
GMAT Application Programming Interface

Release R2025a

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Mar 11, 2025

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INTRODUCTION

The General Mission Analysis Tool, GMAT, is a general purpose spacecraft mission design, analysis, and operations tool. GMAT is in active development, and has been used for multiple spacecraft missions. GMAT is the operational tool for maneuver design and navigation on several missions in the Goddard Space Flight Center's Flight Dynamics Facility. It is used for mission design at GSFC and at numerous other organizations throughout the world. GMAT is a free and open source tool, available at the GMAT wiki [[GmatWiki](#)].

Core capabilities of GMAT can be accessed using an Application Programming Interface (API). This document describes the GMAT API, and includes sample usage from Python and MATLAB using Java.

GMAT is coded using an object oriented approach documented in the GMAT Architectural Specification [[Architecture](#)]. The system has been under development since 2002. Users interact with GMAT through a spacecraft domain specific language built into the system, modeled on the MATLAB programming language. The GMAT API opens the system's object model to users that want to interact directly with the core system components, outside of the scripted interfaces used when running the application.

The materials presented in this document are divided into two sections:

- The first section documents the design of the API. In it, you will find an extremely high level overview of the GMAT code and a matching API overview, a discussion of the philosophy governing the API that includes use cases, and a description of the additions to the GMAT code base added for the API that enable the examples and features requested by the user community.
- The second section is a user's guide for the GMAT API. It contains instructions for installing the API code, a "Getting Started" tutorial for initial use of the API, and additional hints, tips, and use case descriptions designed to help you start using the GMAT API.

This documentation concludes with appendices that provide additional API guidelines, review notes, and other information for developers and API users.

SYSTEM DESIGN

2.1 GMAT Architectural Components

The GMAT API exposes core GMAT classes and processes to API users. In order to understand the API, it is useful to understand at a high level how GMAT works, and how the API encapsulates the GMAT design for use outside of the program.

2.1.1 The GMAT Architecture

The GMAT system consists of a set of components that set up a framework for executing spacecraft mission analysis simulations, and a set of components used to define and run the simulation. The former is referred to as the GMAT engine. The latter defines the components that users script when they run a simulation. [Fig. 2.1](#) shows the connections between the components of the GMAT engine. The main control element of GMAT is a component called the Moderator. GMAT's Moderator provides an interface into the inner working of GMAT, and manages user interactions with the system. Simulations are run in a Sandbox, using clones of user objects created in factories and stored in the GMAT configuration. Users interact with GMAT through interpreters that convert script or GUI descriptions of simulation components into the objects used for the simulation. The results of a simulation are passed, through a Publisher, to subscribing components, which write files or display data for the user. In a nutshell, that is the architecture shown in [Fig. 2.1](#).

Another view of the components used in GMAT is shown in the component stack diagram in [Fig. 2.2](#). GMAT is built on a set of utility functions used for string, vector and matrix manipulations, core numerical operations, file manipulations, and general purpose time and state representations. The GMAT Engine components are built on these utilities, as are the classes defining the objects used in a GMAT simulation. User interfaces into the GMAT system are built on top of these core elements of the system.

All of the user configured simulation components are built on a class, GmatBase, that provides the serialization interfaces used to set the properties of the components through object fields. GmatBase provides the interfaces used when reading and writing simulation objects, either to script files or to panels on the GMAT graphical user interface. Resources - objects like the spacecraft model, coordinate systems, force models, propagators, environmental elements, hardware components, and numerical engines used for estimating, targeting, and optimizing - are all built on top of the GmatBase class, as is the mission timeline scripted as a sequence of GMAT commands. The mission timeline is referred to as the GMAT mission control sequence in the documentation.

Most users of the GMAT API do not interact directly with the components of the GMAT engine. Those components are described in the GMAT Architectural Specification [\[Architecture\]](#). Typical users of the GMAT API fall into two groups: users that use GMAT components in their work, and users that manipulate scripted components prior to, during, or after the execution of a script. The API design documented below focuses on these users.

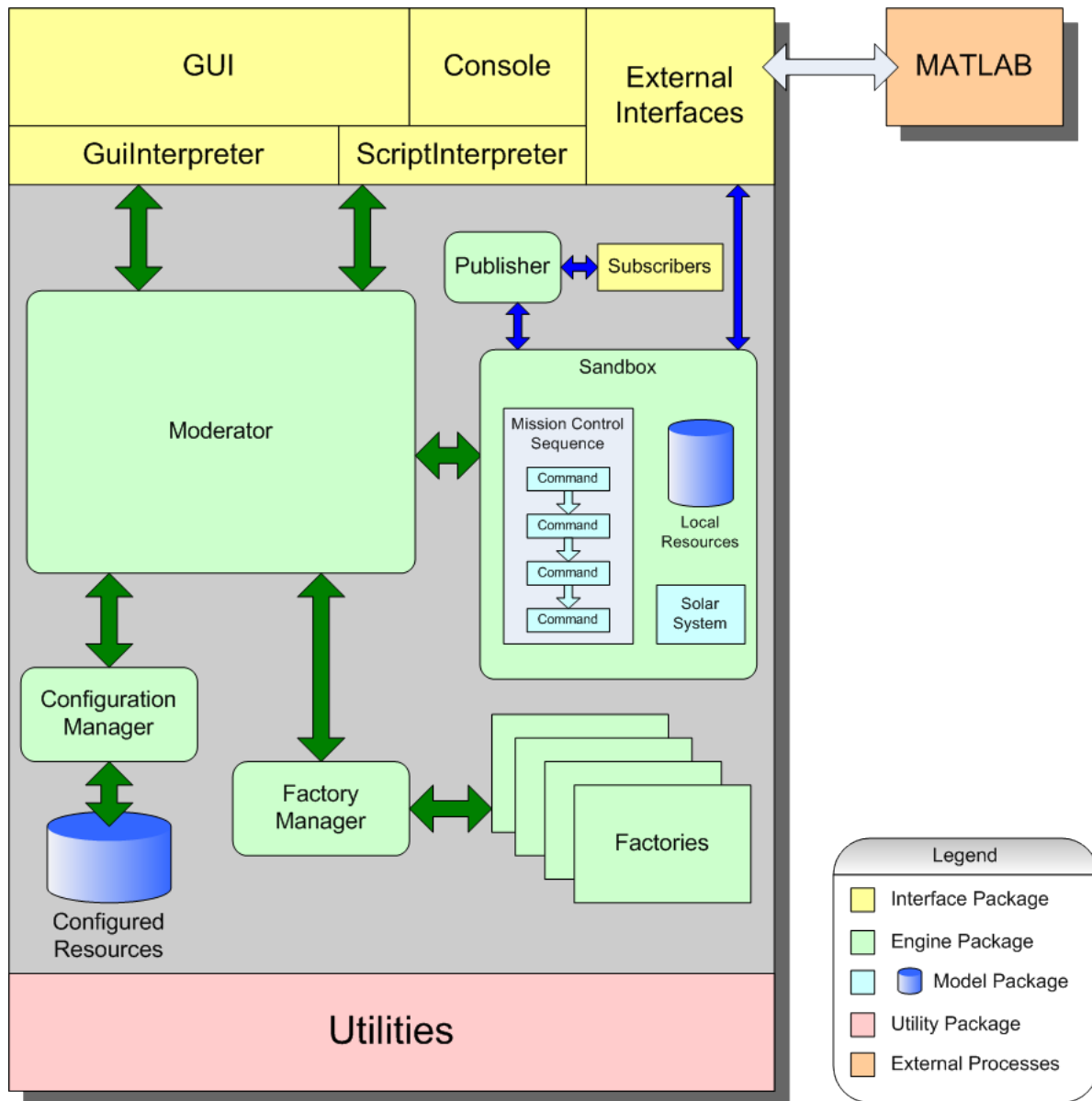


Fig. 2.1: The GMAT engine, showing interactions between the components.

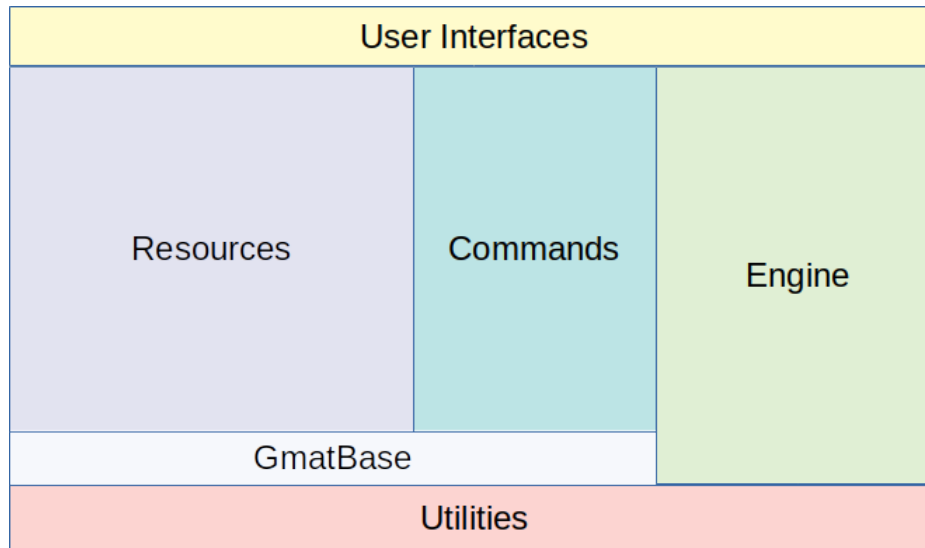


Fig. 2.2: The GMAT component stack.

2.2 The API Design

Fig. 2.2 shows an overview of the GMAT component stack. The stack for the GMAT API, shown in Fig. 2.3, has a similar appearance. Users interact with the GMAT API through an interface layer built using the Simplified Wrapper and Interface Generator, SWIG. SWIG generates interfaces and shared libraries for Python and Java, and can generate similar interface code for other languages when needed. Classes in GMAT's code base are exposed through this interface using language specific wrappers. Users interact with the GMAT classes through these wrappers.

Using the SWIG interface code, users can work directly with GMAT classes on a class by class/object by object level. Users that work this way need a pretty complete understanding of object linkages and interactions in GMAT. Using that expertise, they either imitate many of the steps that are performed by the GMAT engine when GMAT is run or make calls to the components of the engine to perform the required actions.

Most users would rather work at a less detailed level than this object by object interaction. There are two groups of users in this category: those that are familiar with GMAT and want to use the API to run GMAT scripts, making API calls to adapt their scripts along the way, and those that want to use capabilities provided by GMAT inside of models that they are running in a tool like MATLAB or Python, or in a compiled application written in a language like Java. The API provides a set of helper functions that encapsulate the GMAT engine behind calls that simplify the management tasks of the GMAT engine for these users. These API helpers are exposed through the SWIG interface layer for use by these API users.

A driving feature of the GMAT API is the incorporation of usability features for the API user community. During the prototyping exercise for the API, the development team found that the SWIG system provides a simple mechanism for exposing GMAT components in the Python, Java, and MATLAB environments. However, users working in those systems still found it difficult to use the prototype API because of a lack of on line documentation and apparent inconsistencies in the methods in GMAT. The production API addresses the first of these issues through the incorporation of class and object level help functions for classes that are identified as "API ready." Interface inconsistencies are addressed through the addition of methods to the source code that simplify the class and object interfaces, leaving in place where necessary the interfaces that appear to API users to be inconsistent because of internal code needs in the GMAT system.

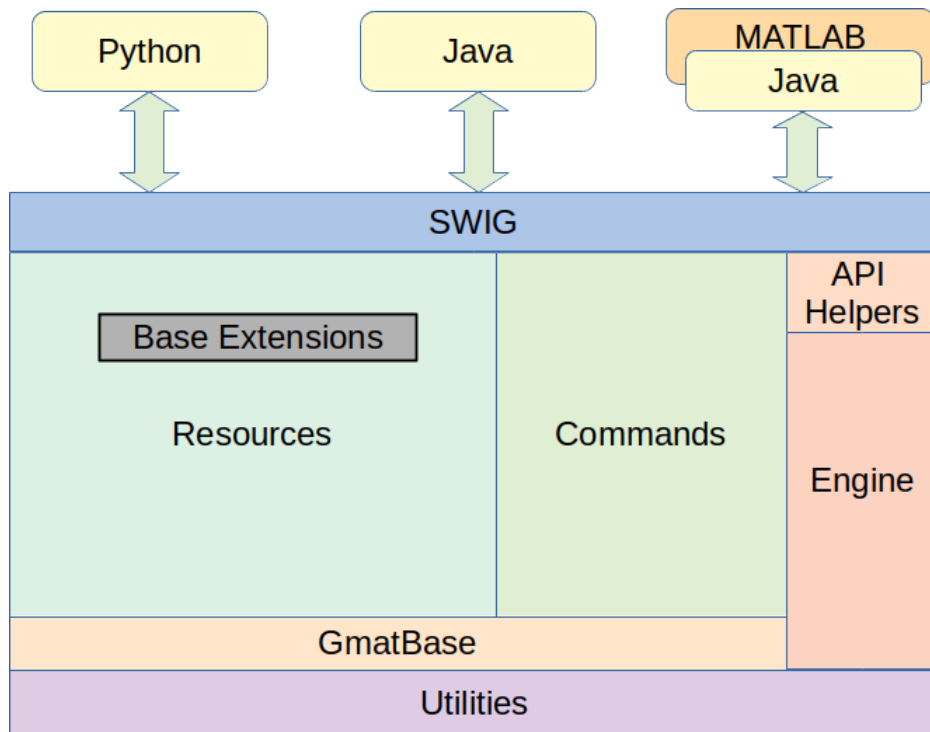


Fig. 2.3: The GMAT API stack.

GMAT API USER'S GUIDE

This chapter contains information and general guidelines for using the GMAT API, along with example use cases, presented in a tutorial fashion.

3.1 Setting up the GMAT API

The GMAT API is included in the GMAT release code beginning with the GMAT R2020a release of the system on SourceForge. The API subsystem included in these packages has been tested using Python and MATLAB calls to the API.

3.1.1 Installation

Installation of the API is complete when the GMAT release bundle is installed on the user's workstation.

Direct Usage

The API can be used immediately by users that want to run it from the GMAT bin directory. Simply open a session in MATLAB or Python, change directories to the GMAT bin folder, and load the GMAT system into the executing environment. The examples shown later in this document can then be run directly in that environment.

Running the API Outside of the GMAT Folders

Users that want to run the API from a different location from the GMAT system need to perform additional steps to configure the system to address two features of the system:

1. GMAT uses a set of data files for its core functions.
2. Running environments need to be able to find the GMAT API interfaces.

The following paragraphs address the configuration settings for these two items.

File Location Access

GMAT uses a text data file, `gmat_startup_file.txt`, to identify and locate GMAT plug-in components, planetary ephemerides, gravitational potentials, and a large variety of other data files required during a run. The GMAT API operates using this data file by default, but that causes problems when running outside of the GMAT folder structure. Rather than change the GMAT startup file, API users can accomplish the folder structure definition by creating an API specific startup file. A python script to create this file, `BuildApiStartupFile.py` is in the `api` folder in the main GMAT folder, as well as more detailed instructions in `API_README.txt`.

Once the `api_startup_file` is created, you are ready to configure your Python or MATLAB environment.

External Access from Python

Note: External access from Python requires configuration of an API startup file, as described in the [File Location Access](#) text, above.

The API is loaded from a Python process running outside of the GMAT folders using the `load_gmat.py` module found in the GMAT `api` folder. The simplest way to proceed is to edit that file in place:

1. Open `load_gmat.py` in a text editor.
2. Change the “<TopLevelGMATFolder>” entry near the top of the file to the absolute path to your top level GMAT folder. Make sure that the path is enclosed in quotation marks.

Windows users will also need to change backslash characters in this string either to double backslashes or to forward slashes so that the Python interpreter can handle the path correctly.

3. Save the file.
4. Copy the edited `load_gmat.py` file into the folder that is used for the API run.

Note one advantage of editing the `load_gmat` file in the `api` folder is that this file can be copied into any folder that needs access to the API. In other words, once the file has the absolute path set, it can be copied to any folder that needs to act as the home folder for an API run.

Test the configuration to make certain that the API can be run. Note that, rather than directly importing `load_gmat`, you will want to preserve the imported symbols. This preservation is done using the syntax “from module import *”, as shown in this Linux example:

```
$ cd APIFromHere/
$ python3
>>> from load_gmat import *
>>> sat = gmat.Construct("Spacecraft","Sat")
>>> gmat.ShowObjects()
Current GMAT Objects

EarthMJ2000Eq
EarthMJ2000Ec
EarthFixed
EarthICRF
SolarSystemBarycenter
Sat
```

The SolarSystem contains the following bodies:

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```
[Sun, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto, Luna]
```

```
>>>
```

External Access from MATLAB

Note: External access from MATLAB requires configuration of an API startup file, as described in the [File Location Access](#) text, above.

The API is loaded from a MATLAB console running outside of the GMAT folders using the `load_gmat.m` module found in the GMAT bin folder. That file configures MATLAB to use the API. The simplest way to use it is to add the GMAT bin folder to your MATLAB path, either in the running MATLAB environment or in the MATLAB configuration on your workstation. You can test the configuration to make certain that the API can be run following the steps below, which run the API from the folder `APIFromHere` outside of the GMAT installation folders:

```
$ cd APIFromHere/
$ matlab -nodesktop
```

To get started, `type doc`.
For product information, visit www.mathworks.com.

```
>> addpath('/<TopLevelGMATFolder>/bin/')
>> load_gmat
No script provided to load.
```

```
ans =
```

Instance of GMAT Moderator is initialized. No script ready to run.

```
>> sat = GMATAPI.Construct('Spacecraft','MySat')
```

```
sat =
```

Object of `type` Spacecraft named MySat

```
>> GMATAPI.ShowObjects()
```

```
ans =
```

Current GMAT Objects

```
EarthMJ2000Eq
EarthMJ2000Ec
EarthFixed
EarthICRF
SolarSystemBarycenter
MySat
```

The SolarSystem contains the following bodies:

(continues on next page)

(continued from previous page)

```
[Sun, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto, Luna]
```

```
>>
```

3.1.2 Loading the API

Packaging

The GMAT API is packaged in a set of libraries encapsulating specific pieces of functionality.

Table 3.1: The component packages built for GMAT’s API

Package Name	Contents	Description
gmat	GMAT Utilities and Core Components	Utility classes used in the rest of GMAT, that do not depend on other GMAT components, built from gmatutil code. Classes used for most of the GMAT spacecraft modeling, along with the GMAT “engine” that drives the main application, built from gmatbase code.
station	Ground station models	Code used to model ground stations
navigation	Estimation Components	Classes used for the GMAT orbit determination subsystem.

Initialization

There are some differences in how to initialize the API between Python, Java, and MATLAB, however they all follow the same basic process. The API is first loaded into the interfacing language, and then the GMAT executive is initialized through the Moderator. The process of initializing the API is detailed in the sections below for each supported language. The initialization example for each language creates an instance of the Moderator object named `myMod` that has been initialized. The `result` variable is a flag which returns `True` if the initialization was successful, or `False` if unsuccessful.

Python

The API is loaded from the GMAT bin folder into Python with an import command

Python initialization example:

```
import gmatpy as gmat
```

At this point, the GMAT Python API is not initialized. A user can initialize it using the `Setup()` command, or by making any call to an API specific function.

The API can be loaded into from any folder from Python if by following the [External Access from Python](#) instructions, above.

Java

Java requires an extra step compared to Python. Not only does the GMAT API need to be imported, a shared library must also be loaded

```
import gmat.*;

public class main {

    public static void main(String[] args) {

        Moderator myMod;
        boolean result;

        // Load the GMAT library
        System.loadLibrary("gmat"); // On Windows

        myMod = Moderator.Instance();
        result = myMod.Initialize("gmat_startup_file.txt");
    }
}
```

At this point, the GMAT Java API is initialized.

MATLAB

While the MATLAB interface uses the Java API, there are a few extra steps required due to how Java packages are used inside MATLAB. The . To simplify this, a MATLAB script which performs all the initialization, `load_gmat.m`, is included with the GMAT installation in the `<install-dir>/bin` directory. The `load_gmat` script also optionally takes as an input the filename of a GMAT script to load, and a filename to a custom startup file.

```
[myMod, gmatStartupPath, result] = load_gmat("sample.script");
```

The extra steps in initializing the GMAT API through MATLAB is because every GMAT library and JAR file needs to be loaded explicitly, and it needs to be loaded by the Java instance inside MATLAB instead of by MATLAB itself. For more details, see the comments inside the `load_gmat.m` file.

3.2 Conventions in the API Examples and Use Cases

The usage section of this documentation shows API users how to perform several common tasks using the GMAT API.

3.2.1 General Conventions

- Numbers that would normally display as 16 digits are truncated to fit on the page when necessary.
- Extraneous white space has been removed from some output.
- Interactive and scripted code segments are shown offset in special blocks, like this:

```
>>> import gmatpy as gmat
```

Interactive Python blocks, like the one shown above, include Python's triple bracket marker. Blocks from Python script files do not have this marker:

```
import gmatpy as gmat
```

Interactive MATLAB elements are displayed similarly, with MATLAB's Command Window line marker:

```
>> load_gmat
```

Note that the typesetting for MATLAB is also different from the Python settings.

3.2.2 User Workspace and GMAT Typography

This documentation provides examples in the two application environments supported by the core GMAT API development team: Python and MATLAB (via Java). The API is built using SWIG, and can be built for other platforms. This documentation does not address other platforms.

Work performed using the API involves interactions with objects created in GMAT that are accessed in the user's application environment. This results in references in the user's environment of objects in the GMAT environment. The following conventions are observed in this document to help clarify this component dichotomy:

- Objects created in GMAT use camel-cased names. User references to those objects are presented in lowercase. For instance, the Python script line

```
mysat = gmat.Construct("Spacecraft", "MySat")
```

creates a GMAT Spacecraft object named "MySat," stored in GMAT, that a user accesses through their mysat environment variable.

3.3 Object Usage with the GMAT API

The goal of this section is to help you start using the GMAT API quickly, while introducing features of the interface in a natural progression of steps needed to solve a simple orbital state conversion problem.

3.4 Overview

The GMAT API is built using the Simplified Wrapper and Interface Generator, SWIG. SWIG connects code written in C and C++ with a variety of high level languages. The production GMAT API provides Python and Java connections for GMAT functionality. C++ programmers can also use the API specific code interfaces through direct calls into the GMAT libraries. The following sections describe the provided interfaces. Following that, three levels of interface usage are described:

1. Usage based primarily on GMAT scripting, with API generated component changes.
2. High level usage of GMAT components to meet specific user needs.
3. Class and object level access to GMAT components for expert users.

3.4.1 GMAT API Interfaces

The production GMAT API is built with Python and Java wrappers. The Java wrappers are used to also provide the MATLAB interface into the API.

The Python Interface

The Python wrappers are identified by the suffix “_py.” Python imports are provided as .py files, which connect to associated shared library files. The Python API is packaged in the gmatpy folder contained in the GMAT bin folder. The API is loaded by importing that folder into the Python environment.

The Java and MATLAB Interface

The Java interface is provided in Java Archive (jar) files and associated libraries. These files include the GMAT base code API interfaces and the interfaces to the components used in the navigation subsystem, tabulated below.

Table 3.2: Java archives for the GMAT API

Java Wrapper	Python Wrapper	Contents
gmat.jar	gmat_py.py	GMAT Base and utility code
station.jar	station_py.py	Groundstation components
navigation.jar	navigation_py.py	Orbit determination components

MATLAB users load the GMAT API by calling the load_gmat.m MATLAB script in the GMAT bin folder.

3.4.2 Interface Complexity

The GMAT API is designed for three different styles of usage: Users working with configurations based on GMAT scripting, users that work with GMAT objects through API calls, and users that work at a low level with GMAT objects directly.

GMAT Script Drivers

One use for the GMAT API is to act as a front end for GMAT mission runs. In this context, the user starts a runtime environment for the controlling language (e.g. a Python session or MATLAB), loads and initializes GMAT using the API, and then loads a GMAT script into the running environment. At this point the user might manipulate setting on the GMAT objects used in the script to tailor the run. Once the configuration is ready, the API is used to run the script.

More details can be found in the *Script Usage* chapter.

High Level Access

A second use of the GMAT API is as a tool for using intermediate level GMAT objects to model portions of an analysis problem, and to feed the modeled results back to the driving system for further analysis. When used this way, the GMAT API provides proven and tested components used to meet the user's needs for building blocks for a problem running outside of GMAT. Examples of this type of usage include

- Converting state data from one coordinate system into another
- Accessing the GMAT force models for accelerations and Jacobians of a given state.
- Accessing the Navigation measurement models for retrieve calculated measurement values.

The walk-through provided in the *Tutorial: Accessing GMAT Propagation and Navigation Features* chapter covers the techniques needed for high level object access and usage.

Component Level Access

Some API users need access to the details of GMAT's components in order to control them at a fine-grained level during use, to extend them with new computed data during use, or to monitor and report their state during use. These users may want to configure the objects by hand, and may want to manipulate the objects differently from the ways anticipated by the GMAT developers. The GMAT API allows for this level of access to GMAT's components. The *Doxygen* generated object level documentation provides a guide to this type of usage.

3.5 Functions Used in the GMAT API

The GMAT API provides several functions that simplify GMAT use from Java and Python. GMAT's user classes include member functions, called methods, that provide interfaces into GMAT objects that help simplify calls into the GMAT objects. These features of the API are described in this chapter. Script users may also want to refer to the *Script Usage* chapter for information about functions tailored to running GMAT scripts through the API.

3.5.1 General API Functions

API specific code can be broken into three blocks: General API functions used to interact with the system, functions specific to driving GMAT using script files, and methods that are implemented on the GMAT classes to simplify object interactions using the API.

Table 3.3: General Purpose Functions Controlling the API

Function	Example	Return Value	Description
Help	gmata.Help("MySat")	string	Returns help for the input item
Setup	gmata.Setup("StartFile.txt")	void	Initializes the GMAT system with a custom startup file
Initialize	gmata.Initialize()	none	Sets up interconnections between objects and reports on missing pieces
ShowObjects	gmata.ShowObjects()	string	Lists the configured objects
ShowClasses	gmata.ShowClasses("Burn")	string	Lists the classes available of a given type
Construct	gmata.Construct ("Spacecraft","Sat")	object	Creates an instance of a class with a given name and adds it to the GMAT configuration
Copy	gmata.Copy(sat, "Sat2")		Creates a new object using the settings on an existing object
GetObject	gmata.GetObject("Sat")	object	Retrieves an object from the configuration

3.5.2 GMAT Object Methods

GMAT's user classes have been updated with member functions (or methods) that facilitate use for the objects by API users. These methods are shown in [Table 3.4](#).

Table 3.4: Methods added to GMAT objects for API users

Function	Example	Return Value	Description
Help	Sat.Help()	string	Retrieves help for an object
SetField	Sat.SetField("X",0.0)	bool	Sets a field on an object
GetField	Sat.GetField("X")	string	Retrieves the setting for a field as a string
GetNumber	Sat.GetNumber("X")	double	Retrieves the setting for numerical field
GetVector	Sat.GetVector("X")	vector	Retrieves the setting for Rvector field
GetMatrix	Sat.GetMatrix("X")	matrix	Retrieves the setting for Rmatrix field

SCRIPT USAGE

The GMAT API can be used as a front end for driving the GMAT application in a “headless” mode. You might want to do this to run GMAT remotely, to script product generation, or to perform a large scale run like a Monte-Carlo run or a scan through a set of parameters. This section introduces the API features that make these processes possible.

4.1 API Functions for Script Users

The GMAT API includes five functions, shown in [Table 4.1](#) specifically designed for script based usage.

Table 4.1: Functions Used to Run Scripts in the API

Function	Example	Return Value	Description
LoadScript	Load-Script(“script”)	bool	Loads a script into the GMAT system
RunScript	RunScript()	bool	Runs a loaded script
SaveScript	SaveScript(“script”)	bool	Saves the configured objects to a file
GetRuntimeObject	GetRuntimeObject(“Sat”)	GmatBase*	Retrieves an object from a GMAT run
GetRunSummary	GetRunSummary()	String	Retrieves a listing of the spacecraft data from a script run for each command in the script

4.1.1 Background: The GMAT Run Script Process

In GMAT, when a user runs a script three steps are taken:

1. The script is read and GMAT objects are created that match the objects described by the script.
 - GMAT Resources are stored in the GMAT Configuration.
 - GMAT Commands are connected together to create the Mission Control Sequence.
2. The objects from the script are copied (“cloned”) into a memory location, the Sandbox, used for the run.
 - This creates a new set of objects used for the run.
 - After cloning, these run time objects are connected together as needed and initialized.
3. The Mission Control Sequence is executed sequentially, starting from the first command in the sequence. Command execution manipulates the run time objects to simulate the scripted mission.

API users drive this process using the functions in [Table 4.1](#).

4.1.2 Driving a Script From the API

API users take the following steps to execute a script:

1. Start the API environment (e.g. Python or MATLAB) from the GMAT bin directory or start the application and change the current directory to the GMAT bin directory.
2. Load GMAT into the environment. The MATLAB implementation includes a scripted function for this process.
 - **Python:** `import gmatpy`
 - **MATLAB:** `load_gmat()`
3. Read a script into the loaded GMAT engine.
 - **Python:** `gmat.LoadScript(script_path_and_name)`
 - **MATLAB:** `GMATAPI.LoadScript(script_path_and_name)`
4. Run the script. This step performs the run time object cloning and initialization and then executes the Mission Control Sequence.
 - **Python:** `gmat.RunScript()`
 - **MATLAB:** `GMATAPI.RunScript()`

4.2 Examples

The sections above describe in general terms how to run GMAT scripts from the API. The following sample usage shows these features in Python and MATLAB.

4.2.1 Example: Running a Sample Mission

The first example shows how to run a sample mission from the API and retrieve data generated from the run. The example runs the sample mission `Ex_GEOTransfer.script` in the GMAT samples folder, then accesses the targeted maneuvers from the script and computes the total delta-V needed for the run.

Python

Use of the API in Python is performed through direct calls to the functions described above.

Listing 4.1: Sample Run: Calculating the Delta-V for the GEO Transfer,
Run in Python

```
1 $ python3
2 Python 3.6.7 (default, Oct 22 2018, 11:32:17)
3 [GCC 8.2.0] on linux
4 Type "help", "copyright", "credits" or "license" for more information.
5 >>> import gmatpy as gmat
6 >>> gmat.LoadScript("../samples/Ex_GEOTransfer.script")
7 True
8 >>> gmat.RunScript()
9 True
10 >>> TOI = gmat.GetRuntimeObject("TOI")
11 >>> MCC = gmat.GetRuntimeObject("MCC")
```

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```

12 >>> MOI = gmat.GetRuntimeObject("MOI")
13 >>> toidv = float(TOI.GetField("Element1"))
14 >>> mccdV = (float(MCC.GetField("Element1"))**2+float(MCC.GetField("Element2"))**2)**0.5
15 >>> moidv = float(MOI.GetField("Element1"))
16 >>> deltaV = abs(toidv)+mccdV+abs(moidv)
17 >>> print("Total Delta-V Cost: ", deltaV, " km/s")
18 Total Delta-V Cost: 4.394839062410714 km/s
19 >>> exit()

```

MATLAB

Loading the GMAT API in MATLAB is a moderately complicated procedure, so the API developers have wrapped the load process in a MATLAB function, `load_gmat.m`. The function takes two optional arguments: the name of a script, and the startup file used to initialize GMAT. The example shown below leaves both inputs blank so that it closely matches the Python example, above.

Listing 4.2: Sample Run: Calculating the Delta-V for the GEO Transfer,
Run in MATLAB

```

1 >> load_gmat()
2 Initialize Moderator Status: 1
3 No script provided to load.
4
5 ans =
6
7 Instance of GMAT Moderator is initialized. No script ready to run.
8
9 >> GMATAPI.LoadScript("../samples/Ex_GEOTransfer.script")
10
11 ans =
12
13     logical
14
15     1
16
17 >> GMATAPI.RunScript()
18
19 ans =
20
21     logical
22
23     1
24
25 >> TOI = GMATAPI.GetRuntimeObject("TOI");
26 >> MCC = GMATAPI.GetRuntimeObject("MCC");
27 >> MOI = GMATAPI.GetRuntimeObject("MOI");
28 >> toidv = str2num(TOI.GetField("Element1"));
29 >> mccdV = sqrt(str2num(MCC.GetField("Element1"))^2+str2num(MCC.GetField("Element2"))^2);
30 >> moidv = str2num(MOI.GetField("Element1"));
31 >> DeltaV = abs(toidv)+mccdV+abs(moidv)
32

```

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```
33 DeltaV =  
34  
35     4.394839062410714  
36  
37 >> exit
```


TUTORIAL: ACCESSING GMAT PROPAGATION AND NAVIGATION FEATURES

The use case demonstration for the first GMAT API Beta build focuses on using the API for models that exercise core GMAT functions. For the purposes of this release of the API, the target use case suite shows how to setup and use force models, propagators, and measurement models. The implemented functionality in the Beta release includes the ability to drive GMAT scripts as well. That capability is described separately in *Script Usage*.

The goal of the use cases described here is to build a GMAT measurement model from core components, using the API functions. GMAT's measurement models require a propagation component in order to solve the light transit time portion of the modeling. Propagation requires configuration of both a numerical integrator and of a force model, along with a spacecraft that supplies model parameters. This guide will walk Python and MATLAB users through the process of configuring these components in order to assemble a range measurement.

The problem demonstrated in the example code here provides modeling for an Earth orbiting spacecraft, "EarthOrbiter." The spacecraft is an 80 kg vehicle modeled in a polar orbit with a 6600 km semimajor axis. That ensures that we need to configure a fair number of system parameters in order to build the simulation.

5.1 Verifying Setup

The GMAT API is included in releases of GMAT beginning with the R2020a release of the system. Once GMAT is installed, the API can be accessed from inside of the folder containing the GMAT application.

- For Python, change directories to the GMAT bin folder and access the API help system:

```
>>> import gmatpy as gmat
>>> gmat.Help()

-----
GMAT Application Programmer's Interface
-----
...
```

- For MATLAB users
 - Start MATLAB
 - Change directories to the installed GMAT bin directory
 - Load the API and access the help system:

```
>> load_gmat()
No script provided to load.
```

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```
ans =  
  
Instance of GMAT Moderator is initialized. No script ready to run.  
  
>> GMATAPI.Help()  
  
ans =  
  
-----  
GMAT Application Programmer's Interface  
-----  
...
```

5.2 Getting Started with the API

Note: This section introduces several API functions and tools for users new to GMAT's API by experimenting interactively with the system in Python. This section introduces interaction with the GMAT API, but is not necessary for the force model, propagation, and measurement configuration described below.

The modeling for this use case uses an Earth centered coordinate system with axes oriented in the mean of J2000 Equatorial frame. The coordinate system can be built using the Construct function of the API. The Python code for this object creation is:

```
import gmatpy as gmat  
eartheq = gmat.Construct("CoordinateSystem", "EarthMJ2000Eq", "Earth", "MJ2000Eq")
```

Users can view the list of objects that have been built during a run using the ShowObjects() function:

```
>>> gmat.ShowObjects()  
Current GMAT Objects  
  
EarthMJ2000Eq  
  
The SolarSystem contains the following bodies:  
  
[Sun, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto, Luna]  
>>>
```

The code above created a coordinate system object, an axis system object, and connected those objects together for later use. The object cannot be fully exercised at this point because it is missing some key connections to the modeled space environment, consisting of a solar system model, member planets and the Sun and Moon, along with other internal objects used to tie a user's components together.

For this example, the solar system is not yet connected to the new coordinate system, and the bodies needed for use - the Earth, for example - are also not yet connected. The coordinate system object's state can be checked using its "IsInitialized()" method:

```
>>> eartheq.IsInitialized()
False
```

Objects that are ready for use return True from this call. The API prepares the objects for use with the Initialize() function:

```
>>> gmat.Initialize()
>>> eartheq.IsInitialized()
True
```

The Initialize() function prepares all of the objects that the user has created for use, and reports any objects that could not be prepared because of missing settings.

Objects can be removed individually from GMAT using the Clear(*ObjectName*) function, or all once using the Clear() function without specifying an object:

```
>>> gmat.ShowObjects()
Current GMAT Objects

    EarthMJ2000Eq

>>> gmat.Clear("EarthMJ2000Eq")
'The object EarthMJ2000Eq has been removed from GMAT.'
>>> gmat.ShowObjects()
Current GMAT Objects

    EMJ2k

>>> eartheq = gmat.Construct("CoordinateSystem", "EMJ2k", "Earth", "MJ2000Eq")
>>> gmat.ShowObjects()
Current GMAT Objects

    EMJ2k

>>> gmat.Clear()
'All configured objects have been removed from GMAT.'
>>> gmat.ShowObjects()
Current GMAT Objects

>>>
```

The full set of GMAT API commands are described in *Functions Used in the GMAT API*.

The functions used above are presented working interactively in the GMAT API. In the remainder of this section, the configuration is built in a Python script included with the GMAT release in the API folder. Matching MATLAB .m scripts are included in the API folder for users more comfortable working in that environment.

5.3 Spacecraft Configuration

Note: The Spacecraft Configuration and Force Model Setup examples are located in the Ex_R2020a_BasicForceModel.py file. An example of the full configuration, showing one configuration for the exercises, is in the Ex_R2020a_CompleteForceModel file.

To use one of these files, copy the file you plan to use into GMAT's bin folder.

Spacecraft configuration requires that we define the initial spacecraft state data for the orbiter, and then configure the spacecraft properties needed for the force modeling.

5.3.1 Construction and The Initial State

Using this coordinate system, the spacecraft state can be configured. For this example, the spacecraft is in a circular polar orbit at the moon on July 20, 2020. The orbital state is set using the scripting

```
# Load GMAT into memory
import gmatpy as gmat

# Spacecraft configuration preliminaries
earthorb = gmat.Construct("Spacecraft", "EarthOrbiter")
earthorb.SetField("DateFormat", "UTCGregorian")
earthorb.SetField("Epoch", "20 Jul 2020 12:00:00.000")

earthorb.SetField("CoordinateSystem", "EarthMJ2000Eq")
earthorb.SetField("DisplayStateType", "Keplerian")

# Orbital state
earthorb.SetField("SMA", 6600)
earthorb.SetField("ECC", 0.05)
earthorb.SetField("INC", 78)
earthorb.SetField("RAAN", 45)
earthorb.SetField("AOP", 90)
earthorb.SetField("TA", 180)
```

5.3.2 Additional Spacecraft Parameters

The force model used for this example may include full field Earth gravity, point mass effects from the Sun and Moon ("Luna" for GMAT), Jacchia-Roberts drag, and solar radiation pressure. The latter forces require settings for the reflectivity and drag coefficients of the spacecraft, its surface areas for those forces, and the spacecraft mass. These settings are made using the SetField method, and resemble the corresponding GMAT scripting:

```
# Spacecraft ballistic properties for the SRP and Drag models
earthorb.SetField("SRPArea", 2.5)
earthorb.SetField("Cr", 1.75)
earthorb.SetField("DragArea", 1.8)
earthorb.SetField("Cd", 2.1)
earthorb.SetField("DryMass", 80)
```

For reference, the GMAT scripting for this configuration is

```
Create Spacecraft EarthOrbiter;
GMAT EarthOrbiter.DateFormat = UTCGregorian;
GMAT EarthOrbiter.Epoch = '20 Jul 2020 12:00:00.000';
GMAT EarthOrbiter.CoordinateSystem = MoonEc;
GMAT EarthOrbiter.DisplayStateType = Keplerian;
GMAT EarthOrbiter.SMA = 4000;
GMAT EarthOrbiter.ECC = 0.05;
GMAT EarthOrbiter.INC = 78;
GMAT EarthOrbiter.RAAN = 45;
GMAT EarthOrbiter.AOP = 90;
GMAT EarthOrbiter.TA = 180;
GMAT EarthOrbiter.DryMass = 80;
GMAT EarthOrbiter.Cd = 2.1;
GMAT EarthOrbiter.Cr = 1.75;
GMAT EarthOrbiter.DragArea = 1.8;
GMAT EarthOrbiter.SRPArea = 2.5;
```

Note: Differences between Python and MATLAB code

The code shown above and throughout this section is Python code. In the MATLAB version of this example, there are several differences worth noting because of the platform differences:

1. GMAT is loaded using the MATLAB `load_gmat.m` script. This script loads the GMAT libraries into MATLAB, initializes the GMAT system by reading a startup file and loading plugins and configuration data identified in that file, and optionally loads a GMAT script into memory.
2. Access to the GMAT functions is made using a call into a nested “gmat” class built for the underlying Java code. In general, where Python users type

```
sat = gmat.Construct("Spacecraft","Sat")
```

MATLAB users enter

```
sat = gmat.gmat.Construct('Spacecraft','Sat');
```

3. Type identification requires a call that sets the object type. In the Python implementation of the API, changes from the base `GmatBase` type to the derived type is automatic. In MATLAB/Java, the user needs to perform the cast. Where Python users type

```
sat = gmat.Construct("Spacecraft","Sat")
```

to work with a `Spacecraft` object, MATLAB users that need to interact with the object **as a `Spacecraft`** need to enter

```
sat = gmat.gmat.Construct('Spacecraft','Sat');
sat = gmat.Spacecraft.SetClass(sat);
```

A MATLAB class, `GMATAPI`, is provided in the bin folder which contains static functions that automatically handle the change from the base `GmatBase` type to the derived type just like in the Python API. MATLAB users can now type

```
sat = GMATAPI.Construct('Spacecraft','Sat');
```

This type setting becomes important when objects are passed to other objects using methods that require specific object type, as is the case when setting forces on a dynamics model or spacecraft on a propagation state manager

(examples below).

5.4 Force Model Setup

GMAT hides the complexity of force modeling in the internal `ODEModel` class, which is aliased to the label “Force-Model” in GMAT scripting. The GMAT scripting for the force model used here is

```
Create ForceModel FM;
GMAT FM.CentralBody = Earth;
GMAT FM.PrimaryBodies = {Earth};
GMAT FM.GravityField.Earth.Degree = 8;
GMAT FM.GravityField.Earth.Order = 8;
GMAT FM.GravityField.Earth.PotentialFile = 'JGM3.cof';
```

5.4.1 Basic Force Model Configuration

Using the API is similar for force configuration, but not identical. The GMAT scripting hides the creation of individual forces and their collection into the `ODEModel` force container. Settings on the forces in an `ODEModel` are made by passing those settings from the force container to the corresponding force. API users access the forces directly, setting their parameters and force by force and passing the configured forces into the `ODEModel` container. The model scripted above is configured using the scripting

```
# Force model settings
fm = gmat.Construct("ForceModel", "FM")
fm.SetField("CentralBody", "Earth")

# An 8x8 JGM-3 Gravity Model
earthgrav = gmat.Construct("GravityField")
earthgrav.SetField("BodyName", "Earth")
earthgrav.SetField("PotentialFile", "../data/gravity/earth/JGM3.cof")
earthgrav.SetField("Degree", 8)
earthgrav.SetField("Order", 8)

# Add force to the dynamics model
fm.AddForce(earthgrav)
```

Note the difference in the calls to `Construct` in this example. The dynamics model is created using the line

```
fm = gmat.Construct("ForceModel", "FM")
```

and the gravity model component, with the code

```
earthgrav = gmat.Construct("GravityField")
```

The dynamics model has a name, “FM.” The gravity field does not have a name. Objects constructed with names are managed by the GMAT code running inside of the API library. Objects that do not have names are not managed by the library. The object ownership for those objects is the responsibility of the code that creates the object. For the dynamics model under construction here, the user has responsibility for the gravity field in this call:

```
# Unnamed: The user is responsible for this object
earthgrav = gmat.Construct("GravityField")
```

and then passes that responsibility to the dynamics model with this call:

```
# Add force to the dynamics model, passing ownership to the dynamics
fm.AddForce(earthgrav)
```

5.4.2 Connecting the Spacecraft

Before the force model can be used, it needs to be connected to the spacecraft that provides state data and force model parameters. GMAT does this using a component called a Propagation State Manager (PSM). The PSM component is not exposed to script users. It is built inside of the scripted Propagator object that connects together integrators and force models.

Users that want to work directly with a force model can do so by creating a Propagation State Manager object and working directly with it. The force model built above can be tested using this approach:

```
psm = gmat.PropagationStateManager()
psm.SetObject(earthorb)
psm.BuildState()
```

The last line here, “psm.BuildState()”, creates an internal state object that connects spacecraft properties to a vector of data used by the force model. The propagation state manager is connected to the force model, and its state set as the force model’s state, using the scripting

```
fm.SetPropStateManager(psm)
fm.SetState(psm.GetState())
```

5.4.3 Testing the Model

The steps above produce a GMAT force model configuration that can be used from the user’s application framework. All that remains is initialization of the objects, post initialization preparation, and then calls that exercise the model. Initialization connects the force model to GMAT’s underlying resources, including the solar system objects and core elements of the system infrastructure:

```
# Assemble all of the objects together
gmata.Initialize()
```

GMAT’s propagation subsystem, which includes the force model components, requires two additional steps before it can be used. First the state vector needs to be set up for the force and propagation modeling. This step determines and sets the size of the state and derivative vectors, and sets up mappings between the spacecraft that are modeled and that state vector. The second step passes the parameters needed for modeling into the force model and propagator objects that are used.

For direct access to the force modeling, the user needs to execute these steps directly:

```
# Finish force model setup:
## Map spacecraft state into the model
fm.BuildModelFromMap()
## Load physical parameters needed for the forces
fm.UpdateInitialData()
```

Users can display the Cartesian form of the state vector used in the modeling by accessing the state vector from the spacecraft:

```
# Now access state and get derivative data
pstate = earthorb.GetState().GetState()
print("State Vector: ", pstate)
```

Finally, the force model can be exercised either in its raw form as used by the integrators by calling the `GetDerivatives()` method:

```
fm.GetDerivatives(pstate)
dv = fm.GetDerivativeArray()
print("Derivative: ", dv)
```

or by calling it for a specific spacecraft object through the `GetDerivativesForSpacecraft()` method:

```
vec = fm.GetDerivativesForSpacecraft(earthorb)
print("SCDerivative: ", vec)
```

When these pieces are assembled together, a run of the `Ex_R2020a_BasicForceModel` script shows the input state and derivative outputs to the user:

Note: numbers have been truncated for display purposes

```
$ python3 Ex_R2020a_BasicForceModel.py
State Vector: [1018.819261, -1018.819261, -6778.562873, 5.226958, 5.226958, -1.374825e-
→15]

Derivative: [5.226958, 5.226958, -1.374825e-15, -0.00121383, 0.00121392, 0.00809840]

SCDerivative: 5.226958 5.226958 -1.374825e-15 -0.00121383 0.00121392 0.00809840
```

5.4.4 Exercises

1. Add point mass forces for the Sun and Moon to the force model. The GMAT class for point mass forces is named “PointMassForce”.
2. Use the propagation state manager to turn on the A-Matrix computation for the force model by passing the “AMatrix” setting to the propagation state manager using its `SetProperty` method.
3. Add a Jacchia-Roberts drag model and a solar radiation pressure model to the force model.

5.5 Propagator Setup

Note: The Propagator Setup example shown here is located in `Ex_R2020a_PropagationStep.m` file. It uses a basic force model by importing from the `Ex_R2020a_BasicFM` file, a stripped down version of the force model used in the previous section. An example of the full configuration, showing one solution for the exercises, is in the `PropagateLoop` file.

To use one of the propagation files, copy the file you plan to use into GMAT’s bin folder. Also copy the `Ex_R2020a_BasicFM` file.

In GMAT scripting the lines of script for a propagator,


```
Create Propagator PDProp
GMAT PDProp.FM = FM;
GMAT PDProp.Type = PrinceDormand78;
GMAT PDProp.InitialStepSize = 60;
GMAT PDProp.Accuracy = 1.0e-12;
GMAT PDProp.MinStep = 0.0;
```

create an object from the GMAT class PropSetup. This object is a container for an object that performs propagation either numerically through an Integrator object or analytically through an object implementing an analytic algorithm. The latter objects are used, in GMAT, for ephemeris propagators. The former are used for Runge-Kutta integrators, predictor-correctors, and other numerical integration algorithms that require associated dynamics models. When the propagator requires a dynamics model, that model is also managed by a PropSetup object. The key feature to know for propagator configuration in the GMAT API is that a “Propagator” is actually a PropSetup object that contains the propagation component and, for numerical integrators, a dynamics model.

Working interactively, an API user can see this relationship in Python:

```
>>> import gmatpy as gmat
>>> pdprop = gmat.Construct("Propagator", "PDProp")
>>> pdprop
<gmatpy.gmat_py.PropSetup; proxy of <Swig Object of type 'PropSetup *' at 0x7f26b76a57e0>
↪ >
```

5.5.1 Propagator Component Setup

When a Propagator is scripted, a PropSetup is created that the user then configures for use. Using the provided MATLAB example, the code that loads the force model and builds the PropSetup is

```
% Load GMAT into memory
[myMod, gmatStartupPath, result] = load_gmat();

Ex_R2020a_BasicFM;

% Build the propagation container class
pdprop = GMATAPI.Construct("Propagator", "PDProp");
```

The PropSetup constructed here is a container for the objects used in propagation. The next step configuring this container is creation and assignment of an integrator, performed using the steps

```
% Create and assign a numerical integrator for use in the propagation
gator = GMATAPI.Construct("PrinceDormand78");
pdprop.SetReference(gator);
```

The dynamics model also needs to be set on the PropSetup:

```
% Assign the force model imported from Ex_R2020a_BasicFM
pdprop.SetReference(fm);
```

Once the local references are set, the integrator settings can be made similarly to the dynamics model setting in the previous section:

```
% Set some of the fields for the integration
pdprop.SetField("InitialStepSize", 60.0);
```

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```
pdprop.SetField("Accuracy", 1.0e-12);
pdprop.SetField("MinStep", 0.0);
```

5.5.2 Spacecraft and Final Initialization

In the preceding section, the propagation state manager was built as a separate component and configured to connect the spacecraft to the dynamics model. When working with a PropSetup component, the propagation state manager is integrated into the component. As an alternative to the manual steps to configure the propagation state manager, the PropSetup provides a function, PrepareInternals(), that handles this configuration for each propagated object added through the AddPropObject() function, and completes the initialization of the component and its integrator:

```
% Setup the spacecraft that is propagated
pdprop.AddPropObject(earthorb);
pdprop.PrepareInternals();
```

GMAT's PropSetup component works by creating copies of the propagator and dynamics models. Those copies need to be set for the application environment so that the user can use them after configuration. The PropSetup provides a simple mechanism for accessing its copies. The code that refreshes the local variables for them to be used, is

```
% Refresh the 'gator' reference
gator = pdprop.GetPropagator();
```

5.5.3 Running the Propagator

The propagator can now be used. A 60-second propagation is performed, showing the state data before and after the step, using the code

```
% Take a 60 second step, showing the state before and after
gator.GetState()
gator.Step(60);
gator.GetState()
```

These calls produce this output from Ex_R2020a_PropagationStep.m:

```
>> Ex_R2020a_PropagationStep
Initialize Moderator Status: 1
No script provided to load.

ans =

    1.0e+03 *

    1.018819261603825
   -1.018819261603827
   -6.778562873085272
    0.005226958779502
    0.005226958779502
   -0.000000000000000
```

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```
ans =

    1.0e+03 *

    1.330028382856595
   -0.703241487939055
   -6.763990149325915
    0.005142965479731
    0.005288543267909
    0.000485610549370

>>
```

5.5.4 Exercises

1. Modify the Ex_R2020a_PropagationStep example to use a force model that includes the point mass Sun and Moon forces and solar radiation pressure.
2. Wrap the propagator in a loop so that propagation extends for a full day, displaying the epoch and position at each propagation step.

5.6 The GMAT API and Plug-in Modules

GMAT plug-in modules package new functionality into shared libraries that GMAT loads when it starts up. The API's copy of GMAT loads these modules when they are identified in the GMAT startup file. Standard GMAT functions work on components from plugins, but the API calls have several restrictions.

5.6.1 Wrapped Plugins

The Station and Estimation plugin libraries in GMAT include SWIG wrapper code for the contained classes. This reduces the restrictions on those components.

As an example of the restrictions on wrapped plugin code, consider the Station plugin, which implements GMAT's GroundStation class. Users of GMAT's GroundStation class can access the full feature set for the class. The user is required in Python to cast constructed components to the derived class type by hand. The Python auto-cast feature in the GMAT core code is not accessible from the plugin component as seen below:

```
>>> import gmatpy as gmat
>>> station = gmat.Construct("GroundStation", "Station")
>>> station
<gmatpy.gmat_py.GmatBase; proxy of <Swig Object of type 'GmatBase *' at 0x7fccdc983f60> >
>>> station=gmat.GroundStation.SetClass(station)
>>> station
<gmatpy.station_py.GroundStation; proxy of <Swig Object of type 'GroundStation *' at 0x7fccdc983fc0> >
>>>
```

Note that in this code, the station object returned from the call to the Construct() function is set as a GmatBase object. In order to treat it as a GroundStation object, the user needed to call the GroundStation.SetClass() method on the object in order for Python to identify the object's subclass correctly.

MATLAB API users are not required to explicitly cast the class, provided they use the GMATAPI MATLAB class, as shown below:

```
>> load_gmat();
No script provided to load.
>> station = GMATAPI.Construct("GroundStation","Station")

station =

Object of type GroundStation named Station

>> station.getClass()

ans =

class gmat.GroundStation

>>
```

5.6.2 Unwrapped Plugins

Plugin code that is not wrapped in SWIG can be accessed using the API, but only in a more restricted manner. As an example, at this writing the VF13ad optimizer is available as a GMAT component for users inside of Goddard Space Flight Center. The associated plugin builds a component with class name “VF13ad” that provides the optimization functionality. The VF13ad optimizer is derived from an Optimizer base class in the GMAT core code. API users can access that component as a GmatBase object, or as an Optimizer object, but not as a VF13ad object, as can be seen here:

```
>>> import gmatpy as gmat
>>> vf13 = gmat.Construct("VF13ad","VF13")
>>> vf13
<gmatpy.gmat_py.GmatBase; proxy of <Swig Object of type 'GmatBase *' at 0x7f615f50c2a0> >
>>> vf13 = gmat.VF13ad.SetClass(vf13)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
AttributeError: module 'gmatpy' has no attribute 'VF13ad'
>>> vf13 = gmat.Optimizer.SetClass(vf13)
>>> vf13
<gmatpy.gmat_py.Optimizer; proxy of <Swig Object of type 'Optimizer *' at 0x7f614d9cff90>
→ >
>>> exit()
```

The underlying object remains a VF13ad component:

```
>>> vf13.Help()

VF13ad  VF13

Field                                     Type    Value
-----
ShowProgress                             Boolean  true
```

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ReportStyle	List	Normal
ReportFile	Filename	<not set>
MaximumIterations	Integer	200
Tolerance	Real	1e-05
UseCentralDifferences	Boolean	false
FeasibilityTolerance	Real	0.001

but, from the perspective of an API user, is manipulated as an Optimizer or GmatBase object.

5.7 Measurement Modeling

Note: The Measurement Modeling example shown here is located in Ex_R2020a_RangeMeasurement.m file (or the Ex_R2020a_RangeMeasurement.py file for Python users).

GMAT's Measurement Models are driven through the TrackingFileSet class. A TrackingFileSet defines a measurement as a tracking configuration consisting of a signal path and measurement type. The signal path is defined by the nodes that a measurement signal traverses to create the measurement. For example, the path may be ground station -> spacecraft -> ground station for a range measurement.

The user configures the hardware for each node, assigning antennae, transmitters, receivers, and transponders as needed to the stations and spacecraft used in the measurement. Error models are configured and assigned to each measurement, media corrections are toggled, and ancillary components configured - like propagators when light time correction is applied - to complete the configuration the user needs. The system is complex because the processes involved have many options. This guide, and the sample script, step through the process element by element to build the model.

5.7.1 Spacecraft, Ground Stations, and Propagators

```
% Construct the PropSetup to control propagation (for light time)
prop = GMATAPI.Construct("PropSetup", "prop");
prop.GetODEModel().SetField("ErrorControl", "None");
prop.GetPropagator().SetNumber("MinStep", 0);

% Create objects for generating measurement
simstat = GMATAPI.Construct("Spacecraft", "SimSat");
gds = GMATAPI.Construct("GroundStation", "GDS");

% Configure Spacecraft initial conditions
simstat.SetField("DateFormat", "A1ModJulian");
simstat.SetField("Epoch", "21550");

% Configure GroundStation
gds.SetField("StateType", "Spherical");
gds.SetField("HorizonReference", "Ellipsoid");
gds.SetField("Location1", 0);
gds.SetField("Location2", 90.0);
gds.SetField("Location3", 0);
```

5.7.2 Hardware Components

```
% Create communication hardware
% Hardware for ground station
ant1 = GMATAPI.Construct("Antenna", "Antenna1");
tmit = GMATAPI.Construct("Transmitter", "Transmitter1");
tmit.SetField("Frequency", 2067.5);
rec = GMATAPI.Construct("Receiver", "Receiver1");

% Hardware for spacecraft
ant2 = GMATAPI.Construct("Antenna", "Antenna2");
tpond = GMATAPI.Construct("Transponder", "Transponder1");
tpond.SetField("TurnAroundRatio", "240/221");

% Set fields
% Use Antenna1 for Transmitter1 and Receiver1
tmit.SetField("PrimaryAntenna", "Antenna1");
rec.SetField("PrimaryAntenna", "Antenna1");

% Use Antenna2 for Transponder1
tpond.SetField("PrimaryAntenna", "Antenna2");

% Add Antenna2 and Transponder1 to spacecraft
simsat.SetField("AddHardware", "{Antenna2, Transponder1}");

% Add Antenna1, Transmitter1, and Receiver1 to station
gds.SetField("AddHardware", "{Antenna1, Transmitter1, Receiver1}");
```

5.7.3 Error Models

```
% Define range measurements and error model
tem = GMATAPI.Construct("ErrorModel", "TheErrorModel");
% Specify these measurements are range measurements in km
tem.SetField("Type", "Range");
tem.SetField("NoiseSigma", 0.050); % Standard deviation of noise
tem.SetField("Bias", 0); % Bias in measurement

% Define doppler range rate measurements and error model
tem2 = GMATAPI.Construct("ErrorModel", "TheErrorModel2");
% Specify these measurements are doppler range rate measurements
tem2.SetField("Type", "RangeRate");
tem2.SetField("NoiseSigma", 5e-5); % Standard deviation of noise
tem2.SetField("Bias", 0); % Bias in measurement

% Add ErrorModels to the ground station
gds.SetField("ErrorModels", "{TheErrorModel, TheErrorModel2}");
```

5.7.4 The Measurement

```
% Create a TrackingFileSet to manage the observations
tfs = GMATAPI.Construct("TrackingFileSet", "SimData");
tfs.SetField("FileName","TrkFile_API_GN.gmd"); % Still needed even though it's not
↳ written to
tfs.SetField("UseLightTime", false);
tfs.SetField("UseRelativityCorrection", false);
tfs.SetField("UseETminusTAI", false);

% Define signal paths and measurement type(s)
% 2-way measurements are used here along the path GDS -> SimSat -> GDS
% Add range measurements to TrackingFileSet
tfs.SetField("AddTrackingConfig", "{{GDS,SimSat,GDS}, Range}");
% Add doppler range rate measurements to TrackingFileSet
tfs.SetField("AddTrackingConfig", "{{GDS,SimSat,GDS}, RangeRate}");
tfs.SetPropagator(prop); % Tell TrackingFileSet the propagator to use
```

5.7.5 Exercising the Model

```
% Initialize the GMAT objects
gmata.gmata.Initialize()

% Calculate the measurement
tdas = tfs.GetAdapters();
numMeas = tdas.size();

tda = tdas.get(0);
md0 = tda.CalculateMeasurement();
disp("GMAT Range Measurement Value:")
disp(md0.getValue().get(0))

% Make sure this is correct
satState = simsat.GetState();
gsPos = gds.GetMJ2000Position(satState.GetEpochGT()).GetDataVector();
satPos = satState.GetState();
r = gsPos - satPos(1:3);
rNorm = norm(r);
disp("Numerical Range Measurement Value (no lighttime):")
disp(2*rNorm)

disp("")

xid = simsat.GetParameterID("CartesianX");
tda.CalculateMeasurementDerivatives(simsat,xid);
for ii = 0:5
    deriv(ii+1) = tda.ApiGetDerivativeValue(0,ii);
end
disp("GMAT Range Measurement Derivatives:")
disp(deriv)
```

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```
disp("")  
  
tda = tdas.get(1);  
md1 = tda.CalculateMeasurement();  
disp("GMAT RangeRate Measurement Value:")  
disp(md1.getValue().get(0))
```

5.7.6 Exercises

1. Modify the one day propagation script to report the range measurement at each step where a valid measurement can be computed.
2. Add a second ground station the Ex_R2020a_RangeMeasurement example and report its measurement data.

API ACCESS TO GMAT COMMANDS

RunScript in the Introduction shows how GMAT responds when a user executes a script. The GMAT API provides a set of functions, described in this chapter, that reproduce the key features of this set of actions for API users.

Note: In the text that follows, the word “command” refers to a GmatCommand member of the Mission Control Sequence when referencing the GMAT application, and to a GmatCommand object when referencing the GMAT API. A set of linked together commands is called a “sequence.” The term “Mission Control Sequence,” abbreviated as “MCS,” is reserved for the linked list of commands that are executed when the GMAT application runs a script.

Running in GMAT, the objects created in a user’s script are copied into the GMAT Sandbox through a cloning process. The scripted objects are preserved as scripted and not changed during the run. Instead, clones of those objects are manipulated during the run. This cloning is the action represented in the “Clone Resources” bubble in the diagram. The Mission Control Sequence (MCS) linked list is not cloned. The MCS linked list created when the script is parsed is directly assigned to the Sandbox used for the run. The Sandbox is then initialized, resources first followed by the MCS commands. This initialization process sets up the references between objects used in the run and sets up internal object data. Resources are initialized first so that the internal object data manipulated by the control sequence is available when the sequence is initialized. The Mission Control Sequence is then initialized by walking the initialization process through the linked list, initializing the commands in the same order as is followed when the sequence executes. Once everything used in the run is initialized, the Mission Control Sequence is executed by walking through the linked list of commands, calling the Execute() method on each command until the end of the list is reached. To summarize, a GMAT run performs these steps when a user runs a loaded script:

1. Clone resources into a Sandbox
2. Assign the first node of the Mission Control Sequence list to the Sandbox
3. Initialize the Resource objects in the Sandbox. (This initialization follows a specific order of object initialization, the details of which are not important here.)
4. Initialize the Mission Control Sequence node by node
5. Execute the Mission Control Sequence

There are several differences between running commands in the managed Sandbox environment of GMAT and running commands through the GMAT API.

- In the GMAT API, runs typically are performed on the configured objects directly.
- Steps 1 and 2 above are not needed.
- The Initialize() command familiar to API users performs step 3, initializing Resources.
- Additional steps are preformed to execute commands

The functions described below are designed to perform steps 4 and 5, addressing the “additional steps” referenced in the final bullet.

6.1 API Functions for the MCS

Control Sequence Functions lists the core functions used to run commands in the GMAT API. Information about each function is provided following the table.

Table 6.1: Control Sequence Functions

Function	Example	Return Value	Description
Command	Com-mand(type, desc)	Gmat-Command	Creates a GmatCommand and adds it to the end of the current sequence of GMAT Commands
Execute	Execute()	Int	Runs the sequence of GMATCommands
Delete Command	DeleteCom-mand(cmd)	Gmat-Command	Deletes the command, removing it from the sequence

Command creates a GmatCommand object using the type of command that is built followed by the script syntax used in the command. The code then chains through the current sequence of commands and places the object at the end of the list. For branch commands, the function inserts the command into the branch until the branch terminator is added, and then moves to the next element in the main list.

Execute runs the current sequence of commands to completion.

Delete Command Removes a command from the command sequence. If deleting branch command, it will remove and delete all children from the branch

6.2 Example: Executing a Command

[Listing 6.1](#) sketches out Python scripting for a call to the GMAT Propagate command that moves a spacecraft from an initial state to perigee, scripted in GMAT like this:

```
Propagate Prop(Sat) {Sat.Earth.Periapsis}
```

The full listing for this script is given in [Listing 8.12](#).

Listing 6.1: Setting up and running a Propagate command

```

1 from load_gmat import gmat
2
3 # Core resources used; Configuration omitted
4 sat = gmat.Construct("Spacecraft", "Sat")
5 fm = gmat.Construct("ForceModel", "FM")
6 prop = gmat.Construct("Propagator", "Prop")
7
8 propagate = gmat.Command("Propagate", "Prop(Sat) {Sat.Periapsis}")
9
10 gmat.Initialize()
11
12 gmat.Execute()
```

6.3 Example: Executing a Sequence

A basic GMAT script block for targeting is shown in [Listing 6.2](#). This scripting targets a burn that moves a spacecraft from an initial orbit to Geosynchronous distance.

Listing 6.2: Setting up and running a Targeter

```

1  % Create resources (configuration omitted)
2  Create Spacecraft Sat
3  Create ForceModel FM
4  Create Propagator Prop
5  Create ImpulsiveBurn Burn1
6  Create DifferentialCorrectorDC
7
8  BeginMissionSequence
9
10 Target DC
11
12 Vary DC(Burn1.Element1 = 0.5, {Perturbation = 0.0001, MaxStep = 0.2})
13 Maneuver Burn1(Sat)
14 Propagate Prop(Sat) {Sat.Periapsis}
15 Achieve DC(Sat.RMAG = 42165.0, {Tolerance = -0.1})
16
17 EndTarget

```

The corresponding API configuration is shown in [Listing 6.3](#).

Listing 6.3: API Calls that Run a Targeter

```

1  from load_gmat import gmat
2
3  # Core resources used; Configuration omitted
4  sat = gmat.Construct("Spacecraft", "Sat")
5  fm = gmat.Construct("ForceModel", "FM")
6  prop = gmat.Construct("Propagator", "Prop")
7  burn = gmat.Construct("ImpulsiveBurn", "Burn1")
8  dc = gmat.Construct("DifferentialCorrector", "DC")
9
10 tcs = gmat.Command("Target", "DC")
11 gmat.Command("Vary", "DC(Burn1.Element1 = 0.5, {Perturbation = 0.0001, MaxStep = 0.2})")
12 gmat.Command("Maneuver", "Burn1(Sat)")
13 gmat.Command("Propagate", "Prop(Sat) {Sat.Periapsis}")
14 gmat.Command("Achieve", "DC(Sat.RMAG = 42165.0, {Tolerance = -0.1})")
15 gmat.Command("EndTarget")
16
17 # Setup
18 gmat.Initialize()
19
20 # and run
21 gmat.Execute()

```


CONFIGURING A COMMAND

GmatCommand objects are the building blocks of the Mission Control Sequence. The mission sequence is coded as a doubly linked list of GmatCommands, with, for some commands, branching enabled that into a subsequence of commands that perform a specific task for the main command. This design means that there are two elements of the GMAT command structure needed by API users: the ability to configure commands that they need to run, and the ability to chain together commands to build a full mission timeline.

This chapter focuses on the procedure that makes a single GMAT command accessible to an API user. The Propagate command is used to illustrate the procedure. Information about sequences of commands can be found in Command-Sequences.

7.1 Command Categories

GMAT commands can be grouped into five different types of commands exposed to the command API:

- **Basic sequence actions**
 - GMAT (used for Assignments)
 - Maneuver
 - Propagate (Base class PropagationEnabledCommand)
 - Report
 - Toggle
 - Write
 - BeginFiniteBurn
 - EndFiniteBurn
- **Commands with subsequences, with base classes BranchCommand and ConditionalBranch**
 - For / EndFor
 - If / Else / EndIf
 - While / EndWhile
- **Solver commands, with base classes SolverSequenceCommand, SolverBranchCommand, or RunSolver**
 - Target / EndTarget Optimize / EndOptimize
- **Solver action commands**
 - Vary
 - Achieve

- Minimize
- NonlinearConstraint
- **Function calling commands**
 - BeginFunction / EndFunction
 - CallFunction
 - CallBuiltinGmatFunction

The basic sequence action commands provide many of the core building blocks of a mission sequence. These commands can be used as stand alone calls by API users to perform specific actions: Propagate to a stopping condition, maneuver a spacecraft, toggle writing for published data, and so forth.

The remaining commands all use a command sequence in one way or another.

In addition to these command types, there are commands that are not exposed to the API at this time, for a variety of reasons stated below:

- **Sequence Management commands**
 - BeginMissionSequence
 - NoOp
- **Sequence utility commands**
 - BeginScript / EndScript
- **Commands that interact with the GMAT GUI**
 - ClearPlot
 - PenDown
 - PenUp
 - MarkPoint
 - PlotCommand
 - SaveMission
 - Stop
 - UpdateDynamicData
 - FindEvents

The command API does not expose the sequence management commands because they are not needed for API users. The BeginScript and EndScript commands are used to group together GMAT commands so that they can be hidden on the Mission tab of the GMAT GUI. The final set of commands are designed to manipulate the GMAT GUI in a variety of ways. Since API users are not running the GUI, they are not needed.

Commands that are built into GMAT plugin code are not included in this list. Of particular for many API users are the RunSimulator and RunEstimator commands. Those commands are configured as single commands that are executed, and are covered by the design described in this chapter. Simulation and Estimation are complex processes, so users that need API access to those two commands in particular, should pay careful attention to the resource creation process for the components needed for orbit determination configurations.

7.2 Setting up a Command

While Resources built with the API use the Construct function. Commands are built using command function. [Listing 7.1](#) illustrates the difference by summarizing the syntax followed by an example.

Listing 7.1: Syntax for the Construct command

```
# Resource creation: gmat.Construct(<Resource Type>, <Resource Name>)
sat = gmat.Construct("Spacecraft", "Sat")
sat.SetField("X", 6600.0)
sat.SetField("Y", 0.0)
sat.SetField("Z", 300.0)
sat.SetField("VX", 0.0)
sat.SetField("VY", 8.0)
sat.SetField("VZ", 0.0)

# Command creation: gmat.Command(<Command Type>, <Command text>)
evolve = gmat.Command("Propagate", "Prop(Sat) {Sat.RMAG = 7200}")
```

In GMAT, resources are objects that have separate script entries for each element that is being built. Those settings are configured in the API using SetField() method calls like those shown in the listing. Commands are scripted using a single line of text with all of the command configuration data on the line of script. The API follows this approach, building resources through construction and field setting and commands in a single construction step. The GMAT scripting that corresponds to [Listing 7.1](#) is shown in [Listing 7.2](#).

Listing 7.2: GMAT scripting corresponding to the API calls in [Listing 7.1](#).

```
Create Spacecraft Sat
Sat.X = 6600.0;
Sat.Y = 0.0;
Sat.Z = 300.0;
Sat.VX = 0.0;
Sat.VY = 8.0;
Sat.VZ = 0.0;

Propagate Prop(Sat) {Sat.RMAG = 7200}
```

APIInterpreter is a new interpreter introduced in the GMAT R2024a code base. It provides, for commands constructed through the API, the same functionality as is provided by the ScriptInterpreter

7.3 Command Initialization and Execution

The Initialize() method in the GMAT API initializes the objects created and named by the user, and stored in GMAT's configuration. Commands are also stored in the configuration, so this method does initialize Mission Control Sequence commands. Command sequences are initialized by the same Initialize() function call.

After initialization, the command or command sequence is run by calling the Execute() method. That method fires current command sequence, running to completion of the passed in sequence and returning a int indicating the result:

- 1 if run was successful
- -1 if sandbox number is invalid

- -2 if exception thrown during sandbox initialization
- -3 if unknown error occurred during sandbox initialization
- -4 if execution interrupted by user
- -5 if exception thrown during the sandbox execution
- -6 if unknown error occurred during sandbox execution
- -7 if unknown error at the API level

USAGE EXAMPLES

8.1 Time and Coordinate Conversions

One simple application of the GMAT API is the construction of routines that convert from one system to another. Two examples of that application are presented here: time system conversion and coordinate system conversion.

8.1.1 Time System Conversion

8.1.2 Coordinate System Conversion

```
>>> import gmatpy as gmat
>>> moonec = gmat.Construct("CoordinateSystem", "MoonEc", "Luna", "MJ2000Ec")
>>> eartheq = gmat.Construct("CoordinateSystem", "EarthEq", "Earth", "MJ2000Eq")
>>> instate = gmat.Rvector6()
>>> outstate = gmat.Rvector6()
>>> instate[0] = 4000.0
>>> instate[1] = 1000.0
>>> instate[2] = 0.0
>>> instate[3] = 0.1
>>> instate[4] = 0.4
>>> instate[5] = 3.1
>>> print(instate)
4000      1000      0      0.1      0.4      3.1
>>> cconverter = gmat.CoordinateConverter()
>>> gmat.Initialize()
>>> cconverter.Convert(28718, instate, moonec, outstate, eartheq)
True
>>> print(outstate)
278537.716 272130.548 84187.769 -0.64373770 -0.28543905 3.30709590
```

8.2 API Examples

Four Python sample use cases were coded using the prototype SWIG API to act as a guide to addressing the changes that are needed for the production system. These cases ranged from a trivial time system conversion use case to a full propagation use case. These cases, shown in *SwigOldAndNew*, were then reworked into the API syntax documented here. The following section previews the changes coming to the GMAT API by presenting each of these cases as planned for the API. The examples presented here are in Python. Java examples are presented in *API Examples in Java*.

8.2.1 Case 1: Time System Conversion

GMAT supports five time systems: A.1 Atomic Time (A1), International Atomic Time (TAI), Coordinated Universal Time (UTC), Barycentric Dynamical Time (TDB), and Terrestrial Time (TT). Times in GMAT are stored internally in a modified Julian format, referenced to January 5, 1941 at noon. Conversions between these time systems are performed using a time system converter, coded in the `TimeSystemConverter` singleton class. The time system converter also provides routines to convert between modified Julian representations and Gregorian representations.

The simplest usage of the time system converter using GMAT's API consists of two lines of code; lines 5 and 9 shown here:

Listing 8.1: Python code for time conversions using the GMAT API

```

1 import gmatpy as gmat
2 gmat.Initialize()
3
4 # Get the converter
5 timeConverter = gmat.TimeSystemConverter.Instance()
6
7 # Convert an epoch
8 UTCEpoch = 21738.22145
9 TAIEpoch = timeConverter.Convert(UTCEpoch, gmat.TimeSystemConverter.UTC, gmat.
  ↳ TimeSystemConverter.TAI)

```

This code shows two features of the API. The first line shows how a Python user loads the GMAT system and initializes it for use. As part of the initialization process, several components are created in the GMAT module that are single instance objects, following a singleton design pattern. These singletons are accessed from the API by calling `.Instance()` on their names. Line 5 is an example of this usage. The time system converter singleton is accessed using the object name `TimeSystemConverter`. In the python code, the object “timeConverter” is connected to the singleton, and then used to convert a UTC epoch to the TAI time system on line 9.

At this point, the singleton is ready for the user to interact with it directly. Using the API, the conversion is immediately available:

```

>>> timeConverter.ConvertMjdToGregorian(UTCEpoch)
'12 Jul 2000 17:18:53.280'
>>> TAIEpoch = timeConverter.Convert(UTCEpoch, 2, 1)
>>> timeConverter.ConvertMjdToGregorian(TAIEpoch)
'12 Jul 2000 17:19:25.280'

```

The interactive call shows the correct time system difference arising from the number of leap seconds needed to convert from UTC time to TAI time. Users can access the leap second count at a specified epoch directly as well:

```

>>> timeConverter.NumberOfLeapSecondsFrom(TAIEpoch)
32.0

```

8.2.2 Case 2: Coordinate System Conversion

The time system converter is a stand alone component in GMAT. It does not require external components to perform conversions. Coordinate systems are more complex. They require connections to other objects in order to compute data. Table 8.1 shows the settings, required and optional, to define a GMAT coordinate system.

Table 8.1: Coordinate System Settings

Field	Type	Required?	Description
AxisType	AxisSystem object	Yes	Defines the orientation of the coordinate axes
Origin	SpacePoint object	Yes	Defines the coordinate system origin
Primary	SpacePoint object	No	Reference body used in coordinate systems that need a primary body
Secondary	SpacePoint object	No	Reference body used in coordinate systems that need a secondary body
J2000 Body	Internal reference object	Yes	Reference origin in GMAT (always set to Earth)
Solar System	Solar System object	Yes	The solar system used in the run

Coordinate systems are defined in GMAT as a collection of objects, using a core composite component that collect together the axis system defining the directions for the coordinate system axes, the bodies used to set the coordinate system origin and the axis references, and core GMAT settings used to tie the coordinate system into the rest of the executing GMAT code. Many of the user objects in GMAT have a structure like this: a core object that uses other objects to form a composite component consistent with the rest of the running GMAT system.

GMAT performs conversions between coordinate systems using a coordinate system converter, coded in the `CoordinateConverter` class. The `CoordinateConverter` class maintains state information about the most recent conversion performed. This state data would cause issues using a state converter in a single instance context, because the state data from one conversion could be accessed in code requesting the state data from a second conversion. For that reason, the `CoordinateConverter` class does not provide a singleton instance, and a separate object must be created for each use.

A basic use case for the coordinate system converter takes a state in Earth-centered Mean-of-J2000 Equatorial coordinates and converts the state into Earth-centered Earth-fixed coordinates. The Python code demonstrating this conversion using the GMAT API is

Listing 8.2: Python code for coordinate system conversions

```

1  import gmatpy as gmat
2
3  # Setup the GMAT data structures for the conversion
4  mjd = gmat.A1Mjd(22326.977184)
5  rvIn = gmat.Rvector6(6988.427, 1073.884, 2247.333, 0.019982, 7.226988, -1.554962)
6  rvOut = gmat.Rvector6(0.0, 0.0, 0.0, 0.0, 0.0, 0.0)
7  UTCEpoch = 19053.293
8
9  # Create the converter
10 csConverter = gmat.CoordinateConverter()
11
12 # Create the input and output coordinate systems
13 eci = gmat.Construct("CoordinateSystem", "ECI", "Earth", "MJ2000Eq")
14 ecef = gmat.Construct("CoordinateSystem", "ECEF", "Earth", "BodyFixed")
15 gmat.Initialize()

```

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```
16 csConverter.Convert(UTCEpoch, rvIn, eci, rvOut, ecef)
```

The key features shown in this example for the API are:

- Default objects (like the solar system and Earth objects) are set automatically.
- GMAT objects are built using the Construct() command.

8.2.3 Cases 3 and 4: Force Modeling and Propagation

Force models in GMAT – or, more properly, dynamics models – are built by creating an object from the force container class, ODEModel, and adding the constituent forces to that container. The ODEModel object is responsible for accumulating the dynamics into a derivative vector. The dynamics are computed when the GetDerivatives() method is called on the object. The resulting computation is stored in a class member, accessible using the GetDerivativeArray() method.

The ODEModel class is one component of a more complicated propagation subsystem in GMAT. That subsystem is designed with spacecraft propagation in mind. Force modeling requires an associated spacecraft object. During initialization, an instance of the GMAT helper class, PropagationStateManager (PSM), is used to collect data and assemble the state vector used to evaluate the dynamics. The PSM determines the size of the state vector by checking to see if the 6 element Cartesian state, mass flow from spacecraft tanks, and the state transition matrix or state Jacobian (A-matrix) are needed during the propagation. Once the size of the propagation state vector is determined, the complete vector is assembled and initialized, and only then can the dynamics be evaluated.

The steps required for this initialization are largely implemented behind the scenes in the GMAT API. Users that want to manage this setup by hand are referred to the sample code in SwigOldAndNew. The third example in that chapter shows force model configuration. API users can access GMAT's dynamics models by configuring the forces piece by piece and assigning them to an ODEModel container. Here is an example of this process for an Earth point mass force model:

Listing 8.3: Python code for force modeling using the API

```
1  import gmatpy as gmat
2
3  sat = gmat.Construct("Spacecraft", "Sat")
4  sat.SetField("Cr", 1.4)
5  sat.SetField("SRPArea", 6.5)
6  sat.SetField("DryMass", 225)
7
8  psm = gmat.PropagationStateManager()
9  psm.SetObject(sat)
10 psm.BuildState()
11
12 dynamics = gmat.Construct("ODEModel", "EPM_SRP")
13 epm = gmat.PointMassForce("EarthPointMass")
14 srp = gmat.SolarRadiationPressure("SRP")
15 dynamics.AddForce(epm)
16 dynamics.AddForce(srp)
17 dynamics.SetPropStateManager(psm)
18 dynamics.SetState(psm.GetState())
19
20 pstate = [7000.0, 0.0, 1000.0, 0.0, 8.0, -0.25]
21
```

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```

22 gmat.Initialize()
23
24 dynamics.BuildModelFromMap()
25 dynamics.UpdateInitialData()
26
27 dynamics.GetDerivatives(pstate, 0.0)
28 pderiv = dynamics.GetDerivativeArray()

```

The setup for dynamics modeling above extends with little additional configuration to numerical integration. The integration piece of the configuration adds the lines

Listing 8.4: Propagator setup and use in the API

```

1 prop = gmat.Construct("PrinceDormand78", "MyIntegrator")
2 prop.SetPhysicalModel(dynamics)
3
4 gmat.Initialize()
5
6 for i in range(10):
7     prop.Step(60.0)

```

To summarize: The goal of the GMAT API is to make API based configuration as simple as possible, while maintaining full access to the capabilities of GMAT. Towards that end, the design of the API can be illustrated through a representative example implementation of a propagation problem. A reference propagation in the GMAT API looks like this:

Listing 8.5: The Propagation example in Python

```

1 import gmatpy as gmat
2
3 # Set up the spacecraft
4 sat = gmat.Construct("Spacecraft", "Sat")
5 sat.SetField("Cr", 1.4)
6 sat.SetField("SRPArea", 6.5)
7 sat.SetField("DryMass", 225)
8
9 # Make a force container and set its spacecraft
10 dynamics = gmat.Construct("ODEModel", "EPM_SRP")
11 dynamics.SetObject(sat)
12
13 # Set the forces
14 epm = gmat.PointMassForce("EarthPointMass")
15 srp = gmat.SolarRadiationPressure("SRP")
16 dynamics.AddForce(epm)
17 dynamics.AddForce(srp)
18
19 # Propagator configuration
20 prop = gmat.Construct("PrinceDormand78", "MyIntegrator")
21 prop.SetPhysicalModel(dynamics)
22
23 gmat.Initialize()
24
25 # Number of steps to take

```

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```
26 count = 60
27
28 for i in range(count):
29     prop.Step(60.0)
```

8.2.4 Cases 5: Working with a GMAT Script

The script examples above show how an API user interacts with GMAT components directly. This final example shows how a user can work with an existing GMAT script that needs to change settings on one of the scripted objects. For this example, the GMAT sample mission that demonstrates finite burns is used. The full script is the `Ex_FiniteBurn.script` file in the GMAT samples folder. Part of that script includes the definition of a chemical thruster, shown through the thrust vector portion here:

Listing 8.6: The Thruster in GMAT’s FiniteBurn Sample Mission

```
1 Create ChemicalThruster engine1;
2 GMAT engine1.CoordinateSystem = Local;
3 GMAT engine1.Origin = Earth;
4 GMAT engine1.Axes = VNB;
5 GMAT engine1.ThrustDirection1 = 1;
6 GMAT engine1.ThrustDirection2 = 0;
7 GMAT engine1.ThrustDirection3 = 0;
8 ...
```

An API user might want to change the thrust direction before running the script. The following API code loads the script, adds an orbit normal component to the thrust direction and then runs the script.

Listing 8.7: Changing an Object and then Running a Script

```
1 import gmatpy as gmat
2
3 gmat.LoadScript("../samples/Ex_FiniteBurn.script")
4
5 Thruster = gmat.GetObject("engine1")
6 Thruster.SetField("ThrustDirection2", 1.0)
7
8 gmat.RunScript()
```

8.3 API Examples in Java

DesignExamples shows Python scripting for four common GMAT API use cases. This section shows those same use cases in Java.

8.3.1 Time System Conversion

Listing 8.8: Time System Conversion in Java

```

1  import gmat.*;
2
3  public class TimeConvNew {
4
5      public static void main(String[] args) {
6
7          // Get the converter
8          TimeSystemConverter timeConverter = gmat.theTimeSystemConverter;
9
10         // Convert an epoch
11         double UTCepoch = 21738.22145;
12         double TAIepoch = timeConverter.Convert(UTCepoch, UTC, TAI);
13     }
14 }
```

8.3.2 Coordinate System Conversion

Listing 8.9: Coordinate Conversion in Java

```

1  import gmat.*;
2
3  public class CoordConvNew {
4
5      public static void main(String[] args) {
6
7          // Initialize GMAT
8          gmat.Setup("MyCustomStartupFile.txt");
9
10         // Setup the GMAT data structures for the conversion
11         A1Mjd mjd = new A1Mjd(22326.977184);
12         Rvector6 rvIn = new Rvector6(6988.427, 1073.884, 2247.333, 0.019982, 7.226988, -
13         ↪ 1.554962);
14         Rvector6 rvOut = new Rvector6(0.0, 0.0, 0.0, 0.0, 0.0, 0.0);
15
16         // Create the converter
17         CoordinateConverter csConverter = new CoordinateConverter();
18
19         // Create the input and output coordinate systems
20         CoordinateSystem eci = gmat.Construct("CoordinateSystem",
21         "ECI", "Earth", "MJ2000Eq");
22         CoordinateSystem ecef = gmat.Construct("CoordinateSystem",
```

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```

22         "ECEF", "Earth", "BodyFixed");
23
24     csConverter.Convert(mjd, rvIn, eci, rvOut, ecef);
25 }
26 }

```

8.3.3 Force Modeling

Listing 8.10: Force Model Creation and Use in Java

```

1  import gmat.*;
2
3  public class ForceModelNew {
4
5      public static void main(String[] args)
6      {
7          ODEModel dynamics = gmat.Construct("ODEModel", "FM");
8
9          PointMassForce epm = gmat.Construct("PointMassForce", "EPM");
10         dynamics.AddForce(epm);
11
12         gmat.Initialize();
13
14         dynamics.GetDerivatives(state, dt);
15         double[] derivatives = dynamics.GetDerivativeArray();
16     }
17 }

```

8.3.4 Propagation

Listing 8.11: Propagation in Java

```

1  import gmat.*;
2
3  public class PropExampleNew {
4
5      public static void main(String[] args) {
6
7          // Setup the state for propagation
8          double[] state = {7000.0, 0.0, 1000.0, 0.0, 8.0, -0.25};
9          // Setup a Earth/Sun/Moon force model
10         // note: Use Moderator for the forces and Python memory management won't seg fault
11         ODEModel dynamics = gmat.Construct("ODEModel", "Forces");
12
13         PhysicalModel epm = gmat.Construct("PointMassForce", "EarthPointMass");
14         PhysicalModel spm = gmat.Construct("PointMassForce", "SunPointMass");
15         PhysicalModel mpm = gmat.Construct("PointMassForce", "MoonPointMass");
16         spm.SetStringParameter("BodyName", "Sun");
17         mpm.SetStringParameter("BodyName", "Luna");

```

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```

18     dynamics.AddForce(epm);
19     dynamics.AddForce(spm);
20     dynamics.AddForce(mpm);
21
22     // Propagator configuration
23     PrinceDormand78 prop = new PrinceDormand78("Propagator");
24     prop.SetPhysicalModel(dynamics);
25
26     gmat.Initialize();
27
28     // Set the propagation state
29     dynamics.SetState(state);
30
31     for (int i = 0; i < 10; i++) {
32         prop.Step(60.0);
33     }
34 }
35 }
36

```

8.4 Propagation Command

Listing 8.12: Setting up and running a Propagate command

```

1  from load_gmat import gmat
2
3  # Core resources used
4  sat = gmat.Construct("Spacecraft", "Sat")
5  sat.SetField("DateFormat", "UTCGregorian")
6  sat.SetField("Epoch", "02 Jan 2023 12:00:00.000")
7  sat.SetField("X", 0)
8  sat.SetField("Y", -3100)
9  sat.SetField("Z", -11591)
10 sat.SetField("VX", 5.155)
11 sat.SetField("VY", 0.0)
12 sat.SetField("VZ", 0.0)
13
14 fm = gmat.Construct("ForceModel", "Dynamics")
15 epm = gmat.Construct("PointMassForce", "EPM")
16 fm.AddForce(epm)
17
18 prop = gmat.Construct("Propagator", "Prop")
19 prop.SetField("FM", "Dynamics")
20
21 propagate = gmat.Command("Propagate", "Prop(Sat) {Sat.Periapsis}")
22
23 gmat.Initialize()
24
25 gmat.Execute()

```

8.5 Targeting Command

Listing 8.13: Setting up and running a Propagate command

```

1  from load_gmat import gmat
2
3  # Core resources used
4  sat = gmat.Construct("Spacecraft", "Sat")
5  sat.SetField("DateFormat", "UTCGregorian")
6  sat.SetField("Epoch", "10 Feb 2023 12:00:00.000")
7  sat.SetField("DisplayStateType", "Keplerian")
8  sat.SetField("SMA", 6900)
9  sat.SetField("ECC", 0.005)
10 sat.SetField("INC", 28.5)
11 sat.SetField("RAAN", 45)
12 sat.SetField("AOP", 90.0)
13 sat.SetField("TA", 180.0)
14
15 fm = gmat.Construct("ForceModel", "Dynamics")
16 epm = gmat.Construct("PointMassForce", "EPM")
17 fm.AddForce(epm)
18
19 prop = gmat.Construct("Propagator", "Prop")
20 prop.SetField("FM", "Dynamics")
21
22 burn = gmat.Construct("ImpulsiveBurn", "Burn")
23 dc = gmat.Construct("DifferentialCorrector", "DC")
24
25 # First propagate so we start at perigee
26 gmat.Command("Propagate", "Prop(Sat) {Sat.Periapsis}")
27
28 # Target commands
29 gmat.Command("Target", "DC")
30 # Note that commands are added to the branch in the Target command
31 # until the EndTarget command is added
32 gmat.Command("Vary", "DC(Burn.Element1 = 0.5, {Perturbation = 0.0001})")
33 gmat.Command("Maneuver", "Burn(Sat)")
34 gmat.Command("Propagate", "Prop(Sat) {Sat.Apoapsis}")
35 gmat.Command("Achieve", "DC(Sat.Earth.RMAG = 42165.0, {Tolerance = 0.1})")
36 gmat.Command("EndTarget")
37
38 gmat.Initialize()
39
40 # Execute() runs the entire sequence to completion
41 gmat.Execute()

```

8.6 Example: MONTE-GMAT Interoperability

GMAT is able to work with other programs through the API. Examples have been made between GMAT and MONTE for OSIRIS-REx and LUCY missions. In these examples, data will be shared between MONTE and GMAT using interfaces built with MONTE's native Python framework and GMAT's API, accessed through Python.

For access to these example scripts contact the GMAT development team.

8.6.1 Ephemeris Sharing

Both GMAT and MONTE have ephemeris reading and writing capabilities. GMAT supports four types of spacecraft ephemerides: Goddard specific "Code-500", STK time-position-velocity (.e), CCSDS OEM, and SPICE SPK formats. MONTE supports SPICE based SPK ephemerides, so that format is used for data interchange between the systems. Ephemeris sharing between GMAT and MONTE is straightforward: use the system providing the ephemeris to generate the file, and then import it into the other system.

8.6.2 Maneuver Sharing

Allow maneuver planning for both finite and impulse burns.

8.6.3 Covariance Sharing

Possible to share covariance arrays between MONTE and GMAT. The arrays are in slightly different formats so some conversion will be necessary between the two programs.

8.6.4 Dynamics Sharing

Dynamics sharing is done through the External Force Model Plugin. (Currently an alpha feature as of R2022a)

API BEST PRACTICES

9.1 General Practices

API users work more closely with the core GMAT code than users that run GMAT through the console for GUI applications. This feature of the API system adds responsibility for understanding how the system manages objects to the list of items an API user must consider. The following items capture some of the lessons we have learned from using the API.

9.1.1 Understand Object Ownership

The API provides a function, `Construct()`, that builds GMAT objects and retains object ownership in the GMAT module. Objects created using `Construct()` remain GMAT's responsibility for management. Sometimes, API users may need to create objects directly by calling the object's constructor, like this:

Listing 9.1: Creating a propagation state manager in Python

```
psm = gmat.PropagationStateManager()
```

or, in MATLAB:

Listing 9.2: Creating a propagation state manager in MATLAB

```
psm = gmat.gmat.PropagationStateManager()
```

The objects created this way are managed on the client side of the interface: in either Python or the MATLAB Java systems. The garbage collectors on the client side will delete the underlying objects when it determines that the object is no longer needed. This can cause memory management issues for objects that are passed to other GMAT objects. The API code provides a mechanism to assign ownership to the component that needs it, using the `setSwigOwnership()` method in Java code:

Listing 9.3: Managing ownership for a propagation state manager in MATLAB

```
% Create the state manager
psm = gmat.PropagationStateManager();

% Hand the manager to a force model, and assign ownership to the GMAT object
fm.SetPropStateManager(psm);
psm.setSwigOwnership(false());
```

or the `thisown` setting in Python:

Listing 9.4: Managing ownership for a propagation state manager in Python

```
% Create the state manager
psm = gmat.PropagationStateManager();

% Hand the manager to a force model, and assign ownership to the GMAT object
fm.SetPropStateManager(psm);
psm.thisown = False
```

For either of these mechanisms, a false setting indicates that the client does not own the object.

9.2 Java and MATLAB Best Practices

- Adding the bin folder to your MATLAB path allows you to run the GMAT API from any other working directory
- Use the GMATAPI MATLAB class contained in the bin folder when using the API helper functions Construct(), Copy(), GetObject(), or GetRuntimeObject(). These functions in the GMATAPI MATLAB class will automatically perform class casting, so the object returned is the more specific type instead of just being of type GmatBase. The GMATAPI MATLAB class also contains a SetClass() function which will also automatically perform the class casting on any GmatBase object provided.

9.3 Python Best Practices

- The import function loads GMAT by loading all of the libraries in the gmatpy folder (gmat, station, etc). These libraries can be imported separately if you do not need all of the API functions in your application.
- The import can rename the interface calls for user convenience. In this document we often load the engine using

```
import gmatpy as gmat
```
- The GMAT startup file is loaded the first time a GMAT API function is called. Users that want to use a startup file that is different from the default file, gmat_startup_file.txt, can load their file using the Setup(path_and_startup_file_name) function call.

This approach is used for running the API from folders outside of the GMAT bin folder, as described in [Running the API Outside of the GMAT Folders](#).

GMAT API CHEAT SHEET

A.1 Loading the API

Python	MATLAB
<code>import gmatpy as gmat</code>	<code>load_gmat</code>

A.2 Asking for Help

Python	MATLAB
<code>gmat.Help()</code>	<code>GMATAPI.Help()</code>
<code>gmat.Help(<topic>)</code>	<code>GMATAPI.Help(<topic>)</code>
<code>object.Help()</code>	<code>object.Help()</code>
Examples	
<code>gmat.Help("ScriptUsage")</code>	<code>GMATAPI.Help("Objects")</code>
<code>burn.Help()</code>	<code>burn.Help()</code>

A.3 GMAT Objects

A.3.1 Listing Available Classes

Python	MATLAB
<code>gmat.ShowClasses()</code>	<code>GMATAPI.ShowClasses()</code>
<code>gmat.ShowClasses(<type>)</code>	<code>GMATAPI.ShowClasses(<type>)</code>
Examples	
<code>gmat.ShowClasses()</code>	<code>GMATAPI.ShowClasses()</code>
<code>gmat.ShowClasses("PhysicalModel")</code>	<code>GMATAPI.ShowClasses("Propagator")</code>

A.3.2 Listing Created Objects

Python	MATLAB
gmat.ShowObjects()	GMATAPI.ShowObjects()
gmat.ShowObjects(<type>)	GMATAPI.ShowObjects(<type>)
gmat.GetCommands()	GMATAPI.GetCommands()
gmat.GetCommands(<type>)	GMATAPI.GetCommands(<type>)
Examples	
gmat.ShowObjects()	GMATAPI.ShowObjects()
gmat.ShowObjects("Spacecraft")	GMATAPI.ShowObjects("Burn")
gmat.GetCommands()	GMATAPI.GetCommands()
gmat.GetCommands("Propagate")	GMATAPI.GetCommands("Target")

A.3.3 Object Creation

Python	MATLAB
obj = gmat.Construct(<type>,<name>)	obj = GMATAPI.Construct(<type>, <name>)
cmd = gmat.Command(<type>,<desc>)	cmd = GMATAPI.Command(<type>, <desc>)
Examples	
burn = gmat.Construct ("ImpulsiveBurn", "Burn")	counter = GMATAPI.Construct ("Variable","Counter")
maneuver = gmat.Command ("Maneuver", "Burn(Sat)")	assign = GMATAPI.Command ("GMAT", "Counter = 0")

A.3.4 Object Field Access

Python	MATLAB
value = obj.GetField(<FieldLabel>)	value = obj.GetField(<FieldLabel>)
obj.SetField(<FieldLabel>,<value>)	obj.SetField(<FieldLabel>,<value>)
obj.GetNumber(<FieldLabel>)	obj.GetNumber(<FieldLabel>)
obj.GetMatrix(<FieldLabel>)	obj.GetMatrix(<FieldLabel>)
obj.GetVector(<FieldLabel>)	obj.GetVector(<FieldLabel>)
Examples	
V = burn.GetField("Element1")	V = burn.GetField("Element1")
burn.SetField("Element1",1.5)	SetField("Element1",1.5)
burn.SetField("Origin","Mars")	SetField("Origin","Mars")
V = burn.GetNumber("Element1")	V = burn.GetNumber("Element1")
V = Sat.GetMatrix("OrbitErrorCovariance")	V = Sat.GetMatrix("OrbitErrorCovariance")
V = plate.GetVector("PlateNormal")	V = plate.GetVector("PlateNormal")

A.4 GMAT Script Access

A.4.1 Loading a GMAT script

A.4.2 Saving a GMAT script

A.5 Running GMAT

A.5.1 Running GMAT from a loaded script

A.5.2 Running GMAT Commands

A.4. GMAT Script Access

A.5.3 Accessing Run Data After a Run

Python	MATLAB
<code>gmat.GetRuntimeObject(<name>)</code>	<code>GMATAPI.GetRuntimeObject(<name>)</code>
<code>gmat.GetRunSummary()</code>	<code>GMATAPI.GetRunSummary()</code>
Examples	
<code>gmat.GetRuntimeObject("geoSat")</code>	<code>GMATAPI.GetRuntimeObject("geoSat")</code>

API NOTEBOOK WALKTHROUGHS

API builds include several *[Jupyter]* notebooks illustrating specific features of the interface. These notebooks can be found in the `api/Jupyter` folder of the GMAT build. Users with access to the Jupyter system can run these notebooks interactively. Static versions of the notebooks are included in this chapter.

B.1 State Management with the GMAT API

The state data in GMAT can be a bit confusing. This notebook introduces the state variables as used for a GMAT Spacecraft, and provides some pointers on the manipulation of the state data.

B.1.1 Prepare the GMAT Environment

Before the API can be used, it needs to be loaded into the Python system and initialized using a GMAT startup file. This can be done from the GMAT bin folder by importing the `gmatpy` module, but using that approach tends to leave pieces in the bin folder that may annoy other users. Running from an outside folder takes a few steps, which have been captured in the `run_gmat.py` file imported here:

```
from run_gmat import *
```

B.1.2 Configure a Spacecraft

We'll need an object that provides the state. Here's a basic spacecraft, along with a reference to the state data inside of the spacecraft:

```
sat = gmat.Construct("Spacecraft", "MySat")
iState = sat.GetState()
```

The state reference here, `iState`, operates on the member of the `Spacecraft` object that GMAT uses when running a simulation. The “internal state,” referenced by `iState` here, is the Earth-centered mean-of-J2000 equatorial representation of position and velocity of the spacecraft `MySat`. The data is contained in a `GmatState` object:

```
iState
```

```
<gmatpy.gmat_py.GmatState; proxy of <Swig Object of type 'GmatState *' at 0x7f13ceed97e0>
↪ >
```

`GmatState` objects are used to collect together an epoch and a vector of data. These data can be accessed directly:

```
print("The state epoch is ", iState.GetEpoch(), ", the state has ", iState.GetSize(), "
↳elements, and contains the data ", iState.GetState())
```

```
The state epoch is 21545.000000397937 , the state has 6 elements, and contains the
↳data [-999.999, -999.999, -999.999, -999.999, -999.999, -999.999]
```

The data shown here is the default GmatState vector data for a spacecraft. The epoch is January 1, 2000 at 12:00:00.000 in TAI Mod Julian time, or 21545.00000039794 in A.1 Mod Julian time. Note that GMAT uses A.1 Mod Julian as its internal epoch system. The state has 6 elements. The position and velocity data are filled in with the dummy entries -999.999. Working with Cartesian and Keplerian Representations a spacecraft in GMAT has a second collection of data: the state data for the spacecraft in the coordinate system set on the spacecraft. These data are the spacecraft's "display state," named that way because they are the data displayed to the user. Users interact with the display state similarly to the way they interact with the scripting language. Data for a Keplerian state can be set using the SetField() method, as shown here:

```
sat.SetField("StateType", "Keplerian")
sat.SetField("SMA", 7015)
sat.SetField("ECC", 0.0011)
sat.SetField("INC", 98.6)
sat.SetField("RAAN", 75)
sat.SetField("AOP", 90)
sat.SetField("TA", 33.333)
```

At this point it can appear at first glance that the data is set, but it really is not. The spacecraft object cannot interpret the state data. The data set using SetField needs more information than a spacecraft object can provide by itself. Specifically, the spacecraft here does not have a connected coordinate system. Cartesian state data set on the spacecraft does not have connections defining the coordinate origin, nor the structures needed to set the orientation of the axes defining directions. Additionally, the spacecraft does not have the gravitational constant needed to interpret Keplerian data.

In this uninitialized state, the spacecraft uses its GmatState buffer to hold the data entries. We can see that the data is not yet fully populated by posting queries to the spacecraft:

```
print("The internal state buffer just holds preinitialization data (Keplerian here): ",
↳iState.GetState())
print("but access to the Keplerian state shows that it is not correct:", sat.
↳GetKeplerianState())
```

```
The internal state buffer just holds preinitialization data (Keplerian here): [7015.0,
↳0.0011, 98.6, 75.0, 90.0, 33.333]
but access to the Keplerian state shows that it is not correct: 0 0
↳ 0 0 0 0
```

The GMAT objects are not yet initialized, so the Keplerian state data is not correct. Once we initialize the system, the Keplerian state will be correct, and the internal state will be updated to the EarthMJ2000Eq system. The interobject connections necessary for these settings are made by calling the API Initialize() function:

```
gmat.Initialize()
print("The initialized internal state buffer is EarthMJ2000Eq: ", iState.GetState())
print("and the Keplerian state is correct: ", sat.GetKeplerianState())
```

```
The initialized internal state buffer is EarthMJ2000Eq: [-150.99058171804361, -3946.
↳626071010534, 5789.742898439815, -2.23046049968889, -5.931020059857665, -4.
↳095581409074377]
```

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```
and the Keplerian state is correct: 7015.0000000000001 0.001100000000000004 98.
→599999999999999 75 90.000000000000402 33.33299999999598
```

Changes made to the state variables are now applied to the state as expected:

```
sat.SetField("SMA", 8000)
print("Internal state: ", iState.GetState())
print("Cartesianian      ", sat.GetCartesianState())
print("Keplerian:        ", sat.GetKeplerianState())
print()
sat.SetField("INC", 45)
print("Internal state: ", iState.GetState())
print("Cartesianian      ", sat.GetCartesianState())
print("Keplerian:        ", sat.GetKeplerianState())
print()
sat.SetField("TA", 50)
print("Internal state: ", iState.GetState())
print("Cartesianian      ", sat.GetCartesianState())
print("Keplerian:        ", sat.GetKeplerianState())
```

```
Internal state: [-172.19168264352888, -4500.785255607168, 6602.700383110265, -2.
→088638988531676, -5.553902317709759, -3.835168124650226]
Cartesianian    -172.1916826435289 -4500.785255607168 6602.700383110265 -2.
→088638988531676 -5.553902317709759 -3.835168124650226
Keplerian:      8000.0000000000007 0.0011000000000000707 98.5999999999999 75
→ 90.000000000001161 33.33299999999884

Internal state: [-5697.7414619496, -3020.2186545041395, 4721.90552145557, 1.
→1208679033712874, -6.413887097497282, -2.7427113896944304]
Cartesianian    -5697.7414619496 -3020.21865450414 4721.90552145557 1.120867903371287 -
→6.413887097497282 -2.74271138969443
Keplerian:      8000.0000000000011 0.0011000000000000964 45.00000000000001 75.
→000000000000001 90.000000000001836 33.332999999998167

Internal state: [-5094.78342738948, -4974.9069027511405, 3633.5822378210464, 2.
→5169011956354206, -5.379735538828468, -3.8235178821457656]
Cartesianian    -5094.78342738948 -4974.90690275114 3633.582237821046 2.
→516901195635421 -5.379735538828468 -3.823517882145766
Keplerian:      8000.0000000000012 0.0011000000000001075 45.00000000000001 75.
→000000000000001 90.000000000002314 49.99999999999523
```

B.1.3 Changing Coordinate Systems

The previous section shows how to access Cartesian and Keplerian representations of the system. In this section we will work with a couple of different coordinate systems: an Earth fixed coordinate system named “ECF” and accessed using the Python reference `ecf`, and a solar ecliptic system named “SolarEcliptic,” referenced as `sec`. These coordinate systems are built using the code

```
ecf = gmat.Construct("CoordinateSystem", "ECF", "Earth", "BodyFixed")
sec = gmat.Construct("CoordinateSystem", "SolarEcliptic", "Sun", "MJ2000Ec")
```

In this section, the spacecraft sat defined previously will be used with the Earth fixed coordinate system, and a copy of that spacecraft will be used with the solar ecliptic system. GMAT's objects support a method, Copy(), that copies an object into another object of the same type. Rather than set up a new spacecraft from scratch, we'll use that framework to get started by creating a new spacecraft and then setting the coordinate systems so that the original spacecraft uses the ECI coordinate system and the new spacecraft uses the solar ecliptic system.

```
solsat = gmat.Construct("Spacecraft","SolarSat")
solsat.Copy(sat)

# Now set coordinate systems
sat.SetField("CoordinateSystem","ECF")
solsat.SetField("CoordinateSystem","SolarEcliptic")
```

We've reset the coordinate system names on the spacecraft at this point, but have yet to reset the associated objects because the Initialize() function that connects objects together has not been called since making the reassignment. The data reflects this state of the system:

```
# Show the data after setting the new coordinate systems, before initialization
print("The spacecraft ", sat.GetName(), " initialization state is ", sat.IsInitialized())
print("The internal state buffer: ", iState.GetState())
print("The ECF Cartesian State:      ", sat.GetCartesianState())
print("The ECF Keplerian State:      ", sat.GetKeplerianState())
print()
print("The spacecraft ", solsat.GetName(), " initialization state is ", sat.
↳ IsInitialized())
print("The internal state buffer (SolarSat): ", solsat.GetState().GetState())
print("The SolarEcliptic Cartesian State:      ", solsat.GetCartesianState())
print("The SolarEcliptic Keplerian State:      ", solsat.GetKeplerianState())
```

```
The spacecraft MySat initialization state is True
The internal state buffer: [-5094.78342738948, -4974.9069027511405, 3633.5822378210464,
↳ 2.5169011956354206, -5.379735538828468, -3.8235178821457656]
The ECF Cartesian State:      -5094.78342738948 -4974.90690275114 3633.582237821046 2.
↳ 516901195635421 -5.379735538828468 -3.823517882145766
The ECF Keplerian State:      8000.000000000012 0.001100000000001075 45.00000000000001 75.
↳ 000000000000001 90.00000000002314 49.9999999999523

The spacecraft SolarSat initialization state is True
The internal state buffer (SolarSat): [-5094.78342738948, -4974.9069027511405, 3633.
↳ 5822378210464, 2.5169011956354206, -5.379735538828468, -3.8235178821457656]
The SolarEcliptic Cartesian State:      -5094.78342738948 -4974.90690275114 3633.
↳ 582237821046 2.516901195635421 -5.379735538828468 -3.823517882145766
The SolarEcliptic Keplerian State:      8000.000000000012 0.001100000000001075 45.
↳ 000000000000001 75.00000000000001 90.00000000002314 49.9999999999523
```

Note that the initialization state reported here is a bug: resetting object references should toggle the initialization flag, but did not.

Once we initialize the system, replacing the coordinate system references with the correct objects, the data is once again correct:

```
# Connect the GMAT objects together
gmat.Initialize()
```

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```
# And show the data in the new coordinate systems
print("The internal state buffer: ", iState.GetState())
print("The ECF Cartesian State:    ", sat.GetCartesianState())
print("The ECF Keplerian State:    ", sat.GetKeplerianState())
print()
print("The internal state buffer (SolarSat): ", solsat.GetState().GetState())
print("The SolarEcliptic Cartesian State:    ", solsat.GetCartesianState())
print("The SolarEcliptic Keplerian State:    ", solsat.GetKeplerianState())
```

```
The internal state buffer: [-5094.78342738948, -4974.9069027511405, 3633.5822378210464,
↪ 2.5169011956354206, -5.379735538828468, -3.8235178821457656]
The ECF Cartesian State: 3980.769626359613 -5904.072200723337 3633.84663580491 5.
↪ 31337371013498 1.221190102125526 -3.82343374194999
The ECF Keplerian State: 7197.708272712511 0.1106817774544226 47.10837940070086 152.
↪ 2889386356222 322.0637563061007 179.5887814511714

The internal state buffer (SolarSat): [-5094.78342738948, -4974.9069027511405, 3633.
↪ 5822378210464, 2.5169011956354206, -5.379735538828468, -3.8235178821457656]
The SolarEcliptic Cartesian State: -26505087.9080278 144694001.6268158 4700.
↪ 442019894719 -27.27732399951776 -11.92620879192113 -1.367891168160935
The SolarEcliptic Keplerian State: 144849901.1130946 0.2292154440704447 2.
↪ 702016602265948 280.4191667873194 286.9680459339144 252.9931176051724
```

B.2 Propagation with the GMAT API

This document walks you through the configuration and use of the GMAT API for propagation.

B.2.1 Prepare the GMAT Environment

Before the API can be used, it needs to be loaded into the Python system and initialized using a GMAT startup file. This can be done from the GMAT bin folder by importing the gmatpy module, but using that approach tends to leave pieces in the bin folder that may annoy other users. Running from an outside folder takes a few steps, which have been captured in the run_gmat.py file imported here:

```
from run_gmat import *
```

B.2.2 Configure a Spacecraft

We'll need an object to propagate. Here's a basic one:

```
sat = gmat.Construct("Spacecraft", "LeoSat")

sat.SetField("DateFormat", "UTCGregorian")
sat.SetField("Epoch", "27 Sep 2019 15:05:00.000")
sat.SetField("CoordinateSystem", "EarthMJ2000Eq")
sat.SetField("DisplayStateType", "Keplerian")
sat.SetField("SMA", 7005)
sat.SetField("ECC", 0.008)
```

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```
sat.SetField("INC", 28.5)
sat.SetField("RAAN", 75)
sat.SetField("AOP", 90)
sat.SetField("TA", 45)

sat.SetField("DryMass", 50)
sat.SetField("Cd", 2.2)
sat.SetField("Cr", 1.8)
sat.SetField("DragArea", 1.5)
sat.SetField("SRPArea", 1.2)
```

B.2.3 Configure the Forces

Next we'll set up a force model. For this example, we'll use an Earth 8x8 potential model, with Sun and Moon point masses and Jacchia-Roberts drag. In GMAT, forces are collected in the ODEModel class. That class is scripted as a "ForceModel" in the script language. The API accepts either. The force model is built and its (empty) contents displayed using

```
fm = gmat.Construct("ForceModel", "TheForces")
fm.Help()
```

ForceModel TheForces

Field	Type	Value
CentralBody	Object	Earth
PrimaryBodies	ObjectArray	{}
PolyhedralBodies	ObjectArray	{}
PointMasses	ObjectArray	{}
Drag	Object	None
SRP	OnOff	Off
RelativisticCorrection	OnOff	Off
ErrorControl	List	RSSStep
UserDefined	ObjectArray	{}

```
''
```

B.2.4 Add the Potential Field

In this example, the spacecraft is in Earth orbit. The largest force for the model is the Earth gravity field. We'll set it to an 8x8 field and add it to the force model using the code

```
# An 8x8 JGM-3 Gravity Model
earthgrav = gmat.Construct("GravityField")
earthgrav.SetField("BodyName", "Earth")
earthgrav.SetField("Degree", 8)
earthgrav.SetField("Order", 8)
earthgrav.SetField("PotentialFile", "JGM2.cof")
```

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```
# Add forces into the ODEModel container
fm.AddForce(earthgrav)
```

B.2.5 Add the other forces

Next we'll build and add the Sun, Moon, and Drag forces, and then show the completed force model.

```
# The Point Masses
moongrav = gmat.Construct("PointMassForce")
moongrav.SetField("BodyName", "Luna")
sungrav = gmat.Construct("PointMassForce")
sungrav.SetField("BodyName", "Sun")

# Drag using Jacchia-Roberts
jrdrag = gmat.Construct("DragForce")
jrdrag.SetField("AtmosphereModel", "JacchiaRoberts")

# Build and set the atmosphere for the model
atmos = gmat.Construct("JacchiaRoberts")
jrdrag.SetReference(atmos)

# Add all of the forces into the ODEModel container
fm.AddForce(moongrav)
fm.AddForce(sungrav)
fm.AddForce(jrdrag)

fm.Help()
```

ForceModel TheForces

Field	Type	Value
CentralBody	Object	Earth
PrimaryBodies	ObjectArray	{Earth}
PolyhedralBodies	ObjectArray	{}
PointMasses	ObjectArray	{Luna, Sun}
Drag	Object	JacchiaRoberts
SRP	OnOff	Off
RelativisticCorrection	OnOff	Off
ErrorControl	List	RSSStep
UserDefined	ObjectArray	{}

In GMAT, the force model scripting shows the settings for each force. In the API, you can examine the settings for the individual forces:

```
earthgrav.Help()
```

GravityField

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Field	Type	Value
Degree	Integer	8
Order	Integer	8
StmLimit	Integer	100
PotentialFile	Filename	JGM2.cof
TideFile	Filename	
TideModel	String	None

or, with a little work, the scripting for the complete force model:

```
print(fm.GetGeneratingString(0))
```

```
Create ForceModel TheForces;
GMAT TheForces.CentralBody = Earth;
GMAT TheForces.PrimaryBodies = {Earth};
GMAT TheForces.PointMasses = {Luna, Sun};
GMAT TheForces.SRP = Off;
GMAT TheForces.RelativisticCorrection = Off;
GMAT TheForces.ErrorControl = RSSStep;
GMAT TheForces.GravityField.Earth.Degree = 8;
GMAT TheForces.GravityField.Earth.Order = 8;
GMAT TheForces.GravityField.Earth.StmLimit = 100;
GMAT TheForces.GravityField.Earth.PotentialFile = 'JGM2.cof';
GMAT TheForces.GravityField.Earth.TideModel = 'None';
GMAT TheForces.Drag.AtmosphereModel = JacchiaRoberts;
GMAT TheForces.Drag.HistoricWeatherSource = 'ConstantFluxAndGeoMag';
GMAT TheForces.Drag.PredictedWeatherSource = 'ConstantFluxAndGeoMag';
GMAT TheForces.Drag.CSSISpaceWeatherFile = 'SpaceWeather-All-v1.2.txt';
GMAT TheForces.Drag.SchattenFile = 'SchattenPredict.txt';
GMAT TheForces.Drag.F107 = 150;
GMAT TheForces.Drag.F107A = 150;
GMAT TheForces.Drag.MagneticIndex = 3;
GMAT TheForces.Drag.SchattenErrorModel = 'Nominal';
GMAT TheForces.Drag.SchattenTimingModel = 'NominalCycle';
GMAT TheForces.Drag.DragModel = 'Spherical';
```

B.2.6 Configure the Integrator

Finally, in order to propagate, we need an integrator. For this example, we'll use a Prince-Dormand 7(8) Runge-Kutta integrator. The propagator is set using the code

```
# Build the propagation container that connect the integrator, force model, and
↳ spacecraft together
pdprop = gmat.Construct("Propagator", "PDProp")

# Create and assign a numerical integrator for use in the propagation
gator = gmat.Construct("PrinceDormand78", "Gator")
pdprop.SetReference(gator)
```

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```
# Set some of the fields for the integration
pdprop.SetField("InitialStepSize", 60.0)
pdprop.SetField("Accuracy", 1.0e-12)
pdprop.SetField("MinStep", 0.0)
```

B.2.7 Connect the Objects Together

```
# Assign the force model imported from BasicFM
pdprop.SetReference(fm)

# Setup the spacecraft that is propagated
psm = pdprop.GetPropStateManager()
psm.SetObject(sat)
```

True

B.2.8 Initialize the System and Propagate a Step

Finally, the system can be initialized and fired to see a single propagation step. Some of the code displayed here will be folded into the API's `Initialize()` function. For now, the steps needed to initialize the system for a propagation step are:

```
# Perform top level initialization
gmat.Initialize()

# Refresh the object references from the propagator clones
fm = pdprop.GetODEModel()
gator = pdprop.GetPropagator()

psm.BuildState()

# Pass the state manager to the dynamics model
fm.SetPropStateManager(psm)
fm.SetState(psm.GetState())

# Assemble all of the force model objects together
fm.Initialize()

# Finish the force model setup
fm.BuildModelFromMap()
fm.UpdateInitialData()

# Initialize the Propagator components
pdprop.Initialize()
gator.Initialize()
```

True

Note: Alternatively, the above code can be replaced with a call to the `PrepareInternals()` function on the propagator. This also removes the need to manually configure the `PropagationStateManager`. The condensed code can be seen below:

```
# Perform top level initialization
gmatt.Initialize()

# Setup the spacecraft that is propagated
pdprop.AddPropObject(sat)
pdprop.PrepareInternals()

# Refresh the object references from the propagator clones
fm = pdprop.GetODEModel()
gator = pdprop.GetPropagator()
```

and we can then propagate, and start accumulating the data

```
# Take a 60 second step, showing the state before and after, and start buffering
# Buffers for the data
time = []
pos = []
vel = []

gatorstate = gator.GetState()
t = 0.0
r = []
v = []
for j in range(3):
    r.append(gatorstate[j])
    v.append(gatorstate[j+3])
time.append(t)
pos.append(r)
vel.append(v)

print("Starting state: ", t, r, v)

# Take a step and buffer it
gator.Step(60.0)
gatorstate = gator.GetState()
t = t + 60.0
r = []
v = []
for j in range(3):
    r.append(gatorstate[j])
    v.append(gatorstate[j+3])
time.append(t)
pos.append(r)
vel.append(v)

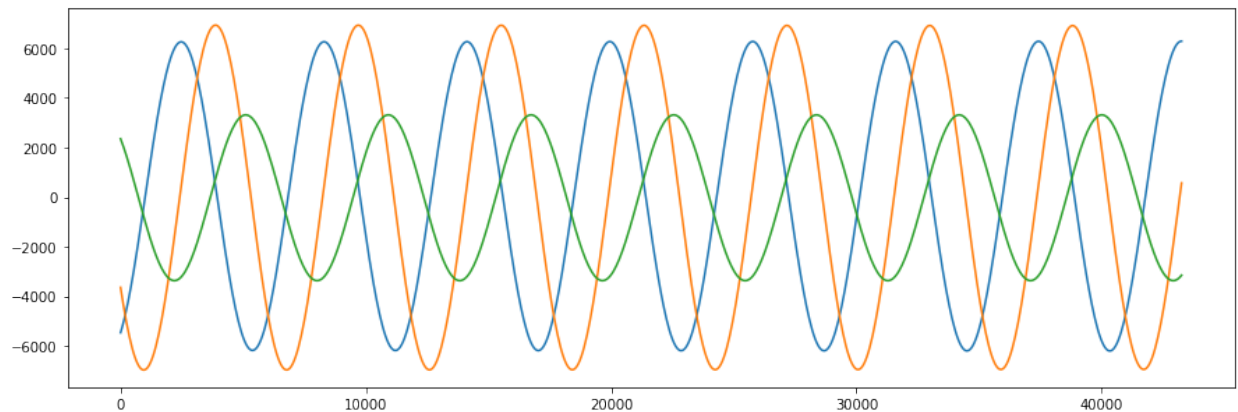
print("Propped state: ", t, r, v)
```

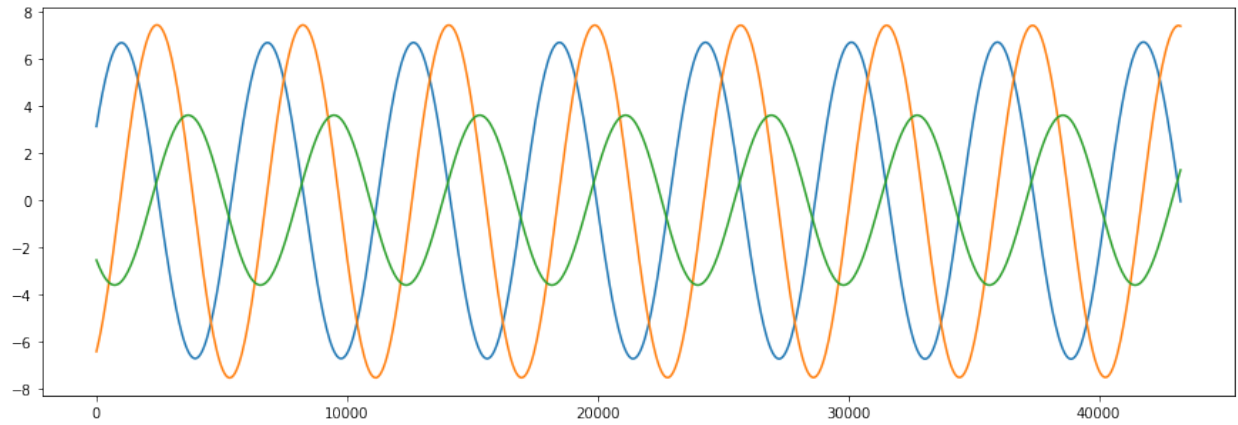
```
Starting state: 0.0 [-5455.495852919224, -3637.0485868833093, 2350.0571814448517] [3.
↳1318014092807545, -6.423940627548709, -2.545227573417657]
Propped state: 60.0 [-5256.1378692623475, -4014.4902800853415, 2192.4488937848546] [3.
↳51104729424038, -6.153042432990329, -2.7064897093764597]
```

Finally, we can run for a few orbits and show the results

```
for i in range(360):
    # Take a step and buffer it
    gator.Step(60.0)
    gatorstate = gator.GetState()
    t = t + 60.0
    r = []
    v = []
    for j in range(3):
        r.append(gatorstate[j])
        v.append(gatorstate[j+3])
    time.append(t)
    pos.append(r)
    vel.append(v)

import matplotlib.pyplot as plt
plt.rcParams['figure.figsize'] = (15, 5)
plt.plot(time, pos)
plt.show()
plt.plot(time, vel)
plt.show()
```





BIBLIOGRAPHY

[GmatWiki] gmatscentral.org

The GMAT Wiki at gmatscentral.org is the main public facing interface for GMAT development and release activities.

[Architecture] The GMAT Development Team, “General Mission Analysis Tool (GMAT) Architectural Specification,” NASA GSFC.

The GMAT Architectural Specification provides a good overview for the GMAT system. The document is included with each GMAT release. The document overview can be viewed at <http://gmatscentral.org:8090/display/GW/Architectural+Specification>.

[CInterface] D. Conway, “GMAT API Tradeoff Study,” Thinking Systems, Inc., February 2012.

The GMAT CInterface plugin was an artifact of the original GMAT API study described here. One recommendation arising from this study was a set of automatic API generation tools, including SWIG.

[SWIGExperiment] D. Conway, “GMAT API Consultation Support,” Thinking Systems, Inc., December 2016.

Goddard personnel, assisted by contractors at Thinking Systems, Inc. and Emergent Space Technologies, performed an in-house study of the use of SWIG as a tool for a production GMAT API. This document describes that study.

[SWIG] [Simplified Wrapper and Interface Generator \(SWIG\)](#)

SWIG is an open source software development tool that connects programs written in C and C++ with other high-level programming languages. The GMAT API is generated using the SWIG tool.

[Doxygen] www.doxygen.nl

The detailed design information for GMAT is generated using the open source Doxygen documentation generation tool.

[Jupyter] www.jupyter.org

Jupyter is an interactive tool that provides writers with the ability to intersperse documentation and Python code. The resulting notebook files can be run interactively, enriching the user’s learning experience through editable Python code that can be executed inside the notebook.

CHANGE HISTORY

Rev 0	December 05, 2018	Original draft specification.
Rev 1	March 29, 2019	Draft specification incorporating review comments.
Rev 2	October 11, 2019	Updates for the first beta release.
Rev 3	January 15, 2020	Updates for GMAT R2020a.
Rev 4	September 27, 2022	Updates for GMAT R2022a.
Rev 5	June 30, 2023	Updates for command functionality.
Rev 6	March 11, 2025	Recompiled for GMAT R2025a