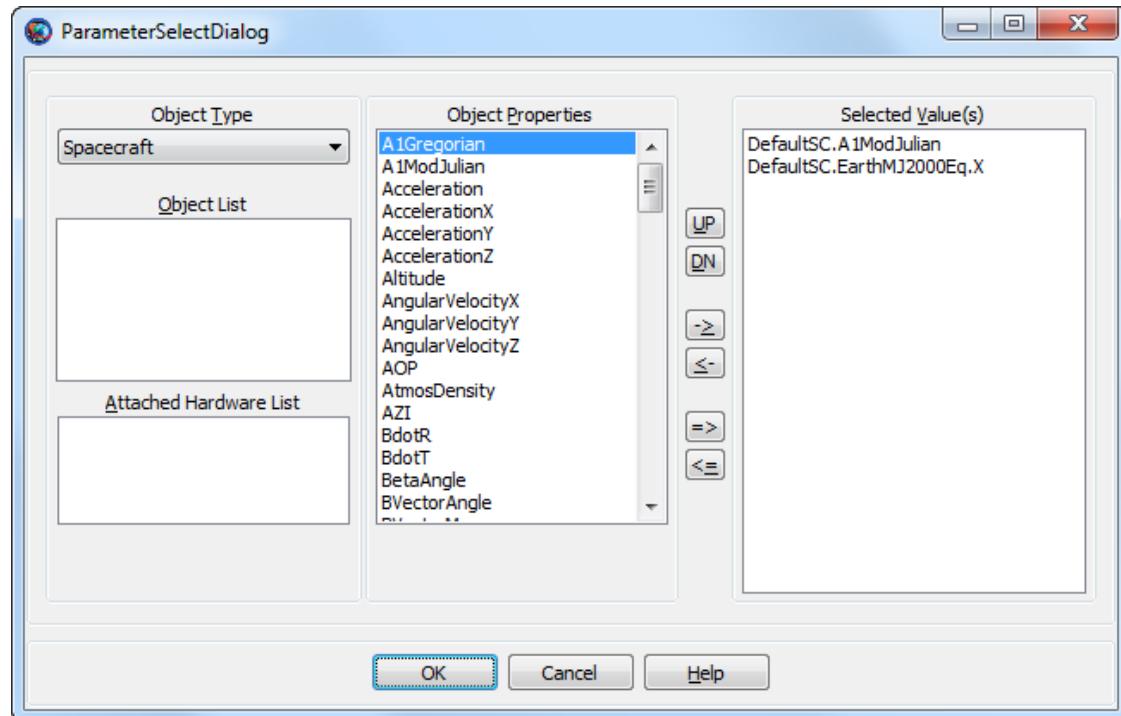
Attached-hardware parameters have no dependencies, but are themselves dependent on being attached to a **Spacecraft**. **ChemicalTank** and **ChemicalThruster** parameters are examples of this. The **FuelMass** parameter of **ChemicalTank** cannot be referenced without first attaching the **ChemicalTank** to a **Spacecraft**. Then, the parameter can be referenced as: *Spacecraft.FuelTank.FuelMass*.

The individual parameters are resource-specific, and are documented in the tables below. The GUI has a parameter selection interface that is common to all parameters. This interface is documented in GUI, below.

See Also: [Array](#), [ChemicalTank](#), [ImpulsiveBurn](#), [FiniteBurn](#), [Spacecraft](#), [String](#), [ChemicalThruster](#), [Variable](#)

## GUI

Parameters can be used as input in several places throughout GMAT, such as the **ReportFile** and **XYPlot** resources and the **If/Else**, **Propagate**, and **Report** commands. In the GUI, all of these use a common interface called the **ParameterSelectDialog** that allows for interactive parameter selection. A basic **ParameterSelectDialog** window looks like the following:



The **ParameterSelectDialog** window is used to build a parameter, along with any dependencies, for use in a command or resource. Some resources and commands have different requirements for the types of parameters that can be used, so the **ParameterSelectDialog** can take slightly different forms, depending on where it's used. This section will describe the generic interface, then mention any resource- or command-specific exceptions.

## General Usage

The first step in choosing a parameter is to select the object (or resource) type from the **Object Type** list in the upper left. Seven types can appear in this list: **Spacecraft**, **SpacePoint**, **ImpulsiveBurn**, **FiniteBurn**, **Variable**, **Array**, and **String**.

Once you've selected a type, The **Object List** box is populated with all existing resources of that type. Use this list to choose the specific resource you'd like to reference.

If the **Spacecraft** type is selected, the **Attached Hardware List** appears below the **Object List**. This list displays any hardware (such as **ChemicalTank** or **ChemicalThruster** resources) attached to the selected **Spacecraft**. If the **Array** type is selected, **Row** and **Col** boxes appear. Use these to specify a row and column to select an individual array element, or check **Select Entire Object** to choose the entire array.

Once a resource is selected, the **Object Properties** list is populated with all available parameters provided by that resource. Some resources, such as instances of **Variable** or **Array**, are themselves parameters, so this list remains empty.

Parameters with different dependency types are commingled in the **Object Properties** list. When you select one, the appropriate dependency (if any) appears below the list. For example, after selecting the **Spacecraft AOP** parameter, a **CoordinateSystem** list appears. After selecting the **Spacecraft Apoapsis** parameter, a **Central Body** list appears. And after selecting the Spacecraft Cd parameter, no dependency list appears. To select a range of parameters from the **Object Properties** list, hold down the Shift key while selecting the second endpoint of the range. To select multiple individual parameters, hold down the Ctrl key while making each selection.

To select a parameter, select the appropriate **Object Type**, the specific resource from the **Object List** or **Attached Hardware List**, the desired parameter from the **Object Properties** list, and the required dependency, and add it to the **Selected Value(s)** list on the right. There are six buttons available to control this list:

- **UP**: Move the selected item in the **Selected Value(s)** list up one position (if allowed).
- **DN**: Move the selected item in the **Selected Value(s)** list down one position (if allowed).
- **->**: Add the selected item in the **Object Properties** list to the **Selected Value(s)** list.
- **<-**: Remove the selected item in the **Selected Value(s)** list.
- **=>**: Add all items to the **Selected Value(s)** list.
- **<=**: Remove all items from the **Selected Value(s)** list.

When finished, the **Selected Value(s)** list contains the final selected parameters. Click **OK** to accept the selection.

The ordering of the **Selected Value(s)** list is significant in certain circumstances (such as in the **Add** field of **ReportFile**), but not in others. See the documentation for each resource or command for details.

## Special Considerations

Some resources and commands (such as the **Propagate** command **Parameter** argument) only accept a single parameter as input; in this context the **ParameterSelectDi-**

**alog** only allows one parameter in the **Selected Value(s)** list and does not allow use of the **UP**, **DN**, and **=>** buttons.

In some instances (such as in the **Vary** command), only parameters that are also fields (and so can be set in the **Mission Sequence**) can be used. In this case only the allowed parameters will be shown in the **Object Properties** list.

In the **Propagate** command **Parameter** argument, only parameters of **Spacecraft** can be used. In this case only **Spacecraft** will be shown in the **Object Type** list.

## Parameters

### Spacecraft

Parameter	Set-	Plot-	Description
	tabletable		
<b>A1Gregorian</b>	Y	N	Spacecraft epoch in the A.1 system and the Gregorian format.  <b>Data Type</b> String <b>Dependency</b> (None) <b>Units</b> (N/A)
<b>A1ModJulian</b>	Y	Y	Spacecraft epoch in the A.1 system and the Modified Julian format.  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> d
<b>Acceleration</b>	N	Y	The total acceleration with respect to the inertial system computed using the <b>ForceModel</b> selected for the dependency.  <b>Data Type</b> Real <b>Dependency</b> <b>ForceModel</b> <b>Units</b> km/s <sup>2</sup>
<b>AccelerationX</b>	N	Y	The x-component of acceleration with respect to the inertial system computed using the <b>ForceModel</b> selected for the dependency.  <b>Data Type</b> Real <b>Dependency</b> <b>ForceModel</b> <b>Units</b> km/s <sup>2</sup>
<b>AccelerationY</b>	N	Y	The y-component of acceleration with respect to the inertial system computed using the <b>ForceModel</b> selected for the dependency.  <b>Data Type</b> Real <b>Dependency</b> <b>ForceModel</b> <b>Units</b> km/s <sup>2</sup>

Parameter	Set-	Plot-	Description
	tabletable		
<b>AccelerationZ</b>	N	Y	The z-component of acceleration with respect to the inertial system computed using the <b>ForceModel</b> selected for the dependency.
			<p><b>Data Type</b> String</p> <p><b>Dependency</b> ForceModel</p> <p><b>Units</b> km/s<sup>2</sup></p>
<b>AltEquinoctialP</b>	Y	Y	See <a href="#">Spacecraft.AltEquinoctialP</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> CoordinateSystem</p> <p><b>Units</b> (None)</p>
<b>AltEquinoctialQ</b>	Y	Y	See <a href="#">Spacecraft.AltEquinoctialQ</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> CoordinateSystem</p> <p><b>Units</b> (None)</p>
<b>Altitude</b>	N	Y	Distance to the plane tangent to the surface of the specified celestial body at the sub-satellite point. GMAT assumes the body is an ellipsoid.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> CelestialBody</p> <p><b>Units</b> km</p>
<b>AngularVelocityX</b>	Y	Y	See <a href="#">Spacecraft.AngularVelocityX</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> deg/s</p>
<b>AngularVelocityY</b>	Y	Y	See <a href="#">Spacecraft.AngularVelocityY</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> deg/s</p>
<b>AngularVelocityZ</b>	Y	Y	See <a href="#">Spacecraft.AngularVelocityZ</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> deg/s</p>
<b>AOP</b>	Y	Y	See <a href="#">Spacecraft.AOP</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> CoordinateSystem</p> <p><b>Output Range</b> 0° # AOP &lt; 360°</p> <p><b>Units</b> deg</p>

Parameter	Set- Plot- Description tabletable		
<b>Apoapsis</b>	N	Y	A parameter that equals zero when the spacecraft is at orbit apoapsis. This parameter can only be used as a stopping condition in the <b>Propagate</b> command.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> <b>CelestialBody</b></p> <p><b>Units</b> (None)</p>
<b>AtmosDensi- ty</b>	N	Y	The atmospheric density at the current <b>Spacecraft</b> epoch and location computed using the <b>ForceModel</b> selected for the dependency.
			<p><b>Data Type</b> String</p> <p><b>Dependency</b> <b>ForceModel</b></p> <p><b>Units</b> kg/km<sup>3</sup></p>
<b>AZI</b>		Y	See <a href="#">Spacecraft.AZI</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> <b>CoordinateSystem</b></p> <p><b>Output Range</b> -180° # AZI # 180°</p> <p><b>Units</b> deg</p>
<b>BdotR</b>	N	Y	B-plane B-R magnitude.  GMAT computes the B-plane coordinates in the coordinate system specified in the dependency. In many implementations, the B-plane coordinates are computed in a pseudo-rotating coordinate system where the #xr term is not applied when transforming velocity vectors. GMAT does apply the #xr term in the velocity transformation. When computing B-plane coordinates in inertial systems, this term is identically zero. For rotating systems such as the Sun-Earth body-body rotating system, the effect of including #xr is small but noticeable when comparing results between systems. When the rotation of the selected coordinate system is "fast", the values may differ significantly.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> <b>CoordinateSystem</b></p> <p><b>Units</b> km</p>
<b>BdotT</b>	N	Y	B-plane B-T magnitude. See the <b>BdotR</b> parameter for notes on this calculation.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> <b>CoordinateSystem</b></p> <p><b>Units</b> km</p>

Parameter	Set-	Plot-	Description
	tabletable		
<b>BetaAngle</b>	N	Y	The angle between the orbital plane and the vector from the celestial body to the sun.
			<p><b>Data Type</b> Real  <b>Dependency</b> CelestialBody  <b>Output Range</b> -90° # BetaAngle # 90°  <b>Units</b> deg</p>
<b>BrouwerLon-gAOP</b>	Y	Y	See <a href="#">Spacecraft.BrouwerLongAOP</a> .
			<p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Output Range</b> 0° # BrouwerLongAOP # 360°  <b>Units</b> deg</p>
<b>Brouwer-LongECC</b>	Y	Y	See <a href="#">Spacecraft.BrouwerLongECC</a> .
			<p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Units</b> (None)</p>
<b>Brouwer-LongINC</b>	Y	Y	See <a href="#">Spacecraft.BrouwerLongINC</a> .
			<p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Output Range</b> 0° # BrouwerLongINC # 180°  <b>Units</b> deg</p>
<b>Brouwer-LongMA</b>	Y	Y	See <a href="#">Spacecraft.BrouwerLongMA</a> .
			<p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Output Range</b> 0° # BrouwerLongMA # 360°  <b>Units</b> deg</p>
<b>BrouwerLon-gRAAN</b>	Y	Y	See <a href="#">Spacecraft.BrouwerLongRAAN</a> .
			<p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Output Range</b> 0° # BrouwerLongRAAN # 360°  <b>Units</b> deg</p>
<b>Brouwer-LongSMA</b>	Y	Y	See <a href="#">Spacecraft.BrouwerLongSMA</a> .
			<p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Units</b> km</p>

Parameter	Set-	Plot-	Description								
	tabletable										
BrouwerShortAOP	Y	Y	See <a href="#">Spacecraft.BrouwerShortAOP</a> . <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td>CoordinateSystem</td></tr> <tr> <td><b>Output Range</b></td><td>0° # BrouwerShortAOP # 360°</td></tr> <tr> <td><b>Units</b></td><td>deg</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	CoordinateSystem	<b>Output Range</b>	0° # BrouwerShortAOP # 360°	<b>Units</b>	deg
<b>Data Type</b>	Real										
<b>Dependency</b>	CoordinateSystem										
<b>Output Range</b>	0° # BrouwerShortAOP # 360°										
<b>Units</b>	deg										
BrouwerShortECC	Y	Y	See <a href="#">Spacecraft.BrouwerShortECC</a> . <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td>CoordinateSystem</td></tr> <tr> <td><b>Units</b></td><td>(None)</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	CoordinateSystem	<b>Units</b>	(None)		
<b>Data Type</b>	Real										
<b>Dependency</b>	CoordinateSystem										
<b>Units</b>	(None)										
BrouwerShortINC	Y	Y	See <a href="#">Spacecraft.BrouwerShortINC</a> . <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td>CoordinateSystem</td></tr> <tr> <td><b>Output Range</b></td><td>0° # BrouwerShortINC # 180°</td></tr> <tr> <td><b>Units</b></td><td>deg</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	CoordinateSystem	<b>Output Range</b>	0° # BrouwerShortINC # 180°	<b>Units</b>	deg
<b>Data Type</b>	Real										
<b>Dependency</b>	CoordinateSystem										
<b>Output Range</b>	0° # BrouwerShortINC # 180°										
<b>Units</b>	deg										
BrouwerShortMA	Y	Y	See <a href="#">Spacecraft.BrouwerShortMA</a> . <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td>CoordinateSystem</td></tr> <tr> <td><b>Output Range</b></td><td>0° # BrouwerShortMA # 360°</td></tr> <tr> <td><b>Units</b></td><td>deg</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	CoordinateSystem	<b>Output Range</b>	0° # BrouwerShortMA # 360°	<b>Units</b>	deg
<b>Data Type</b>	Real										
<b>Dependency</b>	CoordinateSystem										
<b>Output Range</b>	0° # BrouwerShortMA # 360°										
<b>Units</b>	deg										
BrouwerShortRAAN	Y	Y	See <a href="#">Spacecraft.BrouwerShortRAAN</a> . <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td>CoordinateSystem</td></tr> <tr> <td><b>Output Range</b></td><td>0° # BrouwerShortRAAN # 360°</td></tr> <tr> <td><b>Units</b></td><td>deg</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	CoordinateSystem	<b>Output Range</b>	0° # BrouwerShortRAAN # 360°	<b>Units</b>	deg
<b>Data Type</b>	Real										
<b>Dependency</b>	CoordinateSystem										
<b>Output Range</b>	0° # BrouwerShortRAAN # 360°										
<b>Units</b>	deg										
BrouwerShortSMA	Y	Y	See <a href="#">Spacecraft.BrouwerShortSMA</a> . <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td>CoordinateSystem</td></tr> <tr> <td><b>Units</b></td><td>km</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	CoordinateSystem	<b>Units</b>	km		
<b>Data Type</b>	Real										
<b>Dependency</b>	CoordinateSystem										
<b>Units</b>	km										
BurnTorque	N	N	The torque occurring on the spacecraft about its center of mass due to firing thrusters. The torque is reported in the spacecraft body frame. <table> <tr> <td><b>Data Type</b></td><td>Real Array (1x3)</td></tr> <tr> <td><b>Dependency</b></td><td>ForceModel</td></tr> <tr> <td><b>Units</b></td><td>N*m</td></tr> </table>	<b>Data Type</b>	Real Array (1x3)	<b>Dependency</b>	ForceModel	<b>Units</b>	N*m		
<b>Data Type</b>	Real Array (1x3)										
<b>Dependency</b>	ForceModel										
<b>Units</b>	N*m										

Parameter	Set-	Plot-	Description
	tabletable		
<b>BVectorAngle</b>	N	Y	<p>B-plane angle between the B vector and the T unit vector. See the <b>BdotR</b> parameter for notes on this calculation.</p> <p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Output Range</b> -180° # <b>BVectorAngle</b> # 180°  <b>Units</b> deg</p>
<b>BVectorMag</b>	N	Y	<p>B-plane B vector magnitude. See the <b>BdotR</b> parameter for notes on this calculation.</p> <p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Units</b> km</p>
<b>C3Energy</b>	N	Y	<p><math>C_3</math> (characteristic) energy.</p> <p><b>Data Type</b> Real  <b>Dependency</b> CelestialBody  <b>Units</b> MJ/kg (<math>\text{km}^2/\text{s}^2</math>)</p>
<b>Cd</b>		Y	See <a href="#">Spacecraft.Cd</a>
			<p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> (None)</p>
<b>Cr</b>		Y	See <a href="#">Spacecraft.Cr</a>
			<p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> (None)</p>
<b>CurrA1MJD</b>	Y	Y	<p><i>Deprecated.</i> Spacecraft epoch in the A.1 system and the Modified Julian format.</p> <p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> d</p>
<b>DCM11</b>		Y	See <a href="#">Spacecraft.DCM11</a>
			<p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> (None)</p>
<b>DCM12</b>		Y	See <a href="#">Spacecraft.DCM12</a>
			<p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> (None)</p>

Parameter	Set- Plot-		Description
	tabletable		
<b>DCM13</b>	Y	Y	See <a href="#">Spacecraft.DCM13</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>DCM21</b>	Y	Y	See <a href="#">Spacecraft.DCM21</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>DCM22</b>	Y	Y	See <a href="#">Spacecraft.DCM22</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>DCM23</b>	Y	Y	See <a href="#">Spacecraft.DCM23</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>DCM31</b>	Y	Y	See <a href="#">Spacecraft.DCM31</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>DCM32</b>	Y	Y	See <a href="#">Spacecraft.DCM32</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>DCM33</b>	Y	Y	See <a href="#">Spacecraft.DCM33</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>DEC</b>	Y	Y	See <a href="#">Spacecraft.DEC</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Output Range</b> -90° # DEC # 90° <b>Units</b> deg

Parameter	Set-	Plot-	Description
	tabletable		
<b>DECV</b>	Y	Y	See <a href="#">Spacecraft.DECV</a>
			<p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Output Range</b> -90° # DECV # 90°  <b>Units</b> deg</p>
<b>Delaunayg</b>	Y	Y	See <a href="#">Spacecraft.Delaunayg</a> .
			<p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Output Range</b> 0° # Delaunayg &lt; 360°  <b>Units</b> deg</p>
<b>DelaunayG</b>	Y	Y	See <a href="#">Spacecraft.DelaunayG</a> .
			<p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Units</b> km<sup>2</sup>/s</p>
<b>Delaunayh</b>	Y	Y	See <a href="#">Spacecraft.Delaunayh</a> .
			<p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Output Range</b> 0° # Delaunayh &lt; 360°  <b>Units</b> deg</p>
<b>DelaunayH</b>	Y	Y	See <a href="#">Spacecraft.DelaunayH</a> .
			<p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Units</b> km<sup>2</sup>/s</p>
<b>Delaunayl</b>	Y	Y	See <a href="#">Spacecraft.Delaunayl</a> .
			<p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Output Range</b> 0° # Delaunayl &lt; 360°  <b>Units</b> deg</p>
<b>DelaunayL</b>	Y	Y	See <a href="#">Spacecraft.DelaunayL</a> .
			<p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Units</b> km<sup>2</sup>/s</p>
<b>DLA</b>	N	Y	Declination of the outgoing hyperbolic asymptote.
			<p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Output Range</b> -90° # DLA # 90°  <b>Units</b> deg</p>

Parameter	Set-	Plot-	Description
	tabletable		
DragArea	Y	Y	See <a href="#">Spacecraft.DragArea</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> m<sup>2</sup></p>
DryCenterOf- MassX	Y	y	See <a href="#">Spacecraft.DryCenterOfMassX</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> m</p>
DryCenterOf- MassY	Y	Y	See <a href="#">Spacecraft.DryCenterOfMassY</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> m</p>
DryCenterOf- MassZ	Y	Y	See <a href="#">Spacecraft.DryCenterOfMassZ</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> m</p>
DryMass	Y	Y	See <a href="#">Spacecraft.DryMass</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> kg</p>
DryMo- mentOfInerti- aXX	Y	Y	See <a href="#">Spacecraft.DryMomentOfInertiaXX</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> kg-m<sup>2</sup></p>
DryMo- mentOfInerti- aXY	Y	Y	See <a href="#">Spacecraft.DryMomentOfInertiaXY</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> kg-m<sup>2</sup></p>
DryMo- mentOfInerti- aXZ	Y	Y	See <a href="#">Spacecraft.DryMomentOfInertiaXZ</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> kg-m<sup>2</sup></p>
DryMo- mentOfInerti- aYY	Y	Y	See <a href="#">Spacecraft.DryMomentOfInertiaYY</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> kg-m<sup>2</sup></p>

Parameter	Set-	Plot-	Description
	tabletable		
DryMo- mentOfInerti- aYZ	Y	Y	See <a href="#">Spacecraft.DryMomentOfInertiaYZ</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> kg·m <sup>2</sup>
DryMo- mentOfInerti- aZZ	Y	Y	See <a href="#">Spacecraft.DryMomentOfInertiaZZ</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> kg·m <sup>2</sup>
EA	N	Y	Eccentric anomaly.
			<b>Data Type</b> Real <b>Dependency</b> CelestialBody <b>Output Range</b> 0° # EA < 360° <b>Units</b> deg
ECC	Y	Y	See <a href="#">Spacecraft.ECC</a>
			<b>Data Type</b> Real <b>Dependency</b> CelestialBody <b>Output Range</b> <b>Units</b> (None)
ElapsedDays	N	Y	The time in elapsed days. Elapsed time is computed based on context. See <a href="#">Elapsed Time Parameters</a> for more information.
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> d
ElapsedSecs	N	Y	The time in elapsed seconds. Elapsed time is computed based on context. See <a href="#">Elapsed Time Parameters</a> for more information.
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> s
Energy	N	Y	Specific orbital energy.
			<b>Data Type</b> Real <b>Dependency</b> CelestialBody <b>Units</b> MJ/kg (km <sup>2</sup> /s <sup>2</sup> )

Parameter	Set-	Plot-	Description
tabletable			
<b>EquinoctialH</b>	Y	Y	See <a href="#">Spacecraft.EquinoctialH</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> (None)
<b>EquinoctialH- N</b>	N	Y	The time rate of change of the spacecraft's Equinoctial H element due to perturbing forces.
<b>Dot</b>			<b>Data Type</b> Real <b>Dependency</b> ForceModel <b>Units</b> s^-1
<b>EquinoctialK</b>	Y	Y	See <a href="#">Spacecraft.EquinoctialK</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> (None)
<b>EquinoctialK- N</b>	N	Y	The time rate of change of the spacecraft's Equinoctial K element due to perturbing forces.
<b>Dot</b>			<b>Data Type</b> Real <b>Dependency</b> ForceModel <b>Units</b> s^-1
<b>EquinoctialP</b>	Y	Y	See <a href="#">Spacecraft.EquinoctialP</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> (None)
<b>EquinoctialP- N</b>	N	Y	The time rate of change of the spacecraft's Equinoctial P element due to perturbing forces.
<b>Dot</b>			<b>Data Type</b> Real <b>Dependency</b> ForceModel <b>Units</b> s^-1
<b>EquinoctialQ</b>	Y	Y	See <a href="#">Spacecraft.EquinoctialQ</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> (None)
<b>EquinoctialQ- N</b>	N	Y	The time rate of change of the spacecraft's Equinoctial Q element due to perturbing forces.
<b>Dot</b>			<b>Data Type</b> Real <b>Dependency</b> ForceModel <b>Units</b> s^-1

Parameter	Set-	Plot-	Description
	table	table	tabletable
EulerAngle1	Y	Y	See <a href="#">Spacecraft.EulerAngle1</a>
			<p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Output Range</b> <math>0^\circ \# \text{EulerAngle1} &lt; 360^\circ</math>  <b>Units</b> deg</p>
EulerAngle2	Y	Y	See <a href="#">Spacecraft.EulerAngle2</a>
			<p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Output Range</b> <math>0^\circ \# \text{EulerAngle2} &lt; 360^\circ</math>  <b>Units</b> deg</p>
EulerAngle3	Y	Y	See <a href="#">Spacecraft.EulerAngle3</a>
			<p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Output Range</b> <math>0^\circ \# \text{EulerAngle3} &lt; 360^\circ</math>  <b>Units</b> deg</p>
EulerAngleRate1	Y	Y	See <a href="#">Spacecraft.EulerAngleRate1</a>
			<p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> deg/s</p>
EulerAngleRate2	Y	Y	See <a href="#">Spacecraft.EulerAngleRate2</a>
			<p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> deg/s</p>
EulerAngleRate3	Y	Y	See <a href="#">Spacecraft.EulerAngleRate3</a>
			<p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> deg/s</p>
FPA	Y	Y	See <a href="#">Spacecraft.FPA</a>
			<p><b>Data Type</b> Real  <b>Dependency</b> CoordinateSystem  <b>Output Range</b> <math>0^\circ \# \text{FPA} \# 180^\circ</math>  <b>Units</b> deg</p>

Parameter	Set- Plot- Description tabletable		
<b>Gravity-Torque</b>	N	N	The torque occurring on the spacecraft about its center of mass due to gravity fields and point masses from the selected force model. The torque is reported in the spacecraft body frame.
			<b>Data Type</b> Real Array (1x3) <b>Dependency</b> ForceModel <b>Units</b> N*m
<b>HA</b>	N	Y	Hyperbolic anomaly.
			<b>Data Type</b> Real <b>Dependency</b> CelestialBody <b>Output Range</b> -# < HA < # <b>Units</b> deg
<b>Hmag</b>	N	Y	Magnitude of the angular momentum vector.
			<b>Data Type</b> Real <b>Dependency</b> CelestialBody <b>Units</b> km <sup>2</sup> /s
<b>Hx</b>	N	Y	X component of the angular momentum vector.
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> km <sup>2</sup> /s
<b>Hy</b>	N	Y	Y component of the angular momentum vector.
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> km <sup>2</sup> /s
<b>Hz</b>	N	Y	Z component of the angular momentum vector.
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> km <sup>2</sup> /s
<b>INC</b>	Y	Y	See <a href="#">Spacecraft.INC</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Output Range</b> 0° # INC # 180° <b>Units</b> deg

Parameter	Set-	Plot-	Description
	tabletable		
<b>IncomingB-VAZI</b>	Y	Y	See <a href="#">Spacecraft.IncomingBVAZI</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Output Range</b> $0^\circ \# \text{IncomingBVAZI} < 360^\circ$ <b>Units</b> deg
<b>IncomingC3Energy</b>	Y		See <a href="#">Spacecraft.IncomingC3Energy</a> .
			<b>Data Type</b> Real <b>Dependency</b> CelestialBody <b>Units</b> MJ/kg ( $\text{km}^2/\text{s}^2$ )
<b>IncomingDHA</b>	Y	Y	See <a href="#">Spacecraft.IncomingDHA</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Output Range</b> $-90^\circ \# \text{IncomingDHA} \# 90^\circ$ <b>Units</b> deg
<b>IncomingRadPer</b>	Y	Y	See <a href="#">Spacecraft.IncomingRadPer</a>
			<b>Data Type</b> Real <b>Dependency</b> CelestialBody <b>Units</b> km
<b>IncomingRHA</b>	Y	Y	See <a href="#">Spacecraft.IncomingRHA</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Output Range</b> $0^\circ \# \text{IncomingRHA} < 360^\circ$ <b>Units</b> deg
<b>Latitude</b>	N	Y	Planetodetic latitude.
			<b>Data Type</b> Real <b>Dependency</b> CelestialBody <b>Output Range</b> $-90^\circ \# \text{Latitude} \# 90^\circ$ <b>Units</b> deg
<b>Longitude</b>	N	Y	Planetodetic longitude.
			<b>Data Type</b> Real <b>Dependency</b> CelestialBody <b>Output Range</b> $-180^\circ \# \text{Longitude} \# 180^\circ$ <b>Units</b> deg

Parameter	Set- Plot- Description tabletable		
<b>LST</b>	N	Y	Local sidereal time of the spacecraft from the celestial body's inertial x-axis.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> CelestialBody</p> <p><b>Output Range</b> <math>0^\circ \# LST &lt; 360^\circ</math></p> <p><b>Units</b> deg</p>
<b>MA</b>	N	Y	Mean anomaly.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> CelestialBody</p> <p><b>Output Range</b> <math>0^\circ \# MA &lt; 360^\circ</math></p> <p><b>Units</b> deg</p>
<b>MHA</b>	N	Y	Angle between celestial body's body-fixed and inertial axes. For Earth, this is the Greenwich Hour Angle.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> CelestialBody</p> <p><b>Output Range</b> <math>0^\circ \# MHA &lt; 360^\circ</math></p> <p><b>Units</b> deg</p>
<b>MLONG</b>	Y	Y	See <a href="#">Spacecraft.MLONG</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> CoordinateSystem</p> <p><b>Output Range</b> <math>0^\circ \# MLONG &lt; 360^\circ</math></p> <p><b>Units</b> deg</p>
<b>MM</b>	N	Y	Mean motion.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> CelestialBody</p> <p><b>Output Range</b></p> <p><b>Units</b> rad/s</p>
<b>ModEquinoctialF</b>	Y	Y	See <a href="#">Spacecraft.ModEquinoctialF</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> CoordinateSystem</p> <p><b>Units</b> (None)</p>
<b>ModEquinoctialG</b>	Y	Y	See <a href="#">Spacecraft.ModEquinoctialG</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> CoordinateSystem</p> <p><b>Units</b> (None)</p>

Parameter	Set-	Plot-	Description
	tabletable		
<b>ModEquinoctialH</b>	Y	Y	See <a href="#">Spacecraft.ModEquinoctialH</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> (None)
<b>ModEquinoctialK</b>	Y	Y	See <a href="#">Spacecraft.ModEquinoctialK</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> (None)
<b>MRP1</b>	Y	Y	See <a href="#">Spacecraft.MRP1</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>MRP2</b>	Y	Y	See <a href="#">Spacecraft.MRP2</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>MRP3</b>	Y	Y	See <a href="#">Spacecraft.MRP3</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>OrbitPeriod</b>	N	Y	Osculating orbit period.
			<b>Data Type</b> Real <b>Dependency</b> CelestialBody <b>Units</b> s
<b>OrbitSTM</b>	N	N	State transition matrix with respect to the origin-independent MJ2000Eq axes.
			<b>Data Type</b> Array (6x6) <b>Dependency</b> (None) <b>Units</b> (None)
<b>OrbitSTMA</b>	N	N	Upper-left quadrant of the state transition matrix, with respect to the origin-independent MJ2000Eq axes.
			<b>Data Type</b> Array (3x3) <b>Dependency</b> (None) <b>Units</b> (None)

Parameter	Set- Plot- Description		tabletable
<b>OrbitSTMB</b>	N	N	Upper-right quadrant of the state transition matrix, with respect to the origin-independent MJ2000Eq axes.
			<b>Data Type</b> Array (3x3) <b>Dependency</b> (None) <b>Units</b> (None)
<b>OrbitSTMC</b>	N	N	Lower-left quadrant of the state transition matrix, with respect to the origin-independent MJ2000Eq axes.
			<b>Data Type</b> Array (3x3) <b>Dependency</b> (None) <b>Units</b> (None)
<b>OrbitSTMD</b>	N	N	Lower-right quadrant of the state transition matrix, with respect to the origin-independent MJ2000Eq axes.
			<b>Data Type</b> Array (3x3) <b>Dependency</b> (None) <b>Units</b> (None)
<b>OrbitTime</b>	N	N	Local Time of the current state.
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> (None)
<b>OutgoingB-VAZI</b>	Y	Y	See <a href="#">Spacecraft.OutgoingBVAZI</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Output Range</b> 0° # OutgoingBVAZI < 360° <b>Units</b> deg
<b>OutgoingC3Energy</b>	Y	Y	See <a href="#">Spacecraft.OutgoingC3Energy</a> .
			<b>Data Type</b> Real <b>Dependency</b> CelestialBody <b>Units</b> MJ/kg (km <sup>2</sup> /s <sup>2</sup> )
<b>OutgoingDHA</b>	Y	Y	See <a href="#">Spacecraft.OutgoingDHA</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Output Range</b> -90° # OutgoingRHA # 90° <b>Units</b> deg
<b>OutgoingRadPer</b>	Y	Y	See <a href="#">Spacecraft.OutgoingRadPer</a>
			<b>Data Type</b> Real <b>Dependency</b> CelestialBody <b>Units</b> km

Parameter	Set-	Plot-	Description
	tabletable		
<b>Outgoi-</b> <b>gRHA</b>	Y	Y	See <a href="#">Spacecraft.OutgoingRHA</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> <a href="#">CoordinateSystem</a></p> <p><b>Output Range</b> <math>0^\circ \# \text{OutgoingRHA} &lt; 360^\circ</math></p> <p><b>Units</b> deg</p>
<b>Periapsis</b>	N	Y	A parameter that equals zero when the spacecraft is at orbit periapsis. This parameter can only be used as a stopping condition in the <a href="#">Propagate</a> command.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> <a href="#">CelestialBody</a></p> <p><b>Units</b> (None)</p>
<b>Planetodeti-</b> <b>cAZI</b>	Y	Y	See <a href="#">Spacecraft.PlanetodeticAZI</a> . This parameter must be used with a <a href="#">CoordinateSystem</a> with <b>BodyFixed</b> axes.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> <a href="#">CoordinateSystem</a> (with <b>BodyFixed</b> axes)</p> <p><b>Output Range</b> <math>-180^\circ \# \text{PlanetodeticAZI} \# 180^\circ</math></p> <p><b>Units</b> deg</p>
<b>Plane-</b> <b>todeticHFPA</b>	Y	Y	See <a href="#">Spacecraft.PlanetodeticHFPA</a> . This parameter must be used with a <a href="#">CoordinateSystem</a> with <b>BodyFixed</b> axes.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> <a href="#">CoordinateSystem</a> (with <b>BodyFixed</b> axes)</p> <p><b>Output Range</b> <math>-90^\circ \# \text{PlanetodeticHFPA} \# 90^\circ</math></p> <p><b>Units</b> deg</p>
<b>Planetodeti-</b> <b>cLAT</b>	Y	Y	See <a href="#">Spacecraft.PlanetodeticLAT</a> . This parameter must be used with a <a href="#">CoordinateSystem</a> with <b>BodyFixed</b> axes.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> <a href="#">CoordinateSystem</a> (with <b>BodyFixed</b> axes)</p> <p><b>Output Range</b> <math>-180^\circ \# \text{PlanetodeticLAT} \# 180^\circ</math></p> <p><b>Units</b> deg</p>
<b>Planetodeti-</b> <b>cLON</b>	Y	Y	See <a href="#">Spacecraft.PlanetodeticLON</a> . This parameter must be used with a <a href="#">CoordinateSystem</a> with <b>BodyFixed</b> axes.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> <a href="#">CoordinateSystem</a> (with <b>BodyFixed</b> axes)</p> <p><b>Output Range</b> <math>-180^\circ \# \text{PlanetodeticLON} \# 180^\circ</math></p> <p><b>Units</b> deg</p>

Parameter	Set- Plot-		Description								
			tabletable								
<b>PlanetodeticRMAG</b>	Y	Y	<p>See <a href="#">Spacecraft.PlanetodeticRMAG</a>. This parameter must be used with a <b>CoordinateSystem</b> with <b>BodyFixed</b> axes.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td><b>CoordinateSystem</b> (with <b>BodyFixed</b> axes)</td></tr> <tr> <td><b>Units</b></td><td>km</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	<b>CoordinateSystem</b> (with <b>BodyFixed</b> axes)	<b>Units</b>	km		
<b>Data Type</b>	Real										
<b>Dependency</b>	<b>CoordinateSystem</b> (with <b>BodyFixed</b> axes)										
<b>Units</b>	km										
<b>PlanetodeticVMAG</b>	Y	Y	<p>See <a href="#">Spacecraft.PlanetodeticVMAG</a>. This parameter must be used with a <b>CoordinateSystem</b> with <b>BodyFixed</b> axes.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td><b>CoordinateSystem</b> (with <b>BodyFixed</b> axes)</td></tr> <tr> <td><b>Units</b></td><td>km/s</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	<b>CoordinateSystem</b> (with <b>BodyFixed</b> axes)	<b>Units</b>	km/s		
<b>Data Type</b>	Real										
<b>Dependency</b>	<b>CoordinateSystem</b> (with <b>BodyFixed</b> axes)										
<b>Units</b>	km/s										
<b>Q1</b>	N	Y	<p>See <a href="#">Spacecraft.Q1</a></p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td>(None)</td></tr> <tr> <td><b>Units</b></td><td>(None)</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	(None)	<b>Units</b>	(None)		
<b>Data Type</b>	Real										
<b>Dependency</b>	(None)										
<b>Units</b>	(None)										
<b>Q2</b>	N	Y	<p>See <a href="#">Spacecraft.Q2</a></p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td>(None)</td></tr> <tr> <td><b>Units</b></td><td>(None)</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	(None)	<b>Units</b>	(None)		
<b>Data Type</b>	Real										
<b>Dependency</b>	(None)										
<b>Units</b>	(None)										
<b>Q3</b>	N	Y	<p>See <a href="#">Spacecraft.Q3</a></p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td>(None)</td></tr> <tr> <td><b>Units</b></td><td>(None)</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	(None)	<b>Units</b>	(None)		
<b>Data Type</b>	Real										
<b>Dependency</b>	(None)										
<b>Units</b>	(None)										
<b>Q4</b>	N	Y	<p>See <a href="#">Spacecraft.Q4</a></p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td>(None)</td></tr> <tr> <td><b>Units</b></td><td>(None)</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	(None)	<b>Units</b>	(None)		
<b>Data Type</b>	Real										
<b>Dependency</b>	(None)										
<b>Units</b>	(None)										
<b>Quaternion</b>	Y	N	Attitude quaternion.								
			<table> <tr> <td><b>Data Type</b></td><td>Array (1x4)</td></tr> <tr> <td><b>Dependency</b></td><td>(None)</td></tr> <tr> <td><b>Units</b></td><td>(None)</td></tr> </table>	<b>Data Type</b>	Array (1x4)	<b>Dependency</b>	(None)	<b>Units</b>	(None)		
<b>Data Type</b>	Array (1x4)										
<b>Dependency</b>	(None)										
<b>Units</b>	(None)										
<b>RA</b>	Y	Y	<p>See <a href="#">Spacecraft.RA</a></p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td><b>CoordinateSystem</b></td></tr> <tr> <td><b>Output Range</b></td><td>-180° # RA # 180°</td></tr> <tr> <td><b>Units</b></td><td>deg</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	<b>CoordinateSystem</b>	<b>Output Range</b>	-180° # RA # 180°	<b>Units</b>	deg
<b>Data Type</b>	Real										
<b>Dependency</b>	<b>CoordinateSystem</b>										
<b>Output Range</b>	-180° # RA # 180°										
<b>Units</b>	deg										

Parameter	Set-	Plot-	Description
	tabletable		
<b>RAAN</b>	Y	Y	See <a href="#">Spacecraft.RAAN</a>
			<b>Data Type</b> Real <b>Dependency</b> <a href="#">CoordinateSystem</a> <b>Output Range</b> $0^\circ \# RAAN < 360^\circ$ <b>Units</b> deg
<b>RadApo</b>	Y	Y	See <a href="#">Spacecraft.RadApo</a>
			<b>Data Type</b> Real <b>Dependency</b> <a href="#">CelestialBody</a> <b>Units</b> km
<b>RadPer</b>	Y	Y	See <a href="#">Spacecraft.RadPer</a>
			<b>Data Type</b> Real <b>Dependency</b> <a href="#">CelestialBody</a> <b>Units</b> km
<b>RAV</b>	Y	Y	See <a href="#">Spacecraft.RAV</a>
			<b>Data Type</b> Real <b>Dependency</b> <a href="#">CoordinateSystem</a> <b>Output Range</b> $-180^\circ \# RAV \# 180^\circ$ <b>Units</b> deg
<b>RLA</b>	N	Y	Right ascension of the outgoing hyperbolic asymptote.
			<b>Data Type</b> Real <b>Dependency</b> <a href="#">CoordinateSystem</a> <b>Output Range</b> $-180^\circ \# RLA \# 180^\circ$ <b>Units</b> deg
<b>RMAG</b>	Y	Y	See <a href="#">Spacecraft.RMAG</a>
			<b>Data Type</b> Real <b>Dependency</b> <a href="#">CelestialBody</a> <b>Units</b> km
<b>Semilatus-Rectum</b>	Y	Y	See <a href="#">Spacecraft.SemilatusRectum</a>
			<b>Data Type</b> Real <b>Dependency</b> <a href="#">CelestialBody</a> <b>Units</b> km
<b>Semilatus-Rectum</b>	N	Y	Semilatus rectum of the osculating orbit.
			<b>Data Type</b> Real <b>Dependency</b> <a href="#">CelestialBody</a> <b>Units</b> km

Parameter	Set- Plot- Description tabletable		
<b>SMA</b>	Y	Y	See <a href="#">Spacecraft.SMA</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> CelestialBody</p> <p><b>Units</b> km</p>
<b>SMADot</b>	N	Y	The time rate of change of the spacecraft's semimajor axis due to perturbing forces.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> ForceModel</p> <p><b>Units</b> km/s</p>
<b>SRPArea</b>	Y	Y	See <a href="#">Spacecraft.SRPArea</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> m<sup>2</sup></p>
<b>SRPTorque</b>	N	N	The torque occurring on the spacecraft about its center of mass due to solar radiation pressure from the selected force model. The torque is reported in the spacecraft body frame.
			<p><b>Data Type</b> Real Array (1x3)</p> <p><b>Dependency</b> ForceModel</p> <p><b>Units</b> N*m</p>
<b>SystemCenterOfMassX</b>	N	Y	X-component of the overall system's center of mass in the spacecraft's body coordinate system. This incorporates the spacecraft mass and any attached fuel tanks.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> m</p>
<b>SystemCenterOfMassY</b>	N	Y	Y-component of the overall system's center of mass in the spacecraft's body coordinate system. This incorporates the spacecraft mass and any attached fuel tanks.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> m</p>
<b>SystemCenterOfMassZ</b>	N	Y	Z-component of the overall system's center of mass in the spacecraft's body coordinate system. This incorporates the spacecraft mass and any attached fuel tanks.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> m<sup>2</sup></p>

Parameter	Set-	Plot-	Description
	tabletable		
<b>SystemMo- mentOfInerti- aXX</b>	N	Y	XX-component of the overall system's moment of inertia in the spacecraft's body coordinate system. This incorporates the spacecraft MOI and any attached fuel tanks.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> kg-m<sup>2</sup></p>
<b>SystemMo- mentOfInerti- aXY</b>	N	Y	XY-component of the overall system's moment of inertia in the spacecraft's body coordinate system. This incorporates the spacecraft MOI and any attached fuel tanks.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> kg-m<sup>2</sup></p>
<b>SystemMo- mentOfInerti- aXZ</b>	N	Y	XZ-component of the overall system's moment of inertia in the spacecraft's body coordinate system. This incorporates the spacecraft MOI and any attached fuel tanks.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> kg-m<sup>2</sup></p>
<b>SystemMo- mentOfInerti- aYY</b>	N	Y	YY-component of the overall system's moment of inertia in the spacecraft's body coordinate system. This incorporates the spacecraft MOI and any attached fuel tanks.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> kg-m<sup>2</sup></p>
<b>SystemMo- mentOfInerti- aYZ</b>	N	Y	YZ-component of the overall system's moment of inertia in the spacecraft's body coordinate system. This incorporates the spacecraft MOI and any attached fuel tanks.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> kg-m<sup>2</sup></p>
<b>SystemMo- mentOfInerti- aZZ</b>	N	Y	ZZ-component of the overall system's moment of inertia in the spacecraft's body coordinate system. This incorporates the spacecraft MOI and any attached fuel tanks.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> kg-m<sup>2</sup></p>

Parameter	Set- Plot- Description tabletable		
<b>TA</b>	Y	Y	See <a href="#">Spacecraft.TA</a> .
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> <b>CelestialBody</b></p> <p><b>Output Range</b> <math>0^\circ \# TA &lt; 360^\circ</math></p> <p><b>Units</b> deg</p>
<b>TAIGregorian</b>	Y	N	Spacecraft epoch in the TAI system and the Gregorian format.
			<p><b>Data Type</b> String</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> (N/A)</p>
<b>TAIModJulian</b>	Y	Y	Spacecraft epoch in the TAI system and the Modified Julian format.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> d</p>
<b>TDBGregorian</b>	Y	N	Spacecraft epoch in the TDB system and the Gregorian format.
			<p><b>Data Type</b> String</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> (N/A)</p>
<b>TDBModJulian</b>	Y	Y	Spacecraft epoch in the TDB system and the Modified Julian format.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> (None)</p> <p><b>Units</b> d</p>
<b>TLONG</b>	Y	Y	See <a href="#">Spacecraft.TLONG</a>
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> <b>CoordinateSystem</b></p> <p><b>Output Range</b> <math>0^\circ \# TLONG &lt; 360^\circ</math></p> <p><b>Units</b> deg</p>
<b>TLONGDot</b>	N	Y	The time rate of change of the spacecraft's true inertial longitude (RAAN + AOP + TA) due to perturbing forces.
			<p><b>Data Type</b> Real</p> <p><b>Dependency</b> <b>ForceModel</b></p> <p><b>Units</b> deg/s</p>

Parameter	Set-	Plot-	Description
	tabletable		
<b>TotalMass</b>	N	Y	<p>Total mass, including fuel mass from attached <b>Chemical-Tank</b> resources.</p> <p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> kg</p>
<b>TotalTorque</b>	N	N	<p>The torque occurring on the spacecraft about its center of mass due to all forces from the selected force model. The torque is reported in the spacecraft body frame.</p> <p><b>Data Type</b> Real Array (1x3)  <b>Dependency</b> <b>ForceModel</b>  <b>Units</b> N*m</p>
<b>TTGregorian</b>	Y	N	<p>Spacecraft epoch in the TT system and the Gregorian format.</p> <p><b>Data Type</b> String  <b>Dependency</b> (None)  <b>Units</b> (N/A)</p>
<b>TTModJulian</b>	Y	Y	<p>Spacecraft epoch in the TT system and the Modified Julian format.</p> <p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> d</p>
<b>UTCGregorian</b>	Y	N	<p>Spacecraft epoch in the UTC system and the Gregorian format.</p> <p><b>Data Type</b> String  <b>Dependency</b> (None)  <b>Units</b> (N/A)</p>
<b>UTCModJulian</b>	Y	Y	<p>Spacecraft epoch in the UTC system and the Modified Julian format.</p> <p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> d</p>
<b>VelApoapsis</b>	N	Y	<p>Scalar velocity at apoapsis.</p> <p><b>Data Type</b> Real  <b>Dependency</b> <b>CelestialBody</b>  <b>Units</b> km/s</p>

Parameter	Set- Plot- Description tabletable		
<b>VelPeriapsis</b>	N	Y	Scalar velocity at periapsis.
			<b>Data Type</b> Real <b>Dependency</b> CelestialBody <b>Units</b> km/s
<b>VMAG</b>	Y	Y	See <a href="#">Spacecraft.VMAG</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Output Range</b> <b>Units</b> km/s
<b>VX</b>	Y	Y	See <a href="#">Spacecraft.VX</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> km/s
<b>VY</b>	Y	Y	See <a href="#">Spacecraft.VY</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> km/s
<b>VZ</b>	Y	Y	See <a href="#">Spacecraft.VZ</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> km/s
<b>X</b>	Y	Y	See <a href="#">Spacecraft.X</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> km
<b>Y</b>	Y	Y	See <a href="#">Spacecraft.Y</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> km
<b>Z</b>	Y	Y	See <a href="#">Spacecraft.Z</a>
			<b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> km

## FuelTank

**ChemicalTank** parameters are accessible only after attaching the **ChemicalTank** resource to a **Spacecraft**, like so:

```
Create FuelTank aTank
Create Spacecraft aSat
aSat.Tanks = {aTank}
```

Then, **ChemicalTank** parameters are accessible by specifying the **ChemicalTank** name as the parameter dependency:

```
Create ReportFile aReport
aReport.Add = {aSat.aTank.FuelMass}
```

Parameter	Settable	Plot-table	Description
<b>FuelDensity</b>	Y	Y	See <a href="#">ChemicalTank.FuelDensity</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> kg/m <sup>3</sup>
<b>FuelMass</b>	Y	Y	See <a href="#">ChemicalTank.FuelMass</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> kg
<b>Pressure</b>	Y	Y	See <a href="#">ChemicalTank.Pressure</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> kPa
<b>RefTemperature</b>	Y	Y	See <a href="#">ChemicalTank.RefTemperature</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> °C
<b>Temperature</b>	Y	Y	See <a href="#">ChemicalTank.Temperature</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> °C
<b>Volume</b>	Y	Y	See <a href="#">ChemicalTank.Volume</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> m <sup>3</sup>

## Space Point Parameters

All Resources that have coordinates in space have Cartesian position and velocity parameters, so you can access ephemeris information. This includes all built-in solar system bodies and other Resources such as **CelestialBody**, **Planet**, **Moon**, **Asteroid**, **Comet**, **Barycenter**, **LibrationPoint**, and **GroundStation**:

- *CelestialBody.CoordinateSystem.X*
- *CelestialBody.CoordinateSystem.Y*
- *CelestialBody.CoordinateSystem.Z*
- *CelestialBody.CoordinateSystem.VX*
- *CelestialBody.CoordinateSystem.VY*
- *CelestialBody.CoordinateSystem.VZ*



### Warning

Note that to use these parameters, you must first set the epoch of the Resource to the desired epoch at which you want the data. Additionally, the epoch should be set after the **BeginMissionSequence** Command. See the following example.

```
Create ReportFile rf  
  
BeginMissionSequence  
  
Luna.Epoch.A1ModJulian = 21545  
Report rf Luna.EarthMJ2000Eq.X Luna.EarthMJ2000Eq.Y Luna.EarthMJ2000Eq.Z ...  
Luna.EarthMJ2000Eq.VX Luna.EarthMJ2000Eq.VY Luna.EarthMJ2000Eq.VZ
```



### Note

Spacecraft parameters are treated slightly different than Space Point parameters primarily because **Spacecraft** Cartesian state parameters are settable, and all other Space Point Cartesian parameters are only gettable. When requesting state information for Space Points other than **Spacecraft**, the coordinates are computed based on the model configured for that Resource. Additionally, not all epoch configuration options supported for **Spacecraft** are supported for Space Points (i.e. **Epoch** and **DateFormat**).

Parameter	Settable	Plot-table	Description
<b>A1Gregorian</b>	Y	N	Resource epoch in the A.1 system and the Gregorian format.
			<b>Data Type</b> String <b>Dependency</b> (None) <b>Units</b> (N/A)

<b>Parameter</b>	<b>Settable</b>	<b>Plot-table</b>	<b>Description</b>
<b>A1ModJulian</b>	Y	Y	Resource epoch in the A.1 system and the Modified Julian format.
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> d
<b>TAIGregorian</b>	Y	N	Resource epoch in the TAI system and the Gregorian format.
			<b>Data Type</b> String <b>Dependency</b> (None) <b>Units</b> (N/A)
<b>TAIModJulian</b>	Y	Y	Resource epoch in the TAI system and the Modified Julian format.
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> d
<b>TDBGregorian</b>	Y	N	Resource epoch in the TDB system and the Gregorian format.
			<b>Data Type</b> String <b>Dependency</b> (None) <b>Units</b> (N/A)
<b>TDBModJulian</b>	Y	Y	Resource epoch in the TDB system and the Modified Julian format.
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> d
<b>TTGregorian</b>	Y	N	Resource epoch in the TT system and the Gregorian format.
			<b>Data Type</b> String <b>Dependency</b> (None) <b>Units</b> (N/A)
<b>TTModJulian</b>	Y	Y	Resource epoch in the TT system and the Modified Julian format.
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> d

Parameter	Settable	Plot-table	Description
<b>UTCGregorian</b>	Y	N	Resource epoch in the UTC system and the Gregorian format.  <b>Data Type</b> String <b>Dependency</b> (None) <b>Units</b> (N/A)
<b>UTCModJulian</b>	Y	Y	Resource epoch in the UTC system and the Modified Julian format.  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> d
<b>VX</b>	N	Y	The x-component of velocity with respect to the <b>CoordinateSystem</b> chosen as the dependency. When no dependency is selected, <b>EarthMJ2000Eq</b> is used.  <b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> km/s
<b>VY</b>	N	Y	The y-component of velocity with respect to the <b>CoordinateSystem</b> chosen as the dependency. When no dependency is selected, <b>EarthMJ2000Eq</b> is used.  <b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> km/s
<b>VZ</b>	N	Y	The z-component of velocity with respect to the <b>CoordinateSystem</b> chosen as the dependency. When no dependency is selected, <b>EarthMJ2000Eq</b> is used.  <b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> km/s
<b>X</b>	N	Y	The x-component of position with respect to the <b>CoordinateSystem</b> chosen as the dependency. When no dependency is selected, <b>EarthMJ2000Eq</b> is used.  <b>Data Type</b> Real <b>Dependency</b> CoordinateSystem <b>Units</b> km

Parameter	Settable	Plot-table	Description						
Y	N	Y	<p>The y-component of position with respect to the <b>CoordinateSystem</b> chosen as the dependency. When no dependency is selected, <b>EarthMJ2000Eq</b> is used.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td><b>CoordinateSystem</b></td></tr> <tr> <td><b>Units</b></td><td>km</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	<b>CoordinateSystem</b>	<b>Units</b>	km
<b>Data Type</b>	Real								
<b>Dependency</b>	<b>CoordinateSystem</b>								
<b>Units</b>	km								
Z	N	Y	<p>The z-component of position with respect to the <b>CoordinateSystem</b> chosen as the dependency. When no dependency is selected, <b>EarthMJ2000Eq</b> is used.</p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td><b>CoordinateSystem</b></td></tr> <tr> <td><b>Units</b></td><td>km</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	<b>CoordinateSystem</b>	<b>Units</b>	km
<b>Data Type</b>	Real								
<b>Dependency</b>	<b>CoordinateSystem</b>								
<b>Units</b>	km								

## Thruster

**ChemicalThruster** parameters are accessible only after attaching the **ChemicalThruster** resource to a **Spacecraft**, like so:

```
Create Thruster aThruster
Create Spacecraft aSat
aSat.Thrusters = {aThruster}
```

Then, **ChemicalThruster** parameters are accessible by specifying the **ChemicalThruster** name as the parameter dependency:

```
Create ReportFile aReport
aReport.Add = {aSat.aThruster.DutyCycle}
```

The table below shows reportable thruster based parameters:

Parameter	Settable	Plot-table	Description						
C1	Y	Y	<p>See <a href="#">ChemicalThruster.C1</a></p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td>(None)</td></tr> <tr> <td><b>Units</b></td><td>N</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	(None)	<b>Units</b>	N
<b>Data Type</b>	Real								
<b>Dependency</b>	(None)								
<b>Units</b>	N								
C2	Y	Y	<p>See <a href="#">ChemicalThruster.C2</a></p> <table> <tr> <td><b>Data Type</b></td><td>Real</td></tr> <tr> <td><b>Dependency</b></td><td>(None)</td></tr> <tr> <td><b>Units</b></td><td>N/kPa</td></tr> </table>	<b>Data Type</b>	Real	<b>Dependency</b>	(None)	<b>Units</b>	N/kPa
<b>Data Type</b>	Real								
<b>Dependency</b>	(None)								
<b>Units</b>	N/kPa								

Parameter	Settable	Plot-table	Description
C3	Y	Y	See <a href="#">ChemicalThruster.C3</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> N
C4	Y	Y	See <a href="#">ChemicalThruster.C4</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> N/kPa
C5	Y	Y	See <a href="#">ChemicalThruster.C5</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> N/kPa <sup>2</sup>
C6	Y	Y	See <a href="#">ChemicalThruster.C6</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> N/kPa <sup>2</sup> <sup>C7</sup>
C7	Y	Y	See <a href="#">ChemicalThruster.C7</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
C8	Y	Y	See <a href="#">ChemicalThruster.C8</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> N/kPa <sup>C9</sup>
C9	Y	Y	See <a href="#">ChemicalThruster.C9</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
C10	Y	Y	See <a href="#">ChemicalThruster.C10</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> N/kPa <sup>C11</sup>
C11	Y	Y	See <a href="#">ChemicalThruster.C11</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)

Parameter	Settable	Plot-table	Description
C12	Y	Y	See <a href="#">ChemicalThruster.C12</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> N
C13	Y	Y	See <a href="#">ChemicalThruster.C13</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
C14	Y	Y	See <a href="#">ChemicalThruster.C14</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> 1/kPa
C15	Y	Y	See <a href="#">ChemicalThruster.C15</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
C16	Y	Y	See <a href="#">ChemicalThruster.C16</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> 1/kPa
DutyCycle	Y	Y	See <a href="#">ChemicalThruster.DutyCycle</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
GravitationalAccel	Y	Y	See <a href="#">ChemicalThruster.GravitationalAccel</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> m/s <sup>2</sup>
Isp	Y	Y	Specific impulse of an individual thruster. When thruster(s) is not turned on, GMAT will report zeros to a report file.  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> s

Parameter	Settable	Plot-table	Description
K1	Y	Y	See <a href="#">ChemicalThruster.K1</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> s
K2	Y	Y	See <a href="#">ChemicalThruster.K2</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> s/kPa
K3	Y	Y	See <a href="#">ChemicalThruster.K3</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> s
K4	Y	Y	See <a href="#">ChemicalThruster.K4</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> s/kPa
K5	Y	Y	See <a href="#">ChemicalThruster.K5</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> s/kPa <sup>2</sup>
K6	Y	Y	See <a href="#">ChemicalThruster.K6</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> s/kPa <sup>C7</sup>
K7	Y	Y	See <a href="#">ChemicalThruster.K7</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
K8	Y	Y	See <a href="#">ChemicalThruster.K8</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> s/kPa <sup>C9</sup>
K9	Y	Y	See <a href="#">ChemicalThruster.K9</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)

Parameter	Settable	Plot-table	Description
<b>K10</b>	Y	Y	See <a href="#">ChemicalThruster.K10</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> s/kPa <sup>C11</sup>
<b>K11</b>	Y	Y	See <a href="#">ChemicalThruster.K11</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>K12</b>	Y	Y	See <a href="#">ChemicalThruster.K12</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> s
<b>K13</b>	Y	Y	See <a href="#">ChemicalThruster.K13</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>K14</b>	Y	Y	See <a href="#">ChemicalThruster.K14</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> 1/kPa
<b>K15</b>	Y	Y	See <a href="#">ChemicalThruster.K15</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>K16</b>	Y	Y	See <a href="#">ChemicalThruster.K16</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> 1/kPa
<b>MassFlowRate</b>	N	Y	Mass flow rate from an individual thruster. When thruster(s) is not turned on, GMAT will report zeros to a report file.  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> kg/s

Parameter	Settable	Plot-table	Description
<b>ThrustDirection1</b>	Y	Y	See <a href="#">ChemicalThruster.ThrustDirection1</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>ThrustDirection2</b>	Y	Y	See <a href="#">ChemicalThruster.ThrustDirection2</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>ThrustDirection3</b>	Y	Y	See <a href="#">ChemicalThruster.ThrustDirection3</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>ThrustMagnitude</b>	Y	Y	Magnitude of the thrust from an individual thruster. When thruster(s) is not turned on, GMAT will report zeros to a report file.
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> Newtons
<b>ThrustScaleFactor</b>	Y	Y	See <a href="#">ChemicalThruster.ThrustScaleFactor</a>
			<b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)

### ImpulsiveBurn

To compute **ImpulsiveBurn** parameters, GMAT requires that an **ImpulsiveBurn** has been executed using a **Maneuver** command like this:

```
Maneuver myImpulsiveBurn(mySat)
```

In the case that an **ImpulsiveBurn** has not been applied, GMAT will output zeros for the **ImpulsiveBurn** components and issue a warning.

We recommended that you evaluate **ImpulsiveBurn** parameters immediately after the **ImpulsiveBurn** is applied using the **Maneuver** command like this:

```
Maneuver myImpulsiveBurn(mySat)
myVar = mySat.MyCoordinateSystem.Element1
```

The above usage avoids issues that may occur if the **ImpulsiveBurn** coordinate system is time varying, and the **ImpulsiveBurn** parameters are requested after further manip-

ulation of the participants using other commands (such as **Propagate**). In that case, it is possible that the participants are no longer at the epoch of the maneuver, and unexpected results can occur due to epoch mismatches.

Parameter	Settable	Plot-table	Description
<b>B</b>	Y	Y	See <a href="#">ImpulsiveBurn.B</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>Element1</b>	Y	Y	See <a href="#">ImpulsiveBurn.Element1</a>  <b>Data Type</b> Real <b>Dependency</b> <a href="#">CoordinateSystem</a> <b>Units</b> (None)
<b>Element2</b>	Y	Y	See <a href="#">ImpulsiveBurn.Element2</a>  <b>Data Type</b> Real <b>Dependency</b> <a href="#">CoordinateSystem</a> <b>Units</b> (None)
<b>Element3</b>	Y	Y	See <a href="#">ImpulsiveBurn.Element3</a>  <b>Data Type</b> Real <b>Dependency</b> <a href="#">CoordinateSystem</a> <b>Units</b> (None)
<b>N</b>	Y	Y	See <a href="#">ImpulsiveBurn.N</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)
<b>V</b>	Y	Y	See <a href="#">ImpulsiveBurn.V</a>  <b>Data Type</b> Real <b>Dependency</b> (None) <b>Units</b> (None)

### FiniteBurn

To compute **FiniteBurn** parameters, GMAT requires that a **FiniteBurn** has been executed using a **BeginFiniteBurn** command like this:

```
BeginFiniteBurn Maneuver myFiniteBurn(mySat)
```

In the case that a **FiniteBurn** has not been applied, GMAT will output zeros for all reportable **FiniteBurn** parameters to a report file. All finite burn parameters will report zeros whenever a finite burn is not turned on. The table below shows reportable finite burn parameters:

Parameter	Settable	Plot-table	Description
<b>TotalAcceleration1</b>	N	Y	<p>First component of the total acceleration from all thrusters in the three coordinate directions of a J2000 system. Zero is reported whenever thruster is not turned on</p> <p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> Km/s<sup>2</sup></p>
<b>TotalAcceleration2</b>	N	Y	<p>Second component of the total acceleration from all thrusters in the three coordinate directions of a J2000 system. Zero is reported whenever thruster is not turned on</p> <p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> Km/s<sup>2</sup></p>
<b>TotalAcceleration3</b>	N	Y	<p>Third component of the total acceleration from all thrusters in the three coordinate directions of a J2000 system. Zero is reported whenever thruster is not turned on</p> <p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> Km/s<sup>2</sup></p>
<b>TotalMass-FlowRate</b>	N	Y	<p>Total mass flow rate from all thrusters. Zero is reported whenever thruster is not turned on</p> <p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> Kg/s</p>
<b>TotalThrust1</b>	N	Y	<p>First component of the total thrust from all thrusters in the three coordinate directions of a J2000 system. Zero is reported whenever thruster is not turned on</p> <p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> Newtons</p>

Parameter	Settable	Plot-table	Description
<b>TotalThrust2</b>	N	Y	<p>Second component of the total thrust from all thrusters in the three coordinate directions of a J2000 system. Zero is reported whenever thruster is not turned on</p> <p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> Newtons</p>
<b>TotalThrust3</b>	N	Y	<p>Third component of the total thrust from all thrusters in the three coordinate directions of a J2000 system. Zero is reported whenever thruster is not turned on</p> <p><b>Data Type</b> Real  <b>Dependency</b> (None)  <b>Units</b> Newtons</p>

## Solver

**Solver** parameters allow you to query a **Solver** for its convergence state to determine if the **Solver** converged. There are both string and numeric parameters which are described in further detail in the table below the following usage example using solver parameters before and after a **Target** sequence.

```
Create Spacecraft aSat
Create Propagator aPropagator

Create ImpulsiveBurn aBurn
Create DifferentialCorrector aDC
Create OrbitView EarthView
EarthView.Add = {Earth,aSat}
EarthView.ViewScaleFactor = 5

Create ReportFile aReport

BeginMissionSequence
Report aReport aDC.SolverStatus aDC.SolverState
Target aDC
    Vary aDC(aBurn.Element1 = 1.0, {Upper = 3})
    Maneuver aBurn(aSat)
    Propagate aPropagator(aSat,{aSat.Apoapsis})
    Achieve aDC(aSat.RMAG = 42164)
EndTarget
Report aReport aDC.SolverStatus aDC.SolverState
```

Parameter	Settable	Plot-table	Description
<b>SolverStatus</b>	N	N	The <b>SolverStatus</b> parameter contains the state of a <b>Solver</b> . If the <b>Solver</b> has not executed, <b>SolverStatus</b> is <b>Initialized</b> . If the <b>Solver</b> has executed and converged, <b>SolverStatus</b> is <b>Converged</b> . If the <b>Solver</b> is iterating, <b>SolverStatus</b> is <b>Running</b> . If the <b>Solver</b> has executed and reached the maximum number of iterations before convergence, <b>SolverStatus</b> is <b>ExceededIterations</b> . If the <b>Solver</b> has executed and failed to converge, but did not exceed the maximum iterations, <b>SolverStatus</b> is <b>DidNotConverge</b> .
			<p><b>Data Type</b> String  <b>Dependency</b> (None)  <b>Units</b> (None)</p>
<b>SolverState</b>	N	Y	The <b>SolverState</b> parameter contains the state of a <b>Solver</b> . If the solver has not executed, <b>SolverState</b> is 0. If the <b>Solver</b> has executed and converged, <b>SolverState</b> is 1. If the <b>Solver</b> is iterating, <b>SolverState</b> is 0. If the <b>Solver</b> has executed and reached the maximum number of iterations before convergence, <b>SolverState</b> is -1. If the <b>Solver</b> has executed and failed to converge, but did not exceed the maximum iterations, <b>SolverState</b> is -2.
			<p><b>Data Type</b> Integer  <b>Dependency</b> (None)  <b>Units</b> (None)</p>

### Array, String, Variable

**Array**, **String**, and **Variable** resources are themselves parameters, and can be used as any other parameter would. All of these are writable parameters, though only **Variable** resources and individual elements of **Array** resources can be plotted.

### Elapsed Time Parameters

Elapsed time parameters such as **ElapsedSecs** and **ElapsedDays** are computed based on a reference epoch that is dependent upon the context of use. In general, the reference epoch is determined by the command where the parameter is used. The example below shows how the reference epoch is computed based on context.

Create Spacecraft Sat

```
Create Propagator Prop

BeginMissionSequence

Sat.Epoch.TAIModJulian = 35000

% The reference epoch for While is TAIModJulian = 35000.
% The ref. epoch is held constant as the while loop executes
While Sat.ElapsedDays <= 1

    % The reference epoch for Propagate changes every pass.
    % It is set to the epoch at start of propagation
    Propagate Prop(Sat){Sat.ElapsedDays = .1}

EndWhile
```

## Examples

Using parameters in the Mission Sequence:

```
Create Spacecraft aSat
Create Propagator aProp
Create ReportFile aReport
Create Variable i

BeginMissionSequence

% propagate for 100 steps
For i=1:100
    Propagate aProp(aSat)
    % write four parameters (one standalone, three coordinate-system-dependent) to a file
    Report aReport aSat.TAIGregorian aSat.EarthFixed.X aSat.EarthFixed.Y aSat.EarthFixed.Z
EndFor
```

Using parameters as plot data:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aPlot
aPlot.XVariable = aSat.TAIModJulian
aPlot.YVariables = {aSat.Earth.Altitude, aSat.Earth.ECC}

Create Variable i

BeginMissionSequence

% propagate for 100 steps
For i=1:100
    Propagate aProp(aSat)
```

```
EndFor
```

Using parameters as stopping conditions:

```
Create Spacecraft aSat
aSat.SMA = 6678

Create ForceModel anFM
anFM.Drag.AtmosphereModel = MSISE90

Create Propagator aProp
aProp.FM = anFM

BeginMissionSequence

Propagate aProp(aSat) {aSat.Earth.Altitude = 100, aSat.ElapsedDays = 365}
```

## Command-Line Usage

Starting the GMAT application from the command line

### Synopsis

GMAT [*option...*] [*script\_file*]

GMATConsole [*option...*] [*script\_file*]

### Description

The GMAT command starts the GMAT graphical interface. If run with no arguments, GMAT starts with the default mission loaded. If *script\_file* is specified, and is a valid path to a GMAT script, GMAT loads the script and remains open, but does not run it. The GMATConsole command starts the GMAT console interface. See below for options supported by each interface.

### Options

#### **-b, --batch**

Runs multiple scripts listed in specified file.

#### **-h, --help**

Start GMAT and display command-line usage information in the message window if using the GUI version, or in the terminal if using the console interface.

#### **-l <filename>, --logfile <filename>**

Specify the log file (ignored in Console interactive mode).

#### **-m, --minimize**

Start GMAT with a minimized interface.

#### **-ns, --no\_splash**

Start GMAT without the splash screen showing.

#### **-r <filename>, --run <filename>**

Automatically run the specified script after loading.

#### **--save <filename>**

Saves current script (interactive mode only).

#### **--start-server**

Starts GMAT Server on start-up (ignored for Console).

#### **-s <filename>, --startup\_file <filename>**

Specify the startup file (ignored in Console interactive mode).

#### **--summary**

Writes command summary (interactive mode only).

#### **--verbose**

Dump info messages to screen during run (default is on).

#### **-v, --version**

Start GMAT and display version information in the message window.

#### **-x, --exit**

Exit GMAT after running the specified script. If specified with only a script name (i.e. NO -run option), GMAT simply opens and closes.

## Precedence Rules

Some file locations, the log file for example, can be set in multiple locations. The precedence rules are as follows. Command line settings have the highest precedence, and those values are always used if set. The second precedence is taken by script level settings, for example, GmatGlobal.LogFile = C:\myLog.txt. Finally, if no other method is set, the value in the startup file is used.

There are additional precedence rules that apply when the startup file is configured to use RUN\_MODE = TESTING. In that case, the log file name from the startup file has precedence, and the output path can be overwritten by settings available in the GUI Set File Paths option in the File menu, or in the Run Scripts option available in the Scripts menu in the Resource Tree.

## Examples

Start GMAT and run the script MyScript.script:

**GMAT MyScript.script**

Run a script with the interface minimized, and exit afterwards:

**GMAT --minimize --exit MyScript.script**

## Keyboard Shortcuts

Keyboard shortcuts in the graphical user interface

### Description

The GMAT graphical user interface (GUI) offers many keyboard shortcuts for easy access to common commands. See the tables below for details.

### General shortcuts

These keyboard shortcuts are available any time when using GMAT.

Key	Meaning
<b>Ctrl+Shift+&lt;number&gt;</b>	Open recent script <number> (1–5).
<b>Ctrl+N</b>	Create a new mission.
<b>Ctrl+Shift+N</b>	Create a new empty script.
<b>Ctrl+O</b>	Open the <b>Open</b> dialog box.
<b>Ctrl+S</b>	Save the current mission.
<b>F1</b>	Open the Help documentation.
<b>Ctrl+F1</b>	Open the <b>Welcome Page</b> .
<b>F5</b>	Run the current mission.
<b>F9</b>	Animate the current graphics window.
<b>F12</b>	Open the <b>Save As</b> dialog box.

### Tree view shortcuts

These keyboard shortcuts are available when navigating the Resources, Mission, and Output trees.

Key	Meaning
<b>Enter</b>	Open.
<b>Space</b>	Open.
<b>Delete</b>	Delete.
<b>Ctrl+Shift+C</b>	Clone (only available for resources).
<b>F2</b>	Rename.
<b>Ctrl+Page Up</b>	View the next tab.
<b>Ctrl+Page Down</b>	View the previous tab.

### Dialog box shortcuts

These keyboard shortcuts are available when interacting with dialog boxes, such as the property windows for the **Spacecraft** resource or the **Propagate** command.

Key	Meaning
<b>Tab</b>	Move to the next item.
<b>Shift+Tab</b>	Move to the previous item.
<b>Ctrl+C</b>	Copy.
<b>Ctrl+V</b>	Paste.
<b>Ctrl+W</b>	Close.
<b>F1</b>	Open feature-specific help.
<b>F7</b>	Show script.

### Script editor shortcuts

These keyboard shortcuts are available when using the script editor.

<b>Tab</b>	Insert a tab character.
<b>Shift+Tab</b>	Remove a tab character on the current line.
<b>Ctrl+Tab</b>	Move to the next editor button.
<b>Ctrl+Shift+Tab</b>	Move to the previous editor button.
<b>Ctrl+A</b>	Select all.
<b>Ctrl+C</b>	Copy.
<b>Ctrl+F</b>	Open the <b>Find and Replace</b> dialog box.
<b>Ctrl+G</b>	Open the <b>Go To</b> dialog box.
<b>Ctrl+H</b>	Open the <b>Find and Replace</b> dialog box.
<b>Ctrl+I</b>	Indent more.
<b>Ctrl+Shift+I</b>	Indent less.
<b>Ctrl+R</b>	Comment the current line.
<b>Ctrl+Shift+S</b>	Save,Sync.
<b>Ctrl+T</b>	Uncomment the current line.
<b>Ctrl+V</b>	Paste.
<b>Ctrl+W</b>	Close.
<b>Ctrl+X</b>	Cut.
<b>Ctrl+Y</b>	Redo.
<b>Ctrl+Z</b>	Undo.
<b>F3</b>	Find next (after using <b>Find and Replace</b> )..
<b>Ctrl+Shift+F5</b>	Save,Sync,Run.
<b>Ctrl+Shift+F12</b>	Save As.

Additionally, the following mouse controls are available:

- Hold down **Ctrl** while rotating the wheel button to increase or decrease the font size.

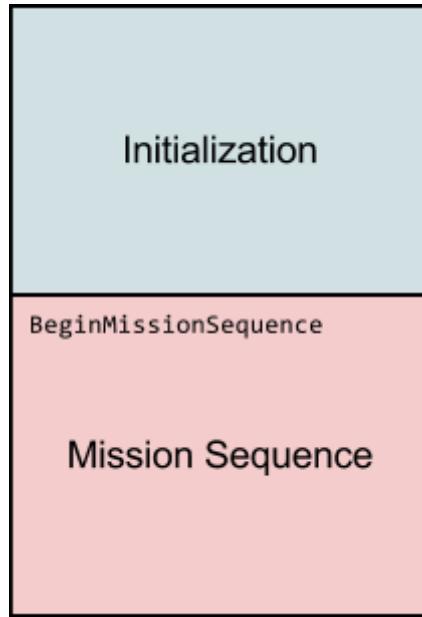
## Script Language

The GMAT script language

### Script Structure

A GMAT script is a text file consisting of valid script syntax elements, such as initialization statements, Mission Sequence commands, and comments. These syntax elements are described later in this specification.

At the highest level, a GMAT script is made up of two sections: Initialization and the Mission Sequence. These sections each contain statements, but they have different rules about which sorts of statements are valid. The **BeginMissionSequence** command defines the beginning of the Mission Sequence section.



### Initialization

The first section in a script file, referred to as Initialization, is responsible for creating resources and setting their initial state. The Initialization section can contain the following types of statements:

- resource creation statements (the **Create** statement)
- initialization statements

Only literal assignments are allowed in this section; no execution of commands or evaluation of parameters is done. In the GUI, the Initialization section maps directly to the Resources tree. All resources created, and all fields set, in this section appear as resources in the GUI when the script is loaded.

## Mission Sequence

The Mission Sequence section contains the Mission Sequence, or the list of GMAT commands that are executed sequentially when the mission is run. The Mission Sequence section can contain the following types of statements:

- command statements

The Mission Sequence begins at the first instance of the **BeginMissionSequence** command; therefore, this must be the first command statement in the script file. For backwards compatibility, if the **BeginMissionSequence** command is missing, the Mission Sequence begins with the first command encountered.

In the GUI, the Mission Sequence section maps directly to the Mission tree. Each statement in the script (with the exception of the **BeginScript/EndScript** compound command) is displayed as a single element in the tree.

## Basic Syntax

### Source Text

A GMAT script consists of a single file containing characters from the 7-bit US-ASCII character set. The script language is case-sensitive, so this line creates four different Variable resources:

```
Create Variable x X y Y
```

The script language is made up of lines. A line can be:

- empty
- a comment (see [Comments](#), below)
- a statement (see [Statements](#))

Statement lines can be split over multiple physical lines with the continuation marker (“...”).

### Line Termination

Script lines are terminated by any of the following ASCII character sequences:

- line feed (hex: 0A)
- carriage return (hex: 0D)
- carriage return followed by line feed (hex: 0D0A)

### White Space

White space can appear above or below any line, before or after any statement within a line, and many other places in a script. The following characters are recognized as white space:

- space (hex: 20)

- horizontal tab (hex: 09)

Horizontal tab characters are preserved in string literals, but are replaced by spaces in some other contexts (e.g. equations, comments).

## Comments

Comments begin with the percent symbol ("%", hex: 25) and extend to the end of the line. There is no multi-line or embedded comment in the script language.

## File Paths

Several resource types have fields that accept file paths as input. The general syntax of such paths is common to the language, but some specific behavior is specified by each resource.

Forward slashes and backslashes can be used interchangeably within GMAT, and can be mixed in a single path. The following three paths are considered identical:

```
data/planetary_ephem/spk/de421.bsp  
data\planetary_ephem\spk\de421.bsp  
data\planetary_ephem\spk\de421.bsp
```

Absolute paths are passed to the underlying operating system as-is, aside from normalizing the slashes.

For input files, relative paths are first considered relative to the script file, then to a location defined by each resource type separately, and usually defined in the GMAT startup file. For details, see the reference documentation for each resource type.

For output files, relative paths are considered relative to the script file. If only a filename is specified, the file is placed into the output location defined in the GMAT startup file (usually GMAT's output folder).

File paths are written as string literals (see [Strings](#) under [Data Types](#)). Quotes are mandatory if the path contains spaces, but are optional otherwise.

## Data Types

### Literals

#### Integers

Integers are written as a sequence of literal digits, with no decimal. Preceding zeros and prepended signs (+ or -) are allowed. Scientific notation is not permitted.

#### Real Numbers

Real numbers can be written in any of the following formats:

- 12 (whole number)
- 12.5 (decimal)

- 1.25e1 or 1.25e-1 (scientific notation)

In all formats, the base can contain preceding or trailing zeros. In scientific notation, the exponent can be prepended by a sign (+ or -) and can contain preceding zeros, but cannot contain a decimal. The exponent delimiter is case-insensitive (e.g. "e" or "E").

## Strings

String literals are delimited by single-quote characters ("'", hex: 27).

All language-supported characters are allowed in strings, with the exceptions below. There are no escape characters or character substitute sequences (such as "\n" for line feed).

In Initialization, the following characters are not allowed in string literals:

- some non-printable characters (NUL, SUB) (hex: 00, 1A)
- line termination characters (LF, CR) (hex: 0A, 0D)
- percent character ("%") (hex: 25)

In the Mission Sequence, the following characters are not allowed in string literals:

- some non-printable characters (NUL, SUB) (hex: 00, 1A)
- line termination characters (LF, CR) (hex: 0A, 0D)
- percent character ("%") (hex: 25)

Quotes are generally optional, but are mandatory in Initialization if the string contains whitespace, any script language symbols, or any GMAT-recognized elements (e.g. keywords, resource names). They are mandatory in the Mission Sequence in the same instances, and additionally if the string contains mathematical operators and certain non-printable characters. We recommend quoting all string literals.

## Booleans

The following boolean values are supported:

- true (alias: on)
- false (alias: off)

Boolean literals are case-insensitive.

## Enumerated Values

Many resource fields accept enumerated values. For example, **Spacecraft.DateFormat** accepts one of 10 values (**A1ModJulian**, **A1Gregorian**, etc.). Enumerated values are written as string literals. Quotes are always optional, as none contain spaces or special characters.

## References

References to resources and resource parameters are indicated by the name of the resource or resource parameter. References are written as string literals. Quotes are

always optional, as resource names and parameters cannot contain spaces or special characters.

## Resources

### Resource Types

Resources in GMAT are instances of a base resource type that are given user-defined names and store data independently of other resources of the same type. Resource types include **Spacecraft**, **GroundStation**, and **Variable**. They cannot be used directly; they must first be instantiated with the **Create** statement. For example:

```
Create Spacecraft aSat
```

In the example, **Spacecraft** is the resource type and **aSat** is the resource. This is similar to the concept of classes and objects in object-oriented programming, where GMAT's resource types are analogous to classes and its resources are analogous to objects.

### Naming Rules

Resources must be named according to these rules:

- Name must be made up of ASCII letters, numbers, or the underscore character (“\_”). This corresponds to hex values 30–39, 41–5A, 5F, and 61–7A.
- Name must begin with a letter (A–Z or a–z, hex: 41–5A or 61–7A)
- Name cannot be a reserved keyword or command name

### Shadowing

When the same name is used for multiple purposes in a script, the shadowing rules apply to determine how a reference to the name is interpreted.

Resource names must be unique within a script. If a script attempts to create multiple resources that have the same case-sensitive name, the first **Create** statement in the script with that name is executed and all subsequent ones are ignored. The conflict is noted in a warning message.



#### Caution

GMAT does not test to ensure that **Resource** names and function names are unique. Care should be taken to use unique names for user-defined GMAT, MATLAB, and Python functions to avoid name clashes.

Command names and keywords are reserved. They cannot be used as resource names. See the [Keywords](#) section for a list of keywords.

Built-in function names (like `sin` or `cos`) can be used as resource names with one exception: a reference to, for example, “`sin(1)`” on the right-hand side of an equal sign will be interpreted as a call to the `sin` built-in function, not element 1 of an **Array** resource named `sin`. The same is true for the other built-in functions.

Resource type names (like “**Spacecraft**”) can be used as resource names. In such an instance, the conflict is resolved by the context. For example:

```
Create Spacecraft Spacecraft
Create Spacecraft aSat
```

In the example, GMAT knows by context that in the second **Create** statement, the argument “Spacecraft” refers to the resource type, not the resource instance created in the first statement.

## Compound Types

### Array of Literals

Arrays of literals are accepted as input by some resources. Arrays of booleans, integers, and real numbers are surrounded by square brackets (“[” and “]”, hex: 5B and 5D). Arrays of strings are surrounded by curly brackets (“{” and “}”, hex: 7B and 7D). In all cases, the values are separated by whitespace or commas. Only one-dimensional arrays of literals are supported. See the following examples.

```
anOrbitView.DrawObject = [true true] % boolean array
aSat.OrbitColor = [255 0 0] % integer array
anOrbitView.ViewPointVector = [3e4, 1.2, -14] % real array
aSpacecraft.OrbitSpiceKernelName = ...
    {'file1.bsp', 'file2.bsp'} % string array
```

### Arrays of References

Some resources accept arrays of references to other resources or resource fields. These reference arrays are surrounded by curly brackets (“{” and “}”, hex: 7B and 7D) and the values are separated by whitespace or commas. Only one-dimensional arrays of references are supported. The values can optionally be surrounded by single quotes. See the following example.

```
aForceModel.PointMasses = {'Luna', Mars} % array of resource references
aReport.Add = {Sat1.X, 'Sat1.Y', Sat1.Z} % array of parameter references
```

### Conversion

In contexts that accept a real number, integer literals (those with no fractional value) are automatically converted to the equivalent floating-point value upon execution.

There is no built-in conversion between string values and numeric values, though such a conversion may be implemented by individual commands.

### Keywords

The script language recognized these reserved keywords:

- Create
- GMAT

- function

In addition, all command names are reserved, including commands created by active plugins.

## Expressions

The only types of expressions common to multiple commands are logical expressions, which are used by the **If/Else** and **While** commands. They are documented here instead of in both command references.

### Relational Operators

The following relational operators are supported in logical expressions:

<	less than
<=	less than or equal to
>	greater than
>=	greater than or equal to
==	equal to
~=	not equal to

The relational operators are scalar operators; they do not operate on **Array** resources (only individual elements).

Each relational operator operates on the values of its arguments, not on their identity. Consider the example:

```
Create Variable x y
x = 5
y = 5

BeginMissionSequence

If x == y
    % body
EndIf
```

### Logical Operators

The following logical operators are supported in logical expressions:

&	logical AND (short-circuit operator)
	logical OR

The logical AND operator exhibits short-circuit behavior. That is, if the left-hand side of the operator evaluates to false, the right-hand side is not evaluated, though it is still parsed for syntactic validity.

## Logical Expressions

Logical expressions are composed of relational expressions combined with logical operators.

Relational expressions must contain one relational operator and two valid arguments. Literal boolean values are not supported, and numeric values are not interpreted as truth or falsehood. See the following examples:

```
1 == 5          % false
1 ~= 5          % true
true            % error
1               % error
A               % where "A" is an Array resource; error
1 == 5 <= 3    % error
```

Logical expressions must contain at least one relational expression. Multiple relational expressions are combined using logical operators. All relational expressions are evaluated first, from left to right, then the full logical expression is evaluated from left to right, though the short-circuit AND operator ("&") may terminate the full evaluation. Parentheses are not allowed. See the following examples:

```
1 == 1          % true
2 ~= 4 | 3 == 3 % true
8 >= 3 & 3 < 4  % true
2 < 4 & 1 > 3 | 5 == 5 % true
2 < 4 & (1 > 3 | 5 == 5) % error
1 & 1           % error
true | false    % error
```

## Statements

### Statement Structure

Script statements consist of (in order):

1. Optional "GMAT " prefix
2. Valid statement syntax (with optional line continuation)
3. Optional semicolon
4. Line termination sequence

Any statement in the script may be prefixed by the characters "GMAT ". This prefix is optional and has no effect, but is supported for backward compatibility.

A statement can be split over multiple physical lines by using the line continuation marker, three sequential period characters ("...", hex: 2E2E2E), before each line break within the statement.

Any statement may be terminated with a semicolon character (";", hex: 3B). The semicolon is optional and has no effect, but is supported for backward compatibility. Multiple statements cannot be combined on a line.

White space may occur before or after a statement, or between any of the components listed above. It is also generally allowed anywhere inside of a statement, and any exceptions are noted in the documentation specific to that statement.

### The Create Statement

The **Create** statement is a special statement that creates resources and assigns them names. It is only valid in the Initialization section of the script. It has the following components:

1. Create keyword
2. Resource type
3. Resource name(s)

The Create keyword indicates the start of the statement. It is followed by the resource type, which indicates the type of resource to create. This is followed by a resource name, a user-defined name that is then used to refer to that particular resource. This name must follow the resource naming rules, listed previously.

The only exception to this syntax is when creating an **Array** resource, in which case the dimension of the resource must also be specified

Multiple resource names are allowed, in which case multiple resources of the same type will be created. Multiple names are separated by white space or by commas (",", hex: 2C).

See the following examples:

```
Create Spacecraft aSat % creates a resource "aSat" of type Spacecraft
Create ForceModel aFM
Create Propagator aProp
Create Variable x y % creates two Variable resources: "x" and "y"
Create String s1, s2 % creates two String resources: "s1" and "s2"
Create Array A[2,2] % creates a 2x2 Array resource named "A"
```

### Initialization Statements

Initialization statements are special statements that assign initial values to resource fields. They are only valid in the Initialization section of the script, and generally take the following form:

```
resource.field = value
```

Some fields, like those on ForceModel resources, have a multiple-dotted form:

```
ForceModel.GravityField.PrimaryBody.Degree = value
```

All initialization statements are composed of the following elements:

1. Resource name
2. Period character (".", hex: 2E)
3. Field name, potentially in multiple-dotted form

4. Equal character (“=”, hex: 3D)
5. Initial field value

The resource name must refer to a resource created previously in same script.

The field name must refer to a valid field that exists for the associated resource type. Parameters cannot be set with an initialization statement, though it is valid to set a dual-mode field (one that can also be a parameter). Fields and parameters are listed in the documentation for each resource type.

All values are taken literally; no evaluation is performed. Therefore, numeric and string values must be specified as literals, and resource names and parameters are stored as references. See the following example:

```
Create Spacecraft aSat
Create XYPlot aPlot
Create Variable x y z

x = 7100           % valid
aSat.X = 7100       % valid
aSat.X = 7100 + 2   % error (mathematical expression)

aSat.X = x          % error (field accepts literal, and variable
                      % evaluation does not occur)
aPlot.XVariable = x    % valid (field accepts reference to Variable x)
aPlot.YVariables = {y, z} % valid (field accepts array of references to
                          % Variables y and z)
```

For backwards compatibility, there is one exception to the literal-value rule: **Spacecraft** resources can be copied with an initialization statement like:

```
Create Spacecraft aSat1 aSat2
aSat2 = aSat1           % Valid only for Spacecraft resources
```

Fields that have no assigned value in the Initialization section of the script remain at their default values, as specified in the documentation for each resource type.

## Command Statements

Command statements invoke GMAT commands. They must appear in the Mission Sequence section of the script. One special command, **BeginMissionSequence**, initiates the Mission Sequence.

Command statements are displayed by the GUI as individual line items in the Mission tree. The only exception is the **BeginScript/EndScript** compound command; this is displayed as a single **ScriptEvent** item by the GUI.

Command statements are composed of the following elements:

1. Command name (except assignment commands)
2. Optional label

### 3. Command arguments

The command name is the name of the command being invoked (e.g. **Propagate** or **BeginFiniteBurn**). The command name is mandatory with one exception: the assignment command is indicated by its structure (“*LHS* = *RHS*”) instead of its name.

A command label is an optional string literal that can be added immediately after the command name. This label is used by the GUI to “name” the statement in the Mission tree, and is intended for a short text description to aid the user. It must be single-quoted, whether or not it contains spaces. The command label may contain any ASCII character except certain non-printable characters (NUL, SUB), line termination characters (LF, CR), the percent sign (“%”), and the single quote (“'”). If the command label is omitted, the Mission tree statement is given a default label made up of the command name and an ID number. For example, if the third **Propagate** command in the script is unlabeled, it will be given the default label “**Propagate3**”.

The command arguments control the behavior of the command. The syntax of the arguments is specified by each command individually, and is documented separately. Some commands, such as **Stop**, have no arguments.

See the following example:

```
Propagate 'Prop to periapsis' aProp(aSat) {aSat.Periapsis}
```

In the example, “Propagate” is the command name, “‘Prop to periapsis’” is the command label, and “aProp(aSat) {aSat.Periapsis}” is the argument string.

## Compound Statements

Compound statements are command statements that control the execution of other command statements. Compound statements are composed of three elements:

1. Begin statement
2. Body
3. End statement

The begin statement carries the name of the command itself, while the end statement begins with the string “End”. For example, the **While** command is a compound command composed of two statements:

```
While ['Label'] arguments
    [body]
EndWhile
```

The **If/Else** compound command is composed of three statements:

```
If ['Label'] arguments
    [body]
Else
    [body]
EndIf
```

The body of a compound command may consist of independent command statements, possibly including other compound statements. Certain compound commands may limit the commands that can be present in the body, while other commands may only be contained within certain compound commands. These limitations are documented separately for each command.

## Processing

GMAT processes a script in two phases: interpretation and execution. This section gives an overview of the processing sequence; low-level details are documented in Chapter 17 of the GMAT Architectural Specification.

### Interpretation

GMAT interprets a script in two stages: a parsing stage and a validation stage. In the parsing stage, GMAT reads and interprets each line of the script sequentially. As it interprets a line, it checks it for syntactic correctness and performs any initialization needed by the line. For example, if the line being interpreted is a **Create** statement, the related resource is created. If GMAT encounters an initialization line, it assigns the appropriate value to the indicated resource field. And if it encounters a command statement, it creates the command structure and interprets its arguments. All language, resource initialization, and command syntax errors are caught during this parsing stage.

In the validation stage, GMAT checks that all references between resources are valid. For example, if the script indicates that a **Spacecraft** resource should be defined in relation to a specific **CoordinateSystem** resource, the reference is validated during this stage. The validation checks that all referenced resources exist and are of the correct type.

The two-stage interpretation method affects the order of statements in the script. For example, **Create** statements must appear in the script above any initialization statements that reference the resource being created. But because validation is performed separately, the **Create** statement for a **CoordinateSystem** resource can appear in the script below an initialization line that references this resource. See the following examples:

```
Create Spacecraft aSat  
  
% This is valid; the aSat resource has been created by the line above.  
aSat.DateFormat = TAIGregorian  
  
% This is invalid; the aReport resource has not yet been created.  
aReport.Filename = 'report.txt'  
Create ReportFile aReport
```

```
Create XYPlot aPlot  
  
% This is valid; the reference to aSat is validated  
% after all resources are created.  
aPlot.XVariable = aSat.A1ModJulian
```

### Create Spacecraft aSat

Once both stages have completed, the script has been loaded into GMAT. In the GUI, if any, the Resources tree is populated with the resources created in the Initialization section of the script, and the Mission tree is populated with the command statements in the Mission Sequence.

The interpretation phase is also sometimes called the “build” phase or the “load” phase.

### Execution

When a mission is run, GMAT first builds interconnections between resources, then performs command execution. In this phase, all commands in the Mission Sequence are executed sequentially, in the order of definition in the script. When a command statement is executed, its arguments are fully processed by the command, and any remaining errors are reported. Examples of execution-phase errors include mismatched data types, out-of-bounds array references, and divide-by-zero errors.

### Processing Errors

If GMAT encounters an error during the interpretation stage (parsing or validation), the mission is not loaded. Instead, GMAT reverts to a minimum mission consisting of:

- **SolarSystem**
- Default **CoordinateSystem** resources: **EarthMJ2000Eq**, **EarthMJ2000Ec**, **Earth-Fixed**, **EarthICRF**

If an error is encountered during the execution stage (linking or command execution), execution of the mission stops at the point of the error.

## Startup File

The `gmat_startup_file.txt` configuration file

### Description

The GMAT startup file (`gmat_startup_file.txt`) contains basic configuration settings for the GMAT application. This includes the locations of data files and plugins, search paths for user-defined functions, and various options that control execution.

The startup file must be located in the same location as the GMAT executable, and must be named `gmat_startup_file.txt`. GMAT loads the startup file once during program initialization.

### File Format

#### Basic Syntax

The startup file is a text file containing characters from the 7-bit US-ASCII character set. The startup file is case-sensitive.

Lines are terminated by any of the following ASCII character sequences:

- line feed (hex: 0A)
- carriage return (hex: 0D)
- carriage return followed by line feed (hex: 0D0A)

White space can appear above or below any line and before or after any key or value. The following characters are recognized as white space:

- space (hex: 20)
- horizontal tab (hex: 09)

Comments begin with the number sign (“#”) and must appear on their own line. Inline comments are not allowed.

#### Setting Properties

Properties are specified via key-value pairs, with the following syntax:

`PROPERTY = VALUE`

Properties are one word, with no spaces. Values extend from the first non-whitespace character after the equal sign to the end of the line. At least one whitespace character is required on both sides of the equal sign.

Properties are named according to the following conventions:

- Properties that accept directory paths end with “`_PATH`”.
- Properties that accept file paths end with “`_FILE`”.

The behavior of duplicate property entries is dependent on the individual property. In general:

- Multiple PLUGIN entries cause GMAT to load each named plugin.
- Multiple identical \*\_FUNCTION\_PATH entries add each path to the search path, starting with the first.
- Multiple identical \*\_FILE entries are ignored; the last value is used.

## Accessing Property Values

The value of any property ending in “\_PATH” (including custom ones) can be referenced by other values. To reference a value, include the property name as part of the value. Repeated slash characters are collapsed. For example:

```
ROOT_PATH = ../  
OUTPUT_PATH = ROOT_PATH/output/
```

sets OUTPUT\_PATH to a value of “../output/”.

## File Paths

Forward slashes and backslashes can be used interchangeably, and can be mixed in a single path. The following three paths are considered identical:

```
data\planetary_ephem\spk\de421.bsp  
data\planetary_ephem\spk\de421.bsp  
data\planetary_ephem\spk\de421.bsp
```

Absolute paths are passed to the underlying operating system as-is, aside from normalizing the slashes.

Relative paths are relative to the location of the GMAT executable.

## Properties

The available properties are shown here, with default values where appropriate.

### System

**ROOT\_PATH=.../**  
Path to GMAT root directory.

### Plugins

#### PLUGIN

Path to plugin library, without extension. Multiple PLUGIN properties are allowed, one per plugin.

### User Functions

#### GMAT\_FUNCTION\_PATH

Search path for GMAT function files (.gmf files). May occur multiple times to add multiple paths.

**MATLAB\_FUNCTION\_PATH**

Search path for MATLAB function files (.m files). May occur multiple times to add multiple paths.

**PYTHON\_MODULE\_PATH**

Search path for Python modules. May occur multiple times to add multiple paths.

**Output****LOG\_FILE=OUTPUT\_PATH/GmatLog.txt**

Path of application log file

**MEASUREMENT\_PATH=OUTPUT\_PATH/**

Path of simulated measurement data files. Only used with the libGmatEstimation plugin.

**OUTPUT\_PATH=../output/**

Output directory path for **ReportFile** resources.

**SCREENSHOT\_FILE=OUTPUT\_PATH/OUTPUT\_PATH**

Output path and base filename for screenshots. The base filename is appended with “\_###.png”, where “###” is a number sequence starting from 001. If the base filename is missing, it defaults to “SCREEN\_SHOT”.

**VEHICLE\_EPHEM\_PATH=OUTPUT\_PATH/**

Default output directory path for **EphemerisFile** resources.

**Data Files**

Note this section only discusses the paths that can be set via the startup file. See [Configuring Data Files](#) or a discussion of file contents of data files that are regularly updated and how to maintain those files.

**CELESTIALBODY\_POT\_PATH=DATA\_PATH/gravity/celestiaLbody/**

Search path for gravity potential files for **CELESTIALBODY**. **CELESTIALBODY** is the name of any celestial body defined in a given GMAT mission. This property has no default for user-defined celestial bodies.

**ATMOSPHERE\_PATH**

Path to directory containing atmosphere model data.

**BODY\_3D\_MODEL\_PATH**

Path to directory containing CelestialBody 3D model files.

**CSSI\_FLUX\_FILE**

Path to default CSSI solar flux file.

**DATA\_PATH=ROOT\_PATH/data/**

Path to directory containing data files.

**DE405\_FILE=DE\_PATH/leDE1941.405**

Path to DE405 DE-file ephemeris file.

**DE421\_FILE**

Path to DE421 DE-file ephemeris file.

**DE424\_FILE**

Path to DE424 DE-file ephemeris file.

**EGM96\_FILE=EARTH\_POT\_PATH/EGM96.cof**

Path to EGM-96 Earth gravity potential file.

**EOP\_FILE**

Path to IERS “EOP 08 C04 (IAU1980)” Earth orientation parameters file.

**ICRF\_FILE**

Path to data required for computing rotation matrix from FK5 to ICRF (ICRF\_Table.txt).

**JGM2\_FILE=EARTH\_POT\_PATH/JGM2.cof**

Path to JGM-2 Earth gravity potential file.

**JGM3\_FILE=EARTH\_POT\_PATH/JGM3.cof**

Path to JGM-3 Earth gravity potential file.

**LEAP\_SECS\_FILE=TIME\_PATH/tai-utc.dat**

Path to cumulative leap seconds file from <http://maia.usno.navy.mil>.

**LP165P\_FILE=LUNA\_POT\_PATH/LP165P.cof**

Path to LP165P Moon gravity potential file.

**LSK\_FILE**

Path to SPICE leap second kernel.

**MARINI\_TROPO\_FILE**

Path to file containing location specific atmospheric data needed for the Marini tropospheric model.

**MARS50C\_FILE=MARS\_POT\_PATH/Mars50c.cof**

Path to Mars50c Mars gravity potential file.

**MGNP180U\_FILE=VENUS\_POT\_PATH/MGNP180U.cof**

Path to MGNP180U Venus gravity potential file.

**NUTATION\_COEFF\_FILE=PLANETARY\_COEFF\_PATH/NUTATION.DAT**

Path to nutation series data for FK5 reduction (NUTATION.DAT).

**PLANETARY\_COEFF\_PATH=DATA\_PATH/planetary\_coeff/**

Path to directory containing planetary coefficient files.

**PLANETARY\_EPHEM\_DE\_PATH**

Path to directory containing DE ephemeris files.

**PLANETARY\_EPHEM\_SPK\_PATH**

Path to directory containing SPICE planetary ephemeris files.

**PLANETARY\_PCK\_FILE**

Path to SPICE planetary constants kernel for default celestial bodies.

**PLANETARY\_SPK\_FILE**

Path to SPICE ephemeris kernel for default celestial bodies.

**SCHATTEN\_FILE**

Path to default Schatten solar flux predict file.

**SPACECRAFT\_MODEL\_FILE**

Default spacecraft 3D model file.

**SPAD\_PATH**

Path to directory containing SPAD data files.

**SPAD\_SRPMODEL\_FILE**

Path to default SPAD SRP model.

**TIME\_PATH=DATA\_PATH/time/**

Path to directory containing leap-second files.

**VEHICLE\_EPHEM\_CCSDS\_PATH**

Path to directory containing spacecraft CCSDS-OEM ephemeris files.

**VEHICLE\_EPHEM\_SPK\_PATH**

Path to directory containing spacecraft SPK ephemeris files.

**VEHICLE\_MODEL\_PATH**

Path to directory containing 3D spacecraft models.

## Application Files

**CELESTIALBODY\_TEXTURE\_FILE=TEXTURE\_PATH/DefaultTextureFile.jpg**

Path to texture file for CELESTIALBODY. CELESTIALBODY is the name of any of the built-in celestial bodies in GMAT. DefaultTextureFile is the default texture file defined for that celestial body.

**BORDER\_FILE**

Path to constellation border catalog.

**CONSTELLATION\_FILE=STAR\_PATH/inp\_Constellation.txt**

Path to constellation catalog.

**GUI\_CONFIG\_PATH=DATA\_PATH/gui\_config/**

Path to directory containing GUI configuration files.

**HELP\_PATH**

Path to directory containing user guide help files.

**HELP\_DIRECTORY\_FILE**

Path to CHM help file, used to navigate user guide contents through the GMAT GUI.

**HELP\_HTML\_FILE**

Path to HTML help file, used to open the entire user guide in a browser.

**ICON\_PATH=DATA\_PATH/graphics/icons/**

Path to directory containing application icons.

**MAIN\_ICON\_FILE**

Path to GUI icon.

**PERSONALIZATION\_FILE=DATA\_PATH/gui\_config/MyGmat.ini**

Path to GUI configuration and history file.

**SPACECRAFT\_MODEL\_FILE=MODEL\_PATH/aura.3ds**

Path to default Spacecraft 3D model file.

**SPLASH\_FILE=SPLASH\_PATH/GMATSplashScreen.tif**

Path to GUI splash image.

**SPLASH\_PATH=DATA\_PATH/graphics/splash/**

Path to directory containing splash file.

**STAR\_FILE=STAR\_PATH/inp\_StarCatalog.txt**

Path to star catalog.

**STAR\_PATH=DATA\_PATH/graphics/stars/**

Path to directory containing star and constellation catalogs.

**TEXTURE\_PATH=DATA\_PATH/graphics/textures/**

Path to directory containing celestial body texture files.

## Program Settings

**MATLAB\_APP\_PATH**

[macOS only] Path to MATLAB app (.app).

**MATLAB\_MODE=SHARED**

MATLAB interface connection mode. The available options are:

**NO\_MATLAB**

Disables the MATLAB interface.

**SHARED**

Each GMAT instance shares a single MATLAB connection. Default.

**SINGLE**

Each GMAT instance uses its own MATLAB connection.

**WRITE\_GMAT\_KEYWORD=ON**

Write "GMAT " prefix before assignment lines when saving a GMAT script file. Accepted values are ON and OFF.

**WRITE\_PERSONALIZATION\_FILE=ON**

Write data on window locations and other local configuration settings to the GMAT.ini file. Setting to OFF avoids issues encountered when simultaneous instances of GMAT try to write to the user config file at the same time, resulting in a system error. Accepted values are ON and OFF.

## Debug Settings

**DEBUG\_FILE\_PATH=OFF**

Debug file path handling. Accepted values are ON and OFF.

**DEBUG\_MATLAB=OFF**

Debug MATLAB Interface connection. Accepted values are ON and OFF.

**DEBUG\_PARAMETERS=OFF**

Write table of available parameters to log file on startup. Accepted values are ON and OFF.

**HIDE\_SAVEMISSION=TRUE**

Hide the **SaveMission** command from the GUI. Accepted values are TRUE and FALSE.

**PLOT\_MODE**

**XYPlot** window placement mode. The only accepted value is TILE, which will cause GMAT to ignore plot window placement fields and tile the windows.

**RUN\_MODE**

GMAT execution mode. The available options are:

**EXIT\_AFTER\_RUN**

When GMAT is called with the -r or --run command-line argument, automatically exit after the run is finished.

**TESTING**

Shows testing options in the GUI.

**TESTING\_NO\_PLOTS**

Same as TESTING, but also disables all graphical output in the GUI.

**ECHO\_COMMANDS**

Write commands to log file as they are executed. Accepted values are TRUE and FALSE.

**NO\_SPLASH**

Skip showing the splash screen on GMAT startup. Accepted values are TRUE and FALSE.

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## GMAT R2025a Release Notes

The General Mission Analysis Tool (GMAT) version R2025a was released in April 2025. This is the first public release since January 2023 and is the 15th release for the project. This is a major project release that includes numerous major improvements and enhancements in general capabilities and models, navigation and orbit determination, scripting and API interfaces, and visualization. Below, we give a summary of key changes in this release.

### Milestones and Accomplishments

We are excited that GMAT continues to see significant adoption for operational mission support.

- GMAT is being used as the primary operational tool for maneuver planning by the Space Weather Follow On (SWFO) flight dynamics team.
- GMAT is being used as the primary operational tool for maneuver planning by the Roman Space Telescope (RST) flight dynamics team.
- GMAT orbit determination is being used by the NASA GSFC Flight Dynamics Facility (FDF) to support various missions.

GMAT was featured in the Spark Volume 22 | Number 4 | Fall 2024 GMAT Article that can be accessed [here](#).

### Major Improvements and Enhancements

#### General Capabilities and Models

The following general capabilities are new to R2025a:

- Support for Moon Mean Earth (ME) frame (GMT-8201/GMT-7604). GMAT now allows the user to assign the Lunar Mean Earth (ME) frame as the Moon (Luna) body-fixed

frame. The Moon ME frame will then be used when computing Lunar latitude and longitude or when assigning the BodyFixed axes for a user-defined CoordinateSystem with Luna as the origin. See the code snippet provided in the CelestialBody resource chapter of the User's Guide for an example of configuring and using the Moon ME frame.

- Addition of Lunar fixed frame from user-supplied BPC kernel (GMT-8000). The definition of the lunar-fixed frame for computing selenodetic coordinates and the Luna BodyFixed axes can be specified using SPICE kernels and an appropriate SPICE frame name on the Luna body in GMAT. See the code snippet provided in the CelestialBody resource chapter of the User's Guide for an example of using a binary SPICE orientation kernel to provide the lunar orientation model.
- Addition of True Equator Mean Earth (TEME) axes to the CoordinateSystem resource (GMT-8166). True Equator Mean Earth (TEME) axes are now available in the CoordinateSystem resource.
- Expansion of CSSI space weather file option for drag prediction (GMT-7777/GMT-7772). The user may now specify 'CSSISpaceWeatherFile' on the propagator Drag.PredictedWeatherSource parameter. This allows the user to model predicted drag using the latest available solar activity predictions. See the example provided in the "CSSI Space Weather Data" section of the Force Model chapter of the User's Guide.
- Addition of multi-body harmonic gravity for mission design in production mode (GMT-8254). GMAT now accepts and models full field gravity for multiple bodies simultaneously. This capability is available for mission design and maneuver planning tasks. See the script Ex\_R2025a\_MultibodySphericalHarmonicGravity in the application samples folder for an example of this capability.
- Allow users to set a negative Cd and Cr (GMT-8181). GMAT now allows negative values of Cd and Cr on the Spacecraft resource. While it is not typical or physical for these values to be negative, it may be useful for them to be negative to alias other unmodeled forces, or they may sometimes be negative if used as optimization parameters.
- Additional optimizer monitoring and controls (GMT-8151). GMAT's VF13ad and SNOPT optimizers now provide optional monitoring of the optimization process iteration by iteration. This enables user defined physical tolerances on constraint values outside of the scaling performed by the optimizers. See also the sample script Ex\_R2025a\_MonitoredLunarTransfer.script in the samples/NeedVF13ad folder.
- Additional AzimuthElevationRangeRangeRate output added to Contact Locator Report (GMT-7810). The new AzimuthElevationRangeRangeRate ContactLocator report type provides an output format that reports pass number, station name, azimuth, elevation, range, and range-rate on each line for a specified time step within each computed pass.
- Analytic mass property modeling (GMT-7983). GMAT now includes analytic modeling of the center of mass and moments of inertia for spacecraft objects. Mass properties are calculated dynamically during mass-loss events like finite maneuvers and available for reporting. See the script Ex\_R2025a\_AnalyticMassProperties in the application samples folder for an example of this capability.
- Updates to External force model plugin (GMT-8022). Use of this capability requires proper configuration of the GMAT Python interface. This adds the capability to define and use an acceleration in an external user-created python file. The python code providing the acceleration model must follow certain conventions. See the details pro-

vided in the External Force Model remarks in the ForceModel chapter of the User's Guide. For examples of this capability, see the Ex\_R2025a\_ExternalForceModel and Ex\_R2025a\_ExternalForceModel\_NoAPI scripts in the samples folder.

- GMAT's factory management system now allows the replacement of internal components with customized replacement objects provided in GMAT plugins (GMT-8265). Users of this capability are responsible for testing of any plugin-based replacements that use the new support.

### Beta- and Alpha-level Capabilities

These are new features that have not yet undergone full testing and may have bugs. To access some of these features, you may need to edit the bin/gmat\_startup\_file.txt file to load the desired alpha plug-in and/or activate features only available in testing mode (set RUN\_MODE = TESTING in the file). These features should be used with caution.

- Inclusion of GMD formatting tools for binary UTDF and CCSDS TDM tracking data formats (GMT-7992). Python scripts are available in the utilities/python/navigation folder for the conversion of a limited selection of UTDF and CCSDS TDM data types to GMD format. The utdf\_to\_gmd.py script supports conversion of UTDF three-way RangeRate, TDRS one-way return Doppler, and TDRS DOWD to GMD. The tdm\_to\_gmd.py script supports conversion of CCSDS TDM DOPPLER\_INTEGRATED to GMAT RangeRate, TRANSMIT\_FREQUENCY to GMAT ramp records, RECEIVE\_FREQUENCY to GMAT DSN\_TCP, and RANGE to GMAT Range or DSN\_SeqRange records.

### Navigation and Orbit Determination (OD)

The following navigation and orbit determination capabilities are new to R2025a:

- New operational data types for orbit determination (navigation)
  - Addition of GN/DTE three-way range-rate measurements (GMT-8222). This provides support for ground-based tracking measurements in km/sec using the RangeRate data type for which the transmit and receive stations are different. See the sample script Ex\_R2025a\_Estimate\_RangeRangeRate3Way in the application samples/Navigation folder.
  - Addition of DSN Pseudo-Noise (PN) range measurements (GMT-8218). This provides support for DSN PN range measurements (DSN data type 14) in range units.
  - Addition of DSN Three-way Total Count Phase (TCP) Doppler measurements (GMT-8136). This provides support for averaged phase difference measurements (derived from DSN data type 17) in Hz for which the receive and transmit stations are different.
  - Addition of TDRS User Doppler One-way Return Doppler measurements (GMT-8068). This provides support for Tracking and Data Relay Satellite (TDRS) user one-way return Doppler measurements. See also the script Ex\_R2025a\_Estimate\_TDRSOneWayReturnDoppler in the application samples/Navigation folder.
  - Addition of TDRS user Range and Doppler measurements (GMT-7549). This provides support for Tracking and Data Relay Satellite (TDRS) user two-way return range and Doppler measure-

ments. See also the scripts `Ex_R2025a_Estimate_TDRSUserTracking` and `Ex_R2025a_Estimate_TDRSAndUser` in the application samples/Navigation folder.

- Addition of TDRS Differenced One-Way Doppler (GMT-7467). This provides support for Tracking and Data Relay Satellite (TDRS) user differenced one-way return Doppler (DOWD) measurements. DOWD measurements are formulated by differencing the measurements from simultaneous one-way return Doppler tracking events.
- Addition of TDRS Bilateration Transponder Ranging System (BRTS) range and Doppler (GMT-7327). This provides support for Tracking and Data Relay Satellite (TDRS) BRTS range and Doppler tracking. BRTS tracking is similar to TDRS user range and Doppler tracking. The BRTS transponder acts like a TDRS user fixed to a known location on the Earth. BRTS tracking is used to precisely determine the orbit of the TDRS spacecraft. See the script `Ex_R2025a_Estimate_BRTSTracking` in the application samples/Navigation folder.
- Addition of a JSON output option for the BLS estimator data file containing observation and residual data records (GMT-7899). This adds a JSON format data file that contains the batch estimator measurements, residuals, and other data to full numerical precision. This new capability replaces the batch estimator MatlabFile option and makes this capability freely available without MATLAB license restrictions. With this update, the MatlabFile option is deprecated, but is still currently available. See the sample script `Ex_R2025a_Estimate_RangeRangeRate3Way` in the application samples/Navigation folder.
- K-band frequency support (GMT-6339). K-band frequencies are now supported for computation of the ionosphere correction on the ground-to-space or space-to-ground tracking legs.

The following navigation and orbit determination capabilities have changed in R2025a:

- Use of `DSN_SeqRange` and `DSN_TCP` as cross-link tracking types is only allowed in testing mode.
- To provide support for three-way tracking paths, the GMD tracking data record format has changed for the RangeRate and `DSN_TCP` measurement types. The old format will still currently work. Please see the User's Guide Reference Guide > Orbit Determination > System > Tracking Data Types for Orbit Determination for details on the changes.

The following navigation and orbit determination capabilities are deprecated beginning with R2025a:

- The `BatchEstimator` MatlabFile output option is deprecated and replaced by the new JSON-format DataFile option. See the sample script `Ex_R2025a_Estimate_RangeRangeRate3Way` in the application samples/Navigation folder for an example demonstrating generation of the JSON batch estimator data file.

## Scripting and API Interface

The following Scripting and API Interface improvements were implemented in R2025a:

- Addition of the API Cookbook (GMT-8268). GMAT now provides use cases and examples of the Python API in a new document, the GMAT API Cookbook. See also the sample API use cases in the GMAT “api” folder.
- Support for commands in the API (GMT-7003). The GMAT API now provides access to the mission control sequence using the API. See the sample scripts Ex\_R2025a\_BasicTarget and Ex\_R2025a\_MarsBPlane in the GMAT “api” folder.
- Expansion of Python access to vector and matrix data using GetNumber (GMT-8083). GMAT fields and variables were accessible as floating-point values in the GMAT API in R2020a and R2022a. This capability is also available for vectors and matrices in R2025a. See also the examples in the GMAT “api” folder.
- Enforcement of required “three-component” syntax for the force model object (GMT-7685). Force models in GMAT releases prior to R2025a ignored the inner delimiter for fields of the form “ForceModel.InnerDelimiter.FieldName.” The inner delimiters are now parsed correctly, so that the settings for multiple gravitational fields (e.g. the degree and order of the harmonics) can be assigned to the correct forces. See the script Ex\_R2025a\_MultibodySphericalHarmonicGravity in the application samples folder for an example of this capability.
- Expansion of Include command to allow a string as a path (GMT-8075). Users can now script the names of include files into GMAT strings and later use those strings to specify the included file.
- Change in script creation to not include the “GMAT” prefix by default (GMT-8034). The optional “GMAT” prefix for field specification and assignment is no longer the default setting in GMAT scripts. See the R2025a sample scripts for examples of the new default scripting.
- Enhancement of Python script interface to support multi-dimensional arrays (GMT-7965). GMAT can now exchange multidimensional arrays with external Python code through the script Python interface.
- Expansion of Write/Report commands to be able to append to an existing file (GMT-7813). A new ReportFile parameter AppendToFile is available. This parameter may be set to True to allow GMAT to write to a report file in append mode instead of overwriting the file each time.

## Optimal Control

### Beta Capabilities

The GMAT Optimal Control capability remains a Beta feature for R2025a.

## OpenFramesInterface Visualizations



### Note

The OFI continues to be the primary 3D visualization component in GMAT. **OrbitView** will continue to be supported for backward compatibility purposes but will only be modified for critical bug fixes.

The complete set of documentation for OFI is available at [the OFI Wiki](#)

## Other Improvements

- Removed restriction of the Array dimensions limit (GMT-8108). GMAT vectors and arrays previously had an upper size restriction of 1000 elements (for vectors) and 1000 rows and columns (for arrays). That restriction has been removed.
- Improvement to error message output (GMT-8104).
- The GMAT users guide, previously called help-letter, was moved to <GMAT-top-level-folder>/docs/ and renamed to GMAT\_UsersGuide to match other users guides.
- The Help drop-down menu has been changed (GMT-8067). Previously, Help->Online Help would take you to an online user guide. This has been renamed to Help->User Guide and now links to a local HTML copy of the users guide that is packaged with GMAT.

## Compatibility Changes

- Support for wxWidgets 3.2.6 (GMT-5612) and Apple Silicon workstations. GMAT R2022a was built using wxWidgets 3.0.4. The GUI components have been updated to build with wxWidgets 3.2.6. This update to the toolkit adds support for Apple Silicon based workstations running recent releases of MacOS.
- GMAT R2025a is compatible with Python 3.10, 3.11, and 3.12 (GMT-8277). The GMAT build packages now include bindings for Python 3.6 through 3.12.

## Fixed & Known Issues

### Fixed Issues

Over 50 high priority bugs were closed in this release. See the "[Critical Issues Fixed in R2025a](#)" report for details. Some significant fixes in R2025a include:

ID	Description
GMT-8153	Optimizers Falsely Claim Convergence
GMT-8023	Incorrect Application of Hardware Delay During Crosslink Measurement

### Known Issues

See the "[All Known Critical Issues for R2025a](#)" report for a list of all known major issues in R2025a. There are several known issues in this release that we consider to be significant:

ID	Description
GMT-8024	Windows Defender pop-up may appear preventing users from initially opening the GMAT application and require additional user actions.
GMT-8243	Windows help contents may appear blank and require additional user actions.
GMT-8322	Replace OrbitView with OFI by mapping the OV scripting to an OFI window, and rework the ground track (The OrbitView and Groundtrack plot components do not work correctly on MacOS 14 and later.)

ID	Description
GMT-8339	R2025a is not notarized on Mac. Some users may have trouble opening the r2025a GMAT GUI on Mac. Scripts can be run on the GMAT console through a terminal window without issue.
GMT-8340	Support the Mac Intel machines. The Mac systems at the moment can either be using an Intel based chipset or a Silicon (Apple) based chipset. Currently the GMAT development team is supporting Silicon based chipset builds.

## GMAT R2022a Release Notes

The General Mission Analysis Tool (GMAT) version R2022a was released in December 2022. This is the first public release since May 2020 and is the 14<sup>th</sup> release for the project. This is a major project release that includes numerous major improvements and enhancements in general capabilities and models, navigation and orbit determination, scripting and API interfaces, optimal control, and visualization.

Below, we give a summary of key changes in this release.

### Milestones and Accomplishments

We are excited that GMAT continues to see significant adoption for operational mission support.

- The Fermi low Earth NASA mission, which uses the GPS point solution data type for ground based orbit determination, started using GMAT's Extended Kalman Filter Smoother (EKFS) for operations in July 2021.

### Major Improvements and Enhancements

#### General Capabilities and Models

The following general capabilities were added in release R2022a:

- Full support for Solar Radiation Pressure (SRP) N-Plate force modeling (No longer alpha/beta level). See the [ForceModel](#) section for details.
- Ability to generate Ground Station (G/S) to spacecraft visibility reports with an optional ability to specify G/S station masks. See the [HorizonMaskFileName](#) parameter description as well as the *Ground Station Masking File* remarks in the [GroundStation](#) section for details. See also

`samples/Ex_R2022a_Contact_Location_Station_Mask.script`

- Support for reading/writing Version 1 CCSDS Orbit Ephemeris Message (OEM) data. To use the OEM propagators, see the [CCSDS OEM Ephemeris-Configured Propagator](#) section of the [Propagator](#) resource for details. See also

`samples/Ex_R2022a_OEMPropagation.script`

- Computation of generalized planetographic region entry and exit times to include South Atlantic Anomaly (SAA) detection and reporting. See the [PlanetographicRegion](#) Resource section for details. See also

`samples/Ex_R2022a_PlanetographicRegion.script`

- Updated library usage to the new CSPICE 067 release from JPL
- Two Line Element (TLE) modeling using the SPICE implementation of the SGP4 propagator in SPICE version 67. See

`samples/Ex_R2022a_TLE_Propagation.script`

## Beta- and Alpha-level Capabilities

These are new features that have not yet undergone full testing and may have bugs. To access these features, you may need to edit the `bin/gmat_startup_file.txt` file to load the desired alpha plug-in and/or activate features only available in testing mode (set `RUN_MODE = TESTING` in the file). These features should be used with caution.

- Beta-level: Force modeling for multiple full field gravity perturbations during propagation and force reporting. (Multi-body spherical harmonics). See

```
samples/AlphaAndBetaFeatures/Ex_R2022a_Beta_MultibodySphericalHarmonicGravity.script
```

- Beta-level support for selected torque modeling and intrusion detection capabilities, focussed on geosynchronous orbits.
  - Beta-level: Modeling of thruster, gravity gradient, and plate based solar radiation pressure torques. See the [Calculation Parameters](#) section for details.
  - Beta-level: Addition of center of mass and moment of inertia to spacecraft models. See the [Spacecraft Ballistic/Mass Properties](#) section for details.
  - Beta-level: Intrusion detection models, used to determine when the Sun or Moon enters a sensor's field of view. See the [Intrusion Locator](#) section for more details.
- Alpha Level Capability: Sample script that inputs a s/c ephemeris and uses an optimization process to output a Two Line Element (TLE). See

```
samples/AlphaAndBetaFeatures/R2022a_TLEWriterSample/CreateTLEfromEphemeris.script
```

```
samples/AlphaAndBetaFeatures/R2022a_TLEWriterSample/CreateTLEfromSPKEphemeris.script
```

- Alpha Level Capability: GMAT's **ForceModel** for a given **Spacecraft** can be either replaced or augmented using a python function. See

```
samples/AlphaAndBetaFeatures/Ex_R2022a_ExternalForceModel.script
```

## Navigation and Orbit Determination (OD)

The following navigation and orbit determination capabilities were developed for R2022a:

- The [ExtendedKalmanFilter](#) and [Smoother](#) (EKFS) resources are now operational (no longer alpha/beta level). For an example of using the EKFS on the GPS point solution data type, see

```
samples/Navigation/Ex_R2022a_FilterSmoother_GpsPosVec.script
```

As with all new releases, missions that use GMAT's Batch and/or Extended Kalman Filter Smoother (EKFS) capability should perform a baseline set of regression/performance tests prior to using it for operational purposes.

- The estimation subsystem now supports a (no longer Beta) N-Plate area model for solar radiation pressure (SRP). The user may configure a detailed multi-plate area model for SRP modeling for both prediction and estimation. The model includes specular and diffuse reflectivity, support for moving panels, like solar arrays, and estimation of one or more SRP correction scale factors. See the [Plate](#) resource for more details on activating and configuring this model. See also

```
samples/Navigation/Ex_R2022a_Estimate_NPlateSRP_AreaCoefficient.script
```

- A new covariance propagation capability, with optional State Noise Compensation (SNC) process noise, using the **Covariance** parameter of the [Propagate](#) command. See

```
samples/Ex_R2022a_Propagate_Covariance.script
```

- Sample scripts, implementing an Initial Orbit Determination (IOD) routine from Vallado using GMAT's python interface. See

```
samples/Ex_R2022a_IOD.script
```

- The Range, Doppler, DSN\_SeqRange, and DSN\_TCP measurement types have been enhanced to support inter-spacecraft (sometimes called "crosslink") tracking. These measurement types may now be used to model range and Doppler measurements between on-orbit spacecraft. See [the section called “Inter-spacecraft Tracking Measurements”](#) and

```
samples/Tut_Inter_Spacecraft_Tracking.script
```

- Multiple simultaneous spacecraft estimation in the **BatchEstimator**. A single batch estimator instance may be used to estimate multiple spacecraft in a single estimation run. This capability is appropriate for spacecraft that are coupled in some fashion, either through use of inter-spacecraft tracking or estimation of biases on shared tracking resources. See

```
samples/Navigation/Ex_R2022a_MultiSpacecraft_Simultaneous_BatchEstimation.script
```

- Use of DSN TRK-2-23 ionosphere and troposphere media corrections for DSN tracking data. See [the section called “TRK-2-23 Model Implementation”](#).
- Batch Estimator estimation of measurement biases "by pass." This capability allows the user to estimate multiple segmented measurement biases for a single station across the batch estimator arc. This feature is not implemented for the Extended Kalman Filter. See [the section called “Pass-dependent Bias Estimation”](#)
- Polynomial thrust angle estimation for finite maneuvers. Errors in the nominal direction of finite thrust provided by a **ThrustHistoryFile** can be estimated as a pair of angles. These angles can be modeled as constant or as a polynomial in time. See [the section called “Overview of Thrust Angle Corrections”](#). See also

```
samples/Navigation/Ex_R2022a_Estimate_ThrustAngles.script
```

- Use of ephemeris propagators in the **Simulator** and **BatchEstimator**. An ephemeris file may be used as the orbit source for simulating measurement data or in a single-iteration "observed minus computed" batch estimator run. State estimation is not possible for spacecraft using an ephemeris propagator. Use of an ephemeris propagator is not yet implemented for the Extended Kalman Filter. For details on configuring ephemeris files for use as propagators, see [Propagator](#)
- Ability to run the **BatchEstimator** in a single-iteration "observed minus computed" configuration. In this mode, the batch estimator runs a single iteration, computing and reporting residuals with respect to the initial state and does not attempt state estimation. See the `SolveMode` option to the [RunEstimator](#) command.

## Scripting and API Interface

The following Scripting and API Interface improvements were implemented in R2022a.

- The API capability is no longer a Beta feature and is now operational. For sample scripts, see the `api` directory. For a complete description of the API capability, see the API UG below.

[docs/GMAT\\_API\\_UsersGuide.pdf](#)

- The python API, which allows the user to call GMAT from a python routine, now supports multiple versions of Python 3.
- The python interface plugin, which allows a user to call a python routine from within a GMAT script, now supports multiple versions of Python 3.

## Optimal Control

### Beta Capabilities

The GMAT Optimal Control capability remains a Beta feature for R2022a. The Optimal Control improvements for R2022a include the following items.

- Beta-level: Additional metadata describing optimizer performance in CSALT output optimal control history files
- Beta-level: Improved wrapper around CSALT nonlinear programming (NLP) solver to save feasible-but-not-optimal solutions
- Beta-level: Added new initial guess types to CSALT based on feasible-but-not-optimal solutions from previous mesh refinement iterations

## OpenFramesInterface Visualizations



### Note

The OFI continues to be the primary 3D visualization component in GMAT. **OrbitView** will continue to be supported for backward compatibility purposes but will only be modified for critical bug fixes.

The following visualization improvements were implemented in the OpenFramesInterface plugin in R2022a. The complete set of documentation for OFI is available at the [OFI Wiki](#)

- Added support for high-fidelity celestial body terrain and imagery using online sources on Windows and Linux (not yet supported on macOS). See `samples/NeedOpenFramesInterface/Ex_R2022a_OFI_HiFiEarthMoon.script` for an example of using online sources for high-fidelity Earth terrain and imagery, and high-fidelity Moon imagery.
- Added support for using the DXF 3D format for spacecraft and celestial bodies.

## Other Improvements

- GMAT R2022a includes a basic script-level debugger accessible in the GMAT GUI. This new feature lets the user set a [Breakpoint](#) in their mission control sequence. When the script is run, GMAT pauses at the Breakpoint and opens a panel showing all of the objects defined in the run. The user can then examine each object, step to the next command in the sequence and see that command's effect on the objects, continue execution of the run, or end the run.

## Compatibility Changes

- The **ExtendedKalmanFilter** **ProcessNoiseTimeStep** option has been moved to the **ProcessNoise** resource and renamed to **UpdateTimeStep**. The ProcessNoiseTimeStep option on the ExtendedKalmanFilter resource will continue to function in the current release. When both **ProcessNoiseModel.UpdateTimeStep** and **ExtendedKalmanFilter.ProcessNoiseTimeStep** have a non-zero value, the **ExtendedKalmanFilter.ProcessNoiseTimeStep** parameter will be used.

## Fixed & Known Issues

### Fixed Issues

Over 100 high priority bugs were closed in this release. See the "[Critical Issues Fixed in R2022a](#)" report for details. Some significant fixes in R2022a include:

ID	Description
GMT-7742	Incorrect handling of DSN_SeqRange transmit frequency when not using a ramp table

### Known Issues

See the "[All Known Critical Issues for R2022a](#)" report for a list of all known major issues in R2022a.

There are several known issues in this release that we consider to be significant:

ID	Description
GMT-7768	When using an ephem propagator for Moon-centered OD, lunar occultations, in the Simulator resource, are not accounted for properly

## GMAT R2020a Release Notes

The General Mission Analysis Tool (GMAT) version R2020a was released in May 2020. This is the first public release since May 2018 and is the 13<sup>th</sup> release for the project. This is a major project release that includes numerous improvements in dynamics modeling and other areas and five major new subsystems and components:

- A new 3D graphics engine based on OpenFrames. OpenFrames is the graphics engine used in NASA's Copernicus software. GMAT and Copernicus now share graphics capability, improving development efficiency and providing greater capability to both systems.
- The first production-quality C++ release of the Collocation Stand-Alone Library and Toolkit (CSALT). CSALT solves the general optimal control problem and supports pseudospectral and Lobatto IIIa transcriptions. CSALT can be used independent of GMAT (though CSALT leverages some low-level GMAT math libraries).
- A new optimal control subsystem that supports finite-thrust optimization. The optimal control plugin uses the CSALT optimization library, electric propulsion models, and GMAT's high-fidelity dynamics models to support high-fidelity finite thrust optimization. This plugin makes extensive use of analytic partial derivatives and employs optimal finite differencing when analytic partials are not provided.
- A new (beta) API developed to provide users low-level access to GMAT functionality and to support interoperability between NASA's GMAT, Copernicus, and MONTE software applications.
- A new (alpha) Extended Kalman Filter Smoother with process noise.

Below is a more detailed summary of key changes in this release. Please see the full R2020a Release Notes on JIRA for a complete list.

## Milestones and Accomplishments

We are excited that GMAT continues to see significant adoption for operational mission support.

- On May 1, 2018, the Lunar Reconnaissance Orbiter (LRO) project held an Operational Readiness Review (ORR) to evaluate GMAT as a replacement for GTDS as the primary operational orbit determination (OD) tool for LRO. GMAT was approved for this purpose at this ORR and LRO began using GMAT for operational OD in June 2018.
- In April 2018, the Transiting Exoplanet Survey Satellite (TESS) mission launched. TESS used GMAT as its primary tool for mission design and maneuver planning from proposal development through operations. For more information about TESS, including a discussion of how GMAT was used, see the [published paper](#).
- The GMAT team is currently developing an Extended Kalman Filter Smoother (EKFS) orbit determination capability for future release. In late 2020, a low Earth NASA mission that uses the GPS point solution data type will help operationally test our new EKFS capability. A publicly available version of GMAT, with EKFS capabilities for all data types supported by GMAT, is planned for the R2021a release.
- The GMAT team is currently integrating CSALT into GSFC's Core Flight System (cFS) to demonstrate the ability to perform optimal control onboard.

## New Features

### General Capabilities

The following general capabilities were added in release R2020a:

- Force models now support Solar Radiation Pressure (SRP) N-Plate force modeling (alpha/beta level). See the [ForceModel](#) section for details.
- Attitude propagation models now support kinematic attitude propagation using initial attitude and angular velocity. See the [Spacecraft Attitude](#) section for details.
- Hardware models (e.g., antennae, sun sensors) are extended to support fields of view including
  - The orientation of the hardware relative to the spacecraft body
  - Field-of-view masks for conical, rectangular and custom fields of view
  - Visibility model for points represented as unit vectors
  - Visualization of sensor cones in OpenFrames graphics
- Force models now include the ability to use continuous thrust files during numerical propagation. For details, see the new [ThrustSegment](#) and [ThrustHistoryFile](#) sections and the sample script `samples/Ex_R2020a_Propagate_ThrustHistoryFile.script` for an example demonstrating the use of finite-thrust modeling in propagation. The thrust history model supports:
  - Interpolation of finite thrust (low, medium, or high continuous thrust) or accelerations
  - Optional integration of mass flow rate in propagation
  - Choice of coordinate system for input thrust/acceleration
  - Scaling of selected inputs
  - Choice of interpolation methods
- The drag model now supports interpolation of a SPAD drag model for attitude dependent drag modeling. SPAD files are created by ray-tracing CAD models to compute an attitude-dependent area profile that is interpolated during numerical propagation. For more information on how to configure a force model and spacecraft to use a SPAD drag model, see the [ForceModel](#) and [Spacecraft Ballistic/Mass Properties](#) sections, respectively, and the sample script `samples/Navigation/Ex_R2020a_Estimate_SPADDragScaleFactor.script`

### Orbit Determination (OD) Enhancements

There are numerous OD enhancements including 5 new Resources **KalmanFilter**, **Smoother**, **ProcessNoiseModel**, **EstimatedParameter**, and **Plate** and numerous improvements to existing functionality.

- The OD subsystem has undergone significant refactoring to prepare for a future release of an extended Kalman Filter with smoother.
- The ionosphere media correction model is faster via correction caching. GMAT re-uses computed ionosphere correction to light-time when multiple independent measurements (such as range, range-rate, and angles) occur from the same station at the same epoch.
- The Batch Least Squares (BLS) now supports inner-loop sigma editing. After each BLS iteration, an iterative linearized approximation is used to predict measurements

likely to be edited on the next BLS iteration and to correct the state accordingly. This can accelerate convergence and help to reduce the overall number of BLS iterations required. See the **UseInnerLoopEditing** option to the **BatchEstimator** resource.

- The Batch Least Squares (BLS) now removes unobservable states from the normal matrix before attempting inversion. This is useful, for example, when the user configures estimation of a measurement bias but all observations of the bias are edited out. GMAT now removes the unobservable state and continues processing instead of terminating with a matrix inversion error.
- Several new measurement types are supported for OD simulation and estimation. See the User Guide section on [Tracking Data Types for Orbit Determination](#) for more details on the new supported measurement types, including:
  - Azimuth, Elevation angles
  - XEast, YNorth angles
  - XSouth, YEast angles
  - Range\_Skin (C-band, non-transponder range)
- The Batch Least Squares (BLS) measurement statistics report now includes summary statistics on user-edited data.
- The estimation subsystem now supports [ThrustHistoryFile](#) and [ThrustSegment](#) resources to model finite burns in the estimation arc for BLS OD, and can optionally estimate a scale factor correction to the nominal finite burn profile.
- The structure of the BLS MATLAB data file has changed. See the [BatchEstimator](#) resource documentation in the Orbit Determination section of the User Guide for details.
- New [ExtendedKalmanFilter](#) and [Smoother](#) resources are available in Testing mode. These resources are currently under development and should not be used in operational support.
- The estimation subsystem now supports a (beta) N-Plate area model for solar radiation pressure (SRP). The user may configure a detailed multi-plate area model for SRP modeling for both prediction and estimation. The model includes specular and diffuse reflectivity, support for moving panels, like solar arrays, and estimation of one or more SRP correction scale factors. This model is currently under development and should not be used in operational support. See the [Plate](#) resource for more details on activating and configuring this model.
- The estimation subsystem now supports the ability to solve for SPAD drag/SRP coefficients.

GMAT's orbit determination (OD) capability has been significantly enhanced. As with all new releases, missions that use GMAT's OD capability should perform a baseline set of regression/performance tests prior to using the new version of GMAT OD for operational purposes. GMAT is distributed with several examples that demonstrate new orbit determination capability in this release, including:

- KalmanFilter and Smoother: See

`samples/Navigation/Ex_R2020a_Alpha_FilterSmoother.script`

- Angle measurement types: See

`samples/Navigation/Ex_R2020a_Estimate_AngleData.script`

- Skin range measurement type:

See `samples/Navigation/Ex_R2020a_Estimate_RangeSkin.script`

- SPAD drag estimation: See

`samples/Navigation/Ex_R2020a_Estimate_SPADDragScaleFactor.script`

- SPAD SRP estimation: See

`samples/Navigation/Ex_R2020a_Estimate_SPADSRPScaleFactor.script`

- Finite thrust estimation: See

`samples/Navigation/Ex_R2020a_Estimate_ThrustScaleFactor.script`

## 3D Visualization Plugin: OpenFramesInterface

GMAT now supports a new 3D graphics component called OpenFramesInterface (OFI), which enables high-performance interactive 3D visualizations with significant additional functionality compared to GMAT's legacy 3D graphics (**OrbitView**) capability. GMAT R2020a includes OFI v1.0, the first tested and documented release of the plugin. The complete set of documentation for OFI is available at <https://gitlab.com/EmergentSpaceTechnologies/OpenFramesInterface/-/wikis/home>. Screen captures of selected components are included in the appendix of this section. A summary of key OFI interface capability is shown below.

- The new OFI graphics component supports all functionality in GMAT's legacy 3D graphics, as well as significant new functionality.
- The system now supports user-defined views of any spacecraft or celestial body. Views can be body-fixed, coordinate system-fixed, or look from one body towards another. Additionally, the user can switch between views in a single graphics window.
- Multithreaded visualizations now make use of multiple processor cores, resulting in a general computation speedup throughout GMAT when compared to OrbitView.
- The 3D graphics now supports full control over simulation time. View scene at any time, animate at various time scales, and synchronize time between multiple OpenFramesInterface windows.
- The system supports granular control over displayed objects, including optionally plotting axes, bodies, trajectories, or many other per-body graphics options.
- Graphics option changes no longer require a mission rerun. This includes switching between user-defined views and enabling/disabling displayed objects.
- Graphics now support high-fidelity rendering, including multisample antialiasing (MSAA), lighting, accurate star map with star colors and sizes (HYGv3 database)
- The system now supports vectors to objects in 3D graphics: body-fixed direction or pointing towards another object.
- The OFI interface now supports visualizing sensor fields of view, including conical, rectangular, and custom fields of view.
- The system supports Virtual Reality visualization via OpenVR. Any scene can be visualized on OpenVR-compatible hardware, including the Oculus Rift or HTC Vive.

There is an extensive set of samples scripts illustrating how to use the new graphics capability in GMAT located in `samples/NeedOpenFramesInterface`. A few scripts of particular interest are:

- Near real-time graphics: See

`samples/NeedOpenFramesInterface/Ex_R2020a_OFI_RealTimeMOC.script`

- Visualization of sensor cones: See

`samples/NeedOpenFramesInterface/Ex_R2020a_OFI_FieldOfView.script`

- Solar eclipse visualization: See

`samples/NeedOpenFramesInterface/Ex_R2020a_OFI_VR_2017SolarEclipse.script`

- Custom segment colors: See

`samples/NeedOpenFramesInterface/Ex_R2020a_OFI_CustomSegmentColors.script`



### Note

The OFI is now the default 3D visualization component in GMAT. **OrbitView** will continue to be supported for backward compatibility purposes but will only be modified for critical bug fixes.

## Trajectory Optimization Plugins

GMAT has a new subsystem for trajectory optimization, including new techniques and a new C++ and script interface, (The legacy parameter optimization functionality is still supported.) The trajectory optimization capability of GMAT is extended to support a stand-alone library for solving the optimal control problem using collocation. This library is called the Collocation Stand Alone Library and Toolkit (CSALT). CSALT solves the general optimal control problem and supports pseudospectral and Lobatto IIIa transcriptions with automatic mesh refinement. CSALT can be used independent of GMAT (though, uses some low-level GMAT math libraries.)

There are two new proprietary plugins -- CsaltInterface and EMTGModels -- for spacecraft trajectory optimization. Together with the CSALT library, those features combine to form the new GMAT optimal control capability. The CsaltInterface plugin contains GMAT's interface to the collocation transcriptions and optimization capabilities in CSALT. The EMTGModels plugin allows GMAT to use spacecraft power and engine models implemented in the Evolutionary Mission Trajectory Generator (EMTG). Together, those components provide extensive support for analytic partial derivatives of optimal control functions, including orbital dynamics and thrust models. When analytic derivatives are not provided, the system uses optimal finite differencing.

The user guide for the optimal control components including CSALT and GMAT optimal control is written in restructured text (rst) and located in the GMAT distribution here: [gmat/docs/GMAT\\_OptimalControl\\_Specification.pdf](#). Extensive training materials, beyond the reference material, is available for GMAT optimal control functionality and CSALT. Below is a brief summary of the new capability.

- CSALT solves the generic optimal control problem, supporting dynamics, Lagrange form of the cost function, path, and boundary constraints. CSALT does not assume the problem is low-thrust and can solve general problems including but not limited to 6-DOF optimization, classical optimal control problems, low-thrust, high-finite thrust, formation and constellation, and re-entry problems. CSALT is distributed with a limited set of models. In general, when using CSALT, the user must provide models of dynamics, cost, and constraint functions. (NOTE: the GMAT optimal control subsystem is used to solve low-thrust trajectory problems in GMAT.)
- The GMAT plugins CsaltInterface and EMTGModels support low-thrust trajectory optimization.
- The GMAT interface to CSALT is fully contained in the GMAT scripting language. GMAT script users do not need to write low-level C++ code. (However, those familiar with C++ can call CSALT directly via the C++ interface.)
- The system can optimize a constrained spacecraft trajectory using one of several collocation transcriptions, with mesh refinement.
- The system supports a trajectory composed of multiple “phases,” each of which may be defined by a different dynamics model. Phases may be “linked” through user-settable constraints (e.g., full-state/time linkage between the end of one phase and the beginning of another phase to enforce continuity).
- Users have the ability to set optimization settings from within a GMAT script. Examples of settable parameters include feasibility/optimality tolerances, upper/lower bounds on states, and initial collocation mesh settings.
- Users can choose from one of multiple commonly used merit functions (e.g., maximum final mass, minimum time of flight).
- Thrust models now include constant thrust and specific impulse (Isp), fixed efficiency, polynomials, and smoothed throttle tables.
- Users may include in their trajectory multiple commonly used spacecraft trajectory constraints, such as an integrated flyby or a celestial body rendezvous.
- There is alpha-level support for scalar inline expressions in optimal control functions. I.e., a user may specify a constraint in a script based on GMAT variables if a built-in constraint does not satisfy the user’s needs.
- New sample scripts and examples of supporting files are included in the release in `gmat/samples/OptimalControl` (for sample scripts) and `gmat/data/misc` and `gmat/data/emtg` (for supporting files).



### Note

The source code for GMAT optimal control and CSALT can be distributed, but is currently not included in the public release as they depend on the non-linear programming solver software SNOPT. Source code for those components can be provided upon request but the user must obtain SNOPT from Standford Business Software to compile those components.

There is an extensive set of sample scripts illustrating optimal control functionality distributed with GMAT in the folder `samples/OptimalControl/`. (Note: For CSALT C++ examples and tutorials see the user guide referenced above.) A few scripts of particular interest are:

- Low-thrust Interplanetary Transfer: See

`samples/OptimalCon-  
trol/Ex_R2020a_EarthToMarsSOI_C3Eq0_CSALTTutorial.script`

- Launch Model: See

`samples/OptimalCon-  
trol/Ex_R2020a_PCLaunch_ConstrainedC3AndDLA_EarthLaunch_EarthOrigin.script`

- Configuring Transcription to Lobatto IIIa: See

`samples/OptimalControl/Ex_R2020a_Phase_Type_ImplicitRKOrder6.script`

- Integrated Flyby Model: See

`samples/OptimalControl/Ex_R2020a_IntegratedFlyby_MarsFlyby.script`

- Thrust Model Configuration: See

`samples/OptimalControl/Ex_R2020a_EMTGSpacecraft_SCOpt_*.script`

## API

GMAT now provides access to many of its internal components from Python and Java, and from MATLAB using the Java-based API. This new Beta-quality functionality enables interoperability between NASA's GMAT, Copernicus, and MONTE software applications. The user guide for the API is written in restructured text (rst) and located in the GMAT distribution here:`docs/GMAT_API_UsersGuide.pdf`. A summary of key API features is shown below.

- Users can now load GMAT scripts, modify parameters, and execute the loaded script via an API interface.
- After running a script, users can now access the objects from the run and retrieve the results of the run.
- Users can now create GMAT objects directly via the API.
  - Created objects can be configured using a syntax similar to GMAT scripting.
  - Object-to-object connections are made by calling an initialization function.
  - Initialized objects provide data that matches the computations performed by GMAT during a run.
- Users can interact with GMAT objects from their platform's console interface - that is, from the MATLAB console, a Python console (Spyder, ipython, or the default Python console application).
- The API can be accessed using Jupyter notebooks.

- The GMAT API provides live help during use.
- Examples of all of these features are included in the api folder for the release.



### Note

The compiled API resources for Python were built using Python 3.7 on Windows and Mac, and the platform-supplied Python 3.6 libraries on Linux.

There is an extensive set of sample scripts illustrating API functionality distributed with GMAT in the folder gmat/api. A few scripts of particular interest are:

- Call GMAT Force Models: See

`gmat/api/Ex_R2020a_CompleteForceModel.*`

- Call GMAT Propagators:

See `gmat/api/Ex_R2020a_RangeMeasurement.*`

- Call GMAT Tracking Data Models: See

`samples/OptimalControl/Ex_R2020a_RangeMeasurement.*`

## Improvements

- There are several new built-in GMAT functions: **Pause**, **SystemTime**, **ConvertTime**, **Num2str**, **Str2num**, **RotationMatrix**, and **Sign**.
- There is a preliminary interface to use the GMAT python interface and python sockets to bring in raw telemetry data into GMAT.
- A new graphical interface, DynamicDataDisplay, allows display of numeric and text data during system execution and can optionally color code the data based on user defined constraints.
- There is a new, minimally tested interface to SNOPT that allows users to provide pre-compiled versions of SNOPT 7.5. Previous versions of GMAT had SNOPT compiled directly into the SNOPT plugin, which prohibits release.
- Updates to the beta polyhedral gravity model allow polyhedral regions with non-uniform density.
- The script editor now supports syntax highlighting.
- A ground station can now be placed on any celestial body (not only Earth as in previous releases).
- When compiling GMAT, dependency configuration is now unified on all platforms via a Python 3 script. Previous versions used bash and windows .bat files.
- There are numerous improvements to the GMAT build system: easier to incorporate external plugins (e.g. OpenFramesInterface), and CMake automatically downloads some dependencies (currently Boost). This makes it easier for developers to compile GMAT.
- The SPAD SRP model supports improved interpolation.

## Compatibility Changes

- The **BatchEstimatorInv** resource has been renamed **BatchEstimator**. **BatchEstimatorInv** will continue to be recognized for R2020a but will be deprecated in the next major release.
- The structure of the **BatchEstimator** MATLAB data file has changed. See the [BatchEstimator](#) resource documentation for details.

## Fixed & Known Issues

### Fixed Issues

Over 150 bugs were closed in this release. See the "[Critical Issues Fixed in R2020a](#)" report for a list of critical bugs and resolutions in R2020a. See the "[Minor Issues Fixed for R2020a](#)" report for minor issues addressed in R2020a. Some fixes in R2020a include:

- The simulator now accounts for occultation of the central body of the orbit when other than the Earth. (GMT-6134).
- An error affecting the ability to simulate data for durations longer than three weeks has been corrected. (GMT-6649)
- Solve-for parameters may now be specified in any order on the **Spacecraft.SolveFors** field. (GMT-6658)
- The **BatchEstimator ResetBestRMSIfDiverging** setting now works. (GMT-7036)
- The MarsGRAM atmosphere model now works correctly for Mac and Linux users. (GMT-5044)
- GMAT now properly interpolates UT1-UTC on the day of a leap second. (GMT-5954)

### Known Issues

See the "[All Known Issues for R2020a](#)" report for a list of all known issues in R2020a.

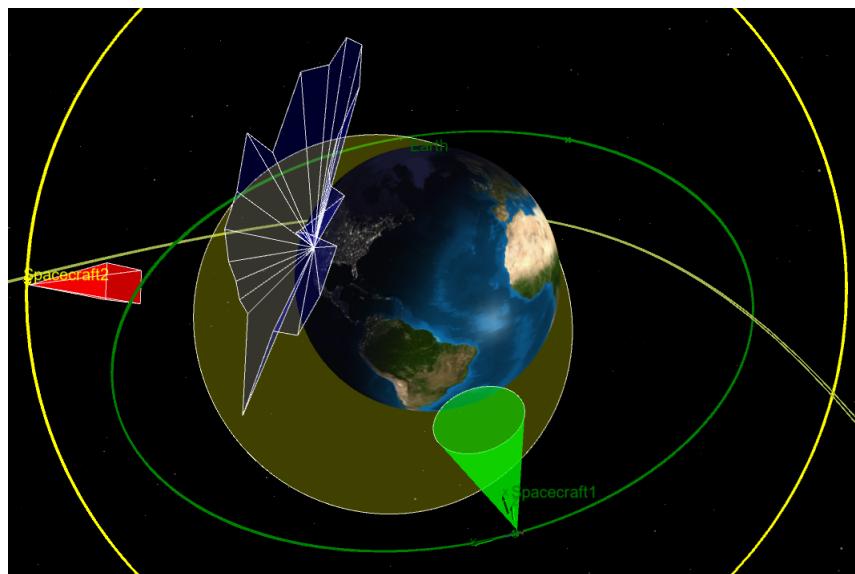
There are several known issues in this release that we consider to be significant:

ID	Description
GMT-5417	Adaptive step size control behaves inconsistently when used in GMAT's navigation system. Fixed-step integration is currently required for simulation and estimation.
GMT-6202	Spikes of up to 1 mm/sec may be observed in some cases in <b>DSN_TCP</b> and <b>Doppler</b> ionospheric corrections. The IRI2007 model has some jumps in the electron density when moving through time. Spikes are caused when the start and end signal paths are located on different sides of these jumps.

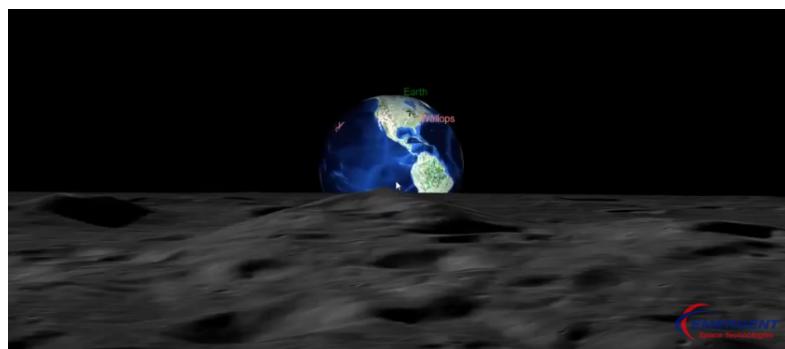
ID	Description
GMT-7207	The GMAT python interface is only designed to work with a standard python installation from <a href="http://python.org">python.org</a> . (For Mac and Windows, we recommend use of Python 3.7. For Linux, we recommend the use of Python 3.6 or 3.7). In the future, we would like to allow the user the choice to install either <a href="http://python.org">python.org</a> python or Anaconda python. Note that preliminary testing shows that, for Windows, the user may be able to use the Anaconda python interface by (1) deleting system variable references to <a href="http://python.org">python.org</a> python and (2) creating the System Variable PYTHONHOME and setting it to the folder where python.exe resides. Note that this is not fully tested and it is not known if this can cause other problems.

## Appendix: Screen Captures of Selected New Graphics Capability

The images below illustrate new graphics capability in GMAT R2020a.



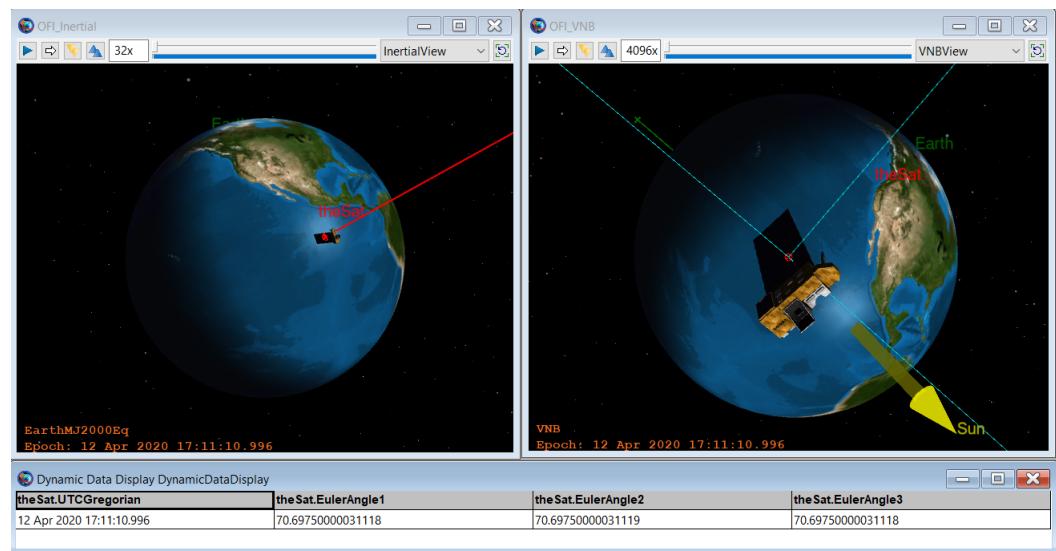
**Figure 121. Visualization of sensor cones.**



**Figure 122. Earth rise from the Moon.**



**Figure 123. Rendering of complex bodies with shadows.**



**Figure 124. Near real-time graphics example with inertial and body views and dynamic data display.**

## GMAT R2018a Release Notes

The General Mission Analysis Tool (GMAT) version R2018a was released March 2018. This is the first public release since June, 2017, and is the 12th release for the project.

Below is a summary of key changes in this release. Please see the full [R2018a Release Notes](#) on JIRA for a complete list.

### Milestones and Accomplishments

We're excited that GMAT has recently seen significant adoption for operational mission support.

- GMAT is now used as the primary system for maneuver planning and product generation for the Solar Dynamics Observatory (SDO).
- GMAT is now used as the primary operational tool for orbit determination for the Solar and Heliospheric Observatory (SOHO) mission.
- GMAT is now used as the primary operational tool for maneuver planning, orbit determination, and product generation for the Advanced Composition Explorer (ACE) mission.
- GMAT is now used as the primary operational tool for maneuver planning, orbit determination, and product generation for the Wind mission.
- In April 2018, the Transiting Exoplanet Survey Satellite (TESS) mission is planned to launch. TESS has used GMAT as its primary tool for mission design and maneuver planning from proposal development through operations.
- In April 2018, the LRO project will hold an operational readiness review to perform final evaluation of GMAT to replace GTDS as the primary operational orbit determination (OD) tool for the Lunar Reconnaissance Orbiter (LRO).

### New Features

#### Orbit Determination Enhancements

The following new features and capabilities have been added to GMAT's estimation system.

- The batch estimator now supports a capability that freezes the measurements used for estimation after a user-specified number of iterations. This functionality avoids estimator chatter that can occur near solutions when some measurements are near the sigma edit boundary and are repeatedly removed during one iteration and then added back in the next iteration.
- Numerics are improved when calculating Doppler and DSN\_TCP measurement residuals, improving noise behavior in the residuals.
- The GroundStation object supports a new troposphere model, the Marini model, matching the implementation used in GTDS. One operational advantage of the Marini model is that it doesn't require input of weather data at the Ground station. (Models that do accept weather data may have more accuracy.)
  - Time is now modeled using three data members, a day number, seconds of day, and fraction of second. High precision time is surgically implemented in appropriate models such as Earth rotation, planetary ephemerides and others.

- Range differences are computed using a Taylor series and differenced Chebyshev polynomials.
- Measurement simulation now accounts for central body occultation when orbiting bodies other than the Earth.
- Estimation now supports solving for the Keplerian state estimation with a priori constraints.
- For BLS estimation, the user may choose to perform measurement editing using either the weighted root-mean-square (WRMS) of residuals, or the predicted weighted root-mean-square (WRMSP) of residuals. Residuals of elevation edited data are now reported.
- The batch estimator report now shows the name of input files used in the configuration and the observation time span. Additionally, spacecraft hardware configurations and new measurement statistics information are included.
- GMD file improvements

As shown by the new features above, GMAT's orbit determination (OD) capability has been significantly enhanced. As with all new releases, missions that use GMAT's OD capability should perform a baseline set of regression/performance tests prior to using the new version of GMAT OD for operational purposes.

Example scripts:

- See `Ex_R2018a_CompareEphemeris.script` for a new example on performing ephemeris compares at non-Earth bodies.
- See `Ex_R2018a_MergeEphemeris.script` for an example demonstrating merging ephemerides.

### Built-in Optimizer

GMAT now contains a built-in optimizer called Yukon, developed by the GMAT team. The algorithm uses an SQP line search algorithm with an active set QP-subproblem algorithm. Yukon is designed for small scale problems and is not applicable to large, sparse optimization problems. See the [Yukon](#) reference for more information.

### Improvements

- Tide modeling is improved, and GMAT now supports lunar tides.
- STM propagation now includes variational terms from drag models.
- The degree and order of STM contributions from harmonic gravity is now settable by the user and defaults to the maximum order on the gravity file or 100, whichever is lower.
- The buffer size that determines the number of plot points stored by the OrbitView Resource is now exposed to the user.
- Significant performance improvements have been made in the IRI2007 ionosphere model.
- The script editor highlights errors and warnings found on the first pass of parsing.
- GMAT now supports body fixed and TOD coordinate systems for Code 500 Ephemerides and supports all central bodies in the Code 500 Ephemeris format.
- The CommandEcho command has been added to GMAT to support printing commands to the message window and log file as they are executed in a mission se-

quence. This command is particularly useful when debugging user scripts. See the [CommandEcho](#) reference for more information.

- The Code500 propagator type now automatically detects the endianness when reading Code500 files.
- The STK ephemeris propagator now uses Hermite interpolation, and includes velocity information in the position interpolation for segments that contain fewer than 7 rows of data. Velocity interpolation for segments with fewer than 7 rows of data is performed by forming the hermite interpolating polynomial for position, and then differentiating the position interpolating polynomial to obtain the velocity.
- You can now set the step size of an ephemeris propagator during mission execution (i.e. after the BeginMissionSequence command).
- The startup file now allows optional updating of the user configuration file. This avoids issues encountered when simultaneous instances of GMAT try to write to the user config file at the same time, resulting in a system error.
- The Python data file utility now updates data files used by the IRI2007 model.
- The GMAT CMake based build system now supports plugin components developed by external groups.
- GMAT now supports GUI plugin components.

## Compatibility Changes

- Batch estimation now requires the use of fixed step integration.
- The RotationDataSource on CelestialBody Resources is deprecated and no longer has an effect.
- The Spacecraft EstimationStateType parameter is deprecated.
- The EphemerisFile OutputFormat options 'UNIX' and 'PC' are deprecated. 'BigEndian' and 'LittleEndian' should be used instead.
- The EarthTideModel on the ForceModel Resource has been renamed to TideModel
- GMAT now returns error codes via the command line interface to indicate if issues were encountered during system execution.
- When using the Write command to write Resource properties to a ReportFile, only scalar, real quantities are written. Properties that are either not real or are arrays are ignored and a warning is issued.

## Upcoming Changes in R2019a

This is the last version of GMAT tested on Windows 7.

## Known & Fixed Issues

### Fixed Issues

Over 112 bugs were closed in this release. See the "[Critical Issues Fixed in R2018a](#)" report for a list of critical bugs and resolutions in R2018a. See the "[Minor Issues Fixed for R2018a](#)" report for minor issues addressed in R2018a.

- The STK ephemeris propagator now correctly handles segments with fewer than 5 rows of data.
- STK ephemeris files that contain event boundaries now correctly count the number of ephemeris rows represented in the NumberOfEphemerisPoints keyword value pair.

- Comments describing the source of ephemeris discontinuities in CCSDS ephemeris files are now written inside of meta data blocks.

## Known Issues

See the "[All Known Issues for R2018a](#)" report for a list of all known issues in R2018a.

There are several known issues in this release that we consider to be significant:

ID	Description
GMT-5417	Adaptive step size control behaves inconsistently when used in GMAT's navigation system. Fixed step integration is currently required for simulation and estimation.
GMT-6202	Spikes of up to 1 mm/sec may be observed in some cases in DSN_TCP and Doppler ionospheric corrections. The IRI2007 model has some jumps in the electron density when moving through time. Spikes are caused when the start and end signal paths are located on different sides of these jumps.
GMT-6367	For Macs with a Touch Bar (GUI issue only): there appears to be an issue with WxWidgets, the third party GUI library used by GMAT, and the Mac Touch Bar. Crashes occur frequently and the traceback indicates that the issue lies in Apple code, related to the Touch bar specifically, possibly caused by a NULL string pointer. Our analysis suggests this issue cannot be addressed by the GMAT team or by WxWidgets; however, we will continue to investigate. In the meantime, the GMAT Console version will continue to work, and the GUI version (Beta) will work on Macs without a Touch Bar.

## GMAT R2017a Release Notes

The General Mission Analysis Tool (GMAT) version R2017a was released June 2017. This is the first public release since Oct. 2016, and is the 11th release for the project. This is the first **64 bit version of GMAT on Windows** (Mac and Linux are 64 bit only).

Below is a summary of key changes in this release. Please see the full [R2017a Release Notes](#) on JIRA for a complete list.

### New Features

#### Orbit Determination Enhancements

The following new features and capabilities have been added to GMAT.

- Three new data types can now be processed in GMAT; GPS point solution (GPS\_PosVec), range data (Range), and range rate (RangeRate) data. Note that all of these data types have been through regression testing but only the DSN range data type has been through substantial operational testing. Thus, the DSN range data type is the most validated data type available in GMAT.
- A minimally tested and documented alpha version of an extended Kalman filter algorithm is now available for experimental use. This plugin is available but turned off by default. To use, enable the "libEKF" plugin in the startup file.
- A second-level data editing capability has been added. This feature allows you to choose observations that are computed and reported but not used in the estimation state update.

#### STK .e Ephemeris Propagator

GMAT now supports a propagator that uses AGI's .e ephemeris file format. See the [Propagator](#) reference for more information.

#### File Manager Utility

You can now manage empirical data updates using a Python file manager. The utility allows you to easily update leap second, EOP, space weather, and other files and optionally archive old versions. See the [Configuring GMAT Data Files](#) section for more information. When you run the the utility, you will see output like that shown below (the data below is only a partial summary of the output).

```
-----UPDATING GMAT LEAP SECOND FILE -----
Process Began At 2017-06-01-11:23:55
-----Downloading tai-utc.dat
tai-utc.dat downloaded successfully
tai-utc.dat archived successfully to 2017-06-01-11h23m55s_tai-utc.dat
tai-utc.dat updated successfully
Process Finished At 2017-06-01-11:23:55

-----UPDATING GMAT EOP FILE -----
Process Began At 2017-06-01-11:23:55
-----Downloading eopc04_08.62-now
```

```
eopc04_08.62-now downloaded successfully
eopc04_08.62-now archived successfully to
2017-06-01-11h23m57s_eopc04_08.62-now
eopc04_08.62-now updated successfully

-----UPDATING SPICE LEAP SECOND FILE -----
Process Began At 2017-06-01-11:23:57
-----Downloading naif0011.tls
SPICELeastSecondKernel.tls downloaded successfully
-----Downloading naif0012.tls
SPICELeastSecondKernel.tls downloaded successfully
SPICELeastSecondKernel.tls archived successfully to
2017-06-01-11h24m00s_SPICELeastSecondKernel.tls
SPICELeastSecondKernel.tls updated successfully
Process Finished At 2017-06-01-11:24:00
```

## Collocation Stand Alone Library and Toolkit (CSALT)

GMAT now has a stand alone C++ library for solving optimal control problems via collocation (CSALT). The library is well tested and available for applications, and is currently undergoing integration into GMAT. The CSALT library is not exposed via GMAT interfaces, but users who are familiar with C++ programming can solve optimal control problems with CSALT now. The source code will be made available via SourceForge. CSALT integration into GMAT is underway and planned for completion in the next GMAT release. For more information on the CSALT Library see the paper entitled [CSALT\\_CollocationBenchmarkingResults.pdf](#) in the docs folder of the GMAT distribution.

## Preliminary API Interface

A preliminary API is under development. The API is not available in the production release and is distributed separately on SourceForge in packages with the name "Alpha" in the title. The API employs SWIG to expose GMAT to several languages. Preliminary testing has been performed on the JAVA interface called from MATLAB. The code snippet below illustrates how to call through the JAVA interface from MATLAB to compute orbital accelerations on a spacecraft. Some testing of the Python binding as also been performed.

```
% Load GMAT
scriptFileName = fullfile(pwd, 'gmat.script');
[myMod, gmatBinPath, result] = load_gmat(scriptFileName);

% Get the SolarSystem object from GMAT
ss = myMod.GetDefaultSolarSystem();

% Prepare the force model to be used for dynamics
fm = myMod.GetODEModel('DefaultProp_ForceModel');
state = gmat.GmatState(6+6^2);
fm.SetSolarSystem(ss); % Set solar system pointer in force model
fm.SetState(state); % Provide force model with the state placeholder
```

```
% Create new Spacecraft
sat = gmat.Spacecraft('Sat');

% Create PropagationStateManager to manage calculation of derivatives
propManager = gmat.PropagationStateManager();
propManager.SetObject(sat); % Add sat PropagationStateManager
propManager SetProperty('AMatrix', sat); % Want to calculate Jacobian
propManager.BuildState();

% Tell force model to use propmanager
fm.SetPropStateManager(propManager);
fm.UpdateInitialData(); % Update model with changes
fm.BuildModelFromMap(); % Sets up the models in the force model
state = gmat.gmat.convertJavaDoubleArray(x(:,tIndex));

% Compute the orbital accelerations including variational terms
fm.GetDerivatives(state, t(tIndex), 1); % Calculate derivatives
deriv = fm.GetDerivativeArray(); % Get calculated derivatives
derivArray = gmat.gmat.convertDoubleArray(deriv, 42);
```

## Improvements

- You can now define the name and location of the gmat startup and log file via the command line interface. This is useful when running multiple GMAT sessions simultaneously or when you have complex, custom file configurations.
- You can now write STK ephem files with units in meters (previously, only km was supported).
- You can now write STK ephem files without discrete event boundaries.

## Compatibility Changes

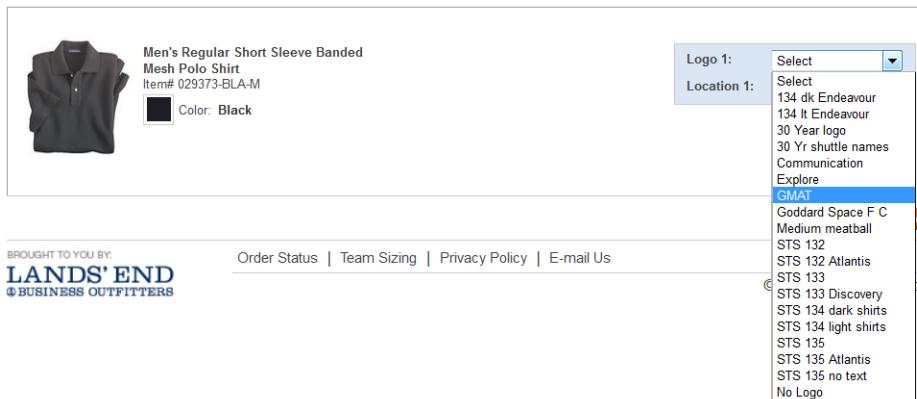
- GMAT now requires Python version 3.6.x.
- Schatten files no longer require the "PREDICTED SOLAR DATA" keyword at the top of the file.
- The names and locations of several data files used by GMAT are no longer hard coded and their names and locations are set in the file `gmat_startup_file.txt` located in the `bin` directory. If you use custom startup files, you MUST add the lines below to your startup file before GMAT will start. Note that the startup files distributed with GMAT have these lines added. This backwards compatibility issue only affects users who customize their startup file.

```
EARTH_LATEST_PCK_FILE      = PLANETARY_COEFF_PATH/earth_latest_high_prec.bpc
EARTH_PCK_PREDICTED_FILE   = PLANETARY_COEFF_PATH/SPICEEarthPredictedKernel.bpc
EARTH_PCK_CURRENT_FILE     = PLANETARY_COEFF_PATH/SPICEEarthCurrentKernel.bpc
LUNA_PCK_CURRENT_FILE     = PLANETARY_COEFF_PATH/SPICELunaCurrentKernel.bpc
LUNA_FRAME_KERNEL_FILE     = PLANETARY_COEFF_PATH/SPICELunaFrameKernel.tf
```

- The syntax for navigation functionality has been significantly changed for consistency throughout the system. See the **Deprecated Measurement Type Names** section of the [Tracking Data Types for OD](#) Help for more details.

## GMAT Stuff

Don't forget you can purchase clothing and other items with the GMAT logo via ©Land's End, Inc at the [GSFC Store](#). Once, you've chosen an item, make sure to select the GMAT logo!



## Known & Fixed Issues

Over 70 bugs were closed in this release. See the "[Critical Issues Fixed in R2017a](#)" report for a list of critical bugs and resolutions in R2017a. See the "[Minor Issues Fixed for R2017a](#)" report for minor issues addressed in R2017a.

### Known Issues

All known issues that affect this version of GMAT can be seen in the "[Known Issues in R2017a](#)" report in JIRA.

There are several known issues in this release that we consider to be significant:

ID	Description
GMT-5269	Atmosphere model affects propagation at GEO.
GMT-2561	UTC Epoch Entry and Reporting During Leap Second is incorrect.
GMT-3043	Inconsistent validation when creating variables that shadow built-in math functions
GMT-3289	First step algorithm fails for backwards propagation using SPK propagator
GMT-3350	Single-quote requirements are not consistent across objects and modes
GMT-3669	Planets not drawn during optimization in OrbitView
GMT-3738	Cannot set standalone FuelTank, Thruster fields in CallMatlabFunction
GMT-4520	Unrelated script line in Optimize changes results (causes crash)
GMT-4398	Coordinate System Fixed attitudes are held constant in SPAD SRP model during a propagation step
GMT-5600	Numerical Issues when calculating the Observation Residuals

ID	Description
GMT-6040	Correct the code for the RunSimulator and RunEstimator commands so that they respect the scripted propagator settings
GMT-5881	Error in Ionosphere modeling

## GMAT R2016a Release Notes

The General Mission Analysis Tool (GMAT) version R2016a was released Oct. 2016. This is the first public release since Nov. 2015, and is the 10th release for the project. Note this will be **the last 32 bit version of GMAT on Windows** (Mac and Linux are 64 bit only).

Below is a summary of key changes in this release. Please see the full [R2016a Release Notes](#) on JIRA for a complete list.

### New Features

#### Orbit Determination

GMAT now supports orbit determination with a focus on batch estimation of DSN data types including range and Doppler. We've been working on navigation functionality for several releases, but this is the first production release containing navigation functionality. Orbit determination functionality has undergone a rigorous QA process including shadow testing in GSFC's Flight Dynamics Facility and is extensively documented in tutorials and reference material. Navigation components include BatchEstimator, Simulator, ErrorModel, StatisticsAcceptFilter, StatisticsRejectFilter, TrackingDataSet, and the RunEstimator and RunSimulator Commands. We recommend taking the tutorials first then reviewing the reference material for orbit determination components to get started.

See the [Simulation](#) and [Estimation](#) tutorials for more information.

#### Code 500 Ephemeris Propagator

GMAT now supports a propagator that uses GSFC's Code 500 ephemeris file format. The Code 500 file format is legacy format still used by some systems at GSFC. This functionality allows users of GSFC legacy systems to simulate and analyze trajectories computed in systems such as GTDS.

See the [Propagator](#) reference for more information.

#### Write Command

You can now export GMAT resources to files during the mission sequence execution. This is a powerful feature that allows you to save configurations at any point in a session for use by in later sessions or by other users.

See the [Write Command](#) reference for more information.

#### #Include Macro

You can now load GMAT resources and script snippets from external files during the script initialization and mission execution. This is a powerful feature that allows you to reuse configurations across multiple users and/or scripts. This feature can also greatly simplify automation for operations and Monte-Carlo and parametric scanning that have

use cases with a lot of common data but some data that changes from one execution to the next.

See the [#Include](#) reference for more information.

## GetEphemStates Built-in Function

Using the built-in GetEphemStates function, you can now query SPICE, Code-500 and STK .e ephemeris types and for a spacecraft's initial epoch, initial state, final epoch and final state in any GMAT supported epoch formats and coordinate systems. This allows you to perform numerical propagation using states off of ephemeris files for comparison and other analysis.

See the [GetEphemStates](#) reference for more information.

## Improvements

- You can now define the EOP file location in a script.
- The system now supports finite burn parameters that report the thrust component data for a finite burn. The parameters include total thrust from all thrusters in the three coordinate directions, the total acceleration from all thrusters in the three coordinate directions, and the total mass flow rate. Furthermore, you can now also report individual thruster parameters such as thrust magnitude, Isp and mass flow rate.
- GMAT now contains built-in string manipulations functions sprintf, strcmp, strcat, strfind, strrep.
- Several new built in math functions are implemented including a built-in cross product function. For manipulation of numeric data we've implemented mod, ceil, floor, fix. For random number generation we've implemented rand, randn, and SetSeed.
- You can now model finite burns that employ multiple tanks. Previous versions were limited to a single tank.
- GMAT now supports generation of STK's ".e" ephemeris format in addition those supported previously such as CCSDS-OEM, SPK and Code-500 formats.
- We've written over 130 pages of new, high-quality user documentation!
- The behavior of the GUI when using large fonts has been improved.

## Compatibility Changes

- You can now override the default **NAIFId** on a **CelestialBody** to allow using body centers or barycenters as the reference for built-in celestial bodies. Previously this field was read-only.

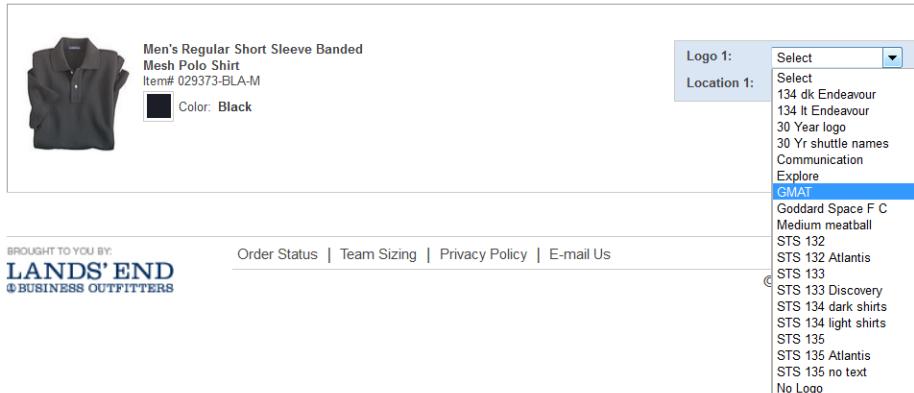
## Development and Tools

### Developer Tools and Dependencies

We updated the CMake-based build system that is used on all platforms. The CMake configuration is maintained by the GMAT team and distributed with the source code. Thanks to CMake, it is much easier to compile GMAT. See the [wiki documentation for details](#). Note that old build files are no longer supported and are considered obsolete.

## GMAT Stuff

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## Known & Fixed Issues

Over 100 bugs were closed in this release. See the "[Critical Issues Fixed in R2016a](#)" report for a list of critical bugs and resolutions in R2016a. See the "[Minor Issues Fixed for R2016a](#)" report for minor issues addressed in R2016a.

### Known Issues

All known issues that affect this version of GMAT can be seen in the "[Known Issues in R2016a](#)" report in JIRA.

There are several known issues in this release that we consider to be significant:

ID	Description
<a href="#">GMT-5269</a>	Atmosphere model affects propagation at GEO.
<a href="#">GMT-2561</a>	UTC Epoch Entry and Reporting During Leap Second is incorrect.
<a href="#">GMT-3043</a>	Inconsistent validation when creating variables that shadow built-in math functions
<a href="#">GMT-3289</a>	First step algorithm fails for backwards propagation using SPK propagator
<a href="#">GMT-3350</a>	Single-quote requirements are not consistent across objects and modes
<a href="#">GMT-3669</a>	Planets not drawn during optimization in OrbitView
<a href="#">GMT-3738</a>	Cannot set standalone FuelTank, Thruster fields in CallMatlabFunction
<a href="#">GMT-4520</a>	Unrelated script line in Optimize changes results (causes crash)
<a href="#">GMT-4520</a>	Coordinate System Fixed attitudes are held constant in SPAD SRP model during a propagation step

## GMAT R2015a Release Notes

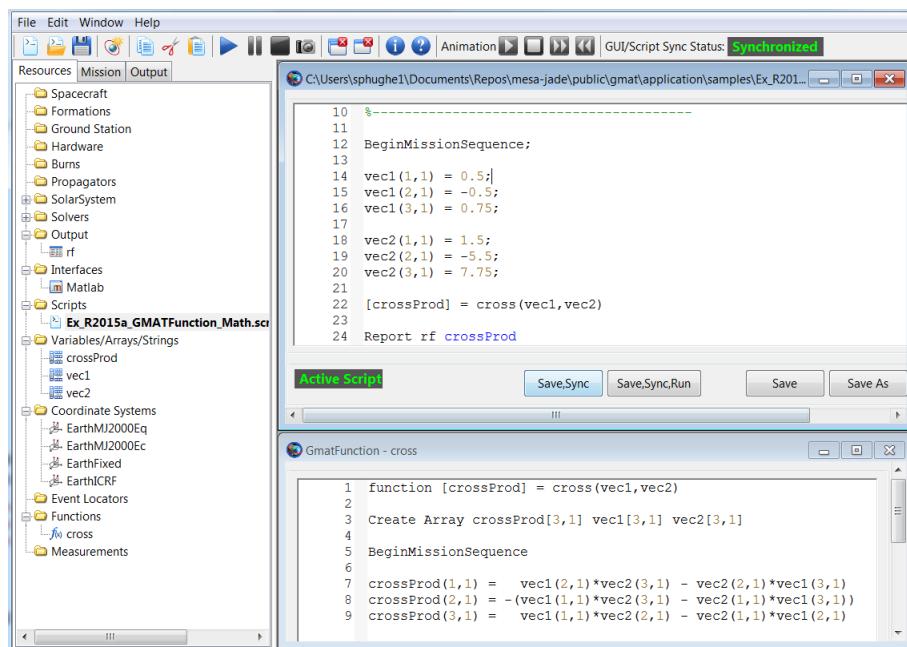
The General Mission Analysis Tool (GMAT) version R2015a was released Nov 2015. This is the first public release since July 2014, and is the 9th release for the project.

Below is a summary of key changes in this release. Please see the full [R2015a Release Notes](#) on JIRA for a complete list.

### New Features

#### GMAT Functions

You can now write functions (sub-routines) in the GMAT script language. This powerful feature greatly expands the practical capability of the system and makes maintaining complex configurations simpler. This feature also enables sharing GMAT script utilities among projects. If you need a new math computation, want to isolate a complex section of code, or re-use code, GMAT functions are a great solution.



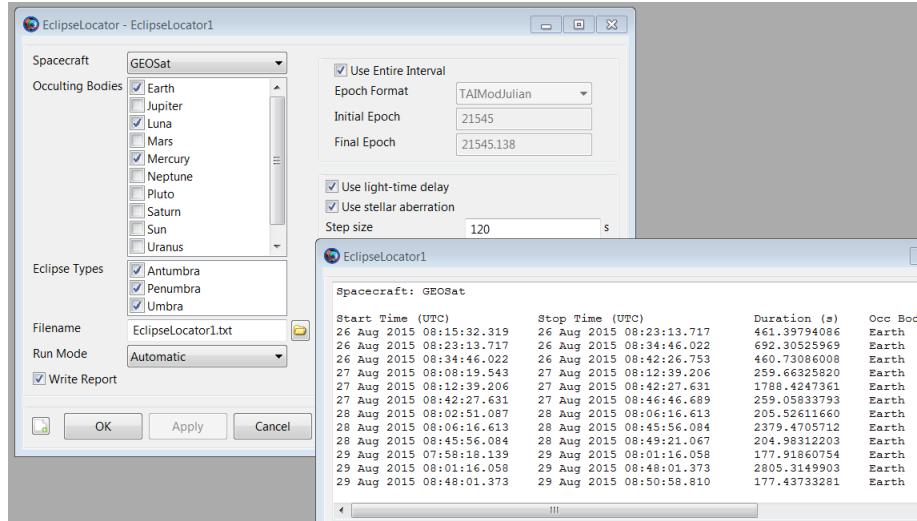
See the [Using GMAT Functions](#) tutorial for more information.

### Eclipse Location

GMAT now supports eclipse location. Under the hood GMAT calls NAIF SPICE routines. Thanks to the NAIF for making this great functionality available.

## Release Notes

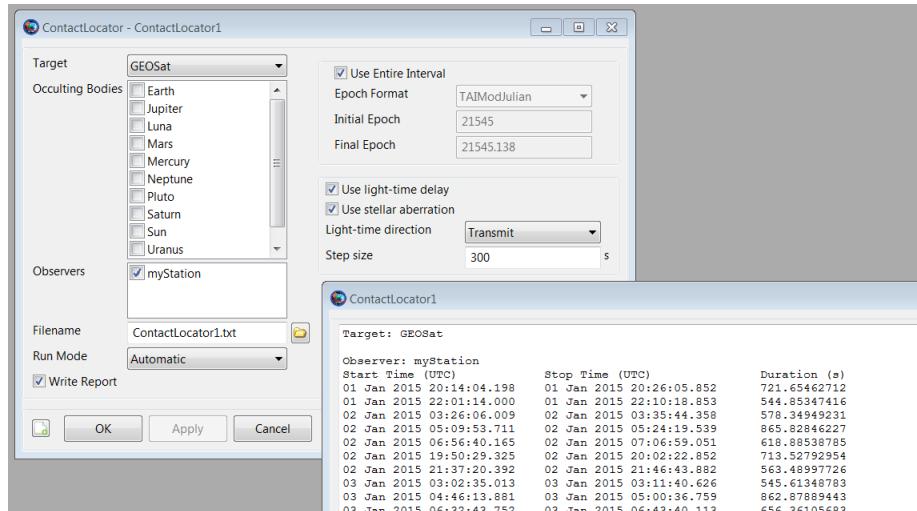
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See the [Eclipse Locator](#) reference for more information.

## Station Contact Location

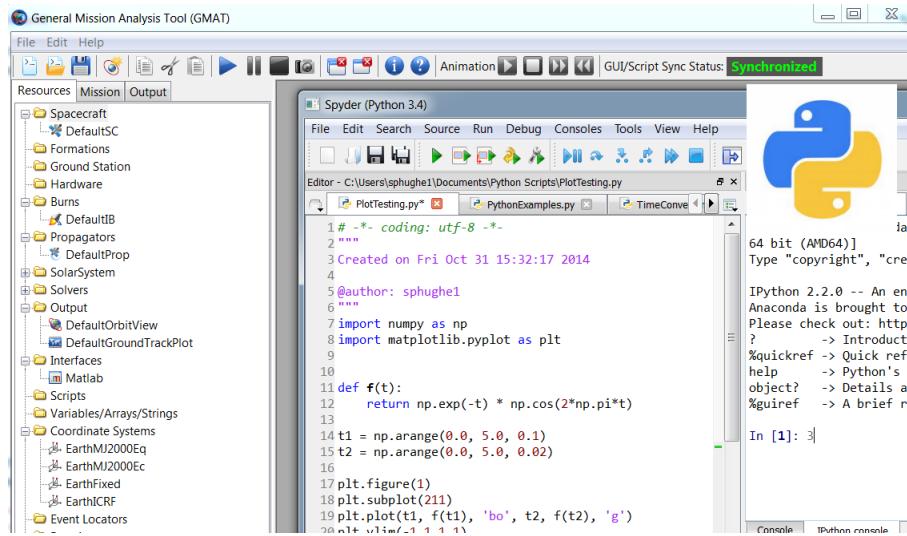
GMAT now supports station contact location. Under the hood GMAT calls NAIF SPICE routines. Thanks to the NAIF for making this great functionality available.



See the [Contact Locator](#) reference for more information.

## Python Interface

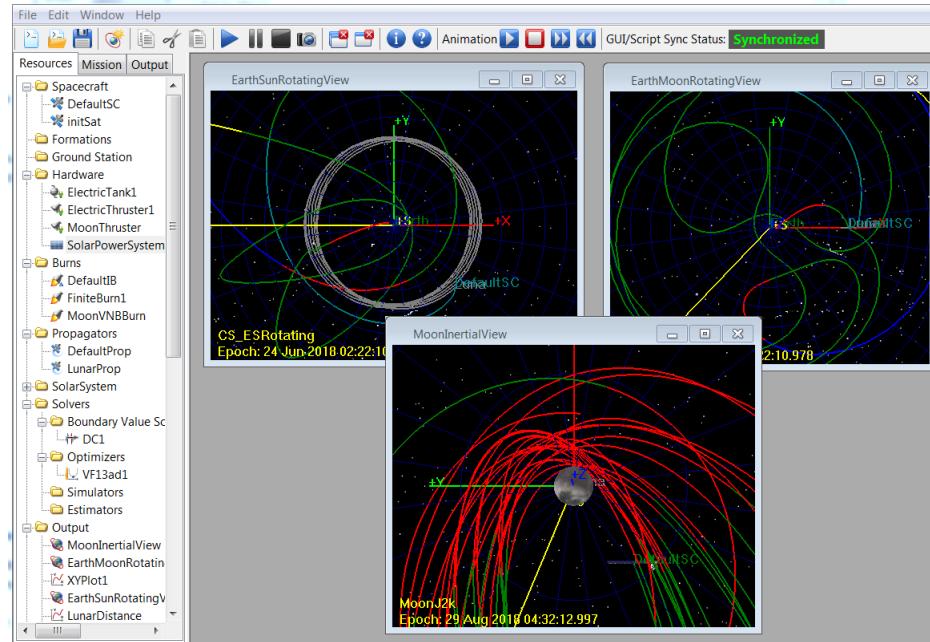
GMAT now supports an interface with Python. The power of the Python ecosystem can now be used with GMAT.



See the [Python](#) reference for more information.

## Electric Propulsion

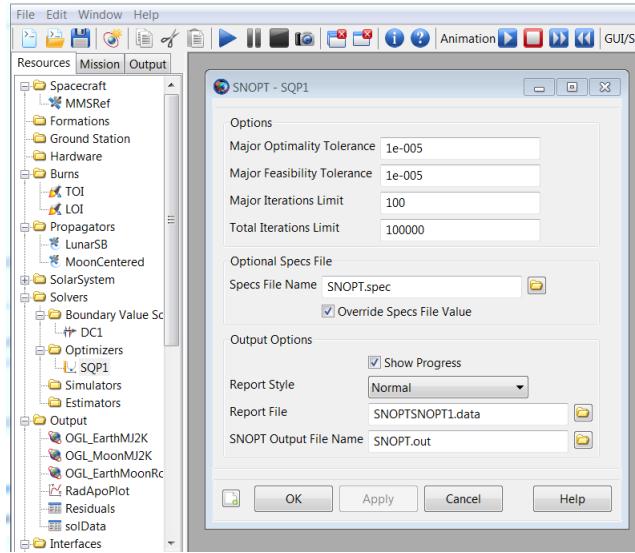
GMAT now supports modeling of electric propulsion systems. Below is an example showing GMAT modeling a cube-sat with electric propulsion in a lunar weak-stability orbit. You can model electric tanks, thrusters, and power systems (both Solar and nuclear).



See the [Electric Propulsion](#) tutorial for more information.

## SNOPT Optimizer

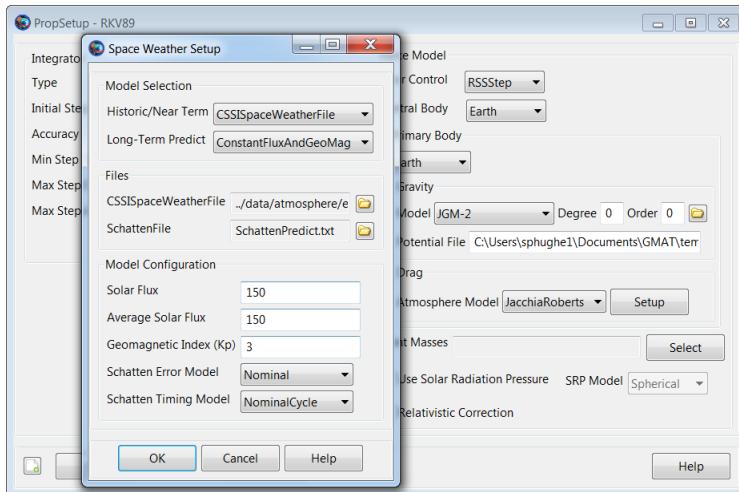
GMAT now interfaces to Stanford Business Software, Inc. SNOPT Optimizer



See the [SNOPT](#) reference for more information.

## Space Weather Modelling

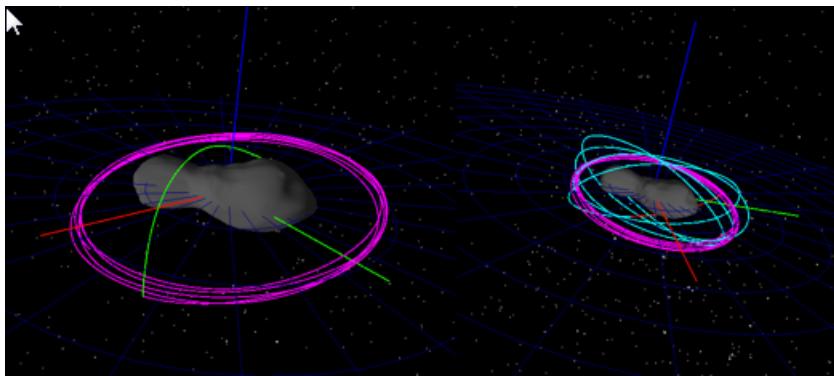
You can now provide flux files for drag modeling including Schatten historical files and Center for Space Standards and Innovation (CSSI) Space Weather Files. This greatly improves long term orbital predictions and reconstructions in the Earth's atmosphere.



See the [Propagator](#) reference for more information.

## Celestial Body 3-D Graphics Models

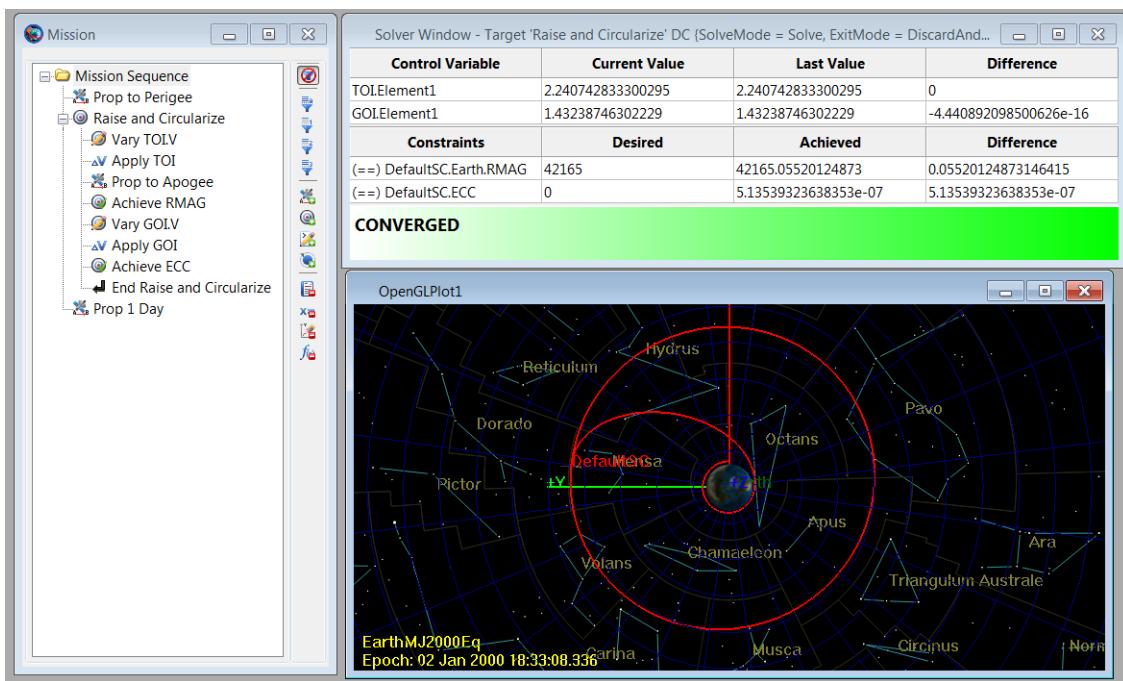
You can now use a 3D model for celestial bodies in 3-D graphics.



See the [Celestial Body](#) reference for more information.

## Solver Status Window

GMAT now displays a window showing solver variables and constraint values during execution. This helps track the progress of targeters and optimizers and is an important aid in troubleshooting convergence issues.



## Improvements

### Documentation

We've written over 70 pages of new, high-quality user documentation! We've also written two conference papers documenting our verification and validation process and results, and the flight qualification program and results for the Advanced Composition Explorer (ACE). Conference papers are located in the "docs" folder of the distribution.

### Verification and Validation of the General Mission Analysis Tool (GMAT)

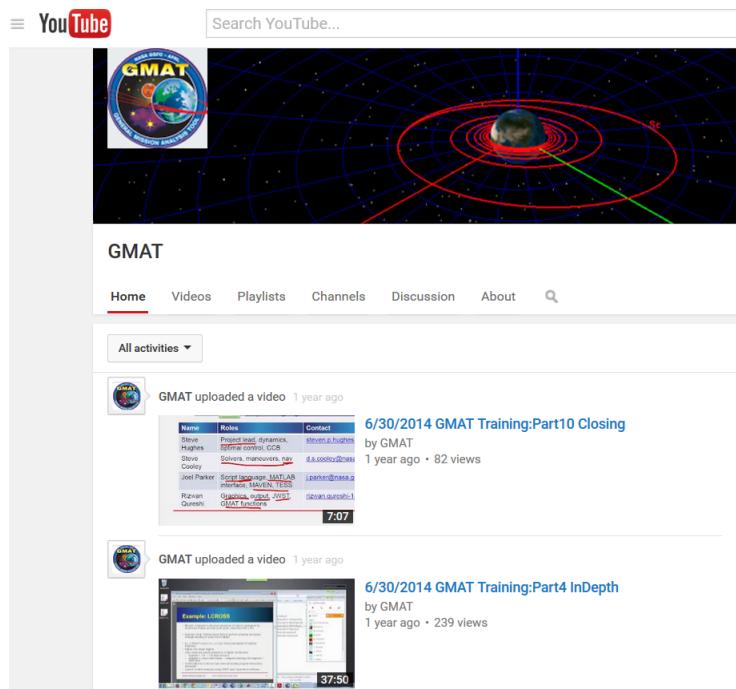
Steven P. Hughes<sup>1</sup>, Rizwan H. Qureshi<sup>1</sup>, D. Steven Cooley<sup>1</sup>, Joel J. K. Parker<sup>1</sup>, Thomas G. Grubb<sup>2</sup>

NASA Goddard Space Flight Center, Greenbelt, MD, 20771, USA

This paper describes the processes and results of Verification and Validation (V&V) efforts for the General Mission Analysis Tool (GMAT). We describe the test program and environments, the tools used for independent test data, and comparison results. The V&V effort produced approximately 13,000 test scripts that are run as part of the nightly build-test process. In addition, we created approximately 3000 automated GUI tests that are run every two weeks. Presenting all test results are beyond the scope of a single paper. Here we present high-level test results in most areas, and detailed test results for key areas. The final product of the V&V effort presented in this paper was GMAT version R2013a, the first Gold release of the software with completely updated documentation and greatly improved quality. Release R2013a was the staging release for flight qualification performed at Goddard Space Flight Center (GSFC) ultimately resulting in GMAT version R2013b.

### Training Videos

We've posted training videos on [YouTube](#). You can now take GMAT training even if you are unable to attend the live classes!



### Other Improvements

- You can now optionally apply an **ImpulsiveBurn** in the backwards direction which is convenient when targeting backwards in time.
- GMAT is distributed with beta plugin Polyhedral gravity model.
- The system now looks in the working directory for scripts run from the command line
- You can now reference supporting files relative to the script file location for ease in sharing complex configurations.
- You can now define an minimum elevation angle for a groundstation used in event location and estimation.
- The appearance of constellations in 3-D graphics has been improved.

- The 3-D model scaling sensitivity in the GUI has been improved.
- The behavior of the GUI when using large fonts has been improved.

## Compatibility Changes

- The **ChemicalTank** Resource has been renamed to **ChemicalTank** to distinguish between chemical and electric systems.
- The **ChemicalThruster** Resource has been renamed to **ChemicalThruster** to distinguish between chemical and electric systems.
- The sensitivity of **Spacecraft** Resource settings such as **ModelOffsetX**, **ModelRotationY**, and **ModelScale** has changed in 3-D graphics.
- When applying an **ImpulsiveBurn** during backwards targeting, GMAT now attempts to compute maneuver values that are consistent with a forward targeting approach. The maneuver values reference the pre-manevuer velocity components instead of the post-maneuver components.

## Development and Tools

### Developer Documentation

We've added extensive documentation describing how to add new Resources and Commands to GMAT. Resources and Commands are key to GMAT development and application. This documentation is essential reading for making fundamental extensions to GMAT. See the [wiki documentation for details](#).

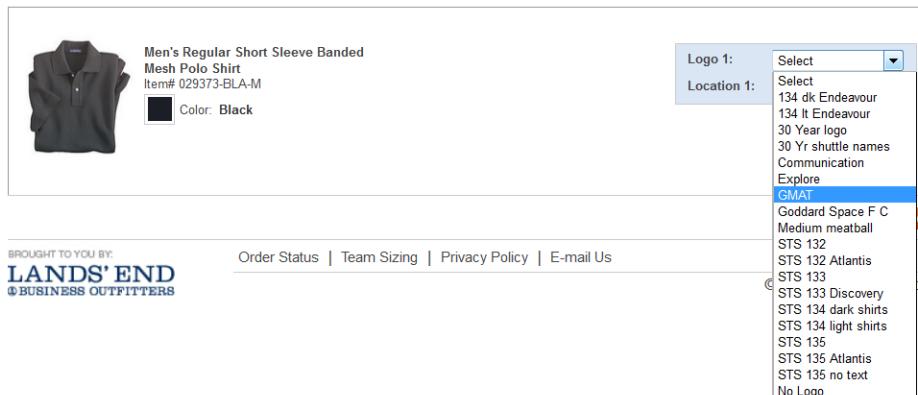
### Developer Tools and Dependencies

We developed a new CMake-based build system that is used on all platforms. The CMake configuration is maintained by the GMAT team and distributed with the source code. Thanks to CMake, it is much easier to compile GMAT. See the [wiki documentation for details](#).

We updated SPICE to version N0065 and updated WxWidgets to version 3.0.2.

## GMAT Stuff

You can now purchase clothing and other items with the GMAT logo via ©Land's End, Inc at the [GSFC Store](#). Once, you've chosen an item, make sure to select the GMAT logo!



## Known & Fixed Issues

Over 215 bugs were closed in this release. See the "[Critical Issues Fixed in R2015a](#)" report for a list of critical bugs and resolutions in R2015a. See the "[Minor Issues Fixed for R2015a](#)" report for minor issues addressed in R2015a.

## Known Issues

All known issues that affect this version of GMAT can be seen in the "[Known Issues in R2015a](#)" report in JIRA.

There are several known issues in this release that we consider to be significant:

ID	Description
GMT-5253	GMAT stuck in script state after bad script load.
GMT-5269	Atmosphere model affects propagation at GEO.
GMT-2561	UTC Epoch Entry and Reporting During Leap Second is incorrect.
GMT-3043	Inconsistent validation when creating variables that shadow built-in math functions
GMT-3289	First step algorithm fails for backwards propagation using SPK propagator
GMT-3350	Single-quote requirements are not consistent across objects and modes
GMT-3669	Planets not drawn during optimization in OrbitView
GMT-3738	Cannot set standalone FuelTank, Thruster fields in CallMatlabFunction
GMT-4520	Unrelated script line in Optimize changes results (causes crash)
GMT-4408	Failed to load icon file and to open DE file
GMT-4520	Coordinate System Fixed attitudes are held constant in SPAD SRP model during a propagation step

## GMAT R2014a Release Notes

The General Mission Analysis Tool (GMAT) version R2014a was released May 2014. This is the first public release since April 2013, and is the 8th release for the project.

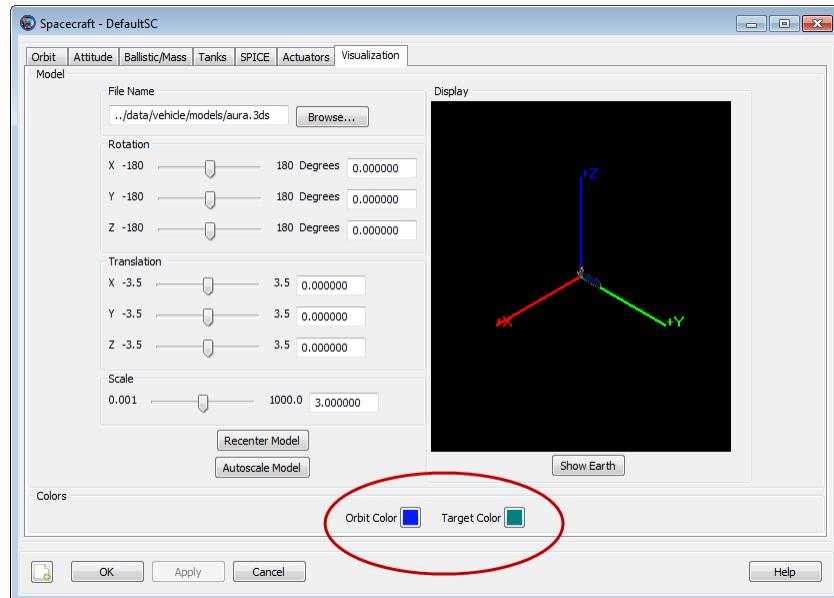
Below is a summary of key changes in this release. Please see the full [R2014a Release Notes](#) on JIRA for a complete list.

### New Features

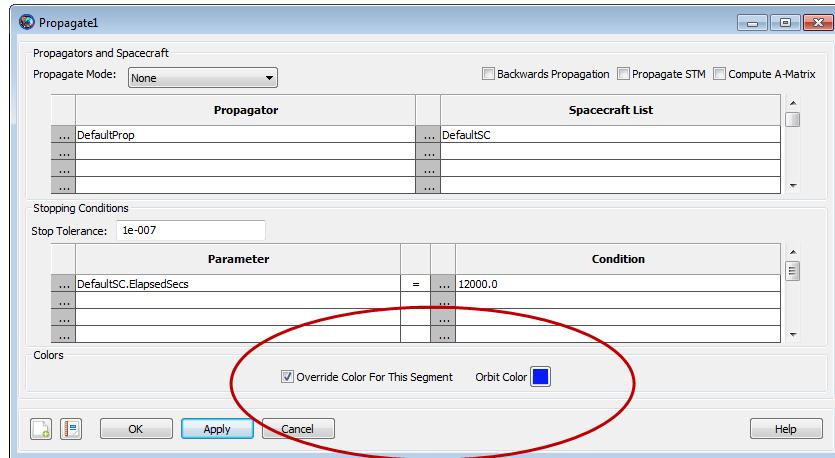
#### Trajectory Colors and Labels

In GMAT R2014a, you can now specify colors for each segment of your trajectory independently, so you can clearly see where a segment begins and ends. This can help define portions of a trajectory, such as before or after maneuvers. All color handling has also been moved from the graphics resources (**OrbitView** and **GroundTrackPlot**) to the resources and commands controlling the trajectory (e.g. **Spacecraft**, **Planet**, **Propagate**).

On Spacecraft, the color specification has moved to the Visualization tab. See the circled area in the screenshot below. Colors for celestial bodies (**Planet**, **Moon**, **Asteroid**, etc.) are specified similarly.



The trajectory color associated with a particular trajectory segment can be changed by changing the color for that particular **Propagate** command. It will override the color for the Spacecraft being propagated for that segment only, and it will return to the default color afterwards.



Additionally, colors can now be specified either by name ('Blue') or by RGB value ([0 0 255]).

This release also adds participant labels in the graphics as well. As long as **OrbitView.ShowLabels** is enabled, each celestial body or **Spacecraft** in the plot will show its name next to it.

See the following example:

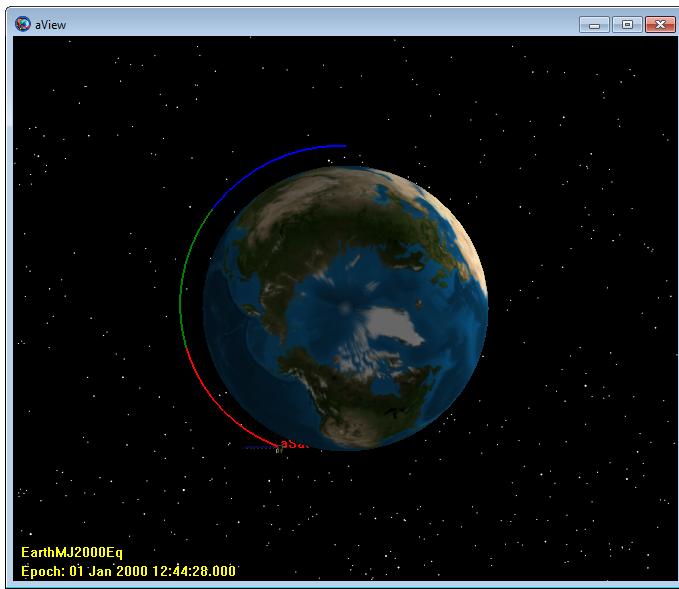
```
Create Spacecraft aSat
aSat.OrbitColor = 'Blue'

Create Propagator aProp

Create OrbitView aView
aView.Add = {aSat, Earth}
aView.XYPlane = off
aView.Axes = off
aView.EnableConstellations = off
aView.ShowLabels = on

BeginMissionSequence
% plots in blue
Propagate aProp(aSat) {aSat.ElapsedSecs = 900}
aSat.OrbitColor = 'Green'
% plots in green
Propagate aProp(aSat) {aSat.ElapsedSecs = 900}
% plots in red
Propagate aProp(aSat) {aSat.ElapsedSecs = 900, OrbitColor = Red}
```

This example results in the following image:



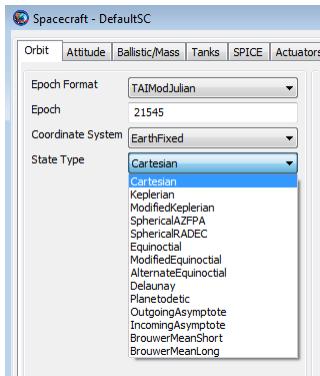
See the [Color](#) reference, as well as the individual [Spacecraft](#), [CelestialBody](#), [Propagate](#), and [OrbitView](#) references, for more information.

## New Orbit State Representations

GMAT now supports six new common orbit state representations, developed with support by the Korea Aerospace Research Institute (KARI). The new representations are:

- Long- and short-period Brouwer-Lyddane mean elements ([BrouwerMeanLong](#) and [BrouwerMeanShort](#))
- Incoming and outgoing hyperbolic asymptote elements ([IncomingAsymptote](#) and [OutgoingAsymptote](#))
- Modified equinoctial elements ([ModifiedEquinoctial](#))
- Alternate equinoctial elements ([AlternateEquinoctial](#))
- Delaunay elements ([Delaunay](#))
- Planetodetic elements, when using a body-fixed coordinate system ([Planetodetic](#))

The new representations are available as options in the **Spacecraft "State Type"** list, and as options to the **Spacecraft.DisplayStateType** field.



See the [Spacecraft Orbit State](#) reference for more information.

## New Attitude Models

GMAT now supports three new kinematic attitude models, developed with support by the Korea Aerospace Research Institute (KARI). The new representations are:

- Precessing spinner
- Nadir pointing
- CCSDS Attitude Ephemeris Message (AEM)

The new representations are available as options in the **Spacecraft "Attitude"** list, and as options to the **Spacecraft.DisplayStateType** field.

See the [Spacecraft Attitude](#) reference for more information.

## Dynamics and Model Improvements

GMAT now supports several new dynamics models and a new numerical integrator.

- Prince Dormand 853 integrator. See the [Propagator](#) reference for more information.
- Mars-GRAM density model. See the [Propagator](#) reference for more information.
- High-fidelity, attitude dependent SRP dynamics model. See the [Propagator](#) reference, and the [Spacecraft Ballistic and Mass Properties](#) reference for more information.

## Targeting and Optimization Improvements

- There are new boundary value solver options on **DifferentialCorrector (Broyden, and ModifiedBroyden)**. Brodyen's method and modified Broyden's method usually take more iterations but fewer function evaluations than **NewtonRaphson** and so are often faster. See the [Differential Corrector](#) reference for more information.
- There are new parameters that check for convergence of solvers. See the [Calculation Parameters](#) reference for more information.

Below is a script example that illustrates the new algorithm and parameter options.

```
Create Spacecraft aSat
Create Propagator aPropagator

Create ImpulsiveBurn aBurn
Create DifferentialCorrector aDC
% This algorithm is often faster, as is ModifiedBroyden
aDC.Algorithm = Broyden

Create OrbitView EarthView
EarthView.Add = {Earth,aSat}
EarthView.ViewScaleFactor = 5

Create ReportFile aReport
```

```

BeginMissionSequence

% Report targeter status here
Report aReport aDC.SolverStatus aDC.SolverState
Target aDC
    Vary aDC(aBurn.Element1 = 1.0, {Upper = 3, MaxStep = 0.4})
    Maneuver aBurn(aSat)
    Propagate aPropagator(aSat,{aSat.Apoapsis})
    Achieve aDC(aSat.RMAG = 42164)
EndTarget
% Report targeter status here
Report aReport aDC.SolverStatus aDC.SolverState

```

## Improvements

### Dependencies in Assignment Command

You can now define settable parameters by using a dependency on the LHS of an assignment command:

```

Create Spacecraft aSat

BeginMissionSequence

aSat.EarthFixed.X = 7000
aSat.EarthMJ2000Eq.VZ = 1

```

### Other Improvements

- You can now set true retrograde orbits when using the Keplerian representation.
- You can now use the quaternion Rvector parameter on the right hand side of an assignment command.
- You can now use a **Spacecraft** body fixed coordinate system as the coordinate system for an **OrbitView**.
- The number of **Spacecraft** that that can be displayed in **OrbitView** is no longer limited to 30.
- The documentation for **OrbitView** has been significantly expanded. See the [Orbit View](#) reference for details.
- You can now save an XY plot graphics window to an image file.
- The supported set of keyboard shortcuts has been greatly expanded. See the [Keyboard Shortcuts](#) reference for more information.
- You can now use many more common ASCII characters in GMAT strings.
- You can now generate orbit state command summary reports using coordinate systems that have any point type as the origin of the selected coordinate system. Previously the origin had to be a **Celestial Body**.

### Compatibility Changes

- Color settings for **Resources** displayed in graphics are now configured on the **Resource** and via the **Propagate** command. **OrbitColor** and **TargetColor** fields on

graphics resources are no longer used.. See the [Spacecraft Visualization](#) reference, and [Propagate](#) command reference for details.

- AtmosDensity is now reported in units of kg/km<sup>3</sup>. See the [Calculation Parameter](#) reference for details.

## Known & Fixed Issues

Over 123 bugs were closed in this release. See the "[Critical Issues Fixed in R2014a](#)" report for a list of critical bugs and resolutions in R2014a. See the "[Minor Issues Fixed for R2014a](#)" report for minor issues addressed in R2014a.

### Known Issues

All known issues that affect this version of GMAT can be seen in the "[Known Issues in R2014a](#)" report in JIRA.

There are several known issues in this release that we consider to be significant:

ID	Description
<a href="#">GMT-2561</a>	UTC Epoch Entry and Reporting During Leap Second is incorrect.
<a href="#">GMT-3043</a>	Inconsistent validation when creating variables that shadow built-in math functions
<a href="#">GMT-3108</a>	OrbitView with STM and Propagate Synchronized does not show space-craft in correct locations
<a href="#">GMT-3289</a>	First step algorithm fails for backwards propagation using SPK propagator
<a href="#">GMT-3350</a>	Single-quote requirements are not consistent across objects and modes
<a href="#">GMT-3556</a>	Unable to associate tank with thruster in command mode
<a href="#">GMT-3629</a>	GUI starts in bad state when started with --minimize
<a href="#">GMT-3669</a>	Planets not drawn during optimization in OrbitView
<a href="#">GMT-3738</a>	Cannot set standalone FuelTank, Thruster fields in CallMatlabFunction
<a href="#">GMT-4520</a>	Unrelated script line in Optimize changes results (causes crash)
<a href="#">GMT-4408</a>	Failed to load icon file and to open DE file
<a href="#">GMT-4520</a>	Coordinate System Fixed attitudes are held constant in SPAD SRP model during a propagation step

## GMAT R2013b Release Notes

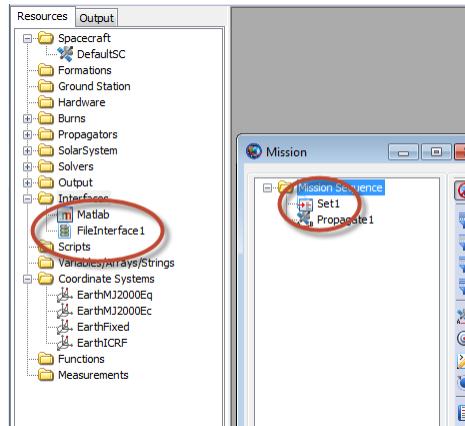
The General Mission Analysis Tool (GMAT) version R2013b was released in August 2013. This is the first public release since April, and is the 7th release for the project. This is an internal-only release, intended to support the ACE mission.

Below is a summary of key changes in this release. Please see the full [R2013b Release Notes](#) on JIRA for a complete list.

### New Features

#### Data File Interface

GMAT now can load **Spacecraft** state and physical properties data directly from a data file. A new resource, **FileInterface**, controls the interface to the data file, and the new **Set** command lets you apply the data as a part of the Mission Sequence.



See the following example:

```
Create Spacecraft aSat
Create FileInterface tvhf
tvhf.Filename = 'statevec.txt'
tvhf.Format = 'TVHF_ASCII'

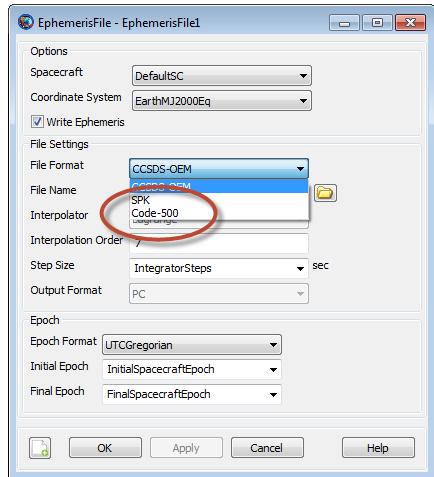
BeginMissionSequence

Set aSat tvhf
```

See the [FileInterface](#) and [Set](#) references for more information.

#### Code-500 Ephemeris Format

GMAT's **EphemerisFile** resource can now write a Code-500 format ephemeris file. The Code-500 format is a binary ephemeris format defined by the NASA Goddard Space Flight Center Flight Dynamics Facility.



```
Create Spacecraft sc
Create Propagator prop
Create EphemerisFile ephem
ephem.Spacecraft = sc
ephem.Filename = 'ephem.eph'
ephem.FileFormat = 'Code-500'
ephem.StepSize = 60
ephem.OutputFormat = 'PC'

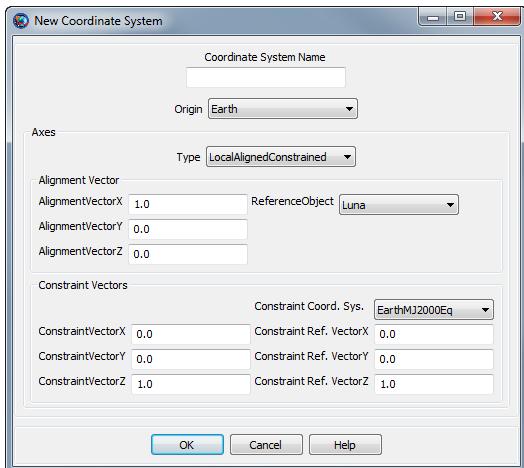
BeginMissionSequence

Propagate prop(sc) {sc.ElapsedDays = 1}
```

See the [EphemerisFile](#) reference for more information on this format.

### New Local Aligned-Constrained Coordinate System

A local aligned-constrained coordinate system is one defined by an alignment vector (defined based on the position of a reference object with respect to the origin) and two constraint vectors. This is a highly flexible coordinate system that can be defined in many ways, depending on mission needs. To use it, select the **LocalAlignedConstrained** axes type when creating a new **CoordinateSystem**.



```
Create CoordinateSystem ACECoordSys
ACECoordSys.Origin = Earth
ACECoordSys.Axes = LocalAlignedConstrained
ACECoordSys.ReferenceObject = ACE
ACECoordSys.AlignmentVectorX = 0
ACECoordSys.AlignmentVectorY = 0
ACECoordSys.AlignmentVectorZ = 1
ACECoordSys.ConstraintVectorX = 1
ACECoordSys.ConstraintVectorY = 0
ACECoordSys.ConstraintVectorY = 0
ACECoordSys.ConstraintCoordinateSystem = EarthMJ2000Ec
ACECoordSys.ConstraintReferenceVectorX = 0
ACECoordSys.ConstraintReferenceVectorY = 0
ACECoordSys.ConstraintReferenceVectorZ = 1
```

See the [CoordinateSystem](#) reference for more information.

## Improvements

### Force Model Parameters

You can now access **ForceModel**-dependent parameters, such as **Spacecraft** acceleration and atmospheric density. The new parameters are:

- *Spacecraft.ForceModel.Acceleration*
- *Spacecraft.ForceModel.AccelerationX*
- *Spacecraft.ForceModel.AccelerationY*
- *Spacecraft.ForceModel.AccelerationZ*
- *Spacecraft.ForceModel.AtmosDensity*

### Space Point Parameters

All Resources that have coordinates in space now have Cartesian position and velocity parameters, so you can access ephemeris information. This includes all built-in solar

system bodies and other Resources such as **CelestialBody**, **Planet**, **Moon**, **Asteroid**, **Comet**, **Barycenter**, **LibrationPoint**, and **GroundStation**:

- *CelestialBody.CoordinateSystem.X*
- *CelestialBody.CoordinateSystem.Y*
- *CelestialBody.CoordinateSystem.Z*
- *CelestialBody.CoordinateSystem.VX*
- *CelestialBody.CoordinateSystem.VY*
- *CelestialBody.CoordinateSystem.VZ*

Note that to use these parameters, you must first set the epoch of the Resource to the desired epoch at which you want the data. See the following example:

```
Create ReportFile rf  
  
BeginMissionSequence  
  
Luna.Epoch.A1ModJulian = 21545  
Report rf Luna.EarthMJ2000Eq.X Luna.EarthMJ2000Eq.Y Luna.EarthMJ2000Eq.Z ...  
    Luna.EarthMJ2000Eq.VX Luna.EarthMJ2000Eq.VY Luna.EarthMJ2000Eq.VZ
```

## Compatibility Changes

- *EphemerisFile.InitialEpoch* now cannot be later than *EphemerisFile.FinalEpoch*. See the [EphemerisFile](#) reference for details.
- When *EphemerisFile.FileFormat* is set to 'SPK', *EphemerisFile.CoordinateSystem* must have MJ2000Eq as the axis system. Other axis systems are no longer allowed with this ephemeris format. See the [EphemerisFile](#) reference for details.
- The deprecated fields *Thruster.Element{1-3}* have been removed. Use *Thruster.ThrustDirection{1-3}* instead. See the [Thruster](#) reference for details.
- Tab characters in strings are now treated literally, instead of being changed to spaces. See [GMT-3336](#) for details.

## Known & Fixed Issues

Over 50 bugs were closed in this release. See the "[Critical Issues Fixed in R2013b](#)" report for a list of critical bugs and resolutions in R2013b. See the "[Minor Issues Fixed for R2013b](#)" report for minor issues addressed in R2013b.

## Known Issues

All known issues that affect this version of GMAT can be seen in the "[Known Issues in R2013b](#)" report in JIRA.

There are several known issues in this release that we consider to be significant:

ID	Description
<a href="#">GMT-2561</a>	UTC Epoch Entry and Reporting During Leap Second is incorrect.

ID	Description
GMT-3043	Inconsistent validation when creating variables that shadow built-in math functions
GMT-3108	OrbitView with STM and Propagate Synchronized does not show space-craft in correct locations
GMT-3289	First step algorithm fails for backwards propagation using SPK propagator
GMT-4097	Ephemeris File is Not Chunking File At Some Discontinuity Types
GMT-3350	Single-quote requirements are not consistent across objects and modes
GMT-3556	Unable to associate tank with thruster in command mode
GMT-3629	GUI starts in bad state when started with --minimize
GMT-3669	Planets not drawn during optimization in OrbitView
GMT-3738	Cannot set standalone FuelTank, Thruster fields in CallMatlabFunction
GMT-3745	SPICE ephemeris stress tests are not writing out ephemeris for the entire mission sequence

## GMAT R2013a Release Notes

The General Mission Analysis Tool (GMAT) version R2013a was released in April, 2013. This is the first public release since May 23, 2012, and is the 6th public release for the project. R2013a is a major release transitioning GMAT from beta to production status. In this release:

- End-user documentation was rewritten and greatly expanded.
- 11,000 script-based regression tests run nightly.
- 5,000 GUI-based regression tests run weekly.
- Code and documentation was contributed by 11 developers from 3 organizations.

## Licensing

GMAT is now licensed under [Apache License, Version 2.0](#). According to the [Open Source Proliferation Report](#), the Apache License 2.0 is one of the most widely-used open source licenses, thereby making GMAT compatible with more existing software and projects.

## Major Improvements

### Production Status

Release R2013a is a major release of GMAT that transitions from beta to production status. Most of our efforts have been devoted to improving the quality of the software and its documentation. This year we made a complete sweep through the system, starting by updating engineering specifications for all features, identifying test gaps, writing new tests, addressing known and newly found bugs, and completing user documentation.

### Tutorials

The GMAT User Guide now contains 5 in-depth tutorials that show how to use GMAT for end-to-end analysis. The tutorials are designed to teach you how to use GMAT in the context of performing real-world analysis and are intended to take between 30 minutes and several hours to complete. Each tutorial has a difficulty level and an approximate duration listed with any prerequisites in its introduction, and is arranged in a general order of difficulty. The simplest tutorial shows you how to enter orbital initial conditions and propagate to orbit perigee, while more advanced tutorials show how to perform finite-maneuver targeting, Mars B-plane targeting, and lunar flyby optimization.

### Reference Guide

We have written a complete reference manual for GMAT for R2013a. The reference manual contains detailed information on all GMAT components. Whether you need detailed information on syntax or application-specific examples, go here. For each GMAT resource (e.g. **Spacecraft**, **ChemicalThruster**, **XYPlot**) and command (e.g. **Optimize**, **Propagate**), the following information is documented:

- Brief description of the feature
- List of related or coupled features
- Complete syntactical specification of the interface

- Tables with detailed options, variable ranges and data types, defaults, and expected behavior
- Copy-and-paste-ready examples

The guide also contains general reference material about the system, such as:

- Script language syntax
- External interfaces
- Parameter listings
- Configuration files
- Command line interface

## Testing

We have spent much of our time preparing for R2013a on testing. Our script and GUI-based regression test systems doubled in size in the last year. They now contain:

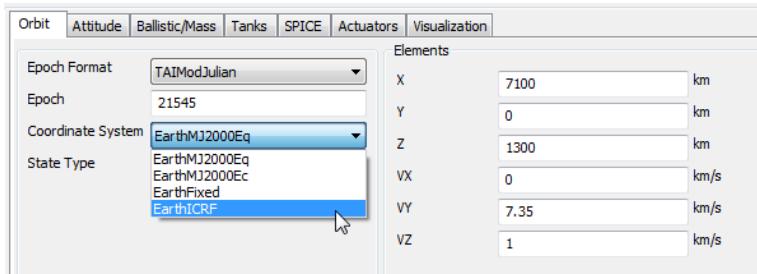
- Over 6,000 new system, validation, and end-to-end script-based tests
- 30 new end-to-end GUI tests
- 3,000 new GUI system tests

GUI test are performed using SmartBear's TestComplete software. Script tests are performed using a custom MATLAB-based automated test system. A complete execution of the regression test system now takes almost four days of computer time.

## Minor Enhancements

While most of our effort has been focused on quality for this release, we have included some new features.

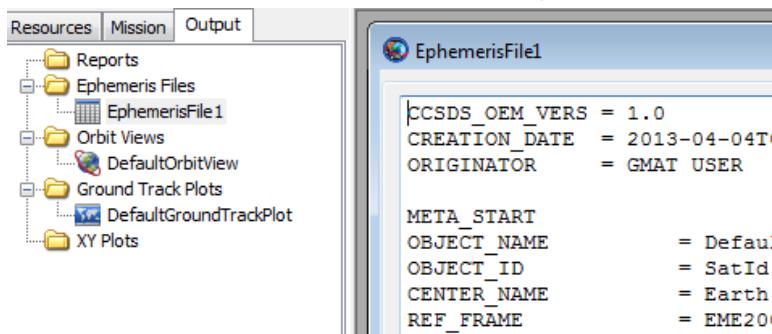
- ICRF is now supported for input and output of orbit state data:



- The Earth texture map is improved:



- CCSDS ephemeris files are now accessible in the output tab:



- Improved mouse controls for interactive 3-D graphics. See the [OrbitView](#) reference for details.
- Improved 3ds model support
- Improved error messages system-wide
- New **BodySpinSun** axis system for asteroid survey missions
- Improved system modularization by moving more features to plugins

## Compatibility Changes

Our last release, R2012a, was beta software. R2013a is mature, production software. We made some changes that may cause backwards compatibility issues with scripts written in previous beta versions. Examples of changes in R2013a that affect backwards compatibility with previous beta versions include:

- Fixed many poorly-named fields and/or parameters (i.e. **OrbitView.CelestialPlane** → **OrbitView.EclipticPlane**)
- Corrected missed or invalid data validation checking
- Removed partially-implemented functionality from previous releases
- Removed improperly-exposed internal fields and functions
- Disabled configuration of some resources in the mission sequence

In all cases, we modified GMAT to work correctly as specified in the documentation, but did not always maintain backwards compatibility with previous versions. This was a one-time, “pull-of-the-Band-Aid” approach, and future releases will maintain backwards compatibility with R2013a or provide deprecation notifications of features that are no longer supported.

In addition, there were some features that did not meet quality expectations for this release and have been turned off in the release package. Most of these features can be turned on for analysis purposes, but they are not fully tested and should be used with caution.

- Orbit Designer (disabled)
- GMAT functions (`libGmatFunctions`)
- Save command (`libSaveCommand`)
- Bulirsh-Stoer integrator (`libExtraPropagators`)

To turn on these features, see the [Startup File](#) reference.

## Known & Fixed Issues

Over 720 bugs and issues were closed in this release. See the "[Critical Issues Fixed for R2013a](#)" report for a list of critical bugs and resolutions for R2013a. See the "[Minor Issues Fixed for R2013a](#)" report for minor issues addressed in R2013a.

### Known Issues

All known issues that affect this version of GMAT can be seen in the "[Known issues in R2013a](#)" report in JIRA.

There are several known issues in this release that we consider to be significant:

ID	Description
GMT-2561	UTC Epoch Entry and Reporting During Leap Second is incorrect.
GMT-3043	Inconsistent validation when creating variables that shadow built-in math functions
GMT-3108	OrbitView with STM and Propagate Synchronized does not show space-craft in correct locations
GMT-3289	First step algorithm fails for backwards propagation using SPK propagator
GMT-3321	MATLAB uses stale version of function if command window isn't restarted between runs
GMT-3350	Single-quote requirements are not consistent across objects and modes
GMT-3556	Unable to associate tank with thruster in command mode
GMT-3629	GUI starts in bad state when started with --minimize
GMT-3669	Planets not drawn during optimization in OrbitView
GMT-3738	Cannot set standalone FuelTank, Thruster fields in CallMatlabFunction
GMT-3745	SPICE ephemeris stress tests are not writing out ephemeris for the entire mission sequence

## GMAT R2012a Release Notes

The General Mission Analysis Tool (GMAT) version R2012a was released May 23, 2012. This is the first public release in over a year, and is the 5th public release for the project. In this release:

- 52,000 lines of code were added
- Code and documentation was contributed by 9 developers from 2 organizations
- 6847 system tests were run every weeknight

This is a beta release. It has undergone extensive testing in many areas, but is not considered ready for production use.

## New Features

### Ground Track Plot

GMAT can now show the ground track of a spacecraft using the new **GroundTrackPlot** resource. This view shows the orbital path of one or more spacecraft projected onto a two-dimensional map of a celestial body, and can use any celestial body that you have configured. Here's an example of the plot created as part of the default mission:



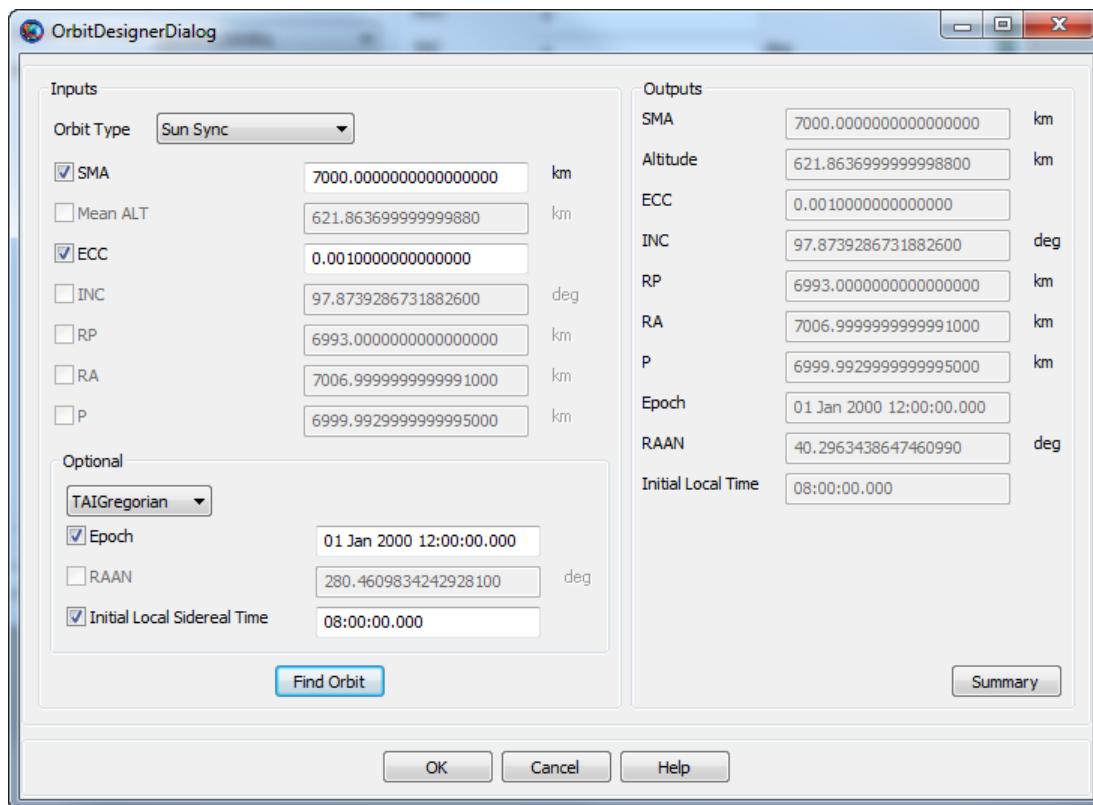
### Orbit Designer

Sometimes you need to create a spacecraft in a particular orbit but don't exactly know the proper orbital element values. Before, you had to make a rough estimate, or go back to the math to figure it out. Now, GMAT R2012a comes with a new **Orbit Designer** that does this math for you.

The **Orbit Designer** helps you create one of six different Earth-centered orbit types, each with a flexible array of input options:

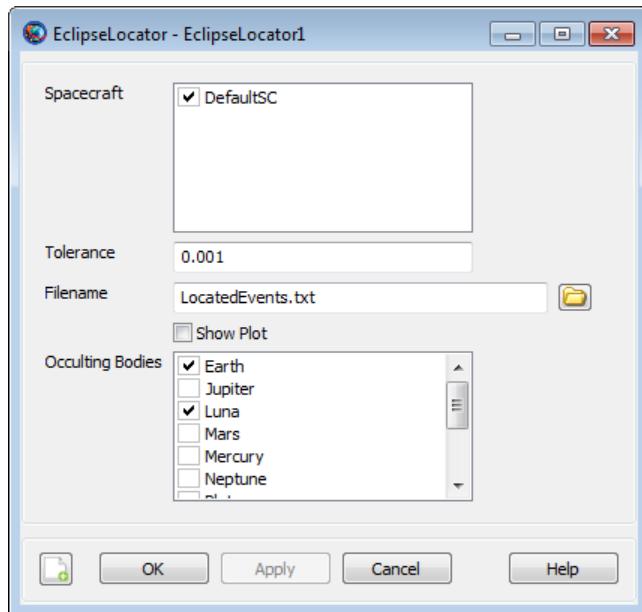
- sun-synchronous
- repeat sun-synchronous
- repeat ground track
- geostationary
- molniya
- frozen

Once you've created your desired orbit, it is automatically imported into the Spacecraft resource for later use. Here's an example of a sun-synchronous orbit using the Designer. To open the **Orbit Designer**, click the button on the **Spacecraft** properties window.



## Eclipse Locator [alpha]

We've done significant work toward having a robust eclipse location tool in GMAT, but this work is not complete. This release comes with an alpha-stage plugin (disabled by default) called `libEventLocator`. When enabled, this plugin adds a new **EclipseLocator** resource that can be configured to calculate eclipse entry and exit times and durations with respect to any configured Spacecraft and celestial bodies. The eclipse data can be reported to a text file or plotted graphically. Some known limitations include an assumption of spherical celestial bodies and a lack of light-time correction. This feature has not been rigorously tested, and may be brittle. We've included it here as a preview of what's coming in future releases.



## C Interface [alpha]

Likewise, we've included an experimental library and plugin that exposes a plain-C interface to GMAT's internal dynamics model functionality. This interface is intended to fill a very specific need: to expose force model derivates from GMAT to external software, especially MATLAB, for use with an external integrator (though GMAT can do the propagation also, if desired). The interface is documented by an [API reference](#) for now.

## Improvements

### Dynamics Models

We've made lots of improvements to GMAT's already capable force model suite. Here's some highlights:

- GMAT now models Earth ocean and pole tides. This is a script-only option that can be turned on alongside an Earth harmonic gravity model; turn it on with a line like this:

```
ForceModel.GravityField.Earth.EarthTideModel = 'SolidAndPole'
```

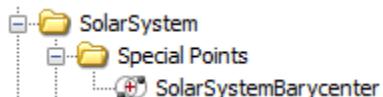
- You can now apply relativistic corrections using the checkbox on the properties for **Propagator**.

### Solar System

GMAT can now use the DE421 and DE424 ephemerides for the solar system. These files are included in the installer, but are not activated by default. To use either of these ephemerides, double-click the **SolarSystem** folder and select it from the **Ephemeris Source** list. Or include the following script line:

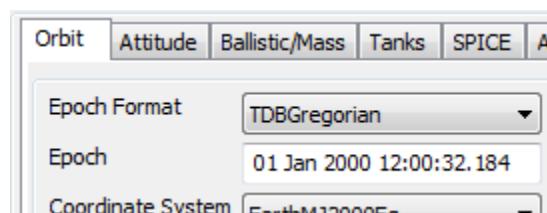
```
SolarSystem.EphemerisSource = 'DE421'
```

There's also a new **SolarSystem** resource called **SolarSystemBarycenter** that represents the barycenter as given by the chosen ephemeris source (DE405, DE421, SPICE, etc.). This resource can be used directly in reports or as the origin of a user-defined coordinate system.



## TDB Input

You can now input the epoch of a **Spacecraft** orbit in the TDB time system (in both Modified Julian and Gregorian formats).

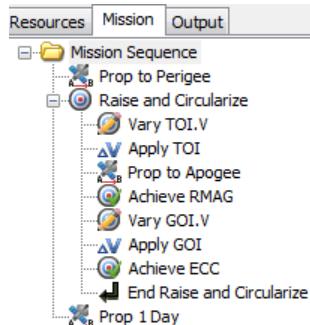


## Mission Tree

We've made significant improvements to the mission tree to make it more user-friendly to heavy users. The biggest improvement is that you can now filter the mission sequence in different ways to make complex missions easier to understand, for example by hiding non-physical events or collapsing the tree to only its top-level elements.



GMAT also now lets you name your mission sequence commands. Thus, instead of a sequence made up of commands like "Optimize1" and "Propagate3", you can label them "Optimize LOI" and "Prop to Periapsis". This example shows the Ex\_HohmannTransfer.script sample with labeled commands.



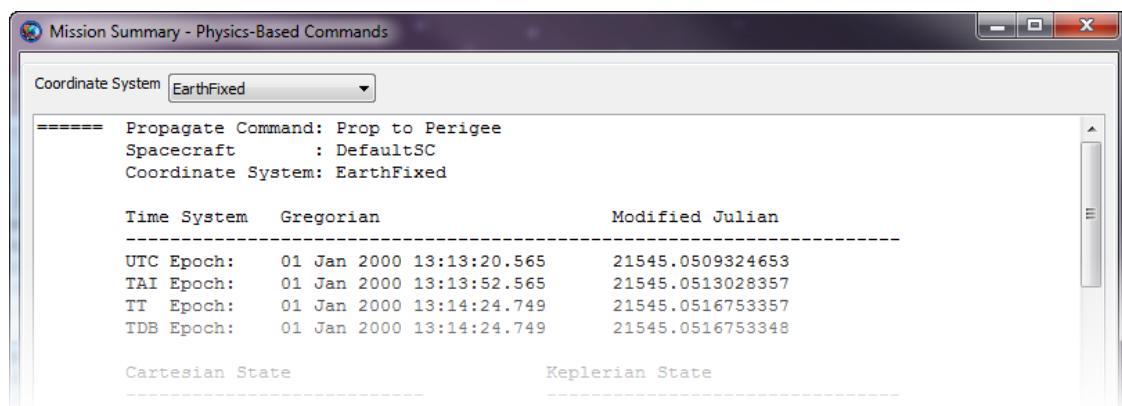
Finally, we added the ability to undock the mission tree so you can place it and the resources tree side by side and see both at the same time. To undock the tree, right-click the **Mission** tab and drag it from its docked position. To dock it again, just close the new **Mission** window.



### Mission Summary

You can now change the coordinate system shown in the **Mission Summary** on the fly: just change the **Coordinate System** list at the top of the window and the numbers will update. This feature can use any coordinate system currently defined in GMAT, including user-defined ones.

There's also a new **Mission Summary - Physics-Based Commands** that shows only physical events (**Propagate** commands, burns, etc.), and further data was added to both **Mission Summary** types.



### Window Persistency

The locations of output windows are now saved with the mission in the script file. This means that when running a mission, all the output windows that were open when the mission was last saved will reappear in their old positions.

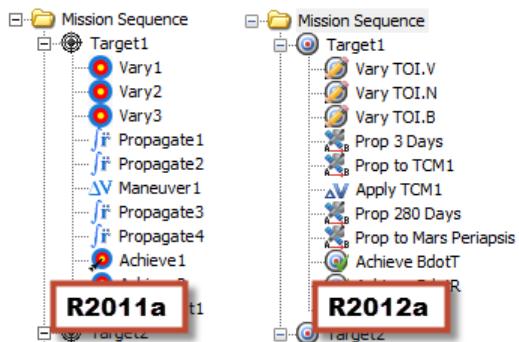
In addition, the locations of certain GMAT windows, like the mission tree, the script editor, and the application window itself are saved to the user preferences file (`MyGMAT.ini`).

## Switch to Visual Studio on Windows

With this release, the official GMAT binaries for Windows are now compiled with Microsoft Visual Studio 2010 instead of GCC. The biggest benefit of this is in performance; we've seen up to a 50% performance improvement in certain cases in unofficial testing. It also leads to more a industry-standard development process on Windows, as the MinGW suite is no longer needed.

## New Icons

The last release saw a major overhaul of GMAT's GUI icons. This time we've revised some and added more, especially in the mission tree.



## Training Manual

The non-reference material in the GMAT User Guide has been overhauled, partially rewritten, and reformatted to form a new GMAT Training Manual. This includes the "Getting Started" material, some short how-to articles, and some longer tutorials. All of this information is included in the GMAT User Guide as well, in addition to reference material that is undergoing a similar rewrite later this year.

## Infrastructure

The GMAT project has implemented several infrastructure improvements in the last year. The biggest of these was switching from our old Bugzilla system to [JIRA](#) for issue tracking.

This year also saw the creation of the [GMAT Blog](#) and the [GMAT Plugins and Extensions Blog](#) with a fair number of posts each, plus reorganizations for the [wiki](#) and the [forums](#). We reactivated our two mailing lists, [gmat-developers](#) and [gmat-users](#), but haven't seen much usage of each yet. And finally, we created a new mailing list, [gmat-buildtest](#), for automated daily build and test updates.

## Compatibility Changes

### Application Control Changes

The command-line arguments for the GMAT executable have changed. See the following table for replacements.

Old	New	Description
-help	--help, -h	Shows available options
-date	--version, -v	Shows GMAT build date
-ms	--start-server	Starts GMAT server on start-up
-br <i>filename</i>	--run, -r <i>scriptname</i>	Builds and runs the script
-minimize	--minimize, -m	Minimizes GMAT window
-exit	--exit, -x	Exits GMAT after a script is run

### Script Syntax Changes

Resource	Field	Replacement
ForceModel	Drag	Drag.AtmosphereModel
Propagator	MinimumTolerance (BullirschStoer)	(none)

### Known & Fixed Issues

Many bugs were closed in this release, but a comprehensive list is difficult to create because of the move from Bugzilla to JIRA. See the "["Bugs closed in R2012a"](#) report in for a partial list.

All known issues that affect this version of GMAT can be seen in [the "Known issues in R2012a"](#) report in JIRA.

## GMAT R2011a Release Notes

The General Mission Analysis Tool (GMAT) version R2011a was released April 29, 2011 on the following platforms:

Windows (XP, Vista, 7)	Beta
Mac OS X (10.6)	Alpha
Linux	Alpha

This is the first release since September 2008, and is the 4th public release for the project. In this release:

- 100,000 lines of code were added
- 798 bugs were opened and 733 were closed
- Code was contributed by 9 developers from 4 organizations
- 6216 system tests were written and run nightly

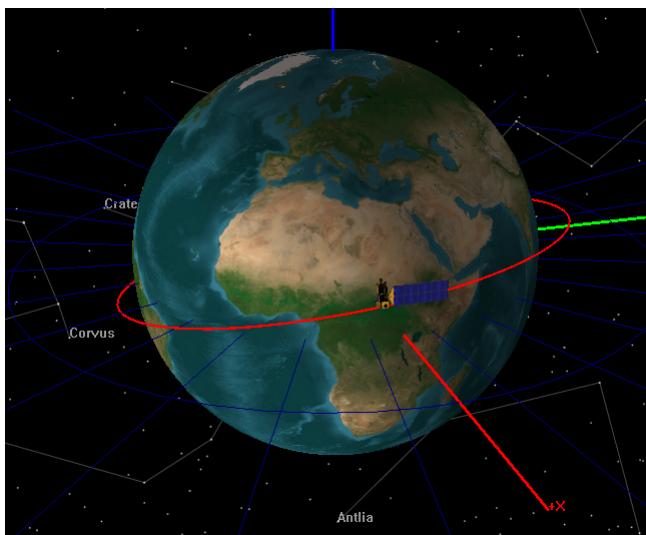
### New Features

#### OrbitView

GMAT's old OpenGLPlot 3D graphics view was completely revamped and renamed OrbitView. The new OrbitView plot supports all of the features of OpenGLPlot, but adds several new ones:

- Perspective view instead of orthogonal
- Stars and constellations (with names)
- A new default Earth texture
- Accurate lighting
- Support for user-supplied spacecraft models in 3ds and POV formats.

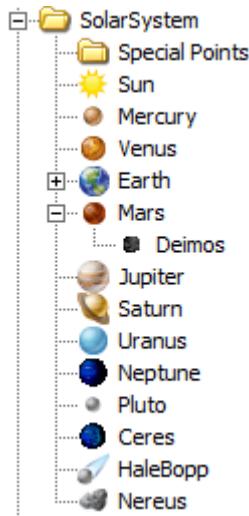
All existing scripts will use the new OrbitView object automatically, with no script changes needed. Here's a sample of what can be done with the new graphics:



## User-Defined Celestial Bodies

Users can now define their own celestial bodies (Planets, Moons, Asteroids, and Comets) through the GMAT interface, by right-clicking on the Sun resource (for Planets, Asteroids, and Comets) or any other Solar System resource (for Moons). User-defined celestial bodies can be customized in many ways:

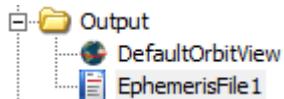
- Mu (for propagation), radius and flattening (for calculating altitude)
- User-supplied texture file, for use with OrbitView
- Ephemeris from two-body propagation of an initial Keplerian state or from a SPICE kernel
- Orientation and spin state



## Ephemeris Output

GMAT can now output spacecraft ephemeris files in CCSDS-OEM and SPK formats by using the EphemerisFile resource. For each ephemeris, you can customize:

- Coordinate system
- Interpolation order
- Step size
- Epoch range



## SPICE Integration for Spacecraft

Spacecraft in GMAT can now be propagated using data from a SPICE kernel rather than by numerical integration. This can be activated on the SPICE tab of the Spacecraft resource, or through the script. The following SPICE kernels are supported:

- SPK/BSP (orbit)

- CK (attitude)
- FK (frame)
- SCLK (spacecraft clock)

## Plugins

New features can now be added to GMAT through plugins, rather than being compiled into the GMAT executable itself. The following plugins are included in this release, with their release status indicated:

libMatlabPlugin	Beta
libFminconOptimizer (Windows only)	Beta
libGmatEstimation	Alpha (preview)

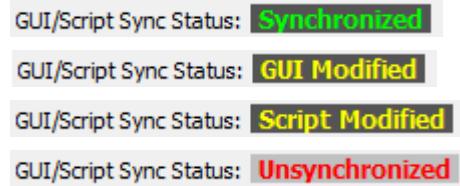
Plugins can be enabled or disabled through the startup file (`gmat_startup_file.txt`), located in the GMAT bin directory. All plugins are disabled by default.

## GUI/Script Synchronization

For those that work with both the script and the graphical interface, GMAT now makes it explicitly clear if the two are synchronized, and which script is active (if you have several loaded). The possible states are:

- Synchronized (the interface and the script have the same data)
- GUI or Script Modified (one of them has been modified with respect to the other)
- Unsynchronized (different changes exist in each place)

The only state in which manual intervention is necessary is Unsynchronized, which must be merged manually (or one set of changes must be discarded). The following status indicators are available on Windows and Linux (on Mac, they appear as single characters on the GMAT toolbar).



## Estimation [Alpha]

GMAT R2011a includes significant new state estimation capabilities in the libGmatEstimation plugin. The included features are:

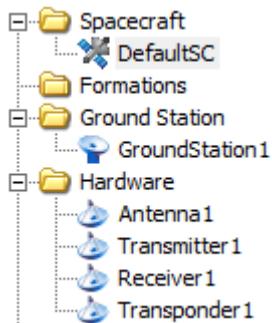
- Measurement models
  - Geometric
  - TDRSS range
  - USN two-way range
- Estimators

- Batch
- Extended Kalman
- Resources
  - GroundStation
  - Antenna
  - Transmitter
  - Receiver
  - Transponder



### Note

This functionality is alpha status, and is included with this release as a preview only. It has not been rigorously tested.



## User Documentation

GMAT's user documentation has been completely revamped. In place of the old wiki, our formal documentation is now implemented in DocBook, with HTML, PDF, and Windows Help formats shipped with GMAT. Our documentation resources for this release are:

- Help (shipped with GMAT, accessed through the Help > Contents menu item)
- Online Help (updated frequently, <http://gmat.sourceforge.net/docs/>)
- Video Tutorials (<http://gmat.sourceforge.net/docs/videos.html>)
- Help Forum (<http://gmat.ed-pages.com/forum/>)
- Wiki (for informal and user-contributed documentation, samples, and tips: <http://gmat.ed-pages.com/wiki/tiki-index.php>)

## Screenshot

GMAT can now export a screenshot of the OrbitView panel to the output folder in PNG format.

## Improvements

### Automatic MATLAB Detection

MATLAB connectivity is now automatically established through the libMatlabInterface plugin, if enabled in your gmat\_startup\_file.txt. We are no longer shipping separate exe-

cutables with and without MATLAB integration. Most recent MATLAB versions are supported, though configuration is necessary.

## Dynamics Model Numerics

All included dynamics models have been thoroughly tested against truth software (AGI STK, and A.I. Solutions FreeFlyer, primarily), and all known numeric issues have been corrected.

## Script Editor [Windows]

GMAT's integrated script editor on Windows is much improved in this release, and now features:

- Syntax highlighting for GMAT keywords
- Line numbering
- Find & Replace
- Active script indicator and GUI synchronization buttons

```

9
10 Create Spacecraft DefaultSC;
11 GMAT DefaultSC.DateFormat = TAIJulian;
12 GMAT DefaultSC.Epoch = 21545;
13 GMAT DefaultSC.CoordinateSystem = EarthMJ2000Eq;
14 GMAT DefaultSC.DisplayStateType = Cartesian;
15 GMAT DefaultSC.X = 7100;
16 GMAT DefaultSC.Y = 0;
17 GMAT DefaultSC.Z = 1300;
18 GMAT DefaultSC.VX = 0;
19 GMAT DefaultSC.VY = 7.349999999999996;
20 GMAT DefaultSC.VZ = 1;
21 GMAT DefaultSC.DryMass = 850;
22 GMAT DefaultSC.Cd = 2.2;
23 GMAT DefaultSC.Cr = 1.8;
24 GMAT DefaultSC.DragArea = 15;
25 GMAT DefaultSC.SRPArea = 1;

```

## Regression Testing

The GMAT project developed a completely new testing system that allows us to do nightly, automated tests across the entire system, and on multiple platforms. The new system has the following features:

- Focused on GMAT script testing
- Written in MATLAB language
- Includes 6216 tests with coverage of most of GMAT's functional requirements
- Allows automatic regression testing on nightly builds
- Compatible with all supported platforms

The project is also regularly testing the GMAT graphical interface on Windows using the SmartBear TestComplete tool. This testing occurs approximately twice a week, and is

focused on entering and running complete missions through the interface and checking that the results match those generated in script mode.

### Visual Improvements

This release features numerous visual improvements, including:

- A new application icon and splash screen (shown below)
- Many new, professionally-created icons
- A welcome page for new users



### Compatibility Changes

#### Platform Support

GMAT supports the following platforms:

- Windows XP
- Windows Vista
- Windows 7
- Mac OS X Snow Leopard (10.6)
- Linux (Intel 64-bit)

With the exception of the Linux version, GMAT is a 32-bit application, but will run on 64-bit platforms in 32-bit mode. The MATLAB interface was tested with 32-bit MATLAB 2010b on Windows, and is expected to support 32-bit MATLAB versions from R2006b through R2011a.

**Mac:** MATLAB 2010a was tested, but version coverage is expected to be identical to Windows.

**Linux:** MATLAB 2009b 64-bit was tested, and 64-bit MATLAB is required. Otherwise, version coverage is expected to be identical to Windows.

#### Script Syntax Changes

The `BeginMissionSequence` command will soon be required for all scripts. In this release a warning is generated if this statement is missing.

The following syntax elements are deprecated, and will be removed in a future release:

Resource	Field	Replacement
DifferentialCorrector	TargeterTextFile	ReportFile
DifferentialCorrector	UseCentralDifferences	DerivativeMethod = "CentralDifference"
EphemerisFile	FileName	Filename
FiniteBurn	Axes	
FiniteBurn	BurnScaleFactor	
FiniteBurn	CoordinateSystem	
FiniteBurn	Origin	
FiniteBurn	Tanks	
FiniteBurn	CoordinateSystem = "Inertial"	CoordinateSystem = "MJ2000Eq"
ImpulsiveBurn	VectorFormat	
ImpulsiveBurn	V	Element1
ImpulsiveBurn	N	Element2
ImpulsiveBurn	B	Element3
FuelTank	PressureRegulated	PressureModel = PressureRegulated
OpenGLPlot		OrbitView
OrbitView	EarthSunLines	SunLine
OrbitView	ViewDirection = Vector	ViewDirection = [0 0 1]
OrbitView	ViewDirection = [0 0 1]	
OrbitView	ViewPointRef	ViewPointReference
OrbitView	ViewPointRef = Vector	ViewPointReference = [0 0 1]
OrbitView	ViewPointRefVector = [0 0 1]	
OrbitView	ViewPointVector = Vector	ViewPointVector = [0 0 1]
OrbitView	ViewPointVectorVector = [0 0 1]	
SolarSystem	Ephemeris	EphemerisSource

Resource	Field	Replacement
Spacecraft	StateType	DisplayStateType
Thruster	X_Direction	ThrustDirection1
	Y_Direction	ThrustDirection2
	Z_Direction	ThrustDirection3
	Element1	
	Element2	
	Element3	
XYPlot	Add	YVariable
XYPlot	Grid	ShowGrid
XYPlot	IndVar	XVariable

Command	Old Syntax	New Syntax
Propagate	Propagate DefaultProp(sc)	- Propagate      BackProp DefaultProp(sc)

## Fixed Issues

733 bugs were closed in this release, including 368 marked “major” or “critical”. See the [full report for details](#).

## Known Issues

There remain 268 open bugs in the project’s [Bugzilla database](#), 42 of which are marked “major” or “critical”. These are tabulated below.

**Table 24. Multiple platforms**

407	Multi-Matlab run bug
636	MATLAB Callbacks on Linux and Mac
648	DOCUMENT BEHAVIOR - Final orbital state does not match for the two report methods
776	Batch vs Individual Runs different
1604	Keplerian Conversion Errors for Hyperbolic Orbits
1668	Decimal marker not flexible enough for international builds
1684	MMS script in GMAT takes 300 times longer than similar run in FreeFlyer
1731	Major Performance issue in GMAT Functions
1734	Spacecraft allows conversion for singular conic section.
1992	Determinant of "large" disallowed due to poor algorithm performance
2058	Can't set SRP Flux and Nominal Sun via GUI
2088	EOP file reader uses Julian Day
2147	Empty parentheses "( )" are not caught in math validation
2313	Finite Burn/Thruster Tests Have errors > 1000 km but may be due to script differences
2322	DOCUMENT: MATLAB interface requires manual configuration by user
2344	when a propagator object is deleted, its associated force model is not deleted
2349	Performance Issue in Force Modelling
2410	Ephemeris propagator has large numeric error
2416	STM Parameters are wrong when using Coordinate System other than EarthMJ2000Eq

**Table 25. Windows**

970	Matlab connection issue
1012	Quirky Numerical Issues 2 in Batch mode
1128	GMAT incompatible with MATLAB R14 and earlier
1417	Some lines prefixed by "function" are ignored
1436	Potential performance issue using many propagate commands
1528	GMAT Function scripts unusable depending on file ownership/permissions
1580	Spacecraft Attitude Coordinate System Conversion not implemented
1592	Atmosphere Model Setup File Features Not Implemented
2056	Reproducibility of script run not guaranteed
2065	Difficult to read low number in Spacecraft Attitude GUI
2066	SC Attitude GUI won't accept 0.0:90.0:0.0 as a 3-2-1 Euler Angle input
2067	Apply Button Sometimes Not Functional in SC Attitude GUI
2374	Crash when GMAT tries to write to a folder without write permissions
2381	TestComplete does not match user inputs to DefaultSC
2382	Point Mass Issue when using Script vs. User Input

**Table 26. Mac OS X**

1216	MATLAB->GMAT not working
2081	Texture Maps not showing on Mac for OrbitView
2092	GMAT crashes when MATLAB engine does not open
2291	LSK file text ctrl remains visible when source set to DE405 or 2Body
2311	Resource Tree - text messed up for objects in folders
2383	Crash running RoutineTests with plots ON

**Table 27. Linux**

<a href="#">1851</a>	On Linux, STC Editor crashes GMAT on Close
<a href="#">1877</a>	On Linux, Ctrl-C crashes GMAT if no MDIChildren are open

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