

Multi-Spacecraft Concept and Autonomy Tool (MuSCAT) Version 2

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Chapter 1

Introduction

Multi-Spacecraft Concept and Autonomy Tool (MuSCAT) open-source simulation software offers an integrated platform for conducting low-fidelity simulations of single/multiple cruising/orbiting spacecraft mission concepts and test of autonomy algorithms. MuSCAT encompasses various spacecraft subsystems such as (i) Navigation, (ii) Attitude Determination and Control, (iii) Power Management, (iv) Data Handling, (v) Communication (including direct-to-Earth and inter-spacecraft), and (vi) Scientific Instruments. It provides mission designers with a means to quantitatively verify if the mission concept meets level-1 science functional requirements.

[1] provides a detailed description of the software architecture and use cases of MuSCAT.

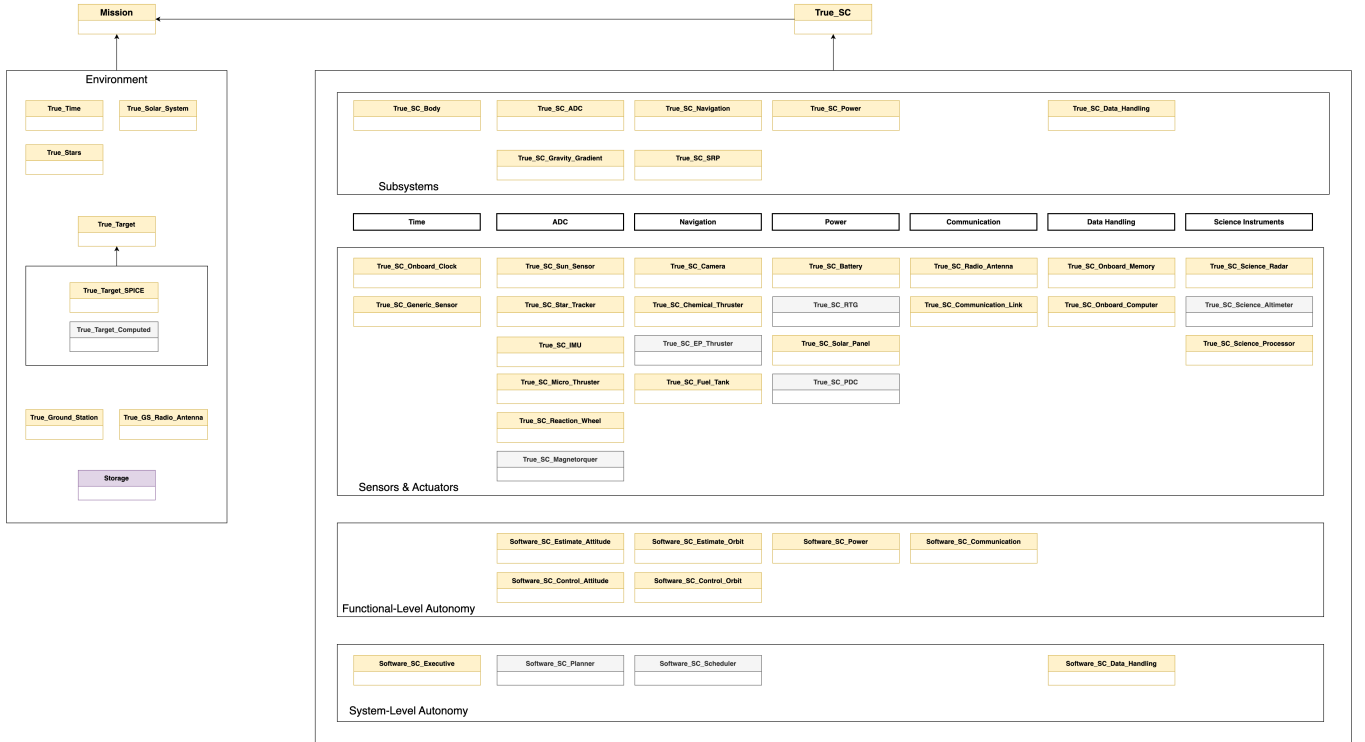


Figure 1.1: Diagram showing all the classes that are inside MuSCAT. Classes in gray are currently under development.

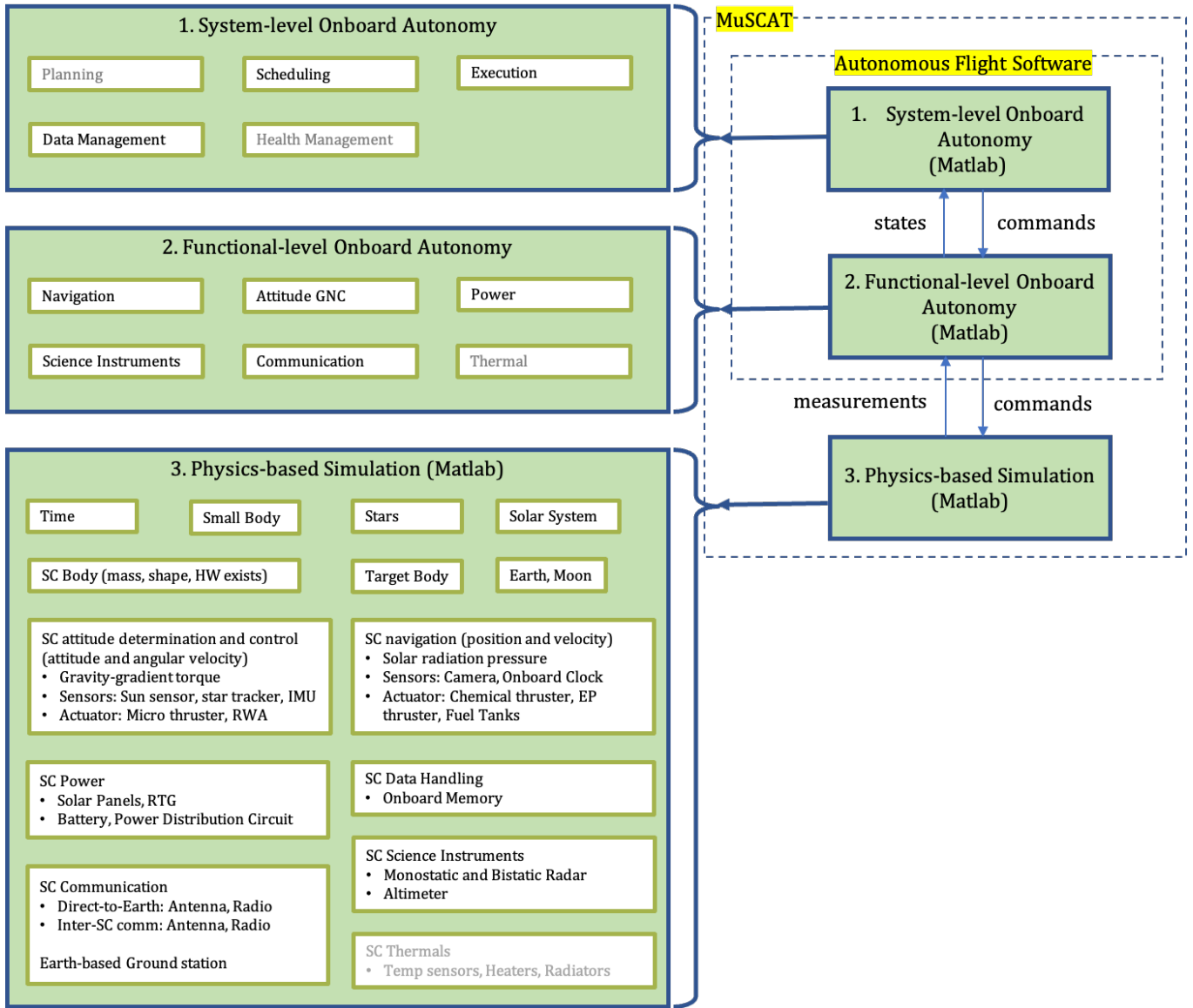


Figure 1.2: Block diagram that shows the different components inside the MuSCAT simulator. The blocks in gray are currently under development.

1.1 Coding Conventions

- Items marked with `#` are not initialized, and computed internally
- In naming functions,
`update` is used when the function is called often (every time step),
`compute` is used when it is called rarely (or only once).
- All functions are prefixed with `func_`, and colored green.
- All classes within the physics-based simulation represent real objects like Solar System or small body, and are prefixed with `True_`, and those that belong to the spacecraft are prefixed with `True_SC_`.
- All classes within the autonomous flight software that only exist within the spacecraft's onboard computer are prefixed with `Software_SC_`.

1.2 Coding Tips for Multi-Mission Usage

- Within each class, use `data` to track all mission-specific variables.
- If a component uses different power in different spacecraft modes, use `data.instantaneous_power_consumed_per_SC_mode` to track that.

1.3 Acknowledgment

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Chapter 2

Implementing Custom Missions in MuSCAT

2.1 Overview of Mission Implementation

The Multi-Spacecraft Concept and Autonomy Tool (MuSCAT) provides a flexible framework for simulating spacecraft missions. This chapter explains in detail how to implement your own custom mission using MuSCAT's modular architecture.

At its core, MuSCAT follows an object-oriented approach where various spacecraft subsystems, environmental elements, and software components are instantiated as objects and connected together to form a complete mission simulation. The central data structure that ties everything together is the `mission` structure, which serves as the global state for the entire simulation.

2.2 Understanding the Mission Structure

The `mission` structure contains all the objects and parameters that define your mission:

- **`mission.name`**: Name identifier for the mission
- **`mission.num_SC`**: Number of spacecraft in the mission
- **`mission.num_target`**: Number of target bodies (e.g., asteroids, planets)
- **`mission.frame`**: Reference frame type ('Absolute', 'Relative', or 'Combined')
- **`mission.true_time`**: Time-related parameters and functions
- **`mission.storage`**: Data storage configuration
- **`mission.true_stars`**: Star catalog for attitude determination
- **`mission.true_solar_system`**: Solar system bodies
- **`mission.true_target`**: Target bodies (e.g., asteroids)
- **`mission.true_ground_station`**: Ground station parameters
- **`mission.true_SC`**: Array of spacecraft objects

Each spacecraft contains numerous subsystems, all properly organized within the structure:

- `mission.true_SC{i}.true_SC_body`: Physical properties and geometry
- `mission.true_SC{i}.true_SC_navigation`: Position, velocity, and orbital parameters
- `mission.true_SC{i}.true_SC_adc`: Attitude determination and control
- `mission.true_SC{i}.true_SC_power`: Power subsystem
- `mission.true_SC{i}.true_SC_data_handling`: Data management
- `mission.true_SC{i}.true_SC_[hardware]`: Various hardware components
- `mission.true_SC{i}.software_SC_[software]`: Flight software components

2.3 MuSCAT Code Organization

Understanding the organization of MuSCAT's codebase is essential for effectively implementing and customizing missions. The codebase follows a modular structure that separates different aspects of spacecraft simulation into distinct directories, each with a specific purpose.

2.3.1 Top-Level Directory Structure

The MuSCAT codebase is organized into several key directories:

- `/Mission/`: Contains mission definition files that serve as the entry points for simulations
- `/Main/`: Contains the main simulation engine that executes the time steps
- `/True_SC/`: Houses the core spacecraft system classes (body, navigation, power, etc.)
- `/True_Sensors_Actuators/`: Contains sensor and actuator hardware implementations
- `/True_Environment/`: Defines environmental models (solar system, stars, etc.)
- `/Software_SC/`: Implements flight software components
- `/Supporting_Functions/`: Contains utility functions used throughout the codebase
- `/Documentation/`: Contains detailed documentation files
- `/Output/`: Default location for simulation results and visualizations

2.3.2 Mission Files

The `/Mission/` directory is where users should focus most of their attention when creating new simulations. Each mission file (e.g., `Mission_DART.m`) follows the same general structure:

1. Configure mission parameters (name, number of spacecraft, etc.)
 2. Set up time and storage parameters
 3. Configure environmental elements (stars, solar system, targets)
-

4. Set up ground stations
5. For each spacecraft:
 - Define physical properties
 - Set initial position and attitude
 - Configure hardware components
 - Set up flight software
6. Perform final initialization
7. Execute the simulation
8. Generate and save results

These mission files serve as the "glue" that brings together all the individual components into a cohesive simulation.

2.3.3 True_SC: Core Spacecraft Systems

The `/True_SC/` directory contains the fundamental spacecraft subsystem classes:

- **True_SC_Body.m**: Defines the physical properties of the spacecraft, including mass, inertia, and shape
- **True_SC_Navigation.m**: Handles position and velocity dynamics
- **True_SC_ADC.m**: Manages attitude dynamics and control
- **True_SC_Power.m**: Tracks power generation, consumption, and distribution
- **True_SC_Data_Handling.m**: Manages onboard data flows

These core classes form the backbone of each spacecraft model. They work together to provide a complete representation of the physical spacecraft and its core functionalities.

2.3.4 Class Interfaces and Update Functions

All MuSCAT classes follow a consistent interface pattern that enables the simulation loop to update each component appropriately. Understanding this pattern is key to extending MuSCAT with custom components.

2.3.4.1 Main Update Functions

Each class in MuSCAT has a corresponding `func_main_[className]` function that the simulation loop calls to update that component's state. For example:

- `func_main_true_SC_navigation`: Updates spacecraft position and velocity
- `func_main_true_SC_adc`: Updates spacecraft attitude
- `func_main_true_SC_star_tracker`: Updates star tracker measurements

- `func_main_software_SC_executive`: Executes decision-making logic

These functions follow a consistent pattern:

```
function func_main_[className](obj, mission, i_SC, [optional parameters])
    % Update the object's state based on current mission state
    % obj: The object instance being updated
    % mission: The global mission structure
    % i_SC: The spacecraft index (for spacecraft components)
    % [optional parameters]: Component-specific parameters

    % Update code specific to this component
    % ...

    % Update stored data if needed
    func_store_data(obj, mission);
end
```

2.3.4.2 Extension Without Modification

It's important to note that users should **never modify** these core update functions directly. Instead, MuSCAT provides several approaches for customization:

1. **Mode Selectors:** Most classes have a `mode_[className]_selector` parameter that can be set to choose different behavioral modes. For example, setting `mode_true_SC_navigation_dynamics_selector = 'Absolute Dynamics'` selects the absolute dynamics mode.
2. **Mission-Specific Extensions:** Flight software classes are designed to be extended with mission-specific implementations. For instance, the `Software_SC_Executive` class allows you to add a new function named `func_software_SC_executive_YourMission` that implements your custom decision logic.
3. **Custom Component Creation:** You can create entirely new component classes in your mission directory, inheriting from existing parent classes where appropriate.

2.3.4.3 Custom Function Implementation

When implementing custom functions for flight software, follow this pattern:

```
function obj = func_software_SC_[component]_YourMission(obj, mission, i_SC)
    % Your custom implementation
    % ...

    % Return the updated object
end
```

By strictly adhering to these patterns, you ensure that your custom components will integrate seamlessly with the main simulation loop.

2.3.5 True_Sensors_Actuators: Hardware Components

The `/True_Sensors_Actuators/` directory contains all the individual hardware components that can be added to a spacecraft:

- **Sensors:** Star trackers, sun sensors, IMUs, cameras, etc.
- **Actuators:** Reaction wheels, thrusters, etc.
- **Communication:** Radio antennas, communication links, etc.
- **Power:** Solar panels, batteries, etc.
- **Data:** Onboard computers, memory, etc.

Each hardware component is represented by a MATLAB class that inherits from a common parent class. This object-oriented approach allows for easy extension with new components and consistent interfaces across all hardware.

The number of each hardware component is specified in the mission file and directly influences how the simulation behaves. For example, specifying 6 sun sensors will result in 6 separate hardware objects being created and included in the simulation loop. Each component will be updated during the appropriate part of the simulation cycle.

2.3.6 Software_SC: Flight Software

The `/Software_SC/` directory contains the flight software classes that control the spacecraft's autonomous behavior:

- **Software_SC_Executive.m:** The main decision-making component that determines spacecraft operating modes
- **Software_SC_Estimate_Attitude.m:** Algorithms for estimating spacecraft attitude
- **Software_SC_Estimate_Orbit.m:** Algorithms for estimating spacecraft orbit
- **Software_SC_Control_Attitude.m:** Algorithms for controlling spacecraft attitude
- **Software_SC_Control_Orbit.m:** Algorithms for controlling spacecraft orbit
- **Software_SC_Communication.m:** Logic for managing communications
- **Software_SC_Power.m:** Logic for managing power
- **Software_SC_Data_Handling.m:** Logic for managing data

These software components interact with the hardware models and implement the autonomous behavior of the spacecraft. They are executed at each appropriate time step in the simulation loop.

2.3.7 True_Environment: Environmental Models

The `/True_Environment/` directory contains models of the space environment:

- **True_Solar_System.m**: Models of solar system bodies
- **True_Stars.m**: Star catalog for attitude determination
- **True_Target.m**: Models of mission targets (e.g., asteroids)
- **True_Ground_Station.m**: Earth-based ground stations
- **True_SRP.m**: Solar radiation pressure model
- **True_Gravity_Gradient.m**: Gravity gradient torque model

These environmental models provide the context in which the spacecraft operates and influence various aspects of the simulation, from orbital dynamics to sensor measurements.

2.3.8 Main Simulation Engine

The `/Main/` directory contains the main simulation engine in `main_v3.m`. This script implements the time-stepping algorithm that advances the simulation state:

1. Update simulation time and date
2. Update solar system and target bodies
3. For each spacecraft:
 - Update environmental effects (solar radiation pressure, gravity gradient)
 - Update spacecraft body, position, and velocity
 - Update onboard clock and computer systems
 - Execute the Executive software to determine operating mode
 - Update all sensors, actuators, and subsystems
 - Run the attitude dynamics loop at a higher frequency
 - Update communication systems
 - Update power and data handling systems
4. Update ground station systems
5. Save data and update visualizations

The main simulation engine is responsible for calling all the appropriate update functions for each component in the correct order, ensuring that dependencies between components are properly handled.

2.4 Step-by-Step Guide to Implementing a Mission

2.4.1 Customization Best Practices

When implementing your own mission in MuSCAT, it's critical to follow these best practices to ensure maintainability and compatibility with future updates:

1. **Never Modify Core Files:** The core MuSCAT files (`/True_SC/`, `/True_Sensors_Actuators/`, `/Main/`, etc.) should never be directly edited. These files contain the fundamental simulation engine and component models that are designed to be used as-is.
2. **Create Mission-Specific Directories:** For each new mission, create a dedicated directory in `/Mission/` (e.g., `/Mission/YourMission/`) to contain all mission-specific files.
3. **Use Extension Mechanisms:** MuSCAT provides specific extension points (via mode selectors and mission-specific functions) that allow you to customize behavior without modifying core files.
4. **Document Custom Components:** When creating mission-specific extensions, thoroughly document their purpose, interfaces, and requirements to facilitate future maintenance.
5. **Follow Naming Conventions:** Use consistent naming patterns (e.g., `func_software_SC_executive_YourMission`) to ensure that your custom functions are correctly discovered and invoked by the simulation engine.

By adhering to these practices, you ensure that:

- Your mission can be easily upgraded when new MuSCAT versions are released
- You can transfer your custom components between different MuSCAT installations
- Collaboration with other users is simplified through clear separation of core and custom code
- Debugging is easier since modifications are isolated to specific mission files

2.4.2 Creating a New Mission File

1. Navigate to the `/Mission` directory in the MuSCAT codebase
2. Copy `Mission_DART.m` to a new file with your mission name (e.g., `Mission_YourMission.m`)
3. Open the new file and begin customizing according to your mission requirements

Each mission file follows a structured format, with initialization of different subsystems organized into sections. Let's examine each section.

2.4.3 Basic Mission Configuration

The first step is to define basic mission parameters:

```
%% Mission Definition
mission = [];
mission.name = 'YourMission';           % Name of the Mission
mission.num_SC = 1;                     % Number of Spacecraft
mission.num_target = 1;                 % Number of Target bodies
mission.frame = 'Absolute';             % Frame type: 'Absolute', 'Relative', or 'Combined'
mission.flag_stop_sim = 0;              % Boolean flag to stop simulation if needed
```

2.4.4 Time and Storage Configuration

The time configuration is a critical aspect of MuSCAT as it defines the temporal resolution and duration of your simulation. MuSCAT employs a dual-loop architecture to efficiently handle different timescales for spacecraft dynamics:

```
%% Time Configuration
init_data = [];
init_data.t_initial = 0;                 % [sec] Initial time
init_data.t_final = 10000;               % [sec] Final time
init_data.time_step = 5;                 % [sec] Simulation time step
init_data.t_initial_date_string = '01-JAN-2025 00:00:00'; % Starting date
init_data.time_step_attitude = 0.1;      % [sec] Attitude dynamics time step
mission.true_time = True_Time(init_data);
```

2.4.4.1 Understanding the Dual-Loop Architecture

MuSCAT's main simulation engine in `main_v3.m` implements two nested time loops:

1. **Outer Loop (Orbital Dynamics):** Runs at the slower rate specified by `time_step` (typically 5 seconds). This loop handles orbital dynamics, subsystem operations, communications, power systems, and other slower-changing phenomena.
2. **Inner Loop (Attitude Dynamics):** Runs at the faster rate specified by `time_step_attitude` (typically 0.1 seconds). This nested loop simulates attitude dynamics and control, which require higher temporal resolution due to the faster rotational motion of spacecraft.

This dual-loop architecture is essential because attitude dynamics typically evolve much more rapidly than orbital dynamics. For example, a spacecraft might complete a full rotation in minutes while its orbit might take hours or days to complete. Using a single timestep would either:

- Be too slow for accurate attitude simulation (if using the orbital timestep)
- Be computationally prohibitive for long-duration missions (if using the attitude timestep for everything)

In the `main_v3.m` file, you'll see this implemented as:

```
%% Time Loop (Outer Loop)
for k = 1:1:mmission.true_time.num_time_steps
    % Update Time, Date, Storage, Solar System, etc.

    %% Attitude Dynamics Loop (Inner Loop)
    for k_attitude = 1:1:mmission.true_time.num_time_steps_attitude
        % Update attitude, sensors, actuators, etc.
    end

    % Continue with other subsystems...
end
```

2.4.4.2 Storage Configuration

Similarly, storage configuration determines how frequently simulation data is saved:

```
%% Storage Configuration
init_data = [];
init_data.time_step_storage = 1; % Data storage interval
init_data.time_step_storage_attitude = 0.5; % Attitude data storage interval
init_data.flag_visualize_SC_attitude_orbit_during_sim = 0; % Don't show attitude during simulation
init_data.flag_realtime_plotting = 0; % Show mission data during simulation
init_data.flag_save_plots = 1; % Save plots to disk
init_data.flag_save_video = 0; % Save animation to video
mission.storage = Storage(init_data, mission);
```

The storage configuration follows the same dual-timescale approach as the main simulation:

- `time_step_storage`: How often to save orbital and subsystem data (in seconds)
- `time_step_storage_attitude`: How often to save attitude data (in seconds)

Setting appropriate storage intervals is crucial for managing memory usage. Setting them too small can lead to memory issues with large simulations, while setting them too large might miss important transient behaviors.

The visualization flags control real-time display and post-simulation outputs:

- `flag_visualize_SC_attitude_orbit_during_sim`: Toggles 3D visualization during simulation
- `flag_realtime_plotting`: Enables data plots during simulation (can slow performance)
- `flag_save_plots`: Saves figures to disk after simulation completes
- `flag_save_video`: Records video of 3D visualization (memory-intensive)

2.4.5 Environment Configuration

Configure the stars catalog, solar system bodies, and target bodies:

```
%% Star Catalog Configuration
mission.true_stars = True_Stars(mission);
mission.true_stars.maximum_magnitude = 10; % Maximum star magnitude to include

%% Solar System Configuration
init_data = [];
init_data.SS_body_names = ["Sun", "Earth", "Mars"]; % Relevant solar system bodies
mission.true_solar_system = True_Solar_System(init_data, mission);

%% Target Body Configuration
for i_target = 1:1:mission.num_target
    init_data = [];
    init_data.target_name = 'Bennu'; % Target asteroid name
    mission.true_target{i_target} = True_Target_SPICE(init_data, mission);
end
```

2.4.6 Ground Station Configuration

Ground stations are essential elements of spacecraft missions, providing the Earth-based communications infrastructure for telemetry, tracking, and command. In MuSCAT, ground stations are modeled with realistic visibility constraints, antenna properties, and communication capabilities.

2.4.6.1 Ground Station Fundamentals

The ground station model in MuSCAT accounts for:

- **Earth Rotation:** Ground stations rotate with Earth, affecting visibility periods
- **Antenna Characteristics:** Gain patterns, pointing capabilities, and frequency-dependent properties
- **Link Budget Calculations:** Realistic modeling of signal strength, noise, and data rate capabilities
- **Visibility Constraints:** Line-of-sight calculations based on Earth's position and rotation

To configure a ground station, first specify the number of antennas:

```
%% Ground Station Configuration
init_data = [];
init_data.num_GS_radio_antenna = 1; % Number of ground station antennas
mission.true_ground_station = True_Ground_Station(init_data, mission);
```

Then, configure each antenna with appropriate communication parameters:

```
%% Ground Station Radio Antenna Configuration
for i_HW = 1:1:mission.true_ground_station.num_GS_radio_antenna
    init_data = [];

    % Basic configuration
```

```
init_data.antenna_type = 'High Gain';
init_data.mode_true_GS_radio_antenna_selector = 'RX'; % Receive mode

% Link budget parameters
init_data.antenna_gain = 90; % [dB] Very high gain (DSN-like)
init_data.noise_temperature = 100; % [K] System noise temperature
init_data.beamwidth = 0.1; % [MHz] Receiver bandwidth
init_data.energy_bit_required = 4.2; % [dB] Required Eb/N0
init_data.line_loss = 0; % [dB] Transmission line losses
init_data.coding_gain = 7.3; % [dB] Error correction coding gain

% Create the antenna object
mission.true_GS_radio_antenna{i_HW} = True_GS_Radio_Antenna(init_data, mission, i_HW);
end
```

2.4.6.2 Ground Station Parameters

The key parameters affecting ground station performance include:

- **Antenna Gain:** Higher gain provides better signal strength but narrower beamwidth requiring more precise pointing. The value of 90 dB represents a large Deep Space Network (DSN) class antenna.
- **Noise Temperature:** Lower values (in Kelvin) improve signal-to-noise ratio. Typical values range from 20K (very cold, space-pointing receivers) to 290K (room temperature).
- **Beamwidth:** The receiver's frequency bandwidth in MHz. Narrower bandwidths reduce noise but limit data rate.
- **Eb/N0 Requirement:** Energy per bit to noise density ratio required for reliable communication. Higher values increase reliability but reduce achievable data rate.
- **Coding Gain:** The improvement in effective signal-to-noise ratio achieved through error correction coding.

2.4.6.3 Simulation Impact

During simulation, the ground station model:

1. Calculates its position based on Earth's rotation
2. Determines visibility to each spacecraft based on line-of-sight
3. Computes achievable data rates based on distance, antenna parameters, and pointing
4. Transfers data between spacecraft and ground when links are established

The ground station configuration directly affects communication windows and data throughput, which in turn influence mission planning, data collection strategies, and onboard storage requirements.

2.4.7 Spacecraft Configuration

2.4.7.1 Spacecraft Physical Properties

Configure the physical properties of each spacecraft, including shape, mass, and moment of inertia:

```
%% Spacecraft Body Configuration
i_SC = 1; % First spacecraft

init_data = [];
init_data.i_SC = i_SC;

% Body shape model
init_data.shape_model{1} = [];
init_data.shape_model{1}.Vertices = [0 0 0;
    0.3 0 0;
    0.3 0 0.1;
    0 0 0.1;
    0 0.2 0;
    0.3 0.2 0;
    0.3 0.2 0.1;
    0 0.2 0.1]; % [m]
init_data.shape_model{1}.Faces = [1 2 3;
    1 4 3;
    2 3 7;
    2 6 7;
    3 4 8;
    3 7 8;
    1 4 8;
    1 5 8;
    1 2 6;
    1 5 6;
    5 6 7;
    5 8 7];

init_data.shape_model{1}.Face_reflectance_factor = 0.6*ones(size(init_data.shape_model{1}));
init_data.shape_model{1}.type = 'cuboid';
init_data.shape_model{1}.mass = 11; % [kg] Dry mass

% Additional mass components
init_data.mass.supplement{1}.mass = 0.5; % [kg]
init_data.mass.supplement{1}.location = [0.1 0 0]; % [m]
init_data.mass.supplement{1}.MI_over_m = zeros(3,3); % [m^2]

init_data.mode_COM_selector = 'update'; % Compute Center of Mass dynamically
init_data.mode_MI_selector = 'update'; % Compute Moment of Inertia dynamically
```

2.4.7.2 Spacecraft Hardware Complement

When designing a spacecraft in MuSCAT, the hardware complement defines what components are present on the spacecraft and in what quantities. This configuration directly impacts how the simulation behaves by determining:

- What hardware-specific loops will be executed during simulation
- How many instances of each component will be created and updated
- What capabilities the spacecraft will have during the mission
- The physical and performance characteristics of the spacecraft

The hardware complement is specified through the `num hardware_exists` structure:

```
% Define hardware complement
init_data.num_hardware_exists.num_onboard_clock = 1;      % Timing system
init_data.num_hardware_exists.num_camera = 1;             % Imaging system
init_data.num_hardware_exists.num_solar_panel = 3;        % Power generation
init_data.num_hardware_exists.num_battery = 2;            % Energy storage
init_data.num_hardware_exists.num_onboard_memory = 2;     % Data storage
init_data.num_hardware_exists.num_sun_sensor = 6;         % Sun direction sensing
init_data.num_hardware_exists.num_star_tracker = 3;       % Star-based attitude determination
init_data.num_hardware_exists.num_imu = 1;                % Inertial measurement
init_data.num_hardware_exists.num_micro_thruster = 12;    % Small attitude control thrusters
init_data.num_hardware_exists.num_chemical_thruster = 1; % Main propulsion
init_data.num_hardware_exists.num_reaction_wheel = 3;     % Momentum exchange devices
init_data.num_hardware_exists.num_communication_link = 2; % Data links (up/downlink)
init_data.num_hardware_exists.num_radio_antenna = 1;      % Communication hardware
init_data.num_hardware_exists.num_fuel_tank = 1;          % Propellant storage
init_data.num_hardware_exists.num_onboard_computer = 2;   % Computing resources
```

2.4.7.2.1 Simulation Impact Each number specified here has direct consequences for the simulation:

1. **Loop Execution:** In `main_v3.m`, the simulation iterates through each hardware type according to the specified count. For example, with 6 sun sensors:

```
for i_HW = 1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_sun_sensor
    func_main_true_SC_sun_sensor(mission.true_SC{i_SC}.true_SC_sun_sensor{i_HW},
end
```

2. **Resource Consumption:** Each hardware component consumes power and generates data, affecting the overall spacecraft power balance and data handling requirements.
3. **Redundancy and Failure Tolerance:** Multiple instances of critical components (e.g., computers, batteries) provide redundancy for fault tolerance.

4. **Capability Coverage:** The placement and orientation of sensors (like sun sensors or star trackers) determine the spacecraft’s ability to determine attitude in different orientations.
5. **Control Authority:** The number and arrangement of reaction wheels and thrusters determine the spacecraft’s control capabilities.

2.4.7.2.2 Selecting Appropriate Hardware When designing your mission, consider these questions when selecting hardware:

- What sensing capabilities are required for the mission objectives?
- What control authority is needed for attitude and orbital maneuvers?
- How much power generation and storage is needed?
- What data rates and storage capacities are required?
- What level of redundancy is appropriate for mission criticality?

After defining the hardware complement, you must create a `True_SC_Body` object that will encapsulate this information:

```
mission.true_SC{i_SC}.true_SC_body = True_SC_Body(init_data, mission);
```

This object becomes the foundation for all subsequent hardware initialization and will be used to calculate mass properties and other physical characteristics of the spacecraft.

2.4.7.3 Initial Position and Attitude

The initial state of the spacecraft—its position, velocity, and attitude—defines the starting point of the simulation and has profound impacts on mission trajectory, operations, and results. In MuSCAT, there are multiple methods to specify these initial conditions, each serving different purposes.

2.4.7.3.1 Position and Velocity Initialization There are three primary methods to specify the initial position and velocity of a spacecraft:

1. **SPICE-Based Initialization:** Using NASA’s SPICE toolkit for high-fidelity ephemeris data
2. **Direct Specification:** Explicitly defining position and velocity vectors
3. **Orbital Elements:** Specifying Keplerian orbital elements

The SPICE-based method is shown below and is preferred for missions with predefined trajectories:

```
%% Initialize Spacecraft's Position and Velocity
init_data = [];
init_data.spice_filename = '../..MuSCAT_Supporting_Files/SC_data/YourMission/trajectory.
cspice_furnsh(init_data.spice_filename)

init_data.spice_name = '-110'; % SPICE ID for the spacecraft
init_data.SC_pos_vel = cspice_spkezr(init_data.spice_name, mission.true_time.date,
                                     'J2000', 'NONE', 'SUN');
init_data.position = init_data.SC_pos_vel(1:3)'; % [km]
init_data.velocity = init_data.SC_pos_vel(4:6)'; % [km/sec]
```

Alternatively, you can directly specify position and velocity:

```
init_data.position = [149598023, 0, 0]; % [km] Position in Sun-centered frame
init_data.velocity = [0, 29.78, 0]; % [km/sec] Velocity in Sun-centered frame
```

The dynamics mode selection determines how the position and velocity will evolve during simulation:

```
init_data.mode_true_SC_navigation_dynamics_selector = 'Absolute Dynamics';
```

MuSCAT currently supports two navigation dynamics modes:

- **Absolute Dynamics:** Full orbital dynamics with gravitational forces
- **SPICE:** Position/velocity updated directly from SPICE kernels

After configuration, create the navigation object:

```
mission.true_SC{i_SC}.true_SC_navigation = True_SC_Navigation(init_data, mission);
```

2.4.7.3.2 Attitude Initialization Spacecraft attitude defines the orientation in three-dimensional space. In MuSCAT, attitudes can be specified using various representations:

1. **Quaternions:** A four-parameter representation avoiding singularities
2. **Modified Rodrigues Parameters (MRP):** A three-parameter representation
3. **Euler Angles:** Classical roll, pitch, yaw angles (not singularity-free)
4. **Direction Cosine Matrix (DCM):** 3×3 rotation matrix

The example below uses Modified Rodrigues Parameters, then converts to quaternions:

```
%% Initialize Spacecraft's Attitude
init_data = [];
% Method 1: Starting with MRP
init_data.SC_MRP_init = [0.1 0.2 0.3]; % Modified Rodrigues Parameters
init_data.SC_omega_init = [0 0 0.001]; % [rad/sec] Angular velocity

% Convert MRP to quaternion
init_data.SC_e_init = init_data.SC_MRP_init/norm(init_data.SC_MRP_init);
init_data.SC_Phi_init = 4*atand(init_data.SC_MRP_init(1)/init_data.SC_e_init(1)); % [deg]
init_data.SC_beta_v_init = init_data.SC_e_init * sind(init_data.SC_Phi_init/2);
init_data.SC_beta_4_init = cosd(init_data.SC_Phi_init/2);

init_data.attitude = [init_data.SC_beta_v_init, init_data.SC_beta_4_init]; % [quaternion]
init_data.attitude = func_quaternion_properize(init_data.attitude); % [quaternion] proper
init_data.angular_velocity = init_data.SC_omega_init;
```

Alternatively, you can specify quaternions directly:


```
% Method 2: Direct quaternion specification
init_data.attitude = [0, 0, 0, 1]; % Identity quaternion (no rotation)
init_data.angular_velocity = [0, 0, 0]; % [rad/sec] No initial rotation
```

The attitude dynamics mode determines how the orientation will evolve:

```
init_data.mode_true_SC_attitude_dynamics_selector = 'Rigid';
```

Currently, MuSCAT only supports the 'Rigid' mode, which implements standard rigid body dynamics. After configuration, create the attitude dynamics and control object:

```
mission.true_SC{i_SC}.true_SC_adc = True_SC_ADC(init_data, mission);
```

2.4.7.3.3 Simulation Impact The initial state significantly influences the simulation:

- **Orbital Period and Evolution:** Initial position and velocity determine the spacecraft's orbit, affecting visibility of ground stations, targets, and available sunlight
- **Pointing Capabilities:** Initial attitude affects which sensors can view their targets and which solar panels receive sunlight
- **Thermal Conditions:** Orientation relative to the Sun impacts thermal conditions
- **Communication Opportunities:** Position influences when communication with Earth is possible
- **Scientific Observations:** Initial state determines when observation targets are visible

When implementing your mission, carefully consider the initial state based on mission objectives, launch conditions, and operational requirements.

2.4.8 Configuring Spacecraft Subsystems

Configure various spacecraft subsystems such as power, data handling, communications, and sensors:

2.4.8.1 Power Subsystem

```
%% Initialize Spacecraft's Power
init_data = [];
init_data.power_loss_rate = 0.05; % [float] 5% power loss in distribution and conversion
mission.true_SC{i_SC}.true_SC_power = True_SC_Power(init_data, mission);

%% Initialize Spacecraft's Solar Panels
for i_HW = 1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_solar_panel
    init_data = [];
    init_data.instantaneous_power_consumed = 0.01; % [W]
    init_data.instantaneous_data_rate_generated = (1e-3)*8; % [kbps]

    % Define solar panel geometry
    init_data.shape_model = [];
    init_data.shape_model.Vertices = [0 0 0; 0.2 0 0; 0.2 0 -0.6; 0 0 -0.6];
```

```
init_data.shape_model.Faces = [1 2 3; 1 4 3];
init_data.shape_model.Face_reflectance_factor_solar_cell_side = [0.01; 0.01];
init_data.shape_model.Face_reflectance_factor_opposite_side = [0.5; 0.5];
init_data.shape_model.Face_orientation_solar_cell_side = [0 -1 0];
init_data.shape_model.type = 'cuboid';

init_data.mass = 0.24; % [kg]
init_data.type = 'passive_deployed';
init_data.packing_fraction = 0.74; % Packing fraction of solar cells
init_data.solar_cell_efficiency = 0.28; % Efficiency of each solar cell

mission.true_SC{i_SC}.true_SC_solar_panel{i_HW} = True_SC_Solar_Panel(init_data, mission);
end

%% Initialize Spacecraft's Battery
for i_HW = 1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_battery
    init_data = [];
    init_data.maximum_capacity = 40; % [W hr]
    init_data.charging_efficiency = 0.96; % [float <= 1]
    init_data.discharging_efficiency = 0.96; % [float <= 1]
    init_data.instantaneous_power_consumed = 1e-4; % [W]
    init_data.instantaneous_data_rate_generated = (1e-3)*8; % [kbps]

    mission.true_SC{i_SC}.true_SC_battery{i_HW} = True_SC_Battery(init_data, mission, i_HW);
end
```

2.4.8.2 Data Handling Subsystem

```
%% Initialize Spacecraft's Data Handling
init_data = [];
init_data.mode_true_SC_data_handling_selector = 'Generic';
mission.true_SC{i_SC}.true_SC_data_handling = True_SC_Data_Handling(init_data, mission);

%% Initialize Spacecraft's Onboard Memory
for i_HW = 1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_onboard_memory
    init_data = [];
    init_data.maximum_capacity = 1e6; % [kb]
    init_data.instantaneous_power_consumed = 1; % [W]
    init_data.instantaneous_data_rate_generated = (1e-3)*8; % [kbps]

    mission.true_SC{i_SC}.true_SC_onboard_memory{i_HW} = True_SC_Onboard_Memory(init_data, mission, i_HW);
end
```

2.4.8.3 Communication Subsystem

```
%% Initialize Spacecraft's Radio Antenna
for i_HW = 1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_radio_antenna
    init_data = [];
    init_data.location = [0 1 0]; % [unit vector] antenna physical axis in Body frame
```

```
init_data.orientation = [0 0 1]; % [unit vector] antenna pointing direction

% Antenna parameters
init_data.antenna_type = "dipole";
init_data.antenna_gain = 28.1;          % [dB]
init_data.antenna_frequency = 8450;     % [MHz]
init_data.tx_line_loss = 1;             % [dB]
init_data.noise_temperature = 100;      % [K]
init_data.maximum_data_rate = 1000;     % [kbps]
init_data.TX_power_consumed = 50;       % [W]
init_data.RX_power_consumed = 25;       % [W]

mission.true_SC{i_SC}.true_SC_radio_antenna{i_HW} = True_SC_Radio_Antenna(init_data,
end

%% Spacecraft Communication Links Configuration
for i_HW = 1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_communication_1
    init_data = [];

    if i_HW == 1
        % Downlink: Spacecraft to Earth
        init_data.TX_spacecraft = i_SC;
        init_data.TX_spacecraft_Radio_HW = 1;
        init_data.RX_spacecraft = 0;          % Ground Station
        init_data.RX_spacecraft_Radio_HW = 1;
        init_data.given_data_rate = 360;      % [kbps]
    else
        % Uplink: Earth to Spacecraft
        init_data.TX_spacecraft = 0;          % Ground Station
        init_data.TX_spacecraft_Radio_HW = 1;
        init_data.RX_spacecraft = i_SC;
        init_data.RX_spacecraft_Radio_HW = 1;
        init_data.given_data_rate = 0;        % [kbps]
    end

    mission.true_SC{i_SC}.true_SC_communication_link{i_HW} = True_SC_Communication_Link(i
end
```

2.4.8.4 Sensors and Actuators

Configure sensors (cameras, star trackers, IMUs) and actuators (thrusters, reaction wheels):

```
%% Initialize Spacecraft's Cameras
for i_HW = 1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_camera
    init_data = [];
    init_data.instantaneous_power_consumed = 10; % [W]
    init_data.mode_true_SC_camera_selector = 'Simple';
    init_data.measurement_wait_time = 60; % [sec]
```

```
init_data.location = [0.3 0.1 0.05]; % [m]
init_data.orientation = [1 0 0]; % [unit vector]
init_data.orientation_up = [0 0 1]; % [unit vector]

init_data.resolution = [512 512]; % [x y] pixel
init_data.field_of_view = 10; % [deg]
init_data.flag_show_camera_plot = 0;
init_data.flag_show_stars = 1;

mission.true_SC{i_SC}.true_SC_camera{i_HW} = True_SC_Camera(init_data, mission, i_SC,
end

%% Initialize Spacecraft's Star Trackers
for i_HW = 1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_star_tracker
    init_data = [];
    init_data.instantaneous_power_consumed = 1.5; % [W]
    init_data.mode_true_SC_star_tracker_selector = 'Simple with Sun outside FOV';
    init_data.measurement_wait_time = 0.1; % [sec]
    init_data.measurement_noise = 2e-4; % [rad]
    init_data.field_of_view = 90; % [deg]

    init_data.location = [0.3 0.15 0.05]; % [m]
    init_data.orientation = [1 0 0]; % [unit vector]

    mission.true_SC{i_SC}.true_SC_star_tracker{i_HW} = True_SC_Star_Tracker(init_data, mi
end

%% Initialize Spacecraft's Reaction Wheels
for i_HW = 1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_reaction_wheel
    init_data = [];
    init_data.location = [0,0,0];
    init_data.radius = (43e-3)/2; % [m]
    init_data.mass = 0.137; % [kg]
    init_data.max_angular_velocity = 6500*2*pi/60; % [rad/s]
    init_data.max_torque = 3.2*1e-3; % [Nm]

    % Set orientation based on configuration (3 or 4 wheels)
    if mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_reaction_wheel == 3
        % 3-wheel configuration along principal axes
        switch i_HW
            case 1
                init_data.orientation = [1, 0, 0]; % X-axis
            case 2
                init_data.orientation = [0, 1, 0]; % Y-axis
            case 3
                init_data.orientation = [0, 0, 1]; % Z-axis
        end
    end
end
```

```
    mission.true_SC{i_SC}.true_SC_reaction_wheel{i_HW} = True_SC_Reaction_Wheel(init_data,  
end
```

2.4.9 Flight Software Configuration

The final step is to configure the flight software components that control the spacecraft. Each software component serves a specific purpose in the autonomous operation of the spacecraft.

2.4.9.1 Executive Software

The Executive software was described in detail in Section 4.6.1. To briefly recap, it is responsible for determining the spacecraft's operating mode and coordinating subsystem activities. When creating a custom mission, you should:

1. Define the operating modes relevant to your mission in your mission configuration file
2. Create a custom implementation function in `Software_SC_Executive.m`
3. Set the `mode_software_SC_executive_selector` parameter to your custom function name

See Section 4.6.1 for implementation examples and code samples.

2.4.9.2 Attitude & Orbit Estimation

These components determine the spacecraft's current attitude and position:

```
%% Spacecraft Software: Attitude Estimation Configuration  
init_data = [];  
init_data.mode_software_SC_estimate_attitude_selector = 'Truth';  
mission.true_SC{i_SC}.software_SC_estimate_attitude =  
    Software_SC_Estimate_Attitude(init_data, mission, i_SC);  
  
%% Spacecraft Software: Orbit Estimation Configuration  
init_data = [];  
init_data.mode_software_SC_estimate_orbit_selector = 'TruthWithErrorGrowth';  
mission.true_SC{i_SC}.software_SC_estimate_orbit =  
    Software_SC_Estimate_Orbit(init_data, mission, i_SC);
```

For initial mission development, you can use the 'Truth' estimators that simply read the actual spacecraft state. For more realistic simulations, you can implement custom estimators that process sensor data.

2.4.9.3 Orbit & Attitude Control

The control components determine how to move the spacecraft to desired states:

```
%% Spacecraft Software: Orbit Control Configuration  
init_data = [];  
init_data.max_time_before_control = 0.5*60*60 + 900; % 45 minutes  
init_data.mode_software_SC_control_orbit_selector = 'YourMission';
```

```
mission.true_SC{i_SC}.software_SC_control_orbit =  
    Software_SC_Control_Orbit(init_data, mission, i_SC);  
  
%% Spacecraft Software: Attitude Control Configuration  
init_data = [];  
init_data.mode_software_SC_control_attitude_selector = 'YourMission Control';  
init_data.control_gain = [1 0.2]; % Controller gain parameters  
mission.true_SC{i_SC}.software_SC_control_attitude =  
    Software_SC_Control_Attitude(init_data, mission, i_SC);
```

You'll need to implement custom control algorithms that match the mode selector names provided here.

2.4.9.4 Communication & Resource Management

These components manage communication opportunities and onboard resources:

```
%% Spacecraft Software: Communication Configuration  
init_data = [];  
init_data.mode_software_SC_communication_selector = 'YourMission';  
init_data.attitude_error_threshold_deg = 1; % Max attitude error for comms  
mission.true_SC{i_SC}.software_SC_communication =  
    Software_SC_Communication(init_data, mission, i_SC);
```

The communication software determines when to establish links with ground stations and manages the flow of data to and from the spacecraft.

2.4.10 Final Initialization and Simulation Execution

After configuring all subsystems, several final initialization steps must be performed before running the simulation. These steps ensure that all spacecraft properties are properly calculated and that the simulation environment is ready:

```
%% Final Things to Do Before Running the Simulation  
  
% Initialize mass properties  
func_update_SC_body_total_mass_COM_MI(mission.true_SC{i_SC}.true_SC_body);  
  
% Initialize power and data handling storage  
func_initialize_store_HW_power_consumed_generated(mission.true_SC{i_SC}.true_SC_power, mi  
func_initialize_store_HW_data_generated_removed(mission.true_SC{i_SC}.true_SC_data_handli  
  
% Clean up temporary variables  
clear init_data i_SC i_HW i_target  
  
% Visualize the spacecraft in 3D  
func_visualize_SC(mission.storage, mission, true);  
  
% Save initial state
```

```
save([mission.storage.output_folder, 'all_data.mat'], '-v7.3')

%% Execute Main File
run main_v3.m

%% Save All Data and Generate Plots
save([mission.storage.output_folder, 'all_data.mat'], '-v7.3')
func_visualize_simulation_data(mission.storage, mission);
```

The initialization process includes calculating the total mass, center of mass, and moment of inertia for the spacecraft body, setting up storage for power and data handling metrics, and cleaning up temporary variables used during configuration. The spacecraft is then visualized in 3D to provide a visual confirmation of the configuration.

After initialization, the main simulation file (`main_v3.m`) is executed, which runs the simulation according to the configured parameters. Once the simulation is complete, all data is saved to the specified output folder, and visualization functions are called to generate plots of the simulation results.

2.5 Understanding SPICE Integration

MuSCAT uses NASA's SPICE toolkit for accurate ephemeris calculations, providing precise positions and velocities of solar system bodies and spacecraft. This section explains how SPICE is integrated into MuSCAT and how to use it effectively for your mission.

2.5.1 What is SPICE?

SPICE (Spacecraft, Planet, Instrument, C-matrix, Events) is a NASA toolkit developed by the Navigation and Ancillary Information Facility (NAIF) at JPL. It provides essential information for mission design, planning, and science data analysis for space science missions. SPICE consists of data files called "kernels" and a suite of software tools that read and interpret these kernels to provide spacecraft and planetary ephemerides, instrument pointing information, time conversions, and other critical mission data.

2.5.2 Why MuSCAT Uses SPICE

MuSCAT integrates SPICE for several critical reasons:

- **Accurate Ephemerides:** SPICE provides high-precision positions and velocities of solar system bodies based on the latest planetary ephemerides (like DE430 or DE440), ensuring that simulations accurately represent the gravitational influences of planets and other bodies.
- **Realistic Trajectory Modeling:** Enables detailed simulation of spacecraft trajectories, including complex orbital maneuvers and gravity assists, which is essential for mission planning and validation.
- **Time System Conversions:** Provides robust time system conversions between various time standards (UTC, TDB, TDT, etc.), which is crucial for correlating events across different reference frames and mission phases.

- **Reference Frame Transformations:** Handles complex coordinate transformations between different reference frames (J2000, ICRF, body-fixed, etc.), allowing for accurate representation of spacecraft orientation and position relative to various celestial bodies.
- **Industry Standard:** SPICE is the de facto standard for deep space mission design at NASA and other space agencies, making MuSCAT compatible with industry practices and facilitating data exchange with other mission analysis tools.
- **Validation and Verification:** Using SPICE allows MuSCAT simulations to be validated against real mission data and other industry-standard tools, increasing confidence in simulation results.

2.5.3 SPICE Navigation Dynamics Mode

When using the 'SPICE' navigation dynamics mode in MuSCAT, the spacecraft's position and velocity are directly obtained from SPICE kernels rather than being propagated using orbital dynamics equations. This approach:

- Ensures consistency with mission design trajectories
- Allows for simulation of complex trajectories that may be difficult to model with standard orbital dynamics
- Provides a ground truth reference for validating other dynamics models
- Simplifies the simulation of multi-body trajectories (e.g., lunar or interplanetary missions)

2.5.4 SPICE Kernel Types Used in MuSCAT

MuSCAT uses several types of SPICE kernels:

- **SPK (Spacecraft and Planet Kernels):** Contain ephemeris data for spacecraft and celestial bodies. These files define the positions and velocities of objects as functions of time.
- **LSK (Leapseconds Kernels):** Provide information about leap seconds, allowing accurate conversion between different time systems.
- **PCK (Planetary Constants Kernels):** Contain physical and cartographic constants for planets and satellites, such as size, shape, and orientation.
- **FK (Frame Kernels):** Define reference frames needed for coordinate transformations.
- **IK (Instrument Kernels):** Contain geometric and operational parameters of instruments (used for more advanced simulations).

2.5.5 SPICE Setup in MuSCAT

To use SPICE in your MuSCAT mission:

1. Ensure the SPICE toolkit (MICE for MATLAB) is correctly installed in `MuSCAT_Supporting_Files/SP`
2. Collect necessary SPICE kernels for your mission:

- Leapseconds kernel (LSK) for time conversions (e.g., `naif0012.tls`)
- Planetary ephemeris kernel (SPK) for solar system bodies (e.g., `de430.bsp`)
- Spacecraft trajectory kernel (SPK) for your spacecraft (e.g., `YourMission.bsp`)
- Frame kernel (FK) if using custom reference frames

3. Load the required kernels in your mission file:

```
% Load necessary SPICE kernels
cspice_furnsh('../..../MuSCAT_Supporting_Files/SPICE/naif0012.tls'); % Leapsecond
cspice_furnsh('../..../MuSCAT_Supporting_Files/SPICE/de430.bsp'); % Planetary
init_data.spice_filename = '../..../MuSCAT_Supporting_Files/SC_data/YourMission/tr
cspice_furnsh(init_data.spice_filename); % Your spacecraft trajectory
```

4. Retrieve position and velocity data:

```
init_data.spice_name = '-123'; % SPICE ID for your spacecraft (negative integer)
init_data.SC_pos_vel = cspice_spkezr(init_data.spice_name, mission.true_time.dat
                                'J2000', 'NONE', 'SUN');
init_data.position = init_data.SC_pos_vel(1:3)'; % [km]
init_data.velocity = init_data.SC_pos_vel(4:6)'; % [km/sec]
```

5. Specify SPICE mode in navigation dynamics (if using SPICE for position/velocity updates):

```
init_data.mode_true_SC_navigation_dynamics_selector = 'SPICE';
```

2.5.6 Creating SPICE Kernels for Your Mission

You can create your own SPICE SPK kernel for a custom spacecraft trajectory:

1. Generate a trajectory using your preferred method (analytical, numerical integration, etc.)
2. Convert the trajectory to SPICE format using SPICE utilities:
 - For MATLAB, use MICE functions like `cspice_spkw08` or `cspice_spkw09`
 - For standalone processing, use the SPICE utility `mkspk`
3. Format the trajectory data as a time series of position and velocity vectors
4. Assign a NAIF ID for your spacecraft (usually a negative integer)
5. Create the SPK file with appropriate metadata (reference frame, time coverage, etc.)
6. Place your SPK file in the appropriate directory: `MuSCAT_Supporting_Files/SC_data/YourMission/`

2.5.7 SPICE Integration with Main Simulation Loop

During simulation, SPICE integration occurs at several key points:

1. **Initialization:** SPICE kernels are loaded and initial states are obtained
2. **Time Updates:** Each simulation step updates the current epoch used for SPICE queries
3. **Navigation Updates:** When using SPICE mode, the `func_main_true_SC_navigation` function retrieves updated position/velocity directly from SPICE
4. **Environmental Calculations:** SPICE may be used to determine positions of other bodies for gravity calculations
5. **Ground Station Visibility:** SPICE data helps determine line-of-sight between spacecraft and ground stations

This integration provides a seamless interface between MuSCAT's simulation environment and the high-fidelity ephemeris data provided by SPICE, ensuring accurate representation of spacecraft trajectories and celestial body positions throughout the simulation.

2.6 Creating Custom Flight Software

Flight software defines the autonomous behavior of your spacecraft. In MuSCAT, flight software is implemented as MATLAB classes in the `Software_SC` directory. This section explains how to create custom flight software for your mission.

2.6.1 Executive Software

The Executive software was described in detail in Section 4.6.1. To briefly recap, it is responsible for determining the spacecraft's operating mode and coordinating subsystem activities. When creating a custom mission, you should:

1. Define the operating modes relevant to your mission in your mission configuration file
2. Create a custom implementation function in `Software_SC_Executive.m`
3. Set the `mode_software_SC_executive_selector` parameter to your custom function name

See Section 4.6.1 for implementation examples and code samples.

2.6.2 Attitude & Orbit Controllers

Similarly, you can create custom orbit and attitude controllers for your mission:

1. Add your custom controller implementation to the appropriate file (`Software_SC_Control_Orbit.m` or `Software_SC_Control_Attitude.m`)
2. Implement the control logic specific to your mission requirements
3. Reference your controller in the mission file:

```
init_data.mode_software_SC_control_orbit_selector = 'YourMission';  
mission.true_SC{i_SC}.software_SC_control_orbit = Software_SC_Control_Orbit(init
```

2.7 Simulation Execution and Analysis

Once your mission configuration is complete, the simulation is executed by running the `main_v3.m` script. This script contains the main time loop that updates all components of the mission at each time step.

2.7.1 Main Simulation Loop

The main simulation loop in `main_v3.m` proceeds as follows:

1. Update simulation time and date
2. Update solar system and target bodies
3. For each spacecraft:
 - Update environmental effects (solar radiation pressure, gravity gradient)
 - Update spacecraft body, position, and velocity
 - Update onboard clock and computer systems
 - Execute the Executive software to determine operating mode
 - Update all sensors, actuators, and subsystems
 - Run the attitude dynamics loop at a higher frequency
 - Update communication systems
 - Update power and data handling systems
4. Update ground station systems
5. Save data and update visualizations

2.7.2 Visualizing Results

MuSCAT provides comprehensive visualization tools to analyze mission performance:

- `func_visualize_SC`: Creates a 3D visualization of the spacecraft
- `func_visualize_simulation_data`: Generates plots for various subsystems
- Real-time visualization can be enabled with `flag_realtime_plotting = 1`

Key visualizations include:

- Spacecraft configuration and ConOps
- Orbit and attitude dynamics
- Power generation and consumption
- Data handling and communication performance
- Sensor and actuator performance

2.8 Advanced Topics

2.8.1 Creating Custom Hardware Components

If the built-in hardware models don't meet your needs, you can create custom components. This should be done without modifying the core MuSCAT files, following the extension patterns described earlier.

2.8.1.1 Custom Hardware Component Development Steps

1. Create a new MATLAB class file in your mission-specific directory that inherits from the appropriate parent class:

```
classdef Your_Custom_Sensor < True_SC_Sensor
    % Your custom sensor implementation
    properties
        % Custom properties specific to your sensor
        custom_parameter_1
        custom_parameter_2
    end

    methods
        % Constructor
        function obj = Your_Custom_Sensor(init_data, mission, i_SC, i_HW)
            % Call parent constructor
            obj@True_SC_Sensor(init_data, mission, i_SC, i_HW);

            % Initialize custom properties
            obj.custom_parameter_1 = init_data.custom_parameter_1;
            obj.custom_parameter_2 = init_data.custom_parameter_2;
        end
    end
end
```

2. Create a corresponding `func_main_your_custom_sensor` function that follows the standard MuSCAT update pattern:

```
function func_main_your_custom_sensor(obj, mission, i_SC, i_HW)
    % Update the custom sensor state based on current mission state

    % Your custom update logic here
    % ...

    % Store data if needed
    func_store_data(obj, mission);
end
```

3. Add your component to the simulation loop by extending the appropriate hardware update section in a copy of `main_v3.m` that you create for your mission:

```
%% Custom Hardware Update
for i_SC = 1:1:mission.num_SC
    for i_HW = 1:1:mission.true_SC{i_SC}.num_your_custom_sensor
        func_main_your_custom_sensor(mission.true_SC{i_SC}.your_custom_sensor{i_
                                mission, i_SC, i_HW);
    end
end
```

4. In your mission file, instantiate your custom hardware:

```
% Add custom hardware to the hardware complement
init_data.num_hardware_exists.num_your_custom_sensor = 2;

% Create the custom sensor objects
for i_HW = 1:1:init_data.num_hardware_exists.num_your_custom_sensor
    init_data = [];
    init_data.custom_parameter_1 = value1;
    init_data.custom_parameter_2 = value2;

    mission.true_SC{i_SC}.your_custom_sensor{i_HW} =
        Your_Custom_Sensor(init_data, mission, i_SC, i_HW);
end
```

2.8.1.2 Integration with MuSCAT's Core Features

To ensure your custom component works seamlessly with MuSCAT:

- **Power Subsystem Integration:** Implement proper power consumption tracking by setting `instantaneous_power_consumed` and updating it during operation.
- **Data Handling Integration:** Set `instantaneous_data_rate_generated` to track data generation and ensure it's properly routed through the data handling subsystem.
- **Visualization Support:** Implement `func_visualize` methods if your component has visual representation.
- **Error Handling:** Include appropriate error checks and failure modes to enhance simulation realism.
- **Documentation:** Thoroughly document your custom component's interfaces, parameters, and behaviors.

By creating custom components in this way, you maintain compatibility with future MuSCAT updates while extending its capabilities to meet your specific mission requirements.

2.8.2 Multi-Spacecraft Missions

To simulate missions with multiple spacecraft:

1. Set `mission.num_SC` to the desired number of spacecraft
2. Configure each spacecraft using a loop over `i_SC`
3. Implement inter-spacecraft communication using communication links

2.8.3 Monte Carlo Simulations

For uncertainty analysis, you can run Monte Carlo simulations:

1. Create a wrapper script that calls your mission file multiple times
2. Vary key parameters according to your uncertainty model
3. Collect and analyze the results across all simulations

2.9 Conclusion

MuSCAT provides a flexible, modular framework for simulating complex spacecraft missions. By following the steps outlined in this chapter, you can implement your own custom missions, from initial concept to detailed simulation and analysis.

The implementation process involves several key steps:

1. **Mission Definition:** Set up the basic parameters like mission name, number of spacecraft, and target bodies.
2. **Time and Storage Configuration:** Configure the dual-loop time steps to properly handle both orbital and attitude dynamics at appropriate temporal resolutions.
3. **Environment Setup:** Configure the star catalog, solar system bodies, target bodies, and ground stations that form the operational context for your mission.
4. **Spacecraft Configuration:** Define the physical properties, hardware complement, initial position, and attitude for each spacecraft in your mission.
5. **Subsystem Configuration:** Set up power, data handling, communications, sensors, and actuators with the specific properties required for your mission.
6. **Flight Software Implementation:** Configure the executive, estimation, and control algorithms that will govern the autonomous behavior of your spacecraft.
7. **Simulation Execution:** Run the main simulation loop to simulate your mission over the specified time period.
8. **Results Analysis:** Analyze the simulation results using MuSCAT's visualization tools to evaluate mission performance.

MuSCAT's modular architecture allows for extensive customization at every level. You can:

- Create new hardware components by implementing additional classes in the appropriate directories
- Develop custom flight software algorithms to implement novel autonomous behaviors
- Simulate complex multi-spacecraft missions with varied objectives and capabilities
- Perform trade studies by varying parameters and analyzing the impacts on mission performance
- Validate mission concepts and requirements before detailed design

The object-oriented nature of MuSCAT means that each component is self-contained with well-defined interfaces, making it straightforward to extend the functionality without disrupting existing capabilities. This modularity also facilitates incremental development, allowing you to start with a simple mission model and progressively add complexity as your understanding evolves.

By leveraging NASA’s SPICE toolkit for ephemeris calculations, MuSCAT ensures high-fidelity position and velocity data for spacecraft and celestial bodies, enabling realistic simulation of mission scenarios in the complex dynamical environment of space.

Whether you’re designing a simple Earth-orbiting satellite or a complex interplanetary mission with multiple spacecraft, MuSCAT provides the tools and framework to model, simulate, and evaluate your mission concept efficiently and effectively.

2.10 Troubleshooting and Best Practices

2.10.1 Common Issues and Solutions

When implementing missions in MuSCAT, you may encounter several common issues. This section provides guidance on identifying and resolving these problems:

- **Memory Errors:** For large simulations with many time steps or spacecraft:
 - Increase the storage intervals (`time_step_storage` and `time_step_storage_attitude`)
 - Use the `clear` command strategically to free memory during long simulations
 - Consider breaking the simulation into multiple segments and combining results afterward
- **SPICE-Related Errors:** When working with SPICE:
 - Ensure MICE is properly installed and on the MATLAB path
 - Verify kernel coverage spans your entire simulation time period
 - Check for NAIF ID conflicts between different objects
 - Use `cspice_furnsh` with absolute paths to avoid path-related issues
- **Simulation Instability:** If your simulation becomes unstable:
 - Reduce the time step, especially for attitude dynamics
 - Check for physical inconsistencies (e.g., mismatched units, unrealistic parameters)
 - Verify that actuator limitations (e.g., maximum torque) are realistic
 - Implement controllers with appropriate stability margins

- **Missing Data in Results:** If expected data is missing:
 - Verify that storage flags are enabled for relevant components
 - Check that sensor/actuator update times align with storage times
 - Ensure `func_store_data` is called in all custom components

2.10.2 Performance Optimization

For complex missions or Monte Carlo simulations, performance optimization becomes critical:

1. Time Step Optimization:

- Use the largest time step that maintains accuracy for your specific mission
- Consider variable time stepping for different mission phases
- Balance the attitude time step with the dynamics of your spacecraft

2. Hardware Selection:

- Only include hardware components necessary for your mission
- Use a reasonable number of sensors/actuators (e.g., 4-6 sun sensors rather than dozens)
- Group hardware with similar functions when possible

3. Vectorization:

- Rewrite custom component code to use MATLAB's vectorized operations
- Avoid loops when matrix/vector operations can accomplish the same task
- Pre-allocate arrays for storing time-series data

4. Visualization:

- Disable real-time visualization during long simulations
- Generate plots after the simulation completes rather than during execution
- Consider lower-resolution shape models for faster 3D rendering

2.10.3 Units and Conventions

MuSCAT uses a consistent set of units and conventions throughout the codebase:

- **Time:** Seconds (s) for simulation time; UTC for absolute dates
- **Length:** Meters (m) for spacecraft dimensions; Kilometers (km) for orbital distances
- **Mass:** Kilograms (kg)
- **Angles:** Radians (rad) internally
- **Angular Velocity:** Radians per second (rad/s)
- **Force:** Newtons (N)

- **Torque:** Newton-meters (N·m)
- **Power:** Watts (W)
- **Energy:** Watt-hours (W·hr) for batteries
- **Data:** Kilobits (kb) for storage; Kilobits per second (kbps) for rates
- **Reference Frames:**
 - J2000 for inertial references
 - Body-fixed frames for spacecraft-relative quantities

Consistent use of these units is essential for correct simulation behavior.

2.10.4 Glossary of Terms

- **ADC:** Attitude Determination and Control
- **ConOps:** Concept of Operations
- **DCM:** Direction Cosine Matrix
- **DSN:** Deep Space Network
- **Eb/N0:** Energy per bit to noise density ratio
- **FK:** Frame Kernel (SPICE)
- **IMU:** Inertial Measurement Unit
- **LSK:** Leapseconds Kernel (SPICE)
- **MICE:** MATLAB Interface to SPICE
- **MRP:** Modified Rodrigues Parameters
- **NAIF:** Navigation and Ancillary Information Facility
- **PCK:** Planetary Constants Kernel (SPICE)
- **SPK:** Spacecraft and Planet Kernel (SPICE)
- **SRP:** Solar Radiation Pressure

2.10.5 Known Limitations

As with any simulation framework, MuSCAT has some known limitations:

- **Physical Fidelity:** Some physical effects are simplified or not modeled:
 - Thermal effects on spacecraft materials and instruments
 - Detailed propellant slosh dynamics
 - Advanced radiation effects on electronics
 - Detailed structural flexibility
- **Scalability:** Performance may degrade with very complex missions:
 - Formations with many (≥ 10) spacecraft
 - Very long duration missions (≥ 1 year) at high temporal resolution
- **Navigation Models:** Some specialized navigation techniques lack detailed models:
 - Optical navigation using small bodies
 - Inter-spacecraft relative navigation
 - GPS-like navigation in cislunar space
- **Environment Models:** Some environmental effects have simplified models:
 - Higher-order gravitational terms
 - Atmospheric drag variation with solar activity
 - Detailed magnetic field modeling

Users should be aware of these limitations when interpreting simulation results and consider supplementing MuSCAT with specialized tools for detailed analysis of these effects when necessary.

2.11 Practical Examples and Design Patterns

This section provides concrete examples of common tasks and design patterns to help you implement your missions effectively.

2.11.1 Common Mode Implementation Patterns

The following examples illustrate typical implementations for common spacecraft operating modes:

2.11.1.1 Sun-Safe Mode

This mode orients the spacecraft to maximize solar panel exposure while keeping sensitive instruments safe:

```
% In your Executive implementation function
if strcmp(obj.this_sc_mode, 'Sun-Safe')
    % Get Sun direction in spacecraft body frame
    sun_body = mission.true_SC{i_SC}.true_SC_navigation.sun_direction_body;

    % Set attitude target to align solar panels with Sun
    % Assuming Z-axis is normal to solar panels
    target_quaternion = func_quaternion_from_two_vectors([0 0 1], sun_body);

    % Point solar panels at Sun with moderate rotation rate
    mission.true_SC{i_SC}.software_SC_control_attitude.target_attitude = target_quaternion;
    mission.true_SC{i_SC}.software_SC_control_attitude.target_rate = [0 0 0];

    % Disable components to save power
    mission.true_SC{i_SC}.true_SC_camera{1}.flag_executive = 0;
    mission.true_SC{i_SC}.true_SC_micro_thruster{1}.flag_executive = 0;

    % Enable power-critical components
    mission.true_SC{i_SC}.software_SC_estimate_attitude.flag_executive = 1;
    mission.true_SC{i_SC}.software_SC_control_attitude.flag_executive = 1;
end
```

2.11.1.2 Science Observation Mode

This mode points instruments at a target of interest:

```
% In your Executive implementation function
if strcmp(obj.this_sc_mode, 'Science Observation')
    % Get target direction in inertial frame
    target_inertial = mission.true_SC{i_SC}.true_SC_navigation.target_direction_inertial;

    % Convert to required quaternion (assuming camera points along X-axis)
    target_quaternion = func_quaternion_from_two_vectors([1 0 0], target_inertial);

    % Point instrument and stabilize
    mission.true_SC{i_SC}.software_SC_control_attitude.target_attitude = target_quaternion;
    mission.true_SC{i_SC}.software_SC_control_attitude.target_rate = [0 0 0];

    % Enable science instruments
    mission.true_SC{i_SC}.true_SC_camera{1}.flag_executive = 1;

    % Log start of observation if mode just activated
    if ~strcmp(obj.data.previous_mode, 'Science Observation')
        disp(['Science observation started at t = ', ...
            num2str(mission.true_time.time), ' seconds']);
        obj.data.observation_start_time = mission.true_time.time;
    end
end
```

2.11.2 Implementing Common Mission Types

The following patterns demonstrate implementations for common mission types:

2.11.2.1 Earth-Orbiting Remote Sensing Satellite

For an Earth-observing satellite, consider this implementation pattern:

```
%% Mission Definition
mission = [];
mission.name = 'EarthObsSat';
mission.num_SC = 1;
mission.num_target = 1; % Earth as target
mission.frame = 'Absolute';

%% Initialize Spacecraft's Position and Velocity
init_data = [];
% Sun-synchronous orbit at 700 km altitude
orbit_altitude = 700; % [km]
earth_radius = 6378.1; % [km]
orbit_radius = earth_radius + orbit_altitude;
orbit_velocity = sqrt(398600.4415 / orbit_radius); % [km/s]

% Position at ascending node
init_data.position = [0, -orbit_radius, 0]; % [km]
init_data.velocity = [orbit_velocity, 0, 0]; % [km/s]
init_data.mode_true_SC_navigation_dynamics_selector = 'Absolute Dynamics';

% Key operational modes
init_data.sc_modes = {'Nadir Pointing', 'Target Imaging',
                    'Data Downlink', 'Safe Mode'};

% Payload-specific hardware
init_data.num_hardware_exists.num_camera = 2; % Multispectral + Panchromatic
init_data.num_hardware_exists.num_solar_panel = 2; % Two deployable panels
init_data.num_hardware_exists.num_star_tracker = 2; % Redundant attitude determination
init_data.num_hardware_exists.num_reaction_wheel = 4; % 4-wheel configuration
init_data.num_hardware_exists.num_magnetorquer = 3; % For wheel desaturation
```

2.11.2.2 Interplanetary Science Mission

For an interplanetary probe, use this implementation pattern:

```
%% Mission Definition
mission = [];
mission.name = 'MarsMission';
mission.num_SC = 1;
mission.num_target = 1; % Mars as target
mission.frame = 'Absolute';
```

```
%% SPICE-Based Trajectory
init_data = [];
init_data.spice_filename = '../..MuSCAT_Supporting_Files/SC_data/MarsMission/trajectory.
cspice_furnsh(init_data.spice_filename);
cspice_furnsh('../..MuSCAT_Supporting_Files/SPICE/de430.bsp'); % Planetary ephemeris

init_data.spice_name = '-123'; % SPICE ID for the spacecraft
init_data.SC_pos_vel = cspice_spkezr(init_data.spice_name, mission.true_time.date,
                                     'J2000', 'NONE', 'SUN');
init_data.position = init_data.SC_pos_vel(1:3)'; % [km]
init_data.velocity = init_data.SC_pos_vel(4:6)'; % [km/sec]
init_data.mode_true_SC_navigation_dynamics_selector = 'SPICE';

% Mission-specific modes
init_data.sc_modes = {'Cruise', 'TCM', 'Science',
                     'Mars Orbit Insertion', 'Communication', 'Safe Mode'};

% Deep space hardware
init_data.num_hardware_exists.num_high_gain_antenna = 1; % For long-distance comms
init_data.num_hardware_exists.num_camera = 3; % Navigation + Science instruments
init_data.num_hardware_exists.num_chemical_thruster = 1; % Main propulsion
init_data.num_hardware_exists.num_reaction_wheel = 4; % Attitude control
```

2.11.3 Common Attitude Control Implementations

The following examples show implementations for common attitude control laws:

2.11.3.1 PD Controller

A simple Proportional-Derivative controller for attitude:

```
function obj = func_software_SC_control_attitude_PD(obj, mission, i_SC)
    % Get current attitude error quaternion
    att_error_q = func_quaternion_error(mission.true_SC{i_SC}.software_SC_estimate_attitu
                                       obj.target_attitude);

    % Convert quaternion error to angle-axis representation
    [error_axis, error_angle] = func_quaternion_to_axis_angle(att_error_q);

    % Calculate error vectors
    att_error_vec = error_axis * error_angle;
    rate_error = mission.true_SC{i_SC}.software_SC_estimate_attitude.angular_velocity - c

    % PD controller with gains
    Kp = obj.control_gain(1); % Proportional gain
    Kd = obj.control_gain(2); % Derivative gain

    % Calculate desired control torque
    desired_torque = -Kp * att_error_vec - Kd * rate_error;
```

```
% Apply control to reaction wheels
for i_wheel = 1:mission.true_SC{i_SC}.true_SC_body.numHardwareExists.numReactionWheels
    % Get wheel axis
    wheel_axis = mission.true_SC{i_SC}.true_SC_reaction_wheel{i_wheel}.orientation;

    % Project desired torque onto wheel axis
    wheel_torque = dot(desired_torque, wheel_axis) * wheel_axis;

    % Set wheel torque (with limits)
    max_torque = mission.true_SC{i_SC}.true_SC_reaction_wheel{i_wheel}.max_torque;
    commanded_torque = min(max_torque, max(wheel_torque, -max_torque));

    mission.true_SC{i_SC}.true_SC_reaction_wheel{i_wheel}.input_torque = commanded_torque;
end
end
```

2.11.4 Custom Hardware Example: Laser Rangefinder

Below is an example of implementing a custom laser rangefinder for proximity operations:

```
classdef Custom_Laser_Rangefinder < True_SC_Sensor
    properties
        max_range           % Maximum detection range [m]
        min_range           % Minimum detection range [m]
        range_accuracy       % Range measurement accuracy [m]
        field_of_view        % Field of view [deg]
        target_reflectivity  % Target reflectivity factor [0-1]
        last_measurement     % Last valid range measurement [m]
        is_target_detected   % Flag indicating target detection
    end

    methods
        % Constructor
        function obj = Custom_Laser_Rangefinder(init_data, mission, i_SC, i_HW)
            % Call parent constructor
            obj@True_SC_Sensor(init_data, mission, i_SC, i_HW);

            % Initialize properties
            obj.max_range = init_data.max_range;
            obj.min_range = init_data.min_range;
            obj.range_accuracy = init_data.range_accuracy;
            obj.field_of_view = init_data.field_of_view;
            obj.target_reflectivity = init_data.target_reflectivity;
            obj.last_measurement = -1; % Invalid measurement
            obj.is_target_detected = 0;

            % Set standard properties
            obj.instantaneous_power_consumed = 2.5; % [W]
        end
    end
end
```

```
        obj.instantaneous_data_rate_generated = 0.1 * 8; % [kbps]
    end
end
end

% Corresponding update function
function func_main_custom_laser_rangefinder(obj, mission, i_SC, i_HW)
    % Skip if not active
    if ~obj.flag_executive
        obj.is_target_detected = 0;
        obj.last_measurement = -1;
        return;
    end

    % Get target position in spacecraft body frame
    target_pos_inertial = mission.true_target{1}.position;
    sc_pos_inertial = mission.true_SC{i_SC}.true_SC_navigation.position;
    sc_att_q = mission.true_SC{i_SC}.true_SC_adc.attitude;

    % Calculate relative position vector in body frame
    rel_pos_inertial = target_pos_inertial - sc_pos_inertial;
    rel_pos_body = func_quaternion_rotate_vector(sc_att_q, rel_pos_inertial);

    % Calculate range and direction
    true_range = norm(rel_pos_body);
    direction = rel_pos_body / true_range;

    % Check if target is within detector range and FOV
    sensor_axis = obj.orientation;
    angle_to_target = acosd(dot(sensor_axis, direction));

    % Determine if target is detected
    if true_range >= obj.min_range && true_range <= obj.max_range && ...
        angle_to_target <= obj.field_of_view/2

        % Target is within FOV and range limits
        obj.is_target_detected = 1;

        % Add noise to measurement based on accuracy
        noise = randn(1) * obj.range_accuracy;
        obj.last_measurement = true_range + noise;
    else
        % No valid detection
        obj.is_target_detected = 0;
        obj.last_measurement = -1;
    end

    % Store data
```

```
    func_store_data(obj, mission);  
end
```

These examples demonstrate typical implementation patterns for various MuSCAT components. You can use them as starting points for your own mission implementations, adapting them to your specific requirements.

Chapter 3

Environment Classes

3.1 Storage

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Class: Storage

Helps store all the data from the simulation

```
classdef Storage < handle
```

Properties

properties

[] Properties: Initialized Variables

```
time_step_storage % [sec] : Storage time step
time_step_storage_attitude % [sec] : Storage time step for attitude
dynamics loop (Optional)

flag_visualize_SC_attitude_orbit_during_sim % [Boolean] : 1 = Shows
the attitude and position during simulation (Optional)
wait_time_visualize_SC_attitude_orbit_during_sim % [sec] (Optional)
flag_visualize_past_SC_orbit_during_sim % [Boolean] : 1 = Shows the
entire orbit from the start of sim (Optional)
```

[] Properties: Variables Computed Internally

```
time_prev_storage % [sec] : Previous time when variables were stored #
num_storage_steps % [integer] : Number of storage variables #
flag_store_this_time_step % [Boolean] : 1 = Store, else dont store #
k_storage % [integer] : Storage counter variable #

time_prev_storage_attitude % [sec] : Previous time when attitude
variables were stored #
num_storage_steps_attitude % [integer] : Number of storage variables
for Attitude Dynamics Loop #
```

```

        flag_store_this_time_step_attitude % [Boolean] : 1 = Store, else dont
store, for Attitude Dynamics Loop #
        k_storage_attitude % [integer] : Storage counter variable, for
Attitude Dynamics Loop #

        prev_time_visualize_SC_attitude_orbit_during_sim % [sec]

        % Real-time plotting variables
        flag_realtime_plotting % [Boolean] : 1 = Enable real-time performance
plotting
        realtime_plot_handle % Handle to the real-time plot figure
        realtime_plot_last_update % [sec] : Time of last real-time plot update
        realtime_plot_update_interval % [sec] : Minimum time between real-time
plot updates
        realtime_plot_subhandles % Cell array of subplot handles for real-time
plotting

        % Initialize real-time visualization settings
        last_viz_update_time % Time of last visualization update
        viz_update_interval % Update visualization every 50 simulation
seconds (reduced from 100)

```

[] Properties: Other Useful Variables

```

        numerical_accuracy_factor % [float <= 1, but limit -> 1] : Used to
take care of issues arising due to numerical accuracy of integer computations
#

        plot_parameters % Parameters used for plotting
        % - color_array
        % - marker_array
        % - standard_font_size
        % - standard_font_type
        % - title_font_size
        % - flag_save_plots % [Boolean] 1: Save them (takes little time), 0:
Doesnt save them
        % - flag_save_video % [Boolean] 1: Save them (takes a lot more time),
0: Doesnt save them
        % - quiver_auto_scale_factor % [float] : scale factor used for quiver3

        output_folder % [Boolean] Folder to store all outputs

        flag_stop_sim % flag to stop simulation

        last_mode % Cell array to store the last mode of each spacecraft

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```
function obj = Storage(init_data, mission)

    if init_data.time_step_storage == 0
        % Use 0 to use the mission.true_time.time_step value
        obj.time_step_storage = mission.true_time.time_step; % [sec]

    else
        obj.time_step_storage = init_data.time_step_storage; % [sec]
    end

    obj.flag_store_this_time_step = 1;
    obj.time_prev_storage = mission.true_time.time; % [sec]
    obj.num_storage_steps = ceil( (mission.true_time.t_final -
mission.true_time.t_initial)/obj.time_step_storage ) + 1;
    obj.k_storage = 1;

    obj.last_viz_update_time = -inf; % Time of last visualization
update    obj.viz_update_interval = 1000; % Update visualization every 50
simulation seconds (reduced from 100)

    obj.flag_stop_sim = 0;

    if isfield(init_data, 'time_step_storage_attitude')
        % time_step_storage_attitude has been specified

        if init_data.time_step_storage_attitude == 0
            % Use 0 to use the mission.true_time.time_step_attitude
value        obj.time_step_storage_attitude =
mission.true_time.time_step_attitude; % [sec]

        else
            obj.time_step_storage_attitude =
init_data.time_step_storage_attitude; % [sec]
        end

    else
        obj.time_step_storage_attitude = obj.time_step_storage; %
[sec]
    end

    obj.flag_store_this_time_step_attitude = 1;
    obj.time_prev_storage_attitude = mission.true_time.time; % [sec]
    obj.num_storage_steps_attitude = ceil( (mission.true_time.t_final
- mission.true_time.t_initial)/obj.time_step_storage_attitude ) + 1;
    obj.k_storage_attitude = 1;
```

```

obj.numerical_accuracy_factor = 0.99;

% Set plot_parameters
obj.plot_parameters = [];
obj.plot_parameters.color_array = ['b' 'r' 'g' 'c' 'y' 'm' 'k'];
% (Additional colors using rgb.m function from https://
www.mathworks.com/matlabcentral/fileexchange/24497-rgb-triple-of-color-name-
version-2)

obj.plot_parameters.marker_array =
['o' 's' 'd' '^' 'v' '>' '<' 'p' 'h' '+'];
obj.plot_parameters.standard_font_size = 20;
obj.plot_parameters.standard_font_type = 'Times New Roman';
obj.plot_parameters.title_font_size = 40;

if isfield(init_data, 'flag_save_plots')
    obj.plot_parameters.flag_save_plots =
init_data.flag_save_plots;
else
    obj.plot_parameters.flag_save_plots = 1; % [Boolean] 1: Save
them (takes little time), 0: Doesnt save them
end

if isfield(init_data, 'flag_save_video')
    obj.plot_parameters.flag_save_video =
init_data.flag_save_video;
else
    obj.plot_parameters.flag_save_video = 0; % [Boolean] 1: Save
them (takes a lot more time), 0: Doesnt save them
end

if
isfield(init_data, 'flag_visualize_SC_attitude_orbit_during_sim')
    obj.flag_visualize_SC_attitude_orbit_during_sim =
init_data.flag_visualize_SC_attitude_orbit_during_sim;
else
    obj.flag_visualize_SC_attitude_orbit_during_sim = 1;
end

if
isfield(init_data, 'wait_time_visualize_SC_attitude_orbit_during_sim')
    obj.wait_time_visualize_SC_attitude_orbit_during_sim =
init_data.wait_time_visualize_SC_attitude_orbit_during_sim; % [sec]
else
    obj.wait_time_visualize_SC_attitude_orbit_during_sim = 0; %
[sec]
end
obj.prev_time_visualize_SC_attitude_orbit_during_sim = -inf;

if isfield(init_data, 'flag_visualize_past_SC_orbit_during_sim')
    obj.flag_visualize_past_SC_orbit_during_sim =
init_data.flag_visualize_past_SC_orbit_during_sim;
else

```

```

        obj.flag_visualize_past_SC_orbit_during_sim = 1;
    end

    % Initialize real-time plotting variables
    if isfield(init_data, 'flag_realtime_plotting')
        obj.flag_realtime_plotting = init_data.flag_realtime_plotting;
    else
        obj.flag_realtime_plotting = 1;
    end

    if isfield(init_data, 'quiver_auto_scale_factor')
        obj.plot_parameters.quiver_auto_scale_factor =
init_data.quiver_auto_scale_factor;
    else
        obj.plot_parameters.quiver_auto_scale_factor = 0.1;
    end

    % Output Folder
    obj.output_folder = ['../Output/', mission.name, '_',
char(datetime("now", "Format", "yyyy-MM-dd-HH'h'mm'm'ss's'")), ' (SimTime =
', char(string(mission.true_time.t_final/86400)), ' days)'];
    %obj.output_folder = ['../Output/', mission.name, '_',
char(datetime("now", "Format", "yyyy-MM-dd-HH'h'mm'm'ss's'")), ' (SimTime =
',char(string(mission.true_time.t_final/86400)), ' days)'];
    mkdir(obj.output_folder)

    % Store video of func_visualize_SC_attitude_orbit_during_sim
    if (obj.plot_parameters.flag_save_video == 1) &&
(obj.flag_visualize_SC_attitude_orbit_during_sim == 1)
        obj.plot_parameters.video_filename = [obj.output_folder,
mission.name, '_Attitude_Orbit.mp4'];
        obj.plot_parameters.myVideo =
VideoWriter(obj.plot_parameters.video_filename, 'MPEG-4');
        obj.plot_parameters.myVideo.FrameRate = 30; % Default 30
        obj.plot_parameters.myVideo.Quality = 100; % Default 75
        open(obj.plot_parameters.myVideo);
    end

end
end

```

[] Methods: Update Storage Flag

Set the flag_store_this_time_step after sufficient time

```

function obj = func_update_storage_flag(obj, mission)

    % Reset flags
    obj.flag_store_this_time_step = 0;

    if (mission.true_time.time - obj.time_prev_storage) >=
(obj.time_step_storage * obj.numerical_accuracy_factor)
        obj.flag_store_this_time_step = 1;
    end

```

```

end

if mission.true_time.k == mission.true_time.num_time_steps
    obj.flag_store_this_time_step = 1;
end

if obj.flag_store_this_time_step == 1
    obj.time_prev_storage = mission.true_time.time; % [sec]
    obj.k_storage = obj.k_storage + 1;
end

end

```

[] Methods: Update Storage Flag Attitude

Set the flag_store_this_time_step_attitude after sufficient time

```

function obj = func_update_storage_flag_attitude(obj, mission)

    % Reset flags
    obj.flag_store_this_time_step_attitude = 0;

    if (mission.true_time.time_attitude -
        obj.time_prev_storage_attitude) >= (obj.time_step_storage_attitude *
        obj.numerical_accuracy_factor)
        obj.flag_store_this_time_step_attitude = 1;
    end

    if (mission.true_time.k == mission.true_time.num_time_steps) &&
        (mission.true_time.k_attitude == mission.true_time.num_time_steps_attitude)
        obj.flag_store_this_time_step_attitude = 1;
    end

    if obj.flag_store_this_time_step_attitude == 1
        obj.time_prev_storage_attitude =
mission.true_time.time_attitude; % [sec]
        obj.k_storage_attitude = obj.k_storage_attitude + 1;
    end

end

```

[] Methods: Update Real-Time Plot

Update the real-time performance plot

```

function obj = func_update_realtime_plot(obj, mission)
    if obj.flag_realtime_plotting
        % Initialize last_mode property if it doesn't exist
        if ~isfield(obj, 'last_mode')
            obj.last_mode = {};
            for i_SC = 1:mission.num_SC
                obj.last_mode{i_SC} =
mission.true_SC{i_SC}.software_SC_executive.this_sc_mode;
            end
        end
    end
end

```

```

        end
    end

    % Check for mode changes in any spacecraft
    mode_changed = false;
    for i_SC = 1:mission.num_SC
        current_mode =
mission.true_SC{i_SC}.software_SC_executive.this_sc_mode;
        if ~strcmp(current_mode, obj.last_mode{i_SC})
            mode_changed = true;
            obj.last_mode{i_SC} = current_mode;
        end
    end

    % Update visualization if time interval has elapsed OR mode
has changed
    if (mission.true_time.time - obj.last_viz_update_time >=
obj.viz_update_interval) || mode_changed
        % Update visualization with attitude rotation and store
the time

        func_visualize_SC(obj, mission, true);
        obj.last_viz_update_time = mission.true_time.time;

        % Force display update without blocking execution
drawnow limitrate;
    end
end
end
end

```

[] Methods: Visualize Simulation Data

Visualize all simulation data

```

function obj = func_visualize_simulation_data(obj, mission)
    % First, ensure we're not keeping any unnecessary figures open
close all
    mission.flag_stop_sim = 1;

    % Close all video files
    if (obj.plot_parameters.flag_save_video == 1)
        if isfield(mission.storage.plot_parameters, 'myVideo')
            close(obj.plot_parameters.myVideo);
        end

        for i_SC = 1:1:mission.num_SC
            % Close Camera video files
            for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_camera
                if
isfield(mission.true_SC{i_SC}.true_SC_camera{i_HW}.data, 'myVideo')
close(mission.true_SC{i_SC}.true_SC_camera{i_HW}.data.myVideo);
                end
            end
        end
    end
end

```

```

        end

        % Close Radar video files
        for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_science_radar
            if
isfield(mission.true_SC{i_SC}.true_SC_science_radar{i_HW}.data, 'myVideo')
close(mission.true_SC{i_SC}.true_SC_science_radar{i_HW}.data.myVideo);
            end
        end
    end
end

    % Memory optimization: create a function to run between plots to
cleanup memory
    function cleanup_memory()
        drawnow limitrate; % Flush graphics queue and allow MATLAB to
reclaim memory
        % More can be added here in case of need !
    end

    % Process one spacecraft at a time to limit memory usage
    for i_SC = 1:1:mission.num_SC
        % Basic plots for all spacecraft (minimal memory use)
        % Orbit Vizualization (shared plot)

        if i_SC == 1
            % Shared for all spacecraft
            fprintf('Plotting orbit visualization...\n');
            func_plot_orbit_visualization(mission);
            cleanup_memory();
        end

        % Spacecraft-specific plots
        fprintf('Plotting SC%d orbit estimator...\n', i_SC);
        func_plot_orbit_estimator(mission, i_SC);
        cleanup_memory();

        fprintf('Plotting SC%d orbital control performance...\n',
i_SC);
        func_plot_orbital_control_performance(mission, i_SC);
        cleanup_memory();

        fprintf('Plotting SC%d attitude visualization...\n', i_SC);
        func_plot_attitude_visualization(mission, i_SC);
        cleanup_memory();

        fprintf('Plotting SC%d attitude actuator performance...\n',
i_SC);
        func_plot_attitude_actuator_performance(mission, i_SC);
        cleanup_memory();

        fprintf('Plotting SC%d power visualization...\n', i_SC);

```

3.2 True_Ground_Station

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Class: True_Ground_Station

Tracks the data sent and recieved by Ground Station

```
classdef True_Ground_Station < handle
```

Properties

properties

[] Properties: Initialized Variables

```
num_GS_radio_antenna % [integer] Number of GS Radio Antenna
```

[] Properties: Variables Computed Internally

```
instantaneous_data_transmitted % [kb] Data transmitted by GS over  
mission.true_time.time_step sec
```

```
total_data_transmitted % [kb] Data transmitted by GS over time
```

```
instantaneous_data_received % [kb] Data received by GS over  
mission.true_time.time_step sec
```

```
total_data_received % [kb] Data received by GS over time
```

```
list_HW_data_transmitted % List of HW that transmitted data
```

```
array_HW_data_transmitted % [kb] Total data transmitted by this HW
```

```
list_HW_data_received % List of HW that received data
```

```
array_HW_data_received % [kb] Total data received by this HW
```

```
warning_counter % [integer] Counter stops the warning after 10  
displays
```

```
data % Other useful data
```

[] Properties: Storage Variables

```
store  
  
end
```

Methods

```
methods
```

[] Methods: Constructor

Construct an instance of this class

```
function obj = True_Ground_Station(init_data, mission)  
  
    obj.num_GS_radio_antenna = init_data.num_GS_radio_antenna;  
  
    obj.instantaneous_data_transmitted = 0; % [kb]  
    obj.total_data_transmitted = 0; % [kb]  
    obj.instantaneous_data_received = 0; % [kb]  
    obj.total_data_received = 0; % [kb]  
  
    obj.list_HW_data_transmitted = [];  
    obj.array_HW_data_transmitted = [];  
    obj.list_HW_data_received = [];  
    obj.array_HW_data_received = [];  
  
    obj.warning_counter = 0;  
  
    if isfield(init_data, 'data')  
        obj.data = init_data.data;  
    else  
        obj.data = [];  
    end  
  
    % Initialize Variables to store  
    obj.store = [];  
  
    obj.store.instantaneous_data_transmitted =  
zeros(mission.storage.num_storage_steps,  
length(obj.instantaneous_data_transmitted));  
    obj.store.instantaneous_data_received =  
zeros(mission.storage.num_storage_steps,  
length(obj.instantaneous_data_received));
```

```

        obj.store.total_data_transmitted =
zeros(mission.storage.num_storage_steps, length(obj.total_data_transmitted));
        obj.store.total_data_received =
zeros(mission.storage.num_storage_steps, length(obj.total_data_received));

    end

```

[] Methods: Initialize list_HW_data_transmitted

Initialize list_HW_data_transmitted for HW and Classes

```

function obj = func_initialize_list_HW_data_transmitted(obj,
equipment, mission)

    this_name = equipment.name;
    flag_name_exisits = 0;

    for i = 1:length(obj.list_HW_data_transmitted)
        if strcmp( obj.list_HW_data_transmitted{i}, this_name )
            flag_name_exisits = 1;
        end
    end

    if flag_name_exisits == 0
        i = length(obj.list_HW_data_transmitted);
        obj.list_HW_data_transmitted{i+1} = this_name;

        if isprop(equipment, 'instantaneous_data_rate_transmitted')
            this_instantaneous_data_transmitted
= (equipment.instantaneous_data_rate_transmitted *
mission.true_time.time_step); % [kb]
        elseif
isprop(equipment, 'instantaneous_data_transmitted_per_sample')
            this_instantaneous_data_transmitted =
equipment.instantaneous_data_transmitted_per_sample; % [kb]
        else
            error('Data transmitted incorrect!')
        end

        obj.array_HW_data_transmitted(1,i+1) =
this_instantaneous_data_transmitted; % [kb]
    end

end

```

[] Methods: Initialize list_HW_data_received

Initialize list_HW_data_received for HW and Classes

```

function obj = func_initialize_list_HW_data_received(obj, equipment,
mission)

    this_name = equipment.name;

```

```

        flag_name_exisits = 0;

        for i = 1:1:length(obj.list_HW_data_received)
            if strcmp( obj.list_HW_data_received{i}, this_name )
                flag_name_exisits = 1;
            end
        end

        if flag_name_exisits == 0
            i = length(obj.list_HW_data_received);
            obj.list_HW_data_received{i+1} = this_name;

            if isprop(equipment, 'instantaneous_data_rate_received')
                this_instantaneous_data_received =
(equipment.instantaneous_data_rate_received * mission.true_time.time_step); %
[kb]
            elseif
isprop(equipment, 'instantaneous_data_received_per_sample')
                this_instantaneous_data_received =
equipment.instantaneous_data_received_per_sample; % [kb]
            else
                error('Data received incorrect!')
            end

            obj.array_HW_data_received(1,i+1) =
this_instantaneous_data_received; % [kb]
        end

    end
end

```

[] Methods: Initialize Store

Initialize store of array_HW_data_transmitted and array_HW_data_received

```

function obj = func_initialize_store_HW_data_transmitted_received(obj,
mission)

    obj.store.list_HW_data_transmitted = obj.list_HW_data_transmitted;
    obj.store.list_HW_data_received = obj.list_HW_data_received;

    obj.store.array_HW_data_transmitted =
zeros(mission.storage.num_storage_steps,
length(obj.array_HW_data_transmitted));
    obj.store.array_HW_data_received =
zeros(mission.storage.num_storage_steps, length(obj.array_HW_data_received));

    obj = func_update_true_ground_station_store(obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_ground_station_store(obj, mission)

    if mission.storage.flag_store_this_time_step == 1

obj.store.instantaneous_data_transmitted(mission.storage.k_storage,:) =
obj.instantaneous_data_transmitted; % [kb]

obj.store.instantaneous_data_received(mission.storage.k_storage,:) =
obj.instantaneous_data_received; % [kb]

        obj.store.total_data_transmitted(mission.storage.k_storage,:) =
= obj.total_data_transmitted; % [kb]
        obj.store.total_data_received(mission.storage.k_storage,:) =
obj.total_data_received; % [kb]

obj.store.array_HW_data_transmitted(mission.storage.k_storage,:) =
obj.array_HW_data_transmitted; % [kb]
        obj.store.array_HW_data_received(mission.storage.k_storage,:) =
= obj.array_HW_data_received; % [kb]
    end

end

```

[] Methods: Main

Main Ground Station code

```

function obj = func_main_true_ground_station(obj, mission, i_SC)

    obj.total_data_transmitted = obj.total_data_transmitted +
obj.instantaneous_data_transmitted; % [kb]
    obj.total_data_received = obj.total_data_received +
obj.instantaneous_data_received; % [kb]

    % Store
    obj = func_update_true_ground_station_store(obj, mission);

    % Reset All Variables
    obj.instantaneous_data_transmitted = 0; % [kb]
    obj.instantaneous_data_received = 0; % [kb]

end

```

[] Methods: Update Instantaneous Data Transmitted

Updates instantaneous_data_transmitted by all HW and Classes

```

function obj = func_update_instantaneous_data_transmitted(obj,
equipment, mission)

```

```

        if isprop(equipment, 'instantaneous_data_rate_transmitted')
            this_instantaneous_data_transmitted
= (equipment.instantaneous_data_rate_transmitted *
mission.true_time.time_step); % [kb]
        elseif
isprop(equipment, 'instantaneous_data_transmitted_per_sample')
            this_instantaneous_data_transmitted =
equipment.instantaneous_data_transmitted_per_sample; % [kb]
        else
            error('Data transmitted incorrect!')
        end

        obj.instantaneous_data_transmitted =
obj.instantaneous_data_transmitted + this_instantaneous_data_transmitted; %
[kb]

        this_name = equipment.name;
        flag_name_exisits = 0;
        this_idx = 0;

        for i = 1:length(obj.list_HW_data_transmitted)
            if strcmp( obj.list_HW_data_transmitted{i}, this_name )
                flag_name_exisits = 1;
                this_idx = i;
            end
        end

        if flag_name_exisits == 0
            error('HW not found!')
        else
            obj.array_HW_data_transmitted(1,this_idx)
= obj.array_HW_data_transmitted(1,this_idx) +
this_instantaneous_data_transmitted; % [kb]
        end
    end
end

```

[] Methods: Update Instantaneous Data Received

Updates instantaneous_data_received by all HW and Classes

```

function obj = func_update_instantaneous_data_received(obj, equipment,
mission)

    if isprop(equipment, 'instantaneous_data_rate_received')
        this_instantaneous_data_received =
(equipment.instantaneous_data_rate_received * mission.true_time.time_step); %
[kb]
    elseif isprop(equipment, 'instantaneous_data_received_per_sample')
        this_instantaneous_data_received =
equipment.instantaneous_data_received_per_sample; % [kb]
    end
end

```

```

        else
            error('Data received incorrect!')
        end

        obj.instantaneous_data_received = obj.instantaneous_data_received
+ this_instantaneous_data_received; % [kb]

        this_name = equipment.name;
        flag_name_exisits = 0;
        this_idx = 0;

        for i = 1:1:length(obj.list_HW_data_received)
            if strcmp( obj.list_HW_data_received{i}, this_name )
                flag_name_exisits = 1;
                this_idx = i;
            end
        end

        if flag_name_exisits == 0
            error('HW not found!')
        else
            obj.array_HW_data_received(1,this_idx) =
obj.array_HW_data_received(1,this_idx) + this_instantaneous_data_received; %
[kb]
        end

    end

end

end

```

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3.3 True_GS_Radio_Antenna

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Class: True_GS_Radio_Antenna

Tracks the GS's Radio Antennas

```
classdef True_GS_Radio_Antenna < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
antenna_type % [string]
% - 'Dipole'
% - 'High Gain'

mode_true_GS_radio_antenna_selector % [string]
% - TX
% - RX

% Optional (only for Link Margin Calculations)

antenna_gain % [dB] gain of Earth receiver

noise_temperature % [K] temperature noise

beamwidth % [MHz] receiver beamwidth

energy_bit_required % [dB] Minimum energy bit required

line_loss % [dB] Loss due to pointing or others

coding_gain % [dB] Coding gain
```

[] Properties: Variables Computed Internally

```
name % [string] 'GS Radio Antenna i'
```

```

health % [integer] Health of sensor/actuator
% - 0. Switched off
% - 1. Switched on, works nominally

flag_executive % [Boolean] Executive has told this sensor/actuator to
do its job

instantaneous_data_rate_transmitted % [kbps] : Data rate, in kilo bits
per sec (kbps) due to RX

instantaneous_data_rate_received % [kbps] : Data rate, in kilo bits
per sec (kbps) due to TX

data % Other useful data

```

[] Properties: Storage Variables

```

store

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = True_GS_Radio_Antenna(init_data, mission, i_HW)

    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
        obj.name = ['GS Radio Antenna ', num2str(i_HW)];
    end

    obj.health = 1;
    obj.flag_executive = 0;

    obj.antenna_type = init_data.antenna_type;

    obj.mode_true_GS_radio_antenna_selector =
init_data.mode_true_GS_radio_antenna_selector;

    if isfield(init_data, 'antenna_gain')

        obj.antenna_gain = init_data.antenna_gain; % [dB]
        obj.noise_temperature = init_data.noise_temperature; % [K]
        obj.beamwidth = init_data.beamwidth; % [MHz]
    end
end

```

```

        obj.energy_bit_required = init_data.energy_bit_required; %
[dB]
        obj.line_loss = init_data.line_loss; % [dB]
        obj.coding_gain = init_data.coding_gain; % [dB]

    end

    obj.instantaneous_data_rate_transmitted = 0; % [kbps]
    obj.instantaneous_data_rate_received = 0; % [kbps]

    if isfield(init_data, 'data')
        obj.data = init_data.data;
    else
        obj.data = [];
    end

    % Initialize Variables to store: flag_executive mode_TX_RX
    obj.store = [];

    obj.store.flag_executive =
zeros(mission.storage.num_storage_steps, length(obj.flag_executive)); %
[integer]
    obj.store.mode_TX_RX = zeros(mission.storage.num_storage_steps,
1); % [integer]
    obj.store.instantaneous_data_rate_transmitted =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_data_rate_transmitted)); % [kbps]
    obj.store.instantaneous_data_rate_received =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_data_rate_received)); % [kbps]

    % Update Storage
    obj = func_update_true_GS_radio_antenna_store(obj, mission);

    % Update Ground Station Class (Generated and Removed)

    func_initialize_list_HW_data_transmitted(mission.true_ground_station, obj,
mission);

    func_initialize_list_HW_data_received(mission.true_ground_station,
obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_GS_radio_antenna_store(obj, mission)

    if mission.storage.flag_store_this_time_step == 1
        obj.store.flag_executive(mission.storage.k_storage,:) =
obj.flag_executive; % [integer]
    end

```

```

obj.store.instantaneous_data_rate_transmitted(mission.storage.k_storage,:) =
obj.instantaneous_data_rate_transmitted; % [kbps]

obj.store.instantaneous_data_rate_received(mission.storage.k_storage,:) =
obj.instantaneous_data_rate_received; % [kbps]

        switch obj.mode_true_GS_radio_antenna_selector
            case 'TX'
                obj.store.mode_TX_RX(mission.storage.k_storage,1) = 1;
            case 'RX'
                obj.store.mode_TX_RX(mission.storage.k_storage,1) = 2;
            otherwise
                error('Should not reach here!')
            end
        end

    end

end

```

[] Methods: Main

Update Camera

```

function obj = func_main_true_GS_radio_antenna(obj, mission)

    if (obj.flag_executive == 1) && (obj.health == 1)
        % TX or RX Data

        % Update SC Data Handling Class (Generated and Removed)

        func_update_instantaneous_data_transmitted(mission.true_ground_station, obj,
mission);

        func_update_instantaneous_data_received(mission.true_ground_station, obj,
mission);

    else
        % Do nothing

    end

    % Update Storage
    obj = func_update_true_GS_radio_antenna_store(obj, mission);

    % Reset All Variables
    obj.flag_executive = 0;
    obj.instantaneous_data_rate_transmitted = 0; % [kbps]
    obj.instantaneous_data_rate_received = 0; % [kbps]

end

end

```

end

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3.4 True_Solar_System

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Class: True_Solar_System

Tracks the position of Sun, Earth, Moon, etc. and other useful planetary bodies

```
classdef True_Solar_System < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
num_SS_body
```

[] Properties: Variables Computed Internally

```
SS_body % Data about selected SS body
% - name
% - radius [km]
% - mu [km^3 sec^-2]
% - mass [kg]
% - position [km] wrt Sun-centered J2000
% - velocity [km/sec] wrt Sun-centered J2000
% - position_array % [km] Position array wrt Sun-centered J2000,
corresponding to time array in mission.true_time.time_position_array
% - rgb_color [string] Used for plotting

solar_constant_AU % [W/m^2]
AU_distance % [km]
light_speed % [m/sec]
gravitational_constant % [km^3 kg^{#1} s^{#2}]

index_Sun % [integer] : Index of Sun
index_Earth % [integer] : Index of Earth
```

[] Properties: Storage Variables

```
store  
  
end
```

Methods

```
methods
```

[] Methods: Constructor

Construct an instance of this class

```
function obj = TrueSolarSystem(init_data, mission)  
  
    obj.solar_constant_AU = 1361; % [W/m^2]  
    obj.AU_distance = 1.49598e8; % [km]  
    obj.light_speed = 299792458; % [m/sec]  
    obj.gravitational_constant = 6.67430e-20; % [km^3 kg^{#1} s^{#2}]  
  
    obj.num_SS_body = length(init_data.SS_body_names);  
    obj.SS_body = [];  
  
    all_SS_body_data = func_load_all_SS_body_data(obj);  
  
    for i = 1:1:obj.num_SS_body  
  
        this_SS_body_name =  
convertStringsToChars(init_data.SS_body_names(i));  
  
        for j = 1:1:length(all_SS_body_data)  
  
            if strcmp(this_SS_body_name, all_SS_body_data{j}.name)  
                obj.SS_body{i} = all_SS_body_data{j};  
            end  
  
        end  
  
        obj.SS_body{i}.position = zeros(1,3); % [km]  
        obj.SS_body{i}.velocity = zeros(1,3); % [km/sec]  
        obj.SS_body{i}.position_array =  
zeros( mission.true_time.num_time_steps_position_array,3); % [km]  
  
        if strcmp(obj.SS_body{i}.name, 'Sun')  
            obj.index_Sun = i;  
        end  
  
        if strcmp(obj.SS_body{i}.name, 'Earth')  
            obj.index_Earth = i;  
        end  
    end  
end
```

```

        end

    end

    % Update Position and Velocity
    cspice_furnsh(' ../../MuSCAT_Supporting_Files/SPICE/de440s.bsp')

    obj = func_main_true_solar_system(obj, mission);

    % Initialize Variables to store position and velocity of each body
    obj.store = [];

    for i = 1:1:obj.num_SS_body

        obj.store.SS_body{i}.name = obj.SS_body{i}.name;
        obj.store.SS_body{i}.position =
zeros(mission.storage.num_storage_steps, length(obj.SS_body{i}.position));
        obj.store.SS_body{i}.velocity =
zeros(mission.storage.num_storage_steps, length(obj.SS_body{i}.velocity));

    end

    obj = func_update_solar_system_store(obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_solar_system_store(obj, mission)

    if mission.storage.flag_store_this_time_step == 1
        for i = 1:1:obj.num_SS_body
            obj.store.SS_body{i}.position(mission.storage.k_storage,:)
= obj.SS_body{i}.position; % [km]
            obj.store.SS_body{i}.velocity(mission.storage.k_storage,:)
= obj.SS_body{i}.velocity; % [km/sec]
        end
    end

end

```

[] Methods: Main

% Function to update position of Sun, Earth, Moon, etc. ... given current time

```

function obj = func_main_true_solar_system(obj, mission)

    for i = 1:1:obj.num_SS_body

```

```

        body_pos_vel_this_time =
cspice_spkezr(obj.SS_body{i}.spice_name,mission.true_time.date,'J2000','NONE','SUN');

        obj.SS_body{i}.position = body_pos_vel_this_time(1:3,1)'; %
[km]
        obj.SS_body{i}.velocity = body_pos_vel_this_time(4:6,1)'; %
[km]

        body_pos_vel_array = (cspice_spkezr(obj.SS_body{i}.name,
mission.true_time.prev_date +
mission.true_time.time_position_array' , 'J2000', 'NONE', 'SUN'))';
        obj.SS_body{i}.position_array = body_pos_vel_array(:,1:3);

    end

    % Store
    obj = func_update_solar_system_store(obj, mission);

end

```

[] Methods: Load Data

Store all useful data about all SS bodies

```

function all_SS_body_data = func_load_all_SS_body_data(obj)

    all_SS_body_data = [];
    k = 0;

    % Sun's Data
    this_data = [];
    this_data.name = 'Sun';
    this_data.spice_name = '10'; % [string] : Body's SPICE Name
    this_data.radius = 6.95700e5; % [km]
    this_data.mu = 1.32712440018e11; % [km^3 sec^-2]
    this_data.mass = 1.9885e30; % [kg]
    this_data.rgb_color = 'Gold'; % [string]
    k = k + 1;
    all_SS_body_data{k} = this_data;

    % Mercury's Data
    this_data = [];
    this_data.name = 'Mercury';
    this_data.spice_name = '199'; % [string] : Body's SPICE Name
    this_data.radius = 2.4397e3; % [km] https://en.wikipedia.org/wiki/
    Mercury_(planet)
    this_data.mu = 2.2032e4; % [km^3 sec^-2] https://en.wikipedia.org/
    wiki/Standard_gravitational_parameter
    this_data.mass = 3.3011e23; % [kg]
    this_data.rgb_color = 'Silver'; % [string]
    k = k + 1;
    all_SS_body_data{k} = this_data;

```

```

    % Venus's Data
    this_data = [];
    this_data.name = 'Venus';
    this_data.spice_name = '299'; % [string] : Body's SPICE Name
    this_data.radius = 6.0518e3; % [km] https://en.wikipedia.org/wiki/
Venus
    this_data.mu = 3.24859e5; % [km^3 sec^-2] https://en.wikipedia.org/wiki/Standard\_gravitational\_parameter
    this_data.mass = 4.8675e24; % [kg]
    this_data.rgb_color = 'Yellow'; % [string]
    k = k + 1;
    all_SS_body_data{k} = this_data;

    % Earth's Data
    this_data = [];
    this_data.name = 'Earth';
    this_data.spice_name = '399'; % [string] : Body's SPICE Name
    this_data.radius = 6.371e3; % [km]
    this_data.mu = 3.986004418e5; % [km^3 sec^-2] https://en.wikipedia.org/wiki/Standard\_gravitational\_parameter
    this_data.mass = 5.9722e24; % [kg]
    this_data.rgb_color = 'Navy'; % [string]
    k = k + 1;
    all_SS_body_data{k} = this_data;

    % Moon's Data
    this_data = [];
    this_data.name = 'Moon';
    this_data.spice_name = '301'; % [string] : Body's SPICE Name
    this_data.radius = 1.7374e3; % [km]
    this_data.mu = 4.9048695e3; % [km^3 sec^-2] https://en.wikipedia.org/wiki/Standard\_gravitational\_parameter
    this_data.mass = 7.342e22; % [kg]
    this_data.rgb_color = 'Silver'; % [string]
    k = k + 1;
    all_SS_body_data{k} = this_data;

    % Mars's Data
    this_data = [];
    this_data.name = 'Mars';
    this_data.spice_name = '4'; % [string] : Body's SPICE Name
    this_data.radius = 3.3895e3; % [km] https://en.wikipedia.org/wiki/
Mars
    this_data.mu = 4.282837e4; % [km^3 sec^-2] https://en.wikipedia.org/wiki/Standard\_gravitational\_parameter
    this_data.mass = 6.4171e23; % [kg]
    this_data.rgb_color = 'DarkRed'; % [string]
    k = k + 1;
    all_SS_body_data{k} = this_data;

    % Jupiter's Data
    this_data = [];
    this_data.name = 'Jupiter';
    this_data.spice_name = '5'; % [string] : Body's SPICE Name

```

```

        this_data.radius = 6.9911e4; % [km] https://en.wikipedia.org/wiki/
Jupiter
        this_data.mu = 1.26686534e8; % [km^3 sec^-2] https://
en.wikipedia.org/wiki/Standard_gravitational_parameter
        this_data.mass = 1.8982e27; % [kg]
        this_data.rgb_color = 'Orange'; % [string]
        k = k + 1;
        all_SS_body_data{k} = this_data;

        % Saturn's Data
        this_data = [];
        this_data.name = 'Saturn';
        this_data.spice_name = '699'; % [string] : Body's SPICE Name
        this_data.radius = 5.8232e4; % [km] https://en.wikipedia.org/wiki/
Saturn
        this_data.mu = 3.7931187e7; % [km^3 sec^-2] https://
en.wikipedia.org/wiki/Standard_gravitational_parameter
        this_data.mass = 5.6834e26; % [kg]
        this_data.rgb_color = 'Goldenrod'; % [string]
        k = k + 1;
        all_SS_body_data{k} = this_data;

        % Mimas's Data
        this_data = [];
        this_data.name = 'Mimas';
        this_data.spice_name = '601'; % [string] : Body's SPICE Name
        this_data.radius = 1.982e2; % [km] https://en.wikipedia.org/wiki/
Mimas
        this_data.mass = 3.75094e19; % [kg]
        this_data.mu = obj.gravitational_constant * this_data.mass; %
[km^3 sec^-2]
        this_data.rgb_color = 'Gray'; % [string]
        k = k + 1;
        all_SS_body_data{k} = this_data;

        % Enceladus's Data
        this_data = [];
        this_data.name = 'Enceladus';
        this_data.spice_name = '602'; % [string] : Body's SPICE Name
        this_data.radius = 2.521e2; % [km] https://en.wikipedia.org/wiki/
Enceladus
        this_data.mass = 1.080318e20; % [kg]
        this_data.mu = obj.gravitational_constant * this_data.mass; %
[km^3 sec^-2]
        this_data.rgb_color = 'Gray'; % [string]
        k = k + 1;
        all_SS_body_data{k} = this_data;

        % Tethys's Data
        this_data = [];
        this_data.name = 'Tethys';
        this_data.spice_name = '603'; % [string] : Body's SPICE Name
        this_data.radius = 5.614e2; % [km] https://en.wikipedia.org/wiki/
Tethys_(moon)

```

```

        this_data.mass = 6.1749e20; % [kg]
        this_data.mu = obj.gravitational_constant * this_data.mass; %
[km^3 sec^-2]
        this_data.rgb_color = 'Gray'; % [string]
        k = k + 1;
        all_SS_body_data{k} = this_data;

% Dione's Data
this_data = [];
this_data.name = 'Dione';
this_data.spice_name = '604'; % [string] : Body's SPICE Name
this_data.radius = 5.31e2; % [km] https://en.wikipedia.org/wiki/
Dione_(moon)
        this_data.mass = 1.0954868e21; % [kg]
        this_data.mu = obj.gravitational_constant * this_data.mass; %
[km^3 sec^-2]
        this_data.rgb_color = 'Gray'; % [string]
        k = k + 1;
        all_SS_body_data{k} = this_data;

% Rhea's Data
this_data = [];
this_data.name = 'Rhea';
this_data.spice_name = '605'; % [string] : Body's SPICE Name
this_data.radius = 7.635e2; % [km] https://en.wikipedia.org/wiki/
Rhea_(moon)
        this_data.mass = 2.3064854e21; % [kg]
        this_data.mu = obj.gravitational_constant * this_data.mass; %
[km^3 sec^-2]
        this_data.rgb_color = 'Gray'; % [string]
        k = k + 1;
        all_SS_body_data{k} = this_data;

% Titan's Data
this_data = [];
this_data.name = 'Titan';
this_data.spice_name = '606'; % [string] : Body's SPICE Name
this_data.radius = 2.57473e3; % [km] https://en.wikipedia.org/
wiki/Titan_(moon)
        this_data.mass = 1.3452e23; % [kg]
        this_data.mu = obj.gravitational_constant * this_data.mass; %
[km^3 sec^-2]
        this_data.rgb_color = 'Gray'; % [string]
        k = k + 1;
        all_SS_body_data{k} = this_data;

% Hyperion's Data
this_data = [];
this_data.name = 'Hyperion';
this_data.spice_name = '607'; % [string] : Body's SPICE Name
this_data.radius = 1.35e2; % [km] https://en.wikipedia.org/wiki/
Hyperion_(moon)
        this_data.mass = 5.5510e18; % [kg]

```

```

        this_data.mu = obj.gravitational_constant * this_data.mass; %
[km^3 sec^-2]
        this_data.rgb_color = 'Gray'; % [string]
        k = k + 1;
        all_SS_body_data{k} = this_data;

        % Iapetus's Data
        this_data = [];
        this_data.name = 'Iapetus';
        this_data.spice_name = '608'; % [string] : Body's SPICE Name
        this_data.radius = 7.344e2; % [km] https://en.wikipedia.org/wiki/
Iapetus_(moon)
        this_data.mass = 1.80565e21; % [kg]
        this_data.mu = obj.gravitational_constant * this_data.mass; %
[km^3 sec^-2]
        this_data.rgb_color = 'Gray'; % [string]
        k = k + 1;
        all_SS_body_data{k} = this_data;

        % Phoebe's Data
        this_data = [];
        this_data.name = 'Phoebe';
        this_data.spice_name = '609'; % [string] : Body's SPICE Name
        this_data.radius = 1.065e2; % [km] https://en.wikipedia.org/wiki/
Iapetus_(moon)
        this_data.mass = 8.3123e18; % [kg]
        this_data.mu = obj.gravitational_constant * this_data.mass; %
[km^3 sec^-2]
        this_data.rgb_color = 'Gray'; % [string]
        k = k + 1;
        all_SS_body_data{k} = this_data;

        % Helene's Data
        this_data = [];
        this_data.name = 'Helene';
        this_data.spice_name = '612'; % [string] : Body's SPICE Name
        this_data.radius = 1.81e2; % [km] https://en.wikipedia.org/wiki/
Iapetus_(moon)
        this_data.mass = 7.1e15; % [kg]
        this_data.mu = obj.gravitational_constant * this_data.mass; %
[km^3 sec^-2]
        this_data.rgb_color = 'Gray'; % [string]
        k = k + 1;
        all_SS_body_data{k} = this_data;

end

end

end

```

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3.5 True_Stars

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Class: True_Stars

Stars in the sky

```
classdef True_Stars < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
    maximum_magnitude % [float] Maximum magnitude of stars visible to  
    camera (Optional)
```

[] Properties: Variables Computed Internally

```
    num_stars % [integer] Number of stars  
    sao_name % [string] Smithsonian Astrophysical Observatory (SAO) Star  
    Catalog's name of star  
    magnitude_visible % [float] Magnitude of star  
    all_stars_unit_vector % [] Unit vector denoting position of all stars  
  
end
```

Methods

```
methods
```

[] Methods: Constructor

Construct an instance of this class, Initialize from SAO Catalog

```
function obj = True_Stars(mission)  
  
    YYYY = str2double(mission.true_time.t_initial_date_string(8:11));  
  
    % SAO Star Catalog : http://tdc-www.harvard.edu/catalogs/sao.html
```

```

fid=fopen('saoNAN.txt');
M=textscan(fid, '%f %f %f %f %f %f %f %f', 'headerlines', 1);
fclose(fid);

obj.sao_name=M{1};
obj.magnitude_visible=M{3};
RA=(M{5}+(M{7}*(YYYY-2000)))/15;
DEC=(M{6}+(M{8}*(YYYY-2000)));

obj.num_stars = length(obj.sao_name);

obj.all_stars_unit_vector = zeros(obj.num_stars,3);
for i=1:1:obj.num_stars

    x_hat = [1 0 0]';

    RA_angle = deg2rad(RA(i)*15); % [rad]
    Dec_angle = deg2rad(DEC(i)); % [rad]

    Rot_Z_star_RA = [cos(RA_angle) -sin(RA_angle) 0;
                     sin(RA_angle)  cos(RA_angle) 0;
                     0              0 1];

    Rot_Y_star_Dec = [cos(Dec_angle) 0 sin(Dec_angle);
                     0 1 0;
                     -sin(Dec_angle) 0 cos(Dec_angle)];

    Rot_RA_dec = Rot_Y_star_Dec * Rot_Z_star_RA;

    obj.all_stars_unit_vector(i,:) = (Rot_RA_dec*x_hat)';

end

obj.maximum_magnitude = max(obj.magnitude_visible);

end

end

end

```

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3.6 True_Target_SPICE

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Class: True_Target_SPICE

Tracks the main target body (uses SPICE for updating position, velocity)

```
classdef True_Target_SPICE < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
name % [string] Name of Target
```

[] Properties: Variables Computed Internally

```
rotation_period % [sec] Period of one rotation
rotation_rate % [rad/sec]

gravity_filename % [string] Filename of the Target gravity field in a
particular format
gravity_field % Target's gravity field, computed from gravity_filename
gravity_degree_harmonics % [integer] Degree harmonics of the gravity
field

shape_model % Shape model of Target
% - shape_model.Vertices [m] : Position of vertices
% - shape_model.Faces : Triplet of vertex indices define a face
shape_model_type % [string] Type of shape model
radius % [km] Radius of Target

pole_RA % [deg] Right Ascension (RA) of Target's pole
pole_Dec % [deg] Declination (DEC) of Target's pole
prime_meridian % [deg] : Initial Prime Meridian angle of Target
rotation_matrix_pole_RA_Dec % Rotation matrix of Target's pole due to
RA, Dec only (dosent' change with time)
```

```

        rotation_matrix % Rotation matrix of Target from Body Frame to J2000
        (changes with time)

        spice_filename % [string] Target's SPICE FileName
        spice_name % [string] Target's SPICE Name

        mu % [km^3 sec^-2] Target's standard gravitational parameter  $\mu$  = GM
        mass % [kg] Mass of Target

        position % [km] Current position of Target wrt Sun-centered J2000
        velocity % [km/sec] Current velocity of Target wrt Sun-centered J2000
        position_array % [km] Position array of Target wrt Sun-centered J2000,
        corresponding to time array in mission.true_time.time_position_array

```

[] Properties: Storage Variables

```

store

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = True_Target_SPICE(init_data, mission)

    path_body_data = '../..../MuSCAT_Supporting_Files/SB_data/';

    obj.name = init_data.target_name;

    switch obj.name

        case 'Bennu'
            % obj.name = 'Bennu';

            obj.rotation_period = 4.296057*3600; % [sec] From https://en.wikipedia.org/wiki/101955\_Bennu

            % Gravity Model
            obj.gravity_filename = [path_body_data 'Bennu/
bennu_harmonics_jpl5.txt'];
            obj.gravity_field = GravityField(obj.gravity_filename); %
            Load gravity field
            obj.gravity_degree_harmonics = 8;

            % Shape Model
            % readObj.m from https://www.mathworks.com/matlabcentral/
fileexchange/18957-readobj

```

```

        obj_shape = readObj([path_body_data 'Bennu/
bennu_g_06290mm_spc_obj_0000n00000_v008.obj']);
        % other options are Bennu_OSIRIS-REx_2018.obj (2.6MB) and
        Bennu_OSIRIS-REx_2019.obj (7.2MB)

        obj.shape_model_type = 'trisurf';
        obj.shape_model = [];
        obj.shape_model.Vertices = (1e3)*obj_shape.v; % [m]
        obj.shape_model.Faces = obj_shape.f.v;

        % SPICE
        obj.spice_filename = [path_body_data 'Bennu/
sb-101955-118.bsp'];
        obj.spice_name = '2101955';

        % Pole Data
        obj.pole_RA = 85.65; % [deg]
        obj.pole_Dec = -60.17; % [deg]
        obj.prime_meridian = 0; % [deg] (at t_init)

    case 'Apophis'
        % obj.name = 'Apophis';

        obj.rotation_period = (360/3.155588020452885e+02)*86400; %
[sec] From SPICE

        % Gravity Model
        obj.gravity_filename = [path_body_data 'Apophis/
Apophis_CMoffset.txt'];
        obj.gravity_field = GravityField(obj.gravity_filename); %
Load gravity field
        obj.gravity_degree_harmonics = 8;

        % Shape Model
        obj_shape = readObj([path_body_data 'Apophis/
ApophisModel1.obj']);
        obj.shape_model = [];
        obj.shape_model_type = 'trisurf';
        obj.shape_model.Vertices = obj.gravity_field.R * 1e3 *
obj_shape.v; % [m]
        obj.shape_model.Faces = obj_shape.f.v;

        % SPICE
        obj.spice_filename = [path_body_data 'Apophis/
apophis.bsp'];
        obj.spice_name = '2099942';

        % Pole Data
        obj.pole_RA = 250; % [deg]
        obj.pole_Dec = -75; % [deg]
        obj.prime_meridian = 0; % [deg] (at t_init)

```

```

    case 'Toutatis'
        % obj.name = 'Toutatis';

        % Rotation Rate
        obj.rotation_period = 176*3600; % [sec] https://en.wikipedia.org/wiki/4179\_Toutatis
        obj.rotation_rate = 2*pi/obj.rotation_period; % [rad /sec]
        warning('Toutatis is tumbling!') % http://abyss.uoregon.edu/~js/ast121/lectures/toutatis.html

        % Gravity Model
        obj.gravity_filename = 'Toutatis_CMoffset.txt';
        obj.gravity_field = GravityField(obj.gravity_filename); %
Load gravity field
        obj.gravity_degree_harmonics = 8;

        obj_shape =
readObj([path_body_data 'Toutatis/4179toutatis.tab.obj']);
        obj.shape_model = [];
        obj.shape_model_type = 'trisurf';
        obj.shape_model.Vertices = obj.gravity_field.R * 1e3 *
obj_shape.v; % [m]
        obj.shape_model.Faces = obj_shape.f.v;

        obj.spice_filename =
[path_body_data 'Toutatis/2004179.bsp'];
        obj.spice_name = '2004179';

        % Pole Data
        obj.pole_RA = 0; % [deg]
        obj.pole_Dec = 90*pi/180; % [deg]
        obj.prime_meridian = 0; % [deg] (at t_init)

        obj.mass = 1.9e13;
        obj.ode_options = odeset('RelTol',1e-14,'AbsTol',1e-14);

    case 'Itokawa'
        % obj.name = 'Itokawa';

        % Rotation Rate
        obj.rotation_period = 12.132*3600; % [sec] https://en.wikipedia.org/wiki/25143\_Itokawa
        obj.rotation_rate = 2*pi/obj.rotation_period; % [rad /
sec]

        % Gravity Model
        obj.gravity_filename = 'Itokawa_CMoffset.txt';
        obj.gravity_field = GravityField(obj.gravity_filename); %
Load gravity field

```

```

obj.gravity_degree_harmonics = 8;

% Shape Model
% Shape model from https://sbn.psi.edu/pds/shape-models/
% readObj.m from https://www.mathworks.com/matlabcentral/
fileexchange/18957-readobj
obj_shape = readObj([path_body_data 'Itokawa/
Itokawa_ver64q.tab.obj']);
obj.shape_model = [];
obj.shape_model_type = 'trisurf';
obj.shape_model.Vertices = obj.gravity_field.R * 1e3 *
obj_shape.v; % [m]
obj.shape_model.Faces = obj_shape.f.v;

obj.spice_filename =
[path_body_data 'Itokawa/2025143.bsp'];
obj.spice_name = '2025143';

% Pole Data
obj.pole_RA = 90.53*pi/180; % [rad]
obj.pole_Dec = -66.30*pi/180; % [rad]
obj.prime_meridian = 0; % [deg] (at t_init)

obj.mass = 3.51e10;
obj.ode_options = odeset('RelTol',1e-14,'AbsTol',1e-14);

case '1996HW1'
% obj.name = '1996HW1';

% Rotation Rate
obj.rotation_period = 8.762*3600; % [sec] https://
echo.jpl.nasa.gov/asteroids/1996HW1/1996hw1.html
obj.rotation_rate = 2*pi/obj.rotation_period; % [rad /sec]

% Gravity Model
obj.gravity_filename = '1996HW1_CMoffset.txt';
obj.gravity_field = GravityField(obj.gravity_filename); %
Load gravity field
obj.gravity_degree_harmonics = 8;

% Shape Model
% Shape model from https://sbn.psi.edu/pds/shape-models/
% readObj.m from https://www.mathworks.com/matlabcentral/
fileexchange/18957-readobj
obj_shape =
readObj([path_body_data '1996HW1/1996HW1_a8567.tab.obj']);
obj.shape_model = [];
obj.shape_model_type = 'trisurf';
obj.shape_model.Vertices = obj.gravity_field.R * 1e3 *
obj_shape.v; % [m]
obj.shape_model.Faces = obj_shape.f.v;

```

```

        obj.spice_filename =
[path_body_data 'Itokawa/2008567.bsp'];
        obj.spice_name = '2008567';

        % Pole Data
        obj.pole_RA = 281*pi/180; % [rad]
        obj.pole_Dec = -30*pi/180; % [rad]
        obj.prime_meridian = 0; % [deg] (at t_init)

        obj.mass = 3.51e10; % I CANT FIND IT
        obj.ode_options = odeset('RelTol',1e-14,'AbsTol',1e-14);

        case 'Earth'
            % obj.name = 'Earth';

            obj.rotation_period = 23.9345 * 3600; % [sec] From
https://nssdc.gsfc.nasa.gov/planetary/factsheet/earthfact.html

            % Gravity Model (https://www2.csr.utexas.edu/grace/
gravity/ggm02/)
            obj.gravity_filename = [path_body_data 'Earth/
ggm02c.txt'];
            obj.gravity_field = GravityField(obj.gravity_filename); %
Load gravity field
            if isfield(mission_init_data,'gravity_degree_harmonics')
                obj.gravity_degree_harmonics =
mission_init_data.gravity_degree_harmonics;
            else
                obj.gravity_degree_harmonics = 8;
            end

            % Shape Model
            obj.shape_model = [];
            obj.shape_model_type = 'sphere';
            obj.shape_model_img = [path_body_data 'Earth/
earth_surface.jpg'];

            % SPICE
            obj.spice_name = '399';
            obj.spice_filename = [path_body_data 'Earth/
earth_200101_990825_predict.bpc'];

            % Pole Data
            % From https://nssdc.gsfc.nasa.gov/planetary/factsheet/
earthfact.html

            ref_date_time = cal2sec('01-JAN-2000 00:12:00');
            T = (mission_true_time.t_initial_date - ref_date_time) /
(365.525*86400*100); % Julian centuries from reference date
            obj.pole_RA = 0.00 - 0.641 * T; % [deg]
            obj.pole_Dec = 90.00 - 0.557 * T; % [deg]

            cspice_furnsh([path_body_data 'Earth/naif0012.tls']) %
Leapseconds kernel file

```

```

        JD.UTC =
cspice_et2utc(mission_true_time.t_initial_date, 'J', 6); % Format 'JD
2446533.18834276'

        JD.UTC = strsplit(JD.UTC, ' ');
        JD.UTC = str2double(JD.UTC{2});
        JD_UT1 = JD.UTC; % Approximation, UTC is design to follow
UT1 within +/- 0.9s
        % From NASA TP 20220014814, Sec 4.3.2 Sidereal Motion
        obj.prime_meridian =
rad2deg(wrapTo2Pi(2*pi*(0.7790572732640 + 1.00273781191135448 * (JD_UT1 -
2451545.0)))); % [deg] (at t_init)

        case 'IBD_Asteroid'
            % obj.name = 'IBD_Asteroid';

            obj.rotation_period = (360/3.15588020452885e+02)*86400; %
[sec] From SPICE

            % Gravity Model
            obj.gravity_filename = [path_body_data 'IBDAst/
Apophis_CMoffset.txt'];
            obj.gravity_field = GravityField(obj.gravity_filename); %
Load gravity field
            obj.gravity_degree_harmonics = 8;

            % Shape Model
            obj_shape = readObj([path_body_data 'IBDAst/Bennu-
Radar.obj']);
            obj.shape_model = [];
            obj.shape_model_type = 'trisurf';
            obj.shape_model.Vertices = obj.gravity_field.R * 1e3 *
obj_shape.v; % [m]
            obj.shape_model.Faces = obj_shape.f.v;

            % SPICE
            obj.spice_filename = [path_body_data 'IBDAst/
apophis.bsp'];
            obj.spice_name = '2099942';

            % Pole Data
            obj.pole_RA = 250; % [deg]
            obj.pole_Dec = -75; % [deg]
            obj.prime_meridian = 0; % [deg] (at t_init)

            obj.mass = 6.1e10;
            obj.ode_options = odeset('RelTol',1e-14,'AbsTol',1e-14);

        case 'Enceladus'
            % obj.name = 'Enceladus';

            obj.rotation_period = 1.370218*86400; % [sec] https://
en.wikipedia.org/wiki/Enceladus

```

```

        % Gravity Model
        obj.gravity_filename = [path_body_data 'Bennu/
bennu_harmonics_jpl5.txt'];
        obj.gravity_field = GravityField(obj.gravity_filename); %
        Load gravity field
        obj.gravity_degree_harmonics = 8;

        % Shape Model
        obj.shape_model = [];
        obj.shape_model_type = 'sphere';
        obj.shape_model_img = [path_body_data 'Enceladus/
Enceladus_surface_color.jpg'];

        % SPICE
        obj.spice_filename = '../..../MuSCAT_Supporting_Files/
SC_data/Nightingale/insar_6stride_26d_v7_scpse.bsp';
        obj.spice_name = '602';

        % Pole Data
        obj.pole_RA = 40.7; % [deg]
        obj.pole_Dec = 83.5; % [deg]
        obj.prime_meridian = 0; % [deg] (at t_init)

        % Use SPICE TPC file instead
        cspice_furnsh('../..../MuSCAT_Supporting_Files/SB_data/
Enceladus/enceladus_ssd_230702_v1.tpc')
        % cspice_furnsh('../..../MuSCAT_Supporting_Files/SB_data/
Enceladus/pck_sat441.tpc')
        % cspice_furnsh('../..../MuSCAT_Supporting_Files/SB_data/
Enceladus/pck_sat441_enceladus_frame_edit_only_for_recreation.tpc')

        obj.mass = 1.080318e20; % [kg]
        obj.radius = 252; % [km]

    otherwise
        error('Invalid Target type')
    end

    cspice_furnsh('../..../MuSCAT_Supporting_Files/SPICE/de440s.bsp');
    cspice_furnsh(obj.spice_filename);

    obj.rotation_rate = 360/obj.rotation_period; % [deg /sec]

    % Rotation Matrix to Target's Body-fixed Inertial Frame.
    % See details here: https://naif.jpl.nasa.gov/pub/naif/
    toolkit\_docs/MATLAB/req/pck.html#Orientation%20Models%20used%20by%20PCK
    %20Software
    Rot_Z_pole_RA = [
        cosd(90 + obj.pole_RA) -sind(90 + obj.pole_RA) 0;
        sind(90 + obj.pole_RA) cosd(90 + obj.pole_RA) 0;
        0 0 1];
    Rot_X_pole_Dec = [
        1 0 0;

```

```

        0 cosd(90 - obj.pole_Dec) -sind(90 - obj.pole_Dec);
        0 sind(90 - obj.pole_Dec)  cosd(90 - obj.pole_Dec)];

obj.rotation_matrix_pole_RA_Dec = Rot_Z_pole_RA * Rot_X_pole_Dec;

% Other Parameters
obj.mu = obj.gravity_field.GM; % [km^3 sec^-2]
obj.radius = obj.gravity_field.R ; % [km]

% Initialize position, velocity, and rotation matrix

obj.position = zeros(1,3); % [km]
obj.velocity = zeros(1,3); % [km/sec]
obj.position_array =
zeros( mission.true_time.num_time_steps_position_array,3); % [km]

obj = func_main_true_target(obj, mission);

% Initialize Variables to store position and velocity of target
obj.store = [];

obj.store.name = obj.name;
obj.store.position = zeros(mission.storage.num_storage_steps,
length(obj.position));
obj.store.velocity = zeros(mission.storage.num_storage_steps,
length(obj.velocity));

obj = func_update_target_store(obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_target_store(obj, mission)

    if mission.storage.flag_store_this_time_step == 1
        obj.store.position(mission.storage.k_storage,:) =
obj.position; % [sec]
        obj.store.velocity(mission.storage.k_storage,:) =
obj.velocity; % [sec]
    end

end

```

[] Methods: Main

Update target's position, velocity, rotation matrix for current time

```

function obj = func_main_true_target(obj,mission)

```

```

        target_pos_vel_this_time =
cspice_spkezr(obj.spice_name,mission.true_time.date,'J2000','NONE','SUN');
        obj.position = target_pos_vel_this_time(1:3)'; % [km]
        obj.velocity = target_pos_vel_this_time(4:6)'; % [km/sec]

        target_pos_vel_array = (cspice_spkezr(obj.spice_name,
mission.true_time.prev_date +
mission.true_time.time_position_array' , 'J2000','NONE','SUN'))';
        obj.position_array = target_pos_vel_array(:,1:3);

        % Small bodies
        obj.rotation_matrix = func_compute_target_rotation_matrix(obj,
mission);

        % Planets
        % obj.rotation_matrix = cspice_pxform('J2000', ['IAU_',obj.name],
mission_true_time.date);

        % Store
        obj = func_update_target_store(obj, mission);
end

```

[] Methods: Compute Rotation Matrix

Update target's rotation matrix for current time

```

function rot = func_compute_target_rotation_matrix(obj, mission)

    switch obj.name

        case 'Enceladus'
            fromFrame = 'IAU_ENCELADUS'; % Body-fixed frame of
Enceladus
            toFrame = 'J2000';           % Inertial frame (e.g.,
J2000)

            rot = cspice_pxform(fromFrame, toFrame,
mission.true_time.date);

            otherwise
                theta_PM = obj.prime_meridian + obj.rotation_rate *
(mission.true_time.time - mission.true_time.t_initial);
                Rot_Z_PM = [
                    cosd(theta_PM) sind(theta_PM) 0;
                    -sind(theta_PM) cosd(theta_PM) 0;
                    0 0 1];
                rot = Rot_Z_PM*obj.rotation_matrix_pole_RA_Dec; % From
J2000 to Body frame

                rot = rot'; % From Body frame to J2000
            end
        end
    end
end

```

end

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3.7 True_Time

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Class: True_Time

Keeps track of the all time variables in the simulation

```
classdef True_Time < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
t_initial % [sec] : Start time
t_final % [sec] : Final time
time_step % [sec] : Simulation time step
t_initial_date_string % [string] : Start date of simulation. Format =
[DD-MMM(words)-YYYY HH-MM-SS].
```

```
time_step_attitude % [sec] : Time step for attitude dynamics
(Optional)
```

```
print_progress_steps % [integer] : Number of steps to skip between
printing progress (Optional)
```

```
time_step_position_array % [sec] : Time step for position dynamics
array (Optional)
```

[] Properties: Variables Computed Internally

```
t_initial_date % [sec from J2000] : Start date of simulation.
```

```

        num_time_steps % [integer] : Number of simulation time steps      #
        time % [sec] : Current true time                                  #
        date % [sec from J2000] : Current true date                      #

        num_time_steps_attitude % [integer] : Number of attitude dynamics loop
time steps within one simulation time step #
        time_attitude % [sec] : Current true time within attitude dynamics
loop #

        k % [integer] : Time loop variable                              #
        k_attitude % [integer] : Attitude Dynamics Time loop variable    #

        num_time_steps_position_array % [integer]
        time_position_array % [sec]

        prev_time % [sec] : Previous true time
#
        prev_date % [sec from J2000] Previous true date

        data % to store other values

```

[] Properties: Storage Variables

```

store

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = True_Time(init_data)

    obj.t_initial = init_data.t_initial;
    obj.time = obj.t_initial;

    obj.t_final = init_data.t_final;
    obj.time_step = init_data.time_step;

    if isfield(init_data, 'data')
        obj.data = init_data.data;
    else
        obj.data = [];
    end

    obj.num_time_steps = ceil((obj.t_final - obj.t_initial)/
obj.time_step);

```

```

obj.t_initial_date_string = init_data.t_initial_date_string;
obj.t_initial_date = cal2sec(obj.t_initial_date_string);
obj.date = obj.t_initial_date + obj.time; % Seconds from '01-
JAN-2000 00:00:00'

if isfield(init_data, 'time_step_attitude')
    % time_step_attitude_dynamics has been specified
    obj.time_step_attitude = init_data.time_step_attitude;
else
    obj.time_step_attitude = obj.time_step;
end

obj.num_time_steps_attitude = (obj.time_step/
obj.time_step_attitude);

if ~isinteger(int32(obj.num_time_steps_attitude))
    error('time_step must be divisble by
time_step_attitude_dynamics!');
end

obj.time_attitude = obj.time;

obj.k = 0;
obj.k_attitude = 0;

if isfield(init_data, 'print_progress_steps')
    % print_progress_steps has been specified
    obj.print_progress_steps = init_data.print_progress_steps;
else
    obj.print_progress_steps = ceil((obj.num_time_steps)/1000);
end

% Create Time Array for Position Dynamics

if isfield(init_data, 'time_step_position_array')
    obj.time_step_position_array =
init_data.time_step_position_array;
else
    obj.time_step_position_array = min([10, obj.time_step,
obj.time_step_attitude]); % [sec]
end

obj.num_time_steps_position_array = (obj.time_step/
obj.time_step_position_array) + 1;

if ~isinteger(int32(obj.num_time_steps_position_array))
    error('time_step must be divisble by
time_step_position_array!');
end

obj.time_position_array = [0: obj.time_step_position_array :
obj.time_step];

```

```
obj.prev_time = obj.time; % [sec]
obj.prev_date = obj.date; % [sec from J2000]
```

```
end
```

[] Methods: Initialize Store

Initialize the store variable

```
function obj = func_initialize_time_store(obj, mission)

    % Variables to store: time, date, time_attitude
    obj.store.time = zeros(mission.storage.num_storage_steps,
length(obj.time));
    obj.store.date = zeros(mission.storage.num_storage_steps,
length(obj.date));
    obj.store.time_attitude =
zeros(mission.storage.num_storage_steps_attitude, length(obj.time_attitude));

    % Store first set of variables
    obj = func_update_time_store(obj, mission);
    obj = func_update_time_store_attitude(obj, mission);

end
```

[] Methods: Store

Update the store variable

```
function obj = func_update_time_store(obj, mission)

    if mission.storage.flag_store_this_time_step == 1
        obj.store.time(mission.storage.k_storage,:) = obj.time; %
[sec]
        obj.store.date(mission.storage.k_storage,:) = obj.date; %
[sec]
    end

end
```

[] Methods: Store Attitude

Update the attitude store variable

```
function obj = func_update_time_store_attitude(obj, mission)

    if mission.storage.flag_store_this_time_step_attitude == 1
        obj.store.time_attitude(mission.storage.k_storage_attitude,:)
= obj.time_attitude; % [sec]
    end

end
```

end

[] Methods: Main

Function to update current time and date within main loop

```
function obj = func_update_true_time_date(obj, k)

    obj.k = k;

    obj.prev_time = obj.time; % [sec]
    obj.prev_date = obj.date; % [sec from J2000]

    obj.time = obj.time + obj.time_step;
    obj.date = obj.t_initial_date + obj.time;

    % Print progress
    if mod(obj.k, obj.print_progress_steps) == 0

        % Expected time left
        time_elap = seconds(toc);
        time_per_loop = time_elap / obj.k;
        time_left = time_per_loop * (obj.num_time_steps - obj.k);

        time_sim_elapsed = seconds(obj.time - obj.t_initial);
        time_sim_total = seconds(obj.t_final - obj.t_initial);

        perc = round(time_sim_elapsed / time_sim_total * 100, 1);

        format = 'dd:hh:mm:ss';
        time_elap.Format = format;
        time_left.Format = format;
        time_sim_elapsed.Format = format;
        time_sim_total.Format = format;

        % Base progress message
        progress_msg = ['- Simulation: ', char(time_sim_elapsed), ' /', char(time_sim_total), ' (', num2str(perc), '%), ' ...
            ' Elapsed: ', char(time_elap), ', Left: ',
            char(time_left), ', Total: ', char(time_elap + time_left)];

        % Add memory info every 100 iterations
        if mod(obj.k, obj.print_progress_steps * 100) == 0
            memoryInfo = evalc('dispmemory()');
            progress_msg = [progress_msg, ' | Current Memory Usage
By Matlab: ', strtrim(memoryInfo)];
        end

        disp(progress_msg)
    end

end
```

[] Methods: Main Attitude

Function to update current time within attitude dynamics loop

```
function obj = func_update_true_time_attitude(obj, k_attitude)

    obj.k_attitude = k_attitude;
    obj.time_attitude = obj.time_attitude + obj.time_step_attitude;

end
```

[] Methods: Set Time

Set time to a specific value

```
function obj = func_set_time(obj, time)

    obj.time = time;
    obj.date = obj.t_initial_date + obj.time;

end

end

end
```

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Chapter 4

SC Physics Based Simulation Layer Classes

4.1 True_SC_ADC

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Class: True_SC_ADC

Tracks the attitude and angular velocity of the SC

```
classdef True_SC_ADC < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
    attitude % [quaternion] : Orientation of inertial frame I with  
respect to the body frame B  
  
    angular_velocity % [rad/sec] : Angular velocity of inertial frame I  
with respect to the body frame B  
  
    mode_true_SC_attitude_dynamics_selector % [string] Different attitude  
dynamics modes  
    % - 'Rigid' : Use Rigid Body Dynamics
```

[] Properties: Variables Computed Internally

```
    rotation_matrix % : Rotation matrix that converts vector in body frame  
B to vector in inertial frame I  
    dot_angular_velocity % [rad/sec^2] : Time derivative of  
angular_velocity (needed by RWA)  
    % RWA - Reaction Wheels | MT momentum Thrusters?  
    control_torque % [Nm] : Control torque about Center of Mass of SC,  
usually generated by MT thrusters and RWA  
    disturbance_torque % [Nm] : Disturbance torque about Center of Mass of  
SC  
    total_torque % [Nm] - Sum of the two above
```

```

        total_wheel_momentum % [kg#m^2/s] : Total momentum of all reaction
wheels

        ode_options % : Options for Matlab's ODE function
odeset( 'RelTol',1e-14,'AbsTol',1e-14)

        plot_handle % : plot handle for attitude visualization

```

[] Properties: Storage Variables

```

store

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = True_SC_ADC(init_data, mission)

    obj.attitude = func_quaternion_properize(init_data.attitude); %
[quaternion]
    obj.angular_velocity = init_data.angular_velocity; % [rad/sec]

    % Compute Rotation Matrix
    obj = func_update_true_SC_ADC_rotation_matrix(obj);

    obj.dot_angular_velocity = [0 0 0];
    obj.control_torque = [0 0 0];
    obj.disturbance_torque = [0 0 0];
    obj.total_wheel_momentum = [0 0 0]; % Initialize as 3x1 vector
    obj.total_torque = [0 0 0];

    obj.ode_options = odeset('RelTol',1e-14,'AbsTol',1e-14);

    obj.mode_true_SC_attitude_dynamics_selector =
init_data.mode_true_SC_attitude_dynamics_selector;

    % Initialize Variables to store: attitude and angular velocity of
SC
    obj.store = [];

    obj.store.attitude =
zeros(mission.storage.num_storage_steps_attitude, length(obj.attitude));
    obj.store.angular_velocity =
zeros(mission.storage.num_storage_steps_attitude,
length(obj.angular_velocity));

```

```

        obj.store.control_torque =
zeros(mission.storage.num_storage_steps_attitude,
length(obj.control_torque));
        obj.store.disturbance_torque =
zeros(mission.storage.num_storage_steps_attitude,
length(obj.disturbance_torque));
        obj.store.total_torque =
zeros(mission.storage.num_storage_steps_attitude, length(obj.total_torque));

        obj = func_update_true_SC_adc_store(obj, mission);
    end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_adc_store(obj, mission)
    if mission.storage.flag_store_this_time_step_attitude == 1
        obj.store.attitude(mission.storage.k_storage_attitude,:) =
obj.attitude; % [sec]

        obj.store.angular_velocity(mission.storage.k_storage_attitude,:) =
obj.angular_velocity; % [sec]

        obj.store.control_torque(mission.storage.k_storage_attitude,:) =
obj.control_torque; % [sec]

        obj.store.disturbance_torque(mission.storage.k_storage_attitude,:) =
obj.disturbance_torque; % [sec]
        obj.store.total_torque(mission.storage.k_storage_attitude,:) =
obj.total_torque; % [sec]
    end
end

```

[] Methods: Main

Update SC's Attitude and Angular Velocity

```

function obj = func_main_true_SC_attitude(obj, mission, i_SC)

    switch obj.mode_true_SC_attitude_dynamics_selector

        case 'Rigid'

            % Update disturbance torque is done
            % in the SRP and GG classes

            % Update total wheel momentum
            obj = func_update_total_wheel_momentum(obj, mission,
i_SC);

```

```

        % Update attitude and angular velocity
        obj = func_true_SC_attitude_dynamics_rigid(obj, mission,
i_SC);

        otherwise
            error('Havent written yet!')

        end

        % Sum torques for storage
        obj.total_torque = obj.control_torque + obj.disturbance_torque;

        % Compute Rotation Matrix
        obj = func_update_true_SC_ADC_rotation_matrix(obj);

        % Store
        obj = func_update_true_SC_adc_store(obj, mission);

        % Reset variables
        obj.control_torque = [0 0 0]; % [Nm]

        % Reset every main time step
        if (mission.true_time.k_attitude ==
mission.true_time.num_time_steps_attitude)
            obj.disturbance_torque = [0 0 0]; % Reset torque
        end
    end
end

```

[] Methods: Update Rotation Matrix

Update SC's Rotation Matrix

```

function obj = func_update_true_SC_ADC_rotation_matrix(obj)

    % Compute Rotation Matrix
    SC_True_e_current = obj.attitude(1:3)/norm(obj.attitude(1:3));
    SC_True_Phi_current = 2*acos(obj.attitude(4)); % [rad]
    obj.rotation_matrix =
func_create_rotation_matrix(SC_True_e_current, SC_True_Phi_current);

end

```

[] Methods: Rigid Attitude Dynamics

Update SC's Attitude and Angular Velocity

```

function obj = func_true_SC_attitude_dynamics_rigid(obj, mission,
i_SC)

    SC_Quaternion_Omega_current = [obj.attitude';
obj.angular_velocity'];

    this_time_array = [0 mission.true_time.time_step_attitude];

```

```

        [T,X]=ode45(@(t,X) func_ode_attitude_dynamics(t, X, mission,
i_SC), this_time_array, SC_Quaternion_Omega_current, obj.ode_options);

        new_SC_Quaternion_Omega_current = X(end,:);

        obj.attitude =
func_quaternion_properize(new_SC_Quaternion_Omega_current(1:4)); %
[quaternion]
        obj.angular_velocity = new_SC_Quaternion_Omega_current(5:7); %
[rad/sec]

        %retrieve cache
        X_dot = func_ode_attitude_dynamics(this_time_array(end),
new_SC_Quaternion_Omega_current', mission, i_SC);
        obj.dot_angular_velocity = X_dot(5:7)';

    end

```

[] Methods: Update Reaction Wheel Momentum

```

function obj = func_update_total_wheel_momentum(obj, mission, i_SC)
    % Initialize total wheel momentum as a 3x1 vector
    obj.total_wheel_momentum = zeros(3, 1);

    % Loop through all reaction wheels and add their individual
momentum vectors
    for i =
1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_reaction_wheel
        % Each wheel's total_momentum is already a vector in the body
frame
        if
isfield(mission.true_SC{i_SC}.true_SC_reaction_wheel{i}, 'total_momentum')
&& ...

~isempty(mission.true_SC{i_SC}.true_SC_reaction_wheel{i}.total_momentum)
            obj.total_wheel_momentum = obj.total_wheel_momentum +
mission.true_SC{i_SC}.true_SC_reaction_wheel{i}.total_momentum;
        end
    end
end

end

end
end

```

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4.2 True_SC_Body

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Class: True_SC_Body

Tracks the SC Body

```
classdef True_SC_Body < handle
```

Properties

properties

[] Properties: Initialized Variables

```
name % [string] = 'SC j' for jth SC

mass % : Mass of the SC
% - dry : Dry mass of the SC, that doesn't change position/attitude
% - - mass [kg] : Actual mass
% - - location [m] : Location of this mass in body frame B
% - - MI_over_m [m^2] : Computed once during initialization, shouldn't
change with time (NOTE: NOT MULTIPLIED BY MASS)

% - supplement : Positive/negative mass that is added/removed from the
SC. (e.g. sample collection or projectile) (Optional)

% - # propellant : Propellant mass of the SC that does change value
(Optional)
% Take propellant mass from True_SC_Fuel_Tank

% - # solar_panel : Solar panel mass of the SC, that doesnot change
value (Optional)
% Take solar panel mass from True_SC_Solar_Panel

total_mass % [kg] : Total mass of the SC
```

```

mode_COM_selector % Select which COM to use
% 'given' : Give apriori
% 'update' : Computed by the code

location_COM % [m] : Compute CM from above data

shape_model % : Cell of SC shape models
% - Vertices [m] : Position of vertices in body frame B
% - Faces : Triplet of vertex indices define a face
% - Face_reflectance_factor in [0, 1] : Used for ith face (used for
SRP)
% - r_CM [m] : CM of this shape
% - I_through_r_CM [kg m^2] : Intertia matrix of this shape, about its
CM
% - volume [m^2] : Volume of this shape
% - Face_center [m] : Center of each Face
% - Face_normal [unit vector] : Normal out vector of each face (used
for SRP)
% - Face_area [m^2] : Area of each face
% - type [string] : Type of shape is used for MI and volume
calculations

total_volume % [m^3] : Total volume of the SC

mode_MI_selector % Select which MI to use
% 'given' : Give apriori
% 'update' : Computed by the code

total_MI % [kg m^2] : Total MI of the SC

num_hardware_exists % Data structure that denotes if a hardware exists
on a SC or not (1 >= HW exists, 0 = It doesn't exist)
% Initialized to zero using init_num_hardware_exists.m file
% - num_onboard_clock [integer]
% - num_sun_sensor [integer]
% - num_star_tracker [integer]
% - num_imu [integer]
% - num_micro_thruster [integer]
% - num_reaction_wheel [integer]
% - num_magnetorquer [integer]
% - num_camera [integer]
% - num_chemical_thruster [integer]
% - num_ep_thruster [integer]
% - num_solar_panel [integer]
% - num_RTG [integer]
% - num_battery [integer]
% - num_PDC [integer]
% - num_radio_antenna [integer]
% - num_dte_communication [integer]
% - num_intersat_communication [integer]
% - num_onboard_memory [integer]
% - num_science_radar [integer]
% - num_science_altimeter [integer]
% - num_science_telescope [integer]

```

```
% - num_science_camera [integer]
```

[] Properties: Variables Computed Internally

```
flag_update_SC_body_total_mass_COM_MI % [Boolean] Flag sets if these  
variables should be computed again
```

[] Properties: Storage Variables

```
store
```

```
end
```

Methods

```
methods
```

[] Methods: Constructor

Construct an instance of this class

```
function obj = True_SC_Body(init_data, mission)

    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
        obj.name = ['SC ', num2str(init_data.i_SC)];
    end

    % mass
    obj.mass = [];
    obj.mass.dry{1}.mass = 0; % [kg]
    obj.mass.dry{1}.location = [0 0 0]; % [m]
    obj.mass.dry{1}.MI_over_m = zeros(3,3); % [m^2]

    if isfield(init_data.mass, 'supplement')
        obj.mass.supplement = init_data.mass.supplement;
    else
        obj.mass.supplement{1}.mass = 0;
        obj.mass.supplement{1}.location = [0 0 0]; % [m]
        obj.mass.supplement{1}.MI_over_m = zeros(3,3); % [m^2]
    end

    obj.mass.propellant{1}.mass = 0; % [kg]
    obj.mass.propellant{1}.location = [0 0 0]; % [m]
    obj.mass.propellant{1}.MI_over_m = zeros(3,3); % [m^2]

    obj.mass.solar_panel{1}.mass = 0; % [kg]
    obj.mass.solar_panel{1}.location = [0 0 0]; % [m]
    obj.mass.solar_panel{1}.MI_over_m = zeros(3,3); % [m^2]
```

```

obj.mode_COM_selector = init_data.mode_COM_selector;

if strcmp(obj.mode_COM_selector, 'given')
    obj.total_mass = init_data.total_mass; % [kg]
    obj.location_COM = init_data.location_COM; % [m]
    obj.total_volume = init_data.total_volume; % [m^3]
else

    obj.total_mass = 0; % [kg]
    obj.location_COM = [0 0 0]; % [m]
    obj.total_volume = 0; % [m^3]
end

% shape model
obj.shape_model = init_data.shape_model;

for i_shape = 1:length(obj.shape_model)
    % warning('Shape model should be a cell of structs with fields
(r_CM, I_over_m, volume, etc)');
    shape = obj.shape_model{i_shape};

    % Center of mass
    r_CM = mean(shape.Vertices, 1); % [m]

    switch obj.shape_model{i_shape}.type

        case 'cuboid'

            % Inertia matrix (assume cuboid)
            L = max(shape.Vertices(:,1)) -
min(shape.Vertices(:,1)); % [m]
            W = max(shape.Vertices(:,2)) -
min(shape.Vertices(:,2)); % [m]
            H = max(shape.Vertices(:,3)) -
min(shape.Vertices(:,3)); % [m]
            I_through_r_CM = diag([1/12*(W^2+H^2), 1/12*(L^2+H^2),
1/12*(L^2+W^2)]); % [m^2]

            % Volume
            volume = L*W*H; % [m^3]

        otherwise
            error('Havent written yet!')

    end

    % Update
    obj.shape_model{i_shape}.r_CM = r_CM;
    obj.shape_model{i_shape}.I_through_r_CM = I_through_r_CM;
    obj.shape_model{i_shape}.volume = volume;

    % obj.total_volume = obj.total_volume +
obj.shape_model{i_shape}.volume; % [m^3]

```

```

end

% compute face orientation + normal vector + area
for i_shape = 1:length(obj.shape_model)

    shape = obj.shape_model{i_shape};
    Face_center = zeros(size(shape.Faces));
    Face_normal = zeros(size(shape.Faces));
    Face_area = zeros(size(shape.Faces,1),1);

    SC_centroid = mean(shape.Vertices);

    for i=1:size(shape.Faces,1)
        % face center : [(V1x+V2x+V3x)/3 ; (V1y+V2y+V3y)/3 : (V1z
+V2z+V3z)/3 ]
        Face_center(i,:) = [

            (shape.Vertices(shape.Faces(i,1),1)+shape.Vertices(shape.Faces(i,2),1)+shape.Vertices(shape.Faces(i,3),1))/3 ;
            (shape.Vertices(shape.Faces(i,1),2)+shape.Vertices(shape.Faces(i,2),2)+shape.Vertices(shape.Faces(i,3),2))/3 ;
            (shape.Vertices(shape.Faces(i,1),3)+shape.Vertices(shape.Faces(i,2),3)+shape.Vertices(shape.Faces(i,3),3))/3 ]
        % normal vector : cross(V1-V3,V2-V3)
        normal_vector_unsigned = cross(...
            shape.Vertices(shape.Faces(i,1),:)-
shape.Vertices(shape.Faces(i,3),:), ...
            shape.Vertices(shape.Faces(i,2),:)-
shape.Vertices(shape.Faces(i,3),:));
        normal_vector_unsigned = normal_vector_unsigned/
norm(normal_vector_unsigned);
        % correct to get normal pointing outward
        out_vector = (Face_center(i,:)-SC_centroid)/
norm(Face_center(i,:)-SC_centroid); % vector_pointing_out : form SC centroid
to face centroid
        if acos(dot(out_vector,normal_vector_unsigned)) > pi/2
            Face_normal(i,:) = -normal_vector_unsigned;
        else
            Face_normal(i,:) = normal_vector_unsigned;
        end
        % Face area
        vertex_index = shape.Faces(i,:); % index of vertices for
this face
        a = norm(shape.Vertices(vertex_index(1),:) -
shape.Vertices(vertex_index(2),:));
        b = norm(shape.Vertices(vertex_index(2),:) -
shape.Vertices(vertex_index(3),:));
        c = norm(shape.Vertices(vertex_index(3),:) -
shape.Vertices(vertex_index(1),:));
        s = (a+b+c)/2; %
semi perimeter
        Face_area(i) = sqrt(s*(s-a)*(s-b)*(s-c)); % Heron
formula
    end
end

```

```

        obj.shape_model{i_shape}.Face_center = Face_center;
        obj.shape_model{i_shape}.Face_normal = Face_normal;
        obj.shape_model{i_shape}.Face_area = Face_area;
    end

    % Add all HW on SC
    obj.num_hardware_exists = init_data.num_hardware_exists;

    % Moment of Intertia
    obj.mode_MI_selector = init_data.mode_MI_selector;

    if strcmp(obj.mode_MI_selector, 'given')
        obj.total_MI = init_data.total_MI; % [kg m^2]
    end

    % Compute dry mass
    if ~strcmp(obj.mode_MI_selector, 'given')
        for i_shape = 1:length(obj.shape_model)
            obj.mass_dry{i_shape}.mass =
obj.shape_model{i_shape}.mass; % [kg]
            obj.mass_dry{i_shape}.location =
obj.shape_model{i_shape}.r_CM; % [m]
            obj.mass_dry{i_shape}.MI_over_m =
obj.shape_model{i_shape}.I_through_r_CM; % [m^2]
        end

        % Compute total mass and COM and MI
        obj = func_update_SC_body_total_mass_COM_MI(obj);
    end

    % Reset Flag
    obj.flag_update_SC_body_total_mass_COM_MI = 0;

    % Initialize Variables to store: total_mass location_COM total_MI
    obj.store = [];

    obj.store.total_mass = zeros(mission.storage.num_storage_steps,
length(obj.total_mass));
    obj.store.location_COM = zeros(mission.storage.num_storage_steps,
length(obj.location_COM));
    obj.store.total_MI = zeros(mission.storage.num_storage_steps, 9);

    obj = func_update_true_SC_body_store(obj, mission);

end

```

[] Methods: Store

Update the store variable

```
function obj = func_update_true_SC_body_store(obj, mission)
```

```

        if mission.storage.flag_store_this_time_step == 1
            obj.store.total_mass(mission.storage.k_storage,:) =
obj.total_mass; % [kg]
            obj.store.location_COM(mission.storage.k_storage,:) =
obj.location_COM; % [m]
            obj.store.total_MI(mission.storage.k_storage,:) =
reshape(obj.total_MI,1,9); % [kg m^2]
        end
    end
end

```

[] Methods: Main

Main function

```

function obj = func_main_true_SC_body(obj, mission, i_SC)

% First update fuel and solar panel masses if needed
if obj.flag_update_SC_body_total_mass_COM_MI == 1
    % Update mass values from fuel tanks and solar panels first
    obj = func_update_SC_body_mass(obj, mission, i_SC);

    % Then compute total mass and COM and MI
    obj = func_update_SC_body_total_mass_COM_MI(obj);
end

% Update Store
obj = func_update_true_SC_body_store(obj, mission);

end

```

[] Methods: Update Total Mass, COM, MI

Update total mass and COM

```

function obj = func_update_SC_body_total_mass_COM_MI(obj)

% Reset Flag
obj.flag_update_SC_body_total_mass_COM_MI = 0;

% Update Total Mass and COM
if strcmp(obj.mode_COM_selector, 'update')

    obj.total_mass = 0; % [kg]
    obj.location_COM = [0 0 0]; % [m]

    for i_mass_class = 1:1:4

        this_mass_class = [];

        switch i_mass_class

            case 1

```

```

        this_mass_class = obj.mass.dry;
    case 2
        this_mass_class = obj.mass.supplement;
    case 3
        this_mass_class = obj.mass.propellant;
    case 4
        this_mass_class = obj.mass.solar_panel;
    otherwise
        error('this_mass_class does not exist!')
    end

    for i=1:length(this_mass_class)
        obj.location_COM = ((obj.total_mass
* obj.location_COM) + (this_mass_class{i}.mass *
this_mass_class{i}.location)); % [kg m]
        obj.total_mass = obj.total_mass +
this_mass_class{i}.mass; % [kg]
        obj.location_COM = (obj.location_COM /
obj.total_mass); % [m]
    end

end

end

% Update MI
if strcmp(obj.mode_MI_selector, 'update')

    obj.total_MI = zeros(3,3); % [kg m^2]

    for i_mass_class = 1:4

        this_mass_class = [];

        switch i_mass_class

            case 1
                this_mass_class = obj.mass.dry;
            case 2
                this_mass_class = obj.mass.supplement;
            case 3
                this_mass_class = obj.mass.propellant;
            case 4
                this_mass_class = obj.mass.solar_panel;
            otherwise
                error('this_mass_class does not exist!')
            end

            for i=1:length(this_mass_class)

                % Displacement vector from the shape CM to the SC CM
                r_CM_i = obj.location_COM -
this_mass_class{i}.location;

```

```

        % Parallel Axis Theorem: I_cm_sc = I_cm_shape + m *
        (r' * r * I_3 - r * r')
        I_i = (this_mass_class{i}.mass *
this_mass_class{i}.MI_over_m) + (this_mass_class{i}.mass * ( (r_CM_i *
r_CM_i' * eye(3)) - (r_CM_i' * r_CM_i)));

        % Add inertia matrix to the total inertia matrix
        obj.total_MI = obj.total_MI + I_i;

    end

end

end

end

```

[] Methods: Update Mass

Update the mass class with solar panel and propellant mass

```

function obj = func_update_SC_body_mass(obj, mission, i_SC)

    if isfield(mission.true_SC{i_SC}, 'true_SC_solar_panel')
        for i_SP = 1:1:obj.num_hardware_exists.num_solar_panel
            obj.mass.solar_panel{i_SP}.mass =
mission.true_SC{i_SC}.true_SC_solar_panel{i_SP}.mass; % [kg]
            obj.mass.solar_panel{i_SP}.location =
mission.true_SC{i_SC}.true_SC_solar_panel{i_SP}.shape_model.r_CM; % [m]
            obj.mass.solar_panel{i_SP}.MI_over_m =
mission.true_SC{i_SC}.true_SC_solar_panel{i_SP}.shape_model.I_through_r_CM; %
[kg m^2]
        end
    end

    if isfield(mission.true_SC{i_SC}, 'true_SC_fuel_tank')
        for i_FT = 1:1:obj.num_hardware_exists.num_fuel_tank
            % Update propellant mass from fuel tank
            obj.mass.propellant{i_FT}.mass =
mission.true_SC{i_SC}.true_SC_fuel_tank{i_FT}.instantaneous_fuel_mass; % [kg]
            obj.mass.propellant{i_FT}.location =
mission.true_SC{i_SC}.true_SC_fuel_tank{i_FT}.location; % [m]

            % Calculate approximate moment of inertia for a simple
cuboid fuel mass
            % This is a simplified approach - for greater accuracy, a
detailed shape model would be better
            if
~isempty(mission.true_SC{i_SC}.true_SC_fuel_tank{i_FT}.shape_model)
                % If shape model exists, use it
                if
isfield(mission.true_SC{i_SC}.true_SC_fuel_tank{i_FT}.shape_model, 'I_through_r_CM')

```

```

                                obj.mass.propellant{i_FT}.MI_over_m =
mission.true_SC{i_SC}.true_SC_fuel_tank{i_FT}.shape_model.I_through_r_CM;
                                else
                                    % Approximate as cuboid if dimensions available
                                obj.mass.propellant{i_FT}.MI_over_m = zeros(3,3);
                                end
                                else
                                    % Fallback to simple approximation - treat as point
mass with small inertia
                                obj.mass.propellant{i_FT}.MI_over_m = 1e-3 * eye(3); %
[m^2]
                                end

                                % Set flag to update total mass, COM, and MI
                                obj.flag_update_SC_body_total_mass_COM_MI = 1;
                                end
                            end

                        end

                    end

                end
            end
end

```

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4.3 True_SC_Data_Handling

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Class: True_SC_Data_Handling

Tracks the Data Generated onboard the spacecraft

```
classdef True_SC_Data_Handling < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
mode_true_sc_data_handling_selector % [string] Select which Mode to  
run
```

[] Properties: Variables Computed Internally

```
instantaneous_data_change % [kb] Data generated - Data removed over  
mission.true_time.time_step sec
```

```
instantaneous_data_generated % [kb] Data generated by HW and Classes  
over mission.true_time.time_step sec
```

```
instantaneous_data_removed % [kb] Data removed by Communication over  
mission.true_time.time_step sec
```

```
list_HW_data_generated % List of HW and Classes that generates data
```

```

        array_HW_data_generated % [kb] Total data generated by this HW and
Class

        list_HW_data_removed % List of HW and Classes that removes data

        array_HW_data_removed % [kb] Total data removed by this HW and Class

        warning_counter % [integer] Counter stops the warning after 10
displays

        data % Other useful data

```

[] Properties: Storage Variables

```

store

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = True_SC_Data_Handling(init_data, mission)

    obj.mode_true_SC_data_handling_selector =
init_data.mode_true_SC_data_handling_selector;

    obj.instantaneous_data_change = 0; % [kb]
    obj.instantaneous_data_generated = 0; % [kb]
    obj.instantaneous_data_removed = 0; % [kb]

    obj.list_HW_data_generated = [];
    obj.array_HW_data_generated = [];
    obj.list_HW_data_removed = [];
    obj.array_HW_data_removed = [];

    obj.warning_counter = 0;

    if isfield(init_data, 'data')
        obj.data = init_data.data;
    else
        obj.data = [];
    end
    obj.data.store_instantaneous_data_change =
obj.instantaneous_data_change; % [kb]

    % Initialize Variables to store
    obj.store = [];

```

```

        obj.store.instantaneous_data_change =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_data_change));
        obj.store.instantaneous_data_generated =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_data_generated));
        obj.store.instantaneous_data_removed =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_data_removed));

end

```

[] Methods: Initialize list_HW_data_generated

Initialize list_HW_data_generated for HW and Classes

```

function obj = func_initialize_list_HW_data_generated(obj, equipment,
mission)

    this_name = equipment.name;
    flag_name_exisits = 0;

    for i = 1:length(obj.list_HW_data_generated)
        if strcmp( obj.list_HW_data_generated{i}, this_name )
            flag_name_exisits = 1;
        end
    end

    if flag_name_exisits == 0
        i = length(obj.list_HW_data_generated);
        obj.list_HW_data_generated{i+1} = this_name;

        if isprop(equipment, 'instantaneous_data_rate_generated')
            this_instantaneous_data_generated
= (equipment.instantaneous_data_rate_generated *
mission.true_time.time_step); % [kb]
        elseif
isprop(equipment, 'instantaneous_data_generated_per_sample')
            this_instantaneous_data_generated =
equipment.instantaneous_data_generated_per_sample; % [kb]
        else
            error('Data generated incorrect!')
        end

        obj.array_HW_data_generated(1,i+1) =
this_instantaneous_data_generated; % [kb]
    end

end

```

[] Methods: Initialize list_HW_data_removed

Initialize list_HW_data_removed for HW and Classes

```

function obj = func_initialize_list_HW_data_removed(obj, equipment,
mission)

    this_name = equipment.name;
    flag_name_exisits = 0;

    for i = 1:length(obj.list_HW_data_removed)
        if strcmp( obj.list_HW_data_removed{i}, this_name )
            flag_name_exisits = 1;
        end
    end

    if flag_name_exisits == 0
        i = length(obj.list_HW_data_removed);
        obj.list_HW_data_removed{i+1} = this_name;

        if isprop(equipment, 'instantaneous_data_rate_removed')
            this_instantaneous_data_removed =
(equipment.instantaneous_data_rate_removed * mission.true_time.time_step); %
[kb]
        elseif
isprop(equipment, 'instantaneous_data_removed_per_sample')
            this_instantaneous_data_removed =
equipment.instantaneous_data_removed_per_sample; % [kb]
        else
            error('Data removed incorrect!')
        end

        obj.array_HW_data_removed(1,i+1) =
this_instantaneous_data_removed; % [kb]
    end

end

```

[] Methods: Initialize Store

Initialize store of array_HW_data_generated and array_HW_data_removed

```

function obj = func_initialize_store_HW_data_generated_removed(obj,
mission)

    obj.store.list_HW_data_generated = obj.list_HW_data_generated;
    obj.store.list_HW_data_removed = obj.list_HW_data_removed;

    obj.store.array_HW_data_generated =
zeros(mission.storage.num_storage_steps,
length(obj.array_HW_data_generated));
    obj.store.array_HW_data_removed =
zeros(mission.storage.num_storage_steps, length(obj.array_HW_data_removed));

    obj = func_update_true_SC_data_store(obj, mission);

end

```

[] Methods: Store

Update the store variable

```
function obj = func_update_true_SC_data_store(obj, mission)

    if mission.storage.flag_store_this_time_step == 1

obj.store.instantaneous_data_change(mission.storage.k_storage,:) =
obj.data.store_instantaneous_data_change; % [kb]

obj.store.instantaneous_data_generated(mission.storage.k_storage,:) =
obj.instantaneous_data_generated; % [kb]

obj.store.instantaneous_data_removed(mission.storage.k_storage,:) =
obj.instantaneous_data_removed; % [kb]

        obj.store.array_HW_data_generated(mission.storage.k_storage,:)
= obj.array_HW_data_generated; % [kb]

        if isempty(obj.array_HW_data_removed)
            % Do nothing!
        else

obj.store.array_HW_data_removed(mission.storage.k_storage,:) =
obj.array_HW_data_removed; % [kb]
            end
        end

    end

end
```

[] Methods: Main

Main data handling code

```
function obj = func_main_true_SC_data_handling(obj, mission, i_SC)

    switch obj.mode_true_SC_data_handling_selector

        case 'Generic'
            obj = func_true_SC_data_handling_Generic(obj, mission,
i_SC);

        case 'Nightingale'
            obj = func_true_SC_data_handling_Nightingale(obj, mission,
i_SC);

        otherwise
            error('Data Handling mode not defined!')
        end

    end

    % Store
```

```

obj = func_update_true_SC_data_store(obj, mission);

% Reset All Variables
obj.instantaneous_data_change = 0; % [kb]
obj.instantaneous_data_generated = 0; % [kb]
obj.instantaneous_data_removed = 0; % [kb]

end

```

[] Methods: Main Function for Generic

Generic data handling code

```

function obj = func_true_SC_data_handling_Generic(obj, mission, i_SC)

    obj.instantaneous_data_change = (obj.instantaneous_data_generated
- obj.instantaneous_data_removed); % [kb]
    obj.data.store_instantaneous_data_change =
obj.instantaneous_data_change; % [kb]

    if obj.instantaneous_data_change > 0
        % Add Data to Memory

        for i_memory =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_onboard_memory

            if
mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity
>= mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.maximum_capacity
                % Skip this memory

            elseif
(mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.maximum_capacity -
mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity)
<= obj.instantaneous_data_change
                % Fill this memory as much as possible
                obj.instantaneous_data_change =
obj.instantaneous_data_change -
(mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.maximum_capacity -
mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity); %
[kb]

mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity
= mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.maximum_capacity; %
[kb]

            else
                % Put entirely in this memory

mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity
=
mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity
+ obj.instantaneous_data_change; % [kb]

```

```

        obj.instantaneous_data_change = 0; % [kb]

    end

end

if obj.instantaneous_data_change > 0

    if obj.warning_counter < 10
        warning('All Memories are Full!')
        obj.warning_counter = obj.warning_counter + 1;
    end

mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity
=
mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity
+ obj.instantaneous_data_change; % [kb]
        obj.instantaneous_data_change = 0; % [kb]
    else
        obj.warning_counter = 0;
    end

else
    % Remove Data from Memory and obj.instantaneous_data_change <
0

    for i_memory =
mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_onboard_memory:-1:1

        if
mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity
<= 0

            % Skip this memory

        elseif
mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity
< abs(obj.instantaneous_data_change)

            % Delete all this memory
            obj.instantaneous_data_change =
obj.instantaneous_data_change +
mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity;

mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity
= 0; % [kb]

        else
            % Remove some of this memory

mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity
=
mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity
+ obj.instantaneous_data_change; % [kb]

```

```

        obj.instantaneous_data_change = 0; % [kb]

    end

end

if obj.instantaneous_data_change < 0

    if obj.warning_counter < 10
        warning('All Memories are Empty!')
        obj.warning_counter = obj.warning_counter + 1;
    end

mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity
=
mission.true_SC{i_SC}.true_SC_onboard_memory{i_memory}.instantaneous_capacity
+ obj.instantaneous_data_change; % [kb]
    obj.instantaneous_data_change = 0; % [kb]
    else
        obj.warning_counter = 0;
    end

end

end

end

```

[] Methods: Update Instantaneous Data Generated

Updates instantaneous_data_generated by all HW and Classes

```

function obj = func_update_instantaneous_data_generated(obj,
equipment, mission, varargin)

    if isprop(equipment, 'instantaneous_data_rate_generated')
        this_instantaneous_data_generated
= (equipment.instantaneous_data_rate_generated *
mission.true_time.time_step); % [kb]
    elseif
isprop(equipment, 'instantaneous_data_generated_per_sample')
        this_instantaneous_data_generated =
equipment.instantaneous_data_generated_per_sample; % [kb]
    else
        error('Data generated incorrect!')
    end

    if ~isempty(varargin)
        chosen_memory = varargin{1};
        i_SC = varargin{2};
    end

```

```

mission.true_SC{i_SC}.true_SC_onboard_memory{chosen_memory}.instantaneous_capacity
=
mission.true_SC{i_SC}.true_SC_onboard_memory{chosen_memory}.instantaneous_capacity
+ this_instantaneous_data_generated; % [kb]
    else
        obj.instantaneous_data_generated =
obj.instantaneous_data_generated + this_instantaneous_data_generated; % [kb]
    end

    this_name = equipment.name;
    flag_name_exisits = 0;
    this_idx = 0;

    for i = 1:length(obj.list_HW_data_generated)
        if strcmp( obj.list_HW_data_generated{i}, this_name )
            flag_name_exisits = 1;
            this_idx = i;
        end
    end

    if flag_name_exisits == 0
        error('HW SW not found!')
    else
        obj.array_HW_data_generated(1,this_idx) =
obj.array_HW_data_generated(1,this_idx) +
this_instantaneous_data_generated; % [kb]
    end

end

```

[] Methods: Update Instantaneous Data Generated during Attitude Loop

Updates instantaneous_data_generated by all HW and Classes, in ADL

```

function obj = func_update_instantaneous_data_generated_attitude(obj,
equipment, mission, varargin)

    if isprop(equipment, 'instantaneous_data_rate_generated')
        this_instantaneous_data_generated
= (equipment.instantaneous_data_rate_generated *
mission.true_time.time_step_attitude); % [kb]
    elseif
isprop(equipment, 'instantaneous_data_generated_per_sample')
        this_instantaneous_data_generated =
equipment.instantaneous_data_generated_per_sample; % [kb]
    else
        error('Data generated incorrect!')
    end

    if ~isempty(varargin)

```

```

        chosen_memory = varargin{1};
        i_SC = varargin{2};

mission.true_SC{i_SC}.true_SC_onboard_memory{chosen_memory}.instantaneous_capacity
=
mission.true_SC{i_SC}.true_SC_onboard_memory{chosen_memory}.instantaneous_capacity
+ this_instantaneous_data_generated; % [kb]
    else
        obj.instantaneous_data_generated =
obj.instantaneous_data_generated + this_instantaneous_data_generated; % [kb]
    end

    this_name = equipment.name;
    flag_name_exisits = 0;
    this_idx = 0;

    for i = 1:length(obj.list_HW_data_generated)
        if strcmp( obj.list_HW_data_generated{i}, this_name )
            flag_name_exisits = 1;
            this_idx = i;
        end
    end

    if flag_name_exisits == 0
        error('HW SW not found!')
    else
        obj.array_HW_data_generated(1,this_idx) =
obj.array_HW_data_generated(1,this_idx) +
this_instantaneous_data_generated; % [kb]
    end

end

```

[] Methods: Update Instantaneous Data Removed

Updates instantaneous_data_removed by all HW and Classes

```

function obj = func_update_instantaneous_data_removed(obj, equipment,
mission, varargin)

    if isprop(equipment, 'instantaneous_data_rate_removed')
        this_instantaneous_data_removed =
(equipment.instantaneous_data_rate_removed * mission.true_time.time_step); %
[kb]
    elseif isprop(equipment, 'instantaneous_data_removed_per_sample')
        this_instantaneous_data_removed =
equipment.instantaneous_data_removed_per_sample; % [kb]
    else
        error('Data removed incorrect!')
    end

```

```

        if ~isempty(varargin)
            chosen_memory = varargin{1};
            i_SC = varargin{2};

mission.true_SC{i_SC}.true_SC_onboard_memory{chosen_memory}.instantaneous_capacity
=
mission.true_SC{i_SC}.true_SC_onboard_memory{chosen_memory}.instantaneous_capacity
- this_instantaneous_data_removed; % [kb]
        else
            obj.instantaneous_data_removed =
obj.instantaneous_data_removed + this_instantaneous_data_removed; % [kb]
        end

        this_name = equipment.name;
        flag_name_exisits = 0;
        this_idx = 0;

        for i = 1:length(obj.list_HW_data_removed)
            if strcmp( obj.list_HW_data_removed{i}, this_name )
                flag_name_exisits = 1;
                this_idx = i;
            end
        end

        if flag_name_exisits == 0
            error('HW SW not found!')
        else
            obj.array_HW_data_removed(1,this_idx) =
obj.array_HW_data_removed(1,this_idx) + this_instantaneous_data_removed; %
[kb]
        end

    end

end

end

```

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4.4 True_SC_Gravity_Gradient

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[] Methods: Main	2

Class: True_SC_Gravity_Gradient

Computes Gravity Gradient disturbance torque

```
classdef True_SC_Gravity_Gradient < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
enable_G2 % [boolean]
```

[] Properties: Variables Computed Internally

```
disturbance_torque_G2 % [Nm]
```

[] Properties: Storage Variables

```
store
```

```
end
```

Methods

```
methods
```

[] Methods: Constructor

Construct an instance of this class

```
function obj = True_SC_Gravity_Gradient(init_data, mission, i_SC)

% Optional parameters
```

```

obj.disturbance_torque_G2 = [0 0 0]; % [N]
obj.enable_G2 = init_data.enable_G2;

% Calculate GG before first iteration of ADL
obj.func_main_true_SC_gravity_gradient(mission, i_SC);

% Initialize storage
obj.store.disturbance_torque_G2 =
zeros(mission.storage.num_storage_steps, length(obj.disturbance_torque_G2));

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_gravity_gradient_store(obj, mission)
    if mission.storage.flag_store_this_time_step == 1
        obj.store.disturbance_torque_G2(mission.storage.k_storage,:) =
obj.disturbance_torque_G2;
    end
end

```

[] Methods: Main

Compute GG Disturbance torque

```

function obj = func_main_true_SC_gravity_gradient(obj, mission, i_SC)

% Reset disturbance torque and force
obj.disturbance_torque_G2 = [0 0 0]; % [N]

if obj.enable_G2 == 1
    % Gravity direction from SB
    Rc =
1e3*(mission.true_SC{i_SC}.true_SC_navigation.position_relative_target);
    %[m]
    Rc_sc = (mission.true_SC{i_SC}.true_SC_adc.rotation_matrix') *
Rc';
    %[m]

    % Gravity gradient torque [Nm]
    obj.disturbance_torque_G2 =
( (3*(mission.true_target{mission.true_SC{i_SC}.true_SC_navigation.index_relative_target}
* 1e9)/(norm(Rc_sc)^5)) * cross(Rc_sc,
mission.true_SC{i_SC}.true_SC_body.total_MI *Rc_sc) )';

    % Accumulate disturbances
    mission.true_SC{i_SC}.true_SC_adc.disturbance_torque
= mission.true_SC{i_SC}.true_SC_adc.disturbance_torque +
obj.disturbance_torque_G2;

else
    % Don't do anything!

```

```
        end

        % Update storage after calculation
        obj.func_update_true_gravity_gradient_store(mission);

    end

end

end
```

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4.5 True_SC_Navigation

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Class: True_SC_Navigation

Tracks the position and velocity of the SC

```
classdef True_SC_Navigation < handle
```

Properties

properties

[] Properties: Initialized Variables

```
position % [km] : Current position of SC in inertial frame I
velocity % [km/sec] : Current velocity of SC in inertial frame I
position_relative_target % [km] : Current position of SC relative to
SB-center J2000 inertial frame
velocity_relative_target % [km/sec] : Current velocity of SC relative
to SB-center J2000 inertial frame
name_relative_target % [string] : Name of the target, relative to
which position and velocity are specified

spice_filename % [string] : SC's SPICE FileName
spice_name % [string] : SC's SPICE Name

mode_true_sc_navigation_dynamics_selector % [string] Different
navigation dynamics modes
% - 'SPICE' : Use pre-computed SPICE trajectory
% - 'Absolute Dynamics'
% - 'Relative Dynamics'
```

[] Properties: Variables Computed Internally

```
index_relative_target % [integer] : Index of the target, relative to
which position and velocity are specified
```

```

flag_visible_Sun % [Boolean] Check if Sun is visible
flag_visible_Earth % [Boolean] Check if Earth is visible

flag_SC_crashed % [Boolean] Check if SC has crashed into anything!
position_array % [km] Position array wrt Sun-centered J2000,
corresponding to time array in mission.true_time.time_position_array

control_force % [N] : Control force vector generated by thrusters
(e.g. MT, CT) that passes through Center of Mass of SC
disturbance_force % [N] : Disturbance force vector generated by SRP
that passes through Center of Mass of SC

ode_options % : Options for Matlab's ODE function
odeset( 'RelTol',1e-14,'AbsTol',1e-14)

```

[] Properties: Storage Variables

```

store

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = True_SC_Navigation(init_data, mission)

    if strcmp(mission.frame,'Absolute') ||
isfield(init_data, 'position')
        obj.position = init_data.position; % [km]
        obj.velocity = init_data.velocity; % [km/sec]

        if isfield(init_data, 'name_relative_target')
            obj.name_relative_target = init_data.name_relative_target;
        else
            obj.name_relative_target = mission.true_target{1}.name;
        end

        for i_target = 1:1:mission.num_target
            if strcmp(mission.true_target{i_target}.name,
obj.name_relative_target)
                obj.index_relative_target = i_target;
                position_target =
mission.true_target{i_target}.position;
                velocity_target =
mission.true_target{i_target}.velocity;
            end
        end
    end
end

```

```

        end
    end

    obj.position_relative_target = obj.position -
position_target; % [km]
    obj.velocity_relative_target = obj.velocity -
velocity_target; % [km/sec]

    elseif strcmp(mission.frame,'Relative') ||
isfield(init_data, 'position_relative_target')
        obj.position_relative_target =
sc_body_init_data.position_relative_target; % [km]
        obj.velocity_relative_target =
sc_body_init_data.velocity_relative_target; % [km/sec]
        obj.name_relative_target = init_data.name_relative_target; %
[string]

        for i_target = 1:1:mission.num_target
            if strcmp(mission.true_target{i_target}.name,
obj.name_relative_target)
                obj.index_relative_target = i_target;
                position_target =
mission.true_target{i_target}.position;
                velocity_target =
mission.true_target{i_target}.velocity;
            end
        end

        obj.position = position_target +
obj.position_relative_target; % [km]
        obj.velocity = velocity_target +
obj.velocity_relative_target; % [km/sec]

    else
        error('Navigation initialization incorrect!')
    end

    obj.control_force = [0 0 0]; % [N]
    obj.disturbance_force = [0 0 0]; % [N]
    obj.flag_SC_crashed = 0;

    % Select Dynamics Mode
    obj.mode_true_SC_navigation_dynamics_selector =
init_data.mode_true_SC_navigation_dynamics_selector; % [string]

    if strcmp( obj.mode_true_SC_navigation_dynamics_selector, 'SPICE'
)
        % Use SPICE trajectory
        obj.spice_filename = init_data.spice_filename;
        obj.spice_name = init_data.spice_name;
        cspice_furnsh(obj.spice_filename)
    end

```

```

obj.ode_options = odeset('RelTol',1e-14,'AbsTol',1e-14);

% Update flag visible
obj = func_update_visible_Sun_Earth(obj, mission);

% Initialize Variables to store: position and velocity of SC
obj.store = [];

obj.store.position = zeros(mission.storage.num_storage_steps,
length(obj.position));
obj.store.velocity = zeros(mission.storage.num_storage_steps,
length(obj.velocity));
obj.store.position_relative_target =
zeros(mission.storage.num_storage_steps,
length(obj.position_relative_target));
obj.store.velocity_relative_target =
zeros(mission.storage.num_storage_steps,
length(obj.velocity_relative_target));
obj.store.flag_visible_Sun =
zeros(mission.storage.num_storage_steps, length(obj.flag_visible_Sun));
obj.store.flag_visible_Earth =
zeros(mission.storage.num_storage_steps, length(obj.flag_visible_Earth));

obj = func_update_true_SC_navigation_store(obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_navigation_store(obj, mission)

if mission.storage.flag_store_this_time_step == 1
    obj.store.position(mission.storage.k_storage,:) =
obj.position; % [km]
    obj.store.velocity(mission.storage.k_storage,:) =
obj.velocity; % [km/sec]

obj.store.position_relative_target(mission.storage.k_storage,:) =
obj.position_relative_target; % [km]

obj.store.velocity_relative_target(mission.storage.k_storage,:) =
obj.velocity_relative_target; % [km/sec]
    obj.store.flag_visible_Sun(mission.storage.k_storage,:) =
obj.flag_visible_Sun; % [Boolean]
    obj.store.flag_visible_Earth(mission.storage.k_storage,:) =
obj.flag_visible_Earth; % [Boolean]
end

end

```

[] Methods: Main

Select method to update position and velocity

```
function obj = func_main_true_SC_navigation(obj, mission, i_SC)

    switch obj.mode_true_SC_navigation_dynamics_selector

        case 'SPICE'
            % Use SPICE trajectory
            obj =
func_update_SC_navigation_position_velocity_SPICE(obj, mission);

        case 'Absolute Dynamics'
            % Use Absolute Dynamics
            obj =
func_update_SC_navigation_position_velocity_Absolute_Dynamics(obj, mission,
i_SC);

        otherwise
            error('Navigation mode not defined!')
    end

    % Update flag visible
    obj = func_update_visible_Sun_Earth(obj, mission);

    % Update SC crash
    obj = func_update_flag_SC_crashed(obj, mission, i_SC);

    % Store
    obj = func_update_true_SC_navigation_store(obj, mission);

    obj.control_force = [0 0 0]; % [N]
    obj.disturbance_force = [0 0 0]; % [N]

end
```

[] Methods: Update Position Velocity SPICE

Update position and velocity using SPICE

```
function obj = func_update_SC_navigation_position_velocity_SPICE(obj,
mission)

    SC_pos_vel =
cspice_spekr(obj.spice_name,mission.true_time.date,'J2000','NONE','SUN');

    obj.position = SC_pos_vel(1:3)'; % [km]
    obj.velocity = SC_pos_vel(4:6)'; % [km/sec]

    position_target =
mission.true_target{obj.index_relative_target}.position;
```

```

        velocity_target =
mission.true_target{obj.index_relative_target}.velocity;

        obj.position_relative_target = obj.position - position_target; %
[km]
        obj.velocity_relative_target = obj.velocity - velocity_target; %
[km/sec]

        SC_pos_vel_array = (cspice_spkezr(obj.spice_name,
mission.true_time.prev_date +
mission.true_time.time_position_array' , 'J2000', 'NONE', 'SUN'))';
        obj.position_array = SC_pos_vel_array(:,1:3);

end

```

[] Methods: Update Position Velocity Absolute Dynamics

Update position and velocity using Absolute dynamics

```

function obj =
func_update_SC_navigation_position_velocity_Absolute_Dynamics(obj, mission,
i_SC)

    this_time_array = mission.true_time.time_position_array;

    %           obj = obj.func_update_disturbance_force(mission,
i_SC);

    SC_pos_vel_current = [obj.position'; obj.velocity']; % [km, km/
sec] in (6,1) format
    [T,X]=ode113(@(t,X) func_ode_orbit_inertial_absolute_dynamics(t,
X, mission, i_SC), this_time_array, SC_pos_vel_current, obj.ode_options);

    new_SC_pos_vel_current = X(end,:);

    obj.position = new_SC_pos_vel_current(1:3); % [km]
    obj.velocity = new_SC_pos_vel_current(4:6); % [km/sec]

    position_target =
mission.true_target{obj.index_relative_target}.position;
    velocity_target =
mission.true_target{obj.index_relative_target}.velocity;

    obj.position_relative_target = obj.position - position_target; %
[km]
    obj.velocity_relative_target = obj.velocity - velocity_target; %
[km/sec]

    obj.position_array = X(:,1:3); % [km]

end

```

```

        %          function obj = func_update_disturbance_force(obj,mission,
i_SC)
        %          % Sum up all disturbance forces
        %          obj.disturbance_force =
mission.true_SC{i_SC}.true_SRP.disturbance_force_SRP';
        %          end

```

[] Methods: Update Visible Sun Earth

Update flag_visible_Sun and flag_visible_Earth

```

function obj = func_update_visible_Sun_Earth(obj, mission)

    % Use lins math: https://mathworld.wolfram.com/Point-LineDistance3-Dimensional.html

    for i_vis = 1:1:2

        flag_visible = 1;

        if i_vis == 1
            % Sun
            x1 =
mission.true_solar_system.SS_body{mission.true_solar_system.index_Sun}.position; %
[km]

            elseif i_vis == 2
                % Earth
                x1 =
mission.true_solar_system.SS_body{mission.true_solar_system.index_Earth}.position; %
[km]

            else
                error('Shouldnt reach here')
            end

            % SC Position
            x2 = obj.position; % [km]

            % Check all Targets
            for i_target = 1:1:mission.num_target

                x0 = mission.true_target{i_target}.position; % [km]

                d = norm(cross(x0 - x1, x0 - x2))/norm(x2 - x1);
                if d >= mission.true_target{i_target}.radius % [km]
                    % No chance of eclipse
                else
                    % Check t
                    t = - dot(x1 - x0, x2 - x1) / (norm(x2 - x1))^2;
                    if (t >= 0) && (t <= 1)
                        flag_visible = 0;
                    else

```

```

        % Body is outside the line of sight
    end
end
end

% Check all SS Bodies
for i_SS_body = 1:1:mission.true_solar_system.num_SS_body

    if (i_vis == 1) && (i_SS_body ==
mission.true_solar_system.index_Sun)
        % Skip this!

    elseif (i_vis == 2) && (i_SS_body ==
mission.true_solar_system.index_Earth)
        % Skip this!

    else

        x0 =
mission.true_solar_system.SS_body{i_SS_body}.position; % [km]

        d = norm(cross(x0 - x1, x0 - x2))/norm(x2 - x1);
        if d >=
mission.true_solar_system.SS_body{i_SS_body}.radius % [km]
            % No chance of eclipse
        else
            % Check t
            t = - dot(x1 - x0, x2 - x1) / (norm(x2 - x1))^2;
            if (t >= 0) && (t <= 1)
                flag_visible = 0;
            else
                % Body is outside the line of sight
            end
        end
    end

end
end

if i_vis == 1
    % Sun
    obj.flag_visible_Sun = flag_visible;
elseif i_vis == 2
    % Earth
    obj.flag_visible_Earth = flag_visible;
else
    error('Shouldnt reach here')
end

end

end

```

[] Methods: Check SC Crashed

Update flag_SC_crashed

```
function obj = func_update_flag_SC_crashed(obj, mission, i_SC)

    for t = 1:1:length(mission.true_time.time_position_array)

        % SC position
        x1 = obj.position_array(t,:);

        % Check all Targets
        for i_target = 1:1:mission.num_target

            x0 = mission.true_target{i_target}.position_array(t,:); %
[ km]

            if norm(x0 - x1) <= mission.true_target{i_target}.radius %
[ km]

                obj.flag_SC_crashed = 1;

disp('-----')
                disp(['SC ',num2str(i_SC),' crashed into
',mission.true_target{i_target}.name])

disp('-----')
                mission.storage.flag_stop_sim = 1;
                break;
            end
        end
    end
end
end
end
end
end
end
end
```

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4.6 True_SC_Power

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Class: True_SC_Power

Track the power status onboard the spacecraft

```
classdef True_SC_Power < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
power_loss_rate % [float] Fraction of the total power loss: Power loss  
[W] = (1 + power_loss_rate) * total_instantaneous_power_consumed
```

[] Properties: Variables Computed Internally

```
name % [string] 'Power Subsystem'  
  
instantaneous_total_power_consumed % [W] Total power consumed by all  
sensors and actuators over mission.true_time.time_step sec  
  
instantaneous_total_power_generated % [W] Total power generated by  
solar panels or RTG over mission.true_time.time_step sec  
  
instantaneous_energy % [W hr] Converted into Energy for storage in  
battery  
  
instantaneous_energy_unused % [W hr] Excess Energy, that is usually  
going to heat the SC  
  
list_HW_energy_consumed % List of HW that consumes power
```

```

list_HW_energy_generated % List of HW that generates power

array_HW_energy_consumed % [W hr] Total energy consumed by this HW

array_HW_energy_generated % [W hr] Total energy generated by this HW

warning_counter % [integer] Counter stops the warning after 10
displays

power_emergency % [boolean] Flag to indicate a critical power deficit
when batteries are empty

power_deficit % [W hr] Track power deficit when batteries are empty

data % Other useful data

```

[] Properties: Storage Variables

```

store

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = True_SC_Power(init_data, mission)

    obj.instantaneous_total_power_consumed = 0; % [W]
    obj.instantaneous_total_power_generated = 0; % [W]
    obj.instantaneous_energy = 0; % [W hr]
    obj.instantaneous_energy_unused = 0; % [W hr]

    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
        obj.name = 'Power Subsystem';
    end

    obj.power_loss_rate = init_data.power_loss_rate; % [float]

    obj.list_HW_energy_consumed = [];
    obj.list_HW_energy_generated = [];
    obj.array_HW_energy_consumed = [];
    obj.array_HW_energy_generated = [];
    obj.warning_counter = 0;
    obj.power_emergency = false;
    obj.power_deficit = 0;

```

```

        if isfield(init_data, 'data')
            obj.data = init_data.data;
        else
            obj.data = [];
        end
        obj.data.store_instantaneous_energy = obj.instantaneous_energy; %
[W hr]

% Initialize Variables to store: power and energy
obj.store = [];

        obj.store.instantaneous_power_consumed =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_total_power_consumed));
        obj.store.instantaneous_power_generated =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_total_power_generated));
        obj.store.instantaneous_energy =
zeros(mission.storage.num_storage_steps, length(obj.instantaneous_energy));
        obj.store.instantaneous_energy_unused =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_energy_unused));

    end

```

[] Methods: Initialize list_HW_energy_consumed

Initialize list_HW_energy_consumed for all HW

```

function obj = func_initialize_list_HW_energy_consumed(obj, equipment,
mission)

    this_name = equipment.name;
    flag_name_exists = 0;

    for i = 1:length(obj.list_HW_energy_consumed)
        if strcmp( obj.list_HW_energy_consumed{i}, this_name )
            flag_name_exists = 1;
        end
    end

    if flag_name_exists == 0
        i = length(obj.list_HW_energy_consumed);
        obj.list_HW_energy_consumed{i+1} = this_name;
        obj.array_HW_energy_consumed(1,i
+1) = equipment.instantaneous_power_consumed *
(mission.true_time.time_step/3600); % [W hr]
    end

end

```

[] Methods: Initialize list_HW_energy_generated

Initialize list_HW_energy_generated for Solar Panels or RTG

```
function obj = func_initialize_list_HW_energy_generated(obj,  
equipment, mission)  
  
    this_name = equipment.name;  
    flag_name_exists = 0;  
  
    for i = 1:length(obj.list_HW_energy_generated)  
        if strcmp( obj.list_HW_energy_generated{i}, this_name )  
            flag_name_exists = 1;  
        end  
    end  
  
    if flag_name_exists == 0  
        i = length(obj.list_HW_energy_generated);  
        obj.list_HW_energy_generated{i+1} = this_name;  
        obj.array_HW_energy_generated(1,i  
+1) = equipment.instantaneous_power_generated *  
        (mission.true_time.time_step/3600); % [W hr]  
    end  
  
end
```

[] Methods: Initialize Store

Initialize store of array_HW_energy_consumed and array_HW_energy_generated

```
function obj = func_initialize_store_HW_power_consumed_generated(obj,  
mission)  
  
    obj.store.list_HW_energy_consumed = obj.list_HW_energy_consumed;  
    obj.store.list_HW_energy_generated = obj.list_HW_energy_generated;  
  
    obj.store.array_HW_energy_consumed =  
zeros(mission.storage.num_storage_steps,  
length(obj.array_HW_energy_consumed));  
    obj.store.array_HW_energy_generated =  
zeros(mission.storage.num_storage_steps,  
length(obj.array_HW_energy_generated));  
  
    obj = func_update_true_SC_power_store(obj, mission);  
  
end
```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_power_store(obj, mission)

    if mission.storage.flag_store_this_time_step == 1

obj.store.instantaneous_power_consumed(mission.storage.k_storage,:) =
obj.instantaneous_total_power_consumed; % [W]

obj.store.instantaneous_power_generated(mission.storage.k_storage,:) =
obj.instantaneous_total_power_generated; % [W]
        obj.store.instantaneous_energy(mission.storage.k_storage,:) =
obj.data.store_instantaneous_energy; % [W hr]

obj.store.instantaneous_energy_unused(mission.storage.k_storage,:) =
obj.instantaneous_energy_unused; % [W hr]

obj.store.array_HW_energy_consumed(mission.storage.k_storage,:) =
obj.array_HW_energy_consumed; % [W hr]

obj.store.array_HW_energy_generated(mission.storage.k_storage,:) =
obj.array_HW_energy_generated; % [W hr]
    end

end

```

[] Methods: Main

Main power code

```

function obj = func_main_true_SC_power(obj, mission, i_SC)

    obj.instantaneous_energy =
(obj.instantaneous_total_power_generated -
obj.instantaneous_total_power_consumed) *
(mission.true_time.time_step/3600); % [W hr]
    obj.data.store_instantaneous_energy = obj.instantaneous_energy; %
[W hr]

    if obj.instantaneous_energy > 0
        % Excess Energy use to Recharge Battery
        obj.power_emergency = false; % Clear emergency flag when we
have excess energy

        for i_batt =
mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_battery:-1:1

            if (mission.true_SC{i_SC}.true_SC_battery{i_batt}.health
== 1) && (obj.instantaneous_energy > 0)

                if
mission.true_SC{i_SC}.true_SC_battery{i_batt}.instantaneous_capacity >=
mission.true_SC{i_SC}.true_SC_battery{i_batt}.maximum_capacity

```

```

        % Do nothing!

        elseif
(mission.true_SC{i_SC}.true_SC_battery{i_batt}.instantaneous_capacity
+ (mission.true_SC{i_SC}.true_SC_battery{i_batt}.charging_efficiency *
obj.instantaneous_energy)) <=
mission.true_SC{i_SC}.true_SC_battery{i_batt}.maximum_capacity
        % Charge this Battery

mission.true_SC{i_SC}.true_SC_battery{i_batt}.instantaneous_capacity
= mission.true_SC{i_SC}.true_SC_battery{i_batt}.instantaneous_capacity
+ (mission.true_SC{i_SC}.true_SC_battery{i_batt}.charging_efficiency *
obj.instantaneous_energy); % [W hr]
        obj.instantaneous_energy = 0; % [W hr]

        else
        % Fill this Battery
        obj.instantaneous_energy =
obj.instantaneous_energy -
(mission.true_SC{i_SC}.true_SC_battery{i_batt}.maximum_capacity -
mission.true_SC{i_SC}.true_SC_battery{i_batt}.instantaneous_capacity)/
mission.true_SC{i_SC}.true_SC_battery{i_batt}.charging_efficiency; % [W hr]

mission.true_SC{i_SC}.true_SC_battery{i_batt}.instantaneous_capacity =
mission.true_SC{i_SC}.true_SC_battery{i_batt}.maximum_capacity; % [W hr]

        end

        end

        end

        if obj.instantaneous_energy > 0
            obj.instantaneous_energy_unused =
obj.instantaneous_energy; % [W hr]
        end

        else
        % Discharge Battery (obj.instantaneous_energy < 0)

        for i_batt =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_battery

            if (mission.true_SC{i_SC}.true_SC_battery{i_batt}.health
== 1) && (obj.instantaneous_energy < 0)

                if
mission.true_SC{i_SC}.true_SC_battery{i_batt}.instantaneous_capacity <= 0
                    % Do nothing!

                elseif
(mission.true_SC{i_SC}.true_SC_battery{i_batt}.instantaneous_capacity *
mission.true_SC{i_SC}.true_SC_battery{i_batt}.discharging_efficiency) >=
abs(obj.instantaneous_energy)

```

```

                                % Lots of extra Energy

mission.true_SC{i_SC}.true_SC_battery{i_batt}.instantaneous_capacity =
mission.true_SC{i_SC}.true_SC_battery{i_batt}.instantaneous_capacity -
(abs(obj.instantaneous_energy) /
mission.true_SC{i_SC}.true_SC_battery{i_batt}.discharging_efficiency); % [W
hr]

                                obj.instantaneous_energy = 0;

                                else
                                    % Empty this Battery!
                                    obj.instantaneous_energy =
obj.instantaneous_energy +
(mission.true_SC{i_SC}.true_SC_battery{i_batt}.instantaneous_capacity *
mission.true_SC{i_SC}.true_SC_battery{i_batt}.discharging_efficiency); % [W
hr]

mission.true_SC{i_SC}.true_SC_battery{i_batt}.instantaneous_capacity = 0; %
[W hr]

                                end

                                end

                                end

                                if obj.instantaneous_energy < 0
                                    % All batteries are empty but we still need power
                                    % Set power emergency flag and calculate the deficit
                                    obj.power_emergency = true;
                                    obj.power_deficit = abs(obj.instantaneous_energy); % Track
the deficit

                                    % Limit the number of warnings displayed
                                    if obj.warning_counter < 10
                                        warning('All Batteries are Empty! Power deficit: %0.2f
W-hr', obj.power_deficit);
                                        obj.warning_counter = obj.warning_counter + 1;
                                    end

                                    % Reset instantaneous_energy to 0 to prevent negative
values
                                    obj.instantaneous_energy = 0;
                                else
                                    obj.power_emergency = false;
                                    obj.warning_counter = 0;
                                    obj.power_deficit = 0;
                                end

                                end

                                % Store
                                obj = func_update_true_SC_power_store(obj, mission);

                                % Reset All Variables

```

```

obj.instantaneous_total_power_consumed = 0; % [W]
obj.instantaneous_total_power_generated = 0; % [W]
obj.instantaneous_energy = 0; % [W hr]
obj.instantaneous_energy_unused = 0; % [W hr]

end

```

[] Methods: Update Instantaneous Power Consumed

Updates instantaneous_power_consumed by all HW

```

function obj = func_update_instantaneous_power_consumed(obj,
equipment, mission)

    obj.instantaneous_total_power_consumed =
obj.instantaneous_total_power_consumed +
( equipment.instantaneous_power_consumed * (1 + obj.power_loss_rate) ); % [W]

    this_name = equipment.name;
    flag_name_exists = 0;
    this_idx = 0;

    for i = 1:length(obj.list_HW_energy_consumed)
        if strcmp( obj.list_HW_energy_consumed{i}, this_name )
            flag_name_exists = 1;
            this_idx = i;
        end
    end

    if flag_name_exists == 0
        error('HW not found!')
    else
        obj.array_HW_energy_consumed(1,this_idx)
= obj.array_HW_energy_consumed(1,this_idx) +
(equipment.instantaneous_power_consumed*(mission.true_time.time_step/3600)); %
[W hr]
    end
end

```

[] Methods: Update Instantaneous Power Consumed Attitude

Updates instantaneous_power_consumed by all HW, within ADL

```

function obj = func_update_instantaneous_power_consumed_attitude(obj,
equipment, mission)
    obj.instantaneous_total_power_consumed =
obj.instantaneous_total_power_consumed +

```

```

( equipment.instantaneous_power_consumed * (1 + obj.power_loss_rate) *
(mission.true_time.time_step_attitude/mission.true_time.time_step) ); % [W]

    this_name = equipment.name;
    flag_name_exists = 0;
    this_idx = 0;

    for i = 1:1:length(obj.list_HW_energy_consumed)
        if strcmp( obj.list_HW_energy_consumed{i}, this_name )
            flag_name_exists = 1;
            this_idx = i;
        end
    end

    if flag_name_exists == 0
        error('HW not found!')
    else
        obj.array_HW_energy_consumed(1,this_idx)
= obj.array_HW_energy_consumed(1,this_idx) +
(equipment.instantaneous_power_consumed*(mission.true_time.time_step_attitude/3600)); %
[W hr]
    end

end

```

[] Methods: Update Instantaneous Power Generated

Updates instantaneous_power_generated by Solar Panels or RTG

```

function obj = func_update_instantaneous_power_generated(obj,
equipment, mission)
    obj.instantaneous_total_power_generated =
obj.instantaneous_total_power_generated +
equipment.instantaneous_power_generated; % [W]

    this_name = equipment.name;
    flag_name_exists = 0;
    this_idx = 0;

    for i = 1:1:length(obj.list_HW_energy_generated)
        if strcmp( obj.list_HW_energy_generated{i}, this_name )
            flag_name_exists = 1;
            this_idx = i;
        end
    end

    if flag_name_exists == 0
        error('HW not found!')
    else
        obj.array_HW_energy_generated(1,this_idx)
= obj.array_HW_energy_generated(1,this_idx) +

```

```
(equipment.instantaneous_power_generated*(mission.true_time.time_step/3600)); %  
[w hr]  
    end  
  
    end  
  
end  
  
end
```

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4.7 True_SC_SRP

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Class: True_SC_SRP

Tracks the Solar Radiation Pressure (SRP) effects on spacecraft

```
classdef True_SC_SRP < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
enable_SRP % [boolean] Enable/disable SRP calculations
```

[] Properties: Variables Computed Internally

```
disturbance_torque_SRP % [Nm] Torque induced by solar radiation
pressure
disturbance_force_SRP % [N] Force induced by solar radiation pressure

num_faces % Number of spacecraft body faces
face_data % Data for spacecraft body faces
% - reflectance_factor : # [0, 1] for ith face
% - area [m^2] : Area of face
% - orientation [unit vector] : Normal vector in body frame B
% - location_center_of_pressure [m] : Center of pressure

num_solar_panel_faces % Number of solar panel faces
solar_panels_face_data % Data for solar panel faces
% - reflectance_factor : # [0, 1] for ith face
% - area [m^2] : Area of face
% - orientation [unit vector] : Normal vector in body frame B
% - location_center_of_pressure [m] : Center of pressure
```

[] Properties: Storage Variables

```
store
```

end

Methods

methods

[] Methods: Constructor

Construct an instance of this class

```
function obj = True_SC_SRP(init_data, mission, i_SC)

    % Initialize SRP enable flag
    obj.enable_SRP = init_data.enable_SRP;

    % Initialize disturbance vectors
    obj.disturbance_torque_SRP = zeros(1,3);
    obj.disturbance_force_SRP = zeros(1,3);

    % Process spacecraft body faces
    obj.num_faces = 0;
    for i_shape =
1:length(mission.true_SC{i_SC}.true_SC_body.shape_model)
        shape_i =
mission.true_SC{i_SC}.true_SC_body.shape_model{i_shape};
        obj.num_faces = obj.num_faces + size(shape_i.Faces,1);

        for i_face = 1:size(shape_i.Faces,1)
            i_face_cnt = i_face + (i_shape-1)*size(shape_i.Faces,1);
            obj.face_data(i_face_cnt).reflectance_factor =
shape_i.Face_reflectance_factor(i_face);
            obj.face_data(i_face_cnt).area =
shape_i.Face_area(i_face);
            obj.face_data(i_face_cnt).orientation =
shape_i.Face_normal(i_face,:);
            obj.face_data(i_face_cnt).location_center_of_pressure =
shape_i.Face_center(i_face,:);
        end
    end

    % Process solar panel faces
    obj.num_solar_panel_faces = 0;
    if isfield(mission.true_SC{i_SC}, 'true_SC_solar_panel')
        for i_SP = 1:length(mission.true_SC{i_SC}.true_SC_solar_panel)
            SP = mission.true_SC{i_SC}.true_SC_solar_panel{i_SP};
            n_face = size(SP.shape_model.Faces,1);
            obj.num_solar_panel_faces = obj.num_solar_panel_faces +
2*n_face; % Both sides

            for j = 1:n_face
                % Solar cell side
                idx = (i_SP-1)*2*n_face + j;
```

```

        obj.solar_panels_face_data(idx).reflectance_factor =
SP.shape_model.Face_reflectance_factor_solar_cell_side(j);
        obj.solar_panels_face_data(idx).area =
SP.shape_model.Face_area;
        obj.solar_panels_face_data(idx).orientation =
SP.shape_model.Face_orientation_solar_cell_side;

obj.solar_panels_face_data(idx).location_center_of_pressure =
SP.shape_model.Face_center(j,:);

        % Opposite side
        idx = (i_SP-1)*2*n_face + j + n_face;
        obj.solar_panels_face_data(idx).reflectance_factor =
SP.shape_model.Face_reflectance_factor_opposite_side(j);
        obj.solar_panels_face_data(idx).area =
SP.shape_model.Face_area;
        obj.solar_panels_face_data(idx).orientation = -
SP.shape_model.Face_orientation_solar_cell_side;

obj.solar_panels_face_data(idx).location_center_of_pressure =
SP.shape_model.Face_center(j,:);
    end
end
end

% Calculate SRP before first iteration of ADL
obj.func_main_true_SC_SRP(mission, i_SC);

% Initialize storage
obj.store.disturbance_torque_SRP =
zeros(mission.storage.num_storage_steps, length(obj.disturbance_torque_SRP));
obj.store.disturbance_force_SRP =
zeros(mission.storage.num_storage_steps, length(obj.disturbance_force_SRP));

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_SRP_store(obj, mission)
    if mission.storage.flag_store_this_time_step == 1
        obj.store.disturbance_torque_SRP(mission.storage.k_storage,:)
= obj.disturbance_torque_SRP;
        obj.store.disturbance_force_SRP(mission.storage.k_storage,:) =
obj.disturbance_force_SRP;
    end
end

```

[] Methods: Main

Update SRP Disturbance Force and Torque

```

function obj = func_main_true_SC_SRP(obj, mission, i_SC)

    % Reset disturbance terms
    obj.disturbance_torque_SRP = [0 0 0];
    obj.disturbance_force_SRP = [0 0 0];

    if obj.enable_SRP == 1

        % Process all faces (spacecraft body + solar panels)
        for i = 1:obj.num_faces + obj.num_solar_panel_faces

            % Get face data
            if i <= obj.num_faces
                face_i = obj.face_data(i).orientation';
                faceCP_sc =
obj.face_data(i).location_center_of_pressure';
                face_area = obj.face_data(i).area;
                face_reflectance_factor =
obj.face_data(i).reflectance_factor;
            else
                face_i = obj.solar_panels_face_data(i-
obj.num_faces).orientation';
                faceCP_sc = obj.solar_panels_face_data(i-
obj.num_faces).location_center_of_pressure';
                face_area = obj.solar_panels_face_data(i-
obj.num_faces).area;
                face_reflectance_factor =
obj.solar_panels_face_data(i-obj.num_faces).reflectance_factor;
            end

            % Calculate sun vector and incidence
            faceCP_sun =
(mission.true_SC{i_SC}.true_SC_navigation.position -
mission.true_solar_system.SS_body{mission.true_solar_system.index_Sun}.position)'
+ ...
                mission.true_SC{i_SC}.true_SC_adc.rotation_matrix *
faceCP_sc;

            faceCP_sun_normalized = faceCP_sun/norm(faceCP_sun);

            SC_face_normal =
mission.true_SC{i_SC}.true_SC_adc.rotation_matrix * face_i;
            SC_face_normal_normalized = SC_face_normal/
norm(SC_face_normal);

            % Calculate incidence angle
            incidence = real(acosd(dot(SC_face_normal_normalized,
faceCP_sun_normalized)));

            % Calculate force and torque if face is illuminated
            if abs(incidence) < 90
                % Force calculation

```

```

        F_SRP_magnitude =
mission.true_solar_system.solar_constant_AU /
mission.true_solar_system.light_speed * ...
        (mission.true_solar_system.AU_distance /
norm(mission.true_SC{i_SC}.true_SC_navigation.position -
mission.true_solar_system.SS_body{mission.true_solar_system.index_Sun}.position))^2
* ...
        face_area * (1 + face_reflectance_factor) *
cosd(incidence);

        F_SRP_vector_J2000 = F_SRP_magnitude *
faceCP_sun_normalized;

        % Torque calculation
        force_on_surface_at_cp =
(mission.true_SC{i_SC}.true_SC_adc.rotation_matrix)' * F_SRP_vector_J2000;
        this_face_lever_arm = faceCP_sc -
mission.true_SC{i_SC}.true_SC_body.location_COM';
        this_face_torque = cross(this_face_lever_arm,
force_on_surface_at_cp);

        % Accumulate disturbances
        obj.disturbance_torque_SRP =
obj.disturbance_torque_SRP + this_face_torque';

        obj.disturbance_force_SRP = obj.disturbance_force_SRP
+ F_SRP_vector_J2000';
    end
end

        % Update disturbance Force and Torque
        mission.true_SC{i_SC}.true_SC_navigation.disturbance_force
= mission.true_SC{i_SC}.true_SC_navigation.disturbance_force +
obj.disturbance_force_SRP;
        mission.true_SC{i_SC}.true_SC_adc.disturbance_torque
= mission.true_SC{i_SC}.true_SC_adc.disturbance_torque +
obj.disturbance_torque_SRP;

    else
        % Dont' do anything!
    end

        % Update storage
        obj = func_update_true_SC_SRP_store(obj, mission);
end

end

end
end

```

Chapter 5

SC Sensors and Actuators Classes

5.1 True_SC_Battery

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Class: True_SC_Battery

Tracks the Battery state of charge

```
classdef True_SC_Battery < handle
```

Properties

properties

[] Properties: Initialized Variables

```
instantaneous_power_consumed % [Watts] : Instantaneous power consumed

instantaneous_data_rate_generated % [kbps] : Data rate generated
during current time step, in kilo bits (kb) per sec

maximum_capacity % [Watts * hr] : Maximum energy storage capacity of
the battery
```

[] Properties: Variables Computed Internally

```
name % [string] 'Batt i'

health % [integer] Health of sensor/actuator
% - 0. Switched off
% - 1. Switched on, works nominally

temperature % [deg C] : Temperature of sensor/actuator

instantaneous_capacity % [Watts * hr] : Instantaneous capacity of
battery

state_of_charge % [percentage] : SoC is defined by = 100×
instantaneous_capacity / maximum_capacity
```

```
charging_efficiency % float # [0, 1]

discharging_efficiency % float # [0, 1]
```

[] Properties: Storage Variables

```
store

end
```

Methods

```
methods
```

[] Methods: Constructor

Construct an instance of this class

```
function obj = True_SC_Battery(init_data, mission, i_SC, i_HW)

    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
        obj.name = ['Battery ', num2str(i_HW)];
    end

    obj.health = 1;
    obj.temperature = 10; % [deg C]

    obj.instantaneous_power_consumed =
init_data.instantaneous_power_consumed; % [W]
    obj.instantaneous_data_rate_generated =
init_data.instantaneous_data_rate_generated; % [kbps]

    obj.maximum_capacity = init_data.maximum_capacity; % [W hr]
    obj.instantaneous_capacity = obj.maximum_capacity; % [W hr]
    obj.state_of_charge = 100*obj.instantaneous_capacity/
obj.maximum_capacity; % [percentage]

    obj.charging_efficiency = init_data.charging_efficiency;
    obj.discharging_efficiency = init_data.discharging_efficiency; %
[float <= 1]

    % Initialize Variables to store: instantaneous_capacity
state_of_charge
    obj.store = [];

    obj.store.instantaneous_capacity =
zeros(mission.storage.num_storage_steps, length(obj.instantaneous_capacity));
    obj.store.state_of_charge =
zeros(mission.storage.num_storage_steps, length(obj.state_of_charge));
```

```

        obj = func_update_true_SC_battery_store(obj, mission);

        % Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

        % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_battery_store(obj, mission)

    if mission.storage.flag_store_this_time_step == 1
        obj.store.instantaneous_capacity(mission.storage.k_storage,:)
= obj.instantaneous_capacity; % [W hr]
        obj.store.state_of_charge(mission.storage.k_storage,:) =
obj.state_of_charge; % [percentage]
    end

end

```

[] Methods: Main

Update Battery SoC

```

function obj = func_main_true_SC_battery(obj, mission, i_SC)

    obj.state_of_charge = 100*obj.instantaneous_capacity/
obj.maximum_capacity; % [percentage]

    obj = func_update_true_SC_battery_store(obj, mission);

    % Update Power Consumed

func_update_instantaneous_power_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

    % Update Data Generated

func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end

end

```

end

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5.2 True_SC_Camera

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Class: True_SC_Camera

SC's Navigation Camera

```
classdef True_SC_Camera < handle
```

Properties

properties

[] Properties: Initialized Variables

```
instantaneous_power_consumed % [Watts] : Instantaneous power consumed

instantaneous_data_generated_per_pixel % [kb] : Data generated per
pixel in camera image

instantaneous_data_compression % [float <= 1] : Camera data
compression (Optional)

mode_true_SC_camera_selector % [string]
% - Simple

measurement_wait_time % [sec] How often can measurements be taken?

location % [m] : Location of sensor, in body frame B

orientation % [unit vector] : Normal vector from location

orientation_up % [unit vector] : Up Normal vector from location in
camera frame

resolution % [x y] : Resolution of the camera in pixels (e.g. [1024
1024])

field_of_view % [deg] : Field of view (FOV) of the camera in deg
```

```
flag_show_camera_plot % [Boolean] : 1 = Shows the camera plot

flag_show_stars % [Boolean] : 1 = Show stars upto
mission.true_stars.maximum_magnitude. This takes a lot of time for wide FOV
cameras. (Optional)
```

[] Properties: Variables Computed Internally

```
name % [string] 'Camera i'

health % [integer] Health of sensor/actuator
% - 0. Switched off
% - 1. Switched on, works nominally

temperature % [deg C] : Temperature of sensor/actuator

measurement_vector % [Image]

measurement_time % [sec] SC time when this measurement was taken

flag_executive % [Boolean] Executive has told this sensor/actuator to
do its job

plot_handle % Matlab plot handle for the image

flag_target_visible % [Boolean] : 1 = Target is visible to this camera

instantaneous_data_generated_per_sample % [kb] : Data generated per
sample, in kilo bits (kb)

data % Other useful data
```

[] Properties: Storage Variables

```
store

end
```

Methods

```
methods
```

[] Methods: Constructor

Construct an instance of this class

```
function obj = True_SC_Camera(init_data, mission, i_SC, i_HW)

    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
```

```

        obj.name = ['Camera ', num2str(i_HW)];
    end

    obj.health = 1;
    obj.temperature = 10; % [deg C]

    obj.instantaneous_power_consumed =
init_data.instantaneous_power_consumed; % [W]
    obj.instantaneous_data_generated_per_pixel =
init_data.instantaneous_data_generated_per_pixel; % [kb]
    obj.instantaneous_data_generated_per_sample = 0; % [kb] Data is
only generated when an image is captured

    obj.mode_true_SC_camera_selector =
init_data.mode_true_SC_camera_selector; % [string]
    obj.measurement_wait_time = init_data.measurement_wait_time; %
[sec]

    obj.flag_executive = 0;

    obj.measurement_time = 0; % [sec]

    obj.location = init_data.location; % [m]
    obj.orientation = init_data.orientation; % [unit vector]
    obj.orientation_up = init_data.orientation_up; % [unit vector]

    obj.resolution = init_data.resolution; % [x y] pixel
    obj.field_of_view = init_data.field_of_view; % [deg]

    obj.flag_show_camera_plot = init_data.flag_show_camera_plot;

    if isfield(init_data, 'flag_show_stars')
        obj.flag_show_stars = init_data.flag_show_stars;
    else
        obj.flag_show_stars = 0;
    end

    obj.flag_target_visible = 0;

    if isfield(init_data, 'instantaneous_data_compression')
        obj.instantaneous_data_compression =
init_data.instantaneous_data_compression;
    else
        obj.instantaneous_data_compression = 1;
    end

    if isfield(init_data, 'data')
        obj.data = init_data.data;
    else
        obj.data = [];
    end
    obj.data.flag_take_picture = 0;

    % Initialize Variables to store: flag_target_visible

```

```

        obj.store = [];
        obj.store.flag_target_visible =
zeros(mission.storage.num_storage_steps, length(obj.flag_target_visible));
        obj.store.flag_take_picture =
zeros(mission.storage.num_storage_steps, length(obj.data.flag_take_picture));
        obj.store.flag_executive =
zeros(mission.storage.num_storage_steps, length(obj.flag_executive));
        obj.store.instantaneous_data_generated_per_sample =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_data_generated_per_sample)); % [kbps]
        obj.store.instantaneous_power_consumed =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_power_consumed)); % [W]

        % Update Storage
        obj = func_update_true_SC_camera_store(obj, mission);

        % Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

        % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

        % Store video of func_visualize_SC_attitude_orbit_during_sim
        if (mission.storage.plot_parameters.flag_save_video == 1) &&
(obj.flag_show_camera_plot == 1)
            obj.data.video_filename = [mission.storage.output_folder,
mission.name, '_SC', num2str(i_SC), '_Camera', num2str(i_HW), '.mp4'];
            obj.data.myVideo =
VideoWriter(obj.data.video_filename, 'MPEG-4');
            obj.data.myVideo.FrameRate = 30; % Default 30
            obj.data.myVideo.Quality = 100; % Default 75
            open(obj.data.myVideo);
        end
    end
end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_camera_store(obj, mission)

    if mission.storage.flag_store_this_time_step == 1
        obj.store.flag_executive(mission.storage.k_storage_attitude,:)
= obj.flag_executive; % [Boolean]

        if obj.flag_executive == 1

```

```

        obj.store.flag_target_visible(mission.storage.k_storage,:)
= obj.flag_target_visible; % [Boolean]
        obj.store.flag_take_picture(mission.storage.k_storage,:) =
obj.data.flag_take_picture; % [Boolean]

obj.store.instantaneous_data_generated_per_sample(mission.storage.k_storage,:)
= obj.instantaneous_data_generated_per_sample; % [kbps]

obj.store.instantaneous_power_consumed(mission.storage.k_storage,:) =
obj.instantaneous_power_consumed; % [W]
    end
end
end
end

```

[] Methods: Main

Update Camera

```

function obj = func_main_true_SC_camera(obj, mission, i_SC, i_HW)

    if (obj.flag_executive == 1) && (obj.health == 1)
        % Take measurement

        if (mission.true_time.time - obj.measurement_time) >=
obj.measurement_wait_time

            % Sufficient time has elapsed for a new measurement
            obj.measurement_time = mission.true_time.time; % [sec]
            obj.data.flag_take_picture = 1;

            switch obj.mode_true_SC_camera_selector

                case 'Simple'
                    obj = func_true_SC_camera_Simple(obj, mission,
i_SC, i_HW);

                otherwise
                    error('Camera mode not defined!')
            end

            % Update Data Generated

            func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

        else
            % Data not generated in this time step
            obj.instantaneous_data_generated_per_sample = 0; % [kb]
            Data is only generated when an image is captured
            obj.data.flag_take_picture = 0;
        end
    end
end

```

```

        end

        % Update Power Consumed

func_update_instantaneous_power_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

    else
        % Do nothing
        obj.data.flag_take_picture = 0;
    end

    % Update Storage
    obj = func_update_true_SC_camera_store(obj, mission);

    % Reset Variables
    obj.flag_executive = 0;

end

```

[] Methods: Simple Camera

Simple Camera mode

```

function obj = func_true_SC_camera_Simple(obj, mission, i_SC, i_HW)

    obj.instantaneous_data_generated_per_sample =
obj.instantaneous_data_compression *
obj.instantaneous_data_generated_per_pixel * obj.resolution(1) *
obj.resolution(2); % [kb]

    if obj.flag_show_camera_plot == 1
        % Show Camera Plot

        obj.plot_handle = figure( (5*i_SC) + i_HW);
        clf
        set(obj.plot_handle, 'Color', rgb('Black'));
        set(obj.plot_handle, 'Units', 'pixels', 'Position', [1 1
obj.resolution])
        %
        set(obj.plot_handle, 'PaperPositionMode', 'auto');
        set(obj.plot_handle, 'Resize', 'off');
        hold on

        % Plot Target Body
        for i_target = 1:1:mission.num_target

            func_plot_target_shape(i_target, mission);

        end

        axis vis3d off
        axis equal
    end

```

```

material([0 1 0])

% field of view
camva(obj.field_of_view);

camproj('perspective');
axis image
axis off;

% Light coming from sun
%       camlight('headlight')
h = light;
h.Position =
(mission.true_solar_system.SS_body{mission.true_solar_system.index_Sun}.position
-
mission.true_target{mission.true_SC{i_SC}.true_SC_navigation.index_relative_target}.posit
h.Style = 'local';

% Move SC away from Target

campos(mission.true_SC{i_SC}.true_SC_navigation.position_relative_target);

target_distance =
norm(mission.true_SC{i_SC}.true_SC_navigation.position_relative_target);

% Manage view from current attitude
x_true_hat =
(mission.true_SC{i_SC}.true_SC_adc.rotation_matrix * obj.orientation)';

y_true_hat =
(mission.true_SC{i_SC}.true_SC_adc.rotation_matrix * obj.orientation_up)';

camtarget(target_distance * x_true_hat)
camup([y_true_hat(1), y_true_hat(2), y_true_hat(3)]);

% Plot Stars
if obj.flag_show_stars == 1

    dot_product_angle_array =
acosd(mission.true_stars.all_stars_unit_vector * x_true_hat');
    flag_in_FOV = logical(dot_product_angle_array <=
(obj.field_of_view*2));

    flag_magnitude_limit =
logical(mission.true_stars.magnitude_visible <=
mission.true_stars.maximum_magnitude);

    flag_magnitude_limit_FOV = (flag_in_FOV &
flag_magnitude_limit);

```

```

        idx_array = find(flag_magnitude_limit_FOV);
        hold on

        for s = 1:1:length(idx_array)
            this_star = target_distance *
mission.true_stars.all_stars_unit_vector(idx_array(s),:);

plot3(this_star(1),this_star(2),this_star(3),'*w','MarkerSize',(1 +
mission.true_stars.maximum_magnitude -
mission.true_stars.magnitude_visible(idx_array(s))),'MarkerFaceColor','w','MarkerEdgeColor','r')
        end
    end

    drawnow limitrate

    if (mission.storage.plot_parameters.flag_save_video == 1)
        open(obj.data.myVideo);
        writeVideo(obj.data.myVideo, getframe(obj.plot_handle));
    end

end

obj = func_true_SC_camera_target_visible(obj, mission, i_SC);

% Update Storage
obj = func_update_true_SC_camera_store(obj, mission);

end

```

[] Methods: Check Target Visible

Check if Target is visible in Camera image

```

function obj = func_true_SC_camera_target_visible(obj, mission, i_SC)

    Target_relative_pos_hat =
func_normalize_vec(mission.true_target{mission.true_SC{i_SC}.true_SC_navigation.index_rel
- mission.true_SC{i_SC}.true_SC_navigation.position});

    x_true_hat = (mission.true_SC{i_SC}.true_SC_adc.rotation_matrix *
obj.orientation')';

    Camera_angle = acosd(dot(Target_relative_pos_hat, x_true_hat)); %
[deg]

    if Camera_angle <= (obj.field_of_view)
        obj.flag_target_visible = 1;
    else
        obj.flag_target_visible = 0;
    end

end

end

```

end

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5.3 True_SC_Communication_Link

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Class: True_SC_Communication_Link

Tracks the Links between Radio Antennas

```
classdef True_SC_Communication_Link < handle
```

Properties

properties

[] Properties: Initialized Variables

```
TX_spacecraft % [integer] Use 0 for Ground Station
TX_spacecraft_Radio_HW % [integer]

RX_spacecraft % [integer] Use 0 for Ground Station
RX_spacecraft_Radio_HW % [integer]

% TODO - Decide if this is should stay here or go to software comm
wait_time_comm_dte % [sec] : Wait time without transmitting to earth.
This is a constant.
last_communication_time % [sec] : Last time that data has been sent.
This is updated in SC_Executive

flag_compute_data_rate % [Boolean]

given_data_rate % [kbps]

instantaneous_power_consumed % [Watts] : Communication Link control
overhead power consumption
```

[] Properties: Variables Computed Internally

```
name % [string] 'Comm Link i'

TX_name % [string]
```

```

    RX_name % [string]

    this_data_rate % [kbps] Actually used in simulation

    flag_executive % [Boolean] Executive has told this sensor/actuator to
do its job

    flag_TX_RX_visible % [Boolean]

```

[] Properties: Storage Variables

```

store

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = True_SC_Communication_Link(init_data, mission, i_SC,
i_HW)

    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
        obj.name = ['Comm Link ', num2str(i_HW)];
    end

    obj.flag_executive = 0;
    obj.flag_TX_RX_visible = 0;

    obj.TX_spacecraft = init_data.TX_spacecraft;
    obj.TX_spacecraft_Radio_HW = init_data.TX_spacecraft_Radio_HW;

    obj.RX_spacecraft = init_data.RX_spacecraft;
    obj.RX_spacecraft_Radio_HW = init_data.RX_spacecraft_Radio_HW;

    obj.flag_compute_data_rate = init_data.flag_compute_data_rate;
    obj.given_data_rate = init_data.given_data_rate; % [kbps]

    % Initialize the power consumption property
    if isfield(init_data, 'instantaneous_power_consumed')
        obj.instantaneous_power_consumed =
init_data.instantaneous_power_consumed;
    else
        obj.instantaneous_power_consumed = 0.5; % Default low power
for link control overhead
    end
end

```

```

end

if obj.flag_compute_data_rate == 1
    obj.this_data_rate = 0; % [kbps]
else
    obj.this_data_rate = obj.given_data_rate; % [kbps]
end

% Handle TX name
if obj.TX_spacecraft == 0
    obj.TX_name =
mission.true_GS_radio_antenna{obj.TX_spacecraft_Radio_HW}.name;
else
    tx_sc = mission.true_SC{obj.TX_spacecraft};
    if iscell(tx_sc.true_SC_radio_antenna)
        tx_antenna =
tx_sc.true_SC_radio_antenna{obj.TX_spacecraft_Radio_HW};
    else
        if obj.TX_spacecraft_Radio_HW ~= 1
            error('TX_spacecraft_Radio_HW index is %d, but
true_SC_radio_antenna is not a cell array.', obj.TX_spacecraft_Radio_HW);
        end
        tx_antenna = tx_sc.true_SC_radio_antenna;
    end
    obj.TX_name = ['SC ', num2str(obj.TX_spacecraft), ' ',
tx_antenna.name];
end

% Handle RX name
if obj.RX_spacecraft == 0
    obj.RX_name =
mission.true_GS_radio_antenna{obj.RX_spacecraft_Radio_HW}.name;
else
    rx_sc = mission.true_SC{obj.RX_spacecraft};
    if iscell(rx_sc.true_SC_radio_antenna)
        rx_antenna =
rx_sc.true_SC_radio_antenna{obj.RX_spacecraft_Radio_HW};
    else
        if obj.RX_spacecraft_Radio_HW ~= 1
            error('RX_spacecraft_Radio_HW index is %d, but
true_SC_radio_antenna is not a cell array.', obj.RX_spacecraft_Radio_HW);
        end
        rx_antenna = rx_sc.true_SC_radio_antenna;
    end
    obj.RX_name = ['SC ', num2str(obj.RX_spacecraft), ' ',
rx_antenna.name];
end

% Initialize Variables to store
obj.store = [];

obj.store.flag_executive =
zeros(mission.storage.num_storage_steps, length(obj.flag_executive)); %
[integer]

```

```

        obj.store.flag_TX_RX_visible =
zeros(mission.storage.num_storage_steps, length(obj.flag_TX_RX_visible)); %
[integer]
        obj.store.this_data_rate =
zeros(mission.storage.num_storage_steps, length(obj.this_data_rate)); %
[kbps]

        % Update Storage
        obj = func_update_true_SC_communication_link_store(obj, mission);

        % Register with power system if this is a spacecraft component
(not a ground station)
        if i_SC > 0

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);
        end
    end
end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_communication_link_store(obj,
mission)

    if mission.storage.flag_store_this_time_step == 1

        obj.store.flag_executive(mission.storage.k_storage,:) =
obj.flag_executive; % [integer]
        obj.store.flag_TX_RX_visible(mission.storage.k_storage,:) =
obj.flag_TX_RX_visible; % [integer]
        obj.store.this_data_rate(mission.storage.k_storage,:) =
obj.this_data_rate; % [kbps]

    end

end

```

[] Methods: Main

Update all variables

```

function obj = func_main_true_SC_communication_link(obj, mission,
i_SC)

    % Check Link Visibility
    if obj.TX_spacecraft == 0
        obj.flag_TX_RX_visible =
mission.true_SC{obj.RX_spacecraft}.true_SC_navigation.flag_visible_Earth;

    elseif obj.RX_spacecraft == 0

```

```

        obj.flag_TX_RX_visible =
mission.true_SC{obj.TX_spacecraft}.true_SC_navigation.flag_visible_Earth;

    else
        error('Need to write this code where both are SC!')
    end

    % Compute Data Rate (if visible)
    if obj.flag_TX_RX_visible == 1
        % LOS to Earth available
        if obj.flag_compute_data_rate == 1
            obj.this_data_rate = 0; % [kbps]
            error('Write code to compute Link Margin!')
        else
            obj.this_data_rate = obj.given_data_rate; % [kbps]
        end
    else
        % In eclipse
        obj.this_data_rate = 0; % [kbps]
    end

    % Perform Data Transfer
    if (obj.flag_executive == 1) % && (obj.flag_TX_RX_visible == 1)

        if (obj.TX_spacecraft > 0) && (obj.flag_TX_RX_visible
== 1) && ((obj.this_data_rate * mission.true_time.time_step) >=
mission.true_SC{obj.TX_spacecraft}.software_SC_data_handling.total_data_storage)
            obj.this_data_rate =
mission.true_SC{obj.TX_spacecraft}.software_SC_data_handling.total_data_storage/
mission.true_time.time_step; % [kbps]
        end

        % Start TX and transmit data
        if obj.TX_spacecraft == 0
            % This is GS
            if
mission.true_GS_radio_antenna{obj.TX_spacecraft_Radio_HW}.flag_executive ~= 0
                error('[GS] TX link is already on!')
            else

mission.true_GS_radio_antenna{obj.TX_spacecraft_Radio_HW}.flag_executive = 1;

mission.true_GS_radio_antenna{obj.TX_spacecraft_Radio_HW}.mode_true_GS_radio_antenna_sele
= 'TX';

mission.true_GS_radio_antenna{obj.TX_spacecraft_Radio_HW}.instantaneous_data_rate_transmi
= obj.this_data_rate; % [kbps]
        end

    else
        % This is SC
        tx_sc = mission.true_SC{obj.TX_spacecraft};
        if iscell(tx_sc.true_SC_radio_antenna)

```

```

        tx_antenna =
tx_sc.true_SC_radio_antenna{obj.TX_spacecraft_Radio_HW};
    else
        if obj.TX_spacecraft_Radio_HW ~= 1
            error('TX_spacecraft_Radio_HW index is %d, but
true_SC_radio_antenna is not a cell array.', obj.TX_spacecraft_Radio_HW);
        end
        tx_antenna = tx_sc.true_SC_radio_antenna;
    end

    if tx_antenna.flag_executive ~= 0
        error('[SC] TX link is already on!')
    else
        tx_antenna.flag_executive = 1;
        tx_antenna.mode_true_SC_radio_antenna_selector = 'TX';
        tx_antenna.instantaneous_data_rate_removed =
obj.this_data_rate; % [kbps]
    end

end

% Start RX and receive data
if obj.RX_spacecraft == 0
    % This is GS
    if
mission.true_GS_radio_antenna{obj.RX_spacecraft_Radio_HW}.flag_executive ~= 0
        error('[GS] RX link is already on!')
    else

mission.true_GS_radio_antenna{obj.RX_spacecraft_Radio_HW}.flag_executive = 1;

mission.true_GS_radio_antenna{obj.RX_spacecraft_Radio_HW}.mode_true_GS_radio_antenna_selector = 'RX';

mission.true_GS_radio_antenna{obj.RX_spacecraft_Radio_HW}.instantaneous_data_rate_receive
= obj.this_data_rate; % [kbps]
    end

    else
        % This is SC
        rx_sc = mission.true_SC{obj.RX_spacecraft};
        if iscell(rx_sc.true_SC_radio_antenna)
            rx_antenna =
rx_sc.true_SC_radio_antenna{obj.RX_spacecraft_Radio_HW};
        else
            if obj.RX_spacecraft_Radio_HW ~= 1
                error('RX_spacecraft_Radio_HW index is %d, but
true_SC_radio_antenna is not a cell array.', obj.RX_spacecraft_Radio_HW);
            end
            rx_antenna = rx_sc.true_SC_radio_antenna;
        end

        if rx_antenna.flag_executive ~= 0
            error('[SC] RX link is already on!')

```

```

        else
            rx_antenna.flag_executive = 1;
            rx_antenna.mode_true_SC_radio_antenna_selector = 'RX';
            rx_antenna.instantaneous_data_rate_generated =
obj.this_data_rate; % [kbps]
        end
    end

    % Update power consumption for this link's control overhead
    if i_SC > 0

func_update_instantaneous_power_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);
    end
end

    % Update Storage
    obj = func_update_true_SC_communication_link_store(obj, mission);

    % Reset All Variables
    obj.flag_executive = 0;

end

end

end

```

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5.4 True_SC_Chemical_Thruster

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Class: True_SC_Chemical_Thruster

Individual SC's chemical thruster

```
classdef True_SC_Chemical_Thruster < handle

    % True_SC_Chemical_Thruster class represents a single chemical-thruster
    % with various properties and methods for simulation and analysis.
```

Properties

properties

[] Properties: Initialized Variables

```
    instantaneous_power_consumption    %[Watts] : Instantaneous power
consumed by unit (if it is switched on)

    thruster_warm_up_power_consumed    %[Watts] : Power consumed during
warm-up time

    command_actuation_power_consumed  %[Watts] : Power consumed during
actuation

    name                                % Name of the thruster

    thruster_noise                      %[N] : Added to every dimension of
commanded_thrust

    isp                                %[s] : Specific impulse of the
thruster

    command_wait_time                  %[sec] : Seconds between commands
```

orientation	%[Unit vector] : Normal vector of
thrust in body frame B	
location	%[m] : Location of actuator, in body
frame B	
maximum_thrust	%[N]
minimum_thrust	%[N] : This need not be 0

[] Properties: Variables Computed Internally

instantaneous_power_consumed	%[Watts] : Alias for power tracking
system	
health	% Health of the thruster (0 : Not
working - 1 : Working)	
temperature	%[Celsius] Temperature of the
thruster	
instantaneous_data_generated_per_sample	%[kb] : Data generated
during the current time step, in kilo bits	
control_force_CT	%[N] : Control force vector generated
by the unit that passes through Center of Mass of SC	
control_torque_CT	%[Nm] : Control torque about Center
of Mass of SC, generated by the unit	
mode_true_chemical_thruster_selector	% Mode (Truth/Simple)
flag_executive % [Bool] do we need to fire this time step (set by sw	
orbit control)	
flag_warming_up % [Bool] is the thruster in warm-up mode	
thruster_warm_up_time	%[sec] : How much warm-up time is
needed?	
accumulated_warm_up_time	%[sec] : How long has the thruster
been warming up	
command_time	%[sec] : Time when latest Command was
actuated	
warm_up_start_time	%[sec] : Time when warm-up started
ready_state_start_time	%[sec] : Time when thruster entered
ready state	
pending_fire	%[Boolean] : Flag to indicate a
pending fire command between cycles	
pending_thrust	%[N] : Remembered thrust value for a
pending fire command	
command_actuation	%[Boolean] : 1 = Command actuation
during this time step (after actuator has warmed up)	
command_executed	%[Boolean] : 1 = Command executed
during this time step	
thruster_state	%[String] : Current state of the
thruster: 'idle', 'warming_up', 'ready', 'firing'	

```

        force_inertial                %[N] : Vector force in inertial frame
        applied by this thruster

        commanded_thrust              %[N] : Comes from the SC's orbit
        control software

        true_commanded_thrust          %[N] : Actual thrust with noise
        applied, unknown to SC software

        % New properties for fuel consumption
        fuel_consumed_per_firing       %[kg] : Amount of fuel consumed in
        current firing
        total_fuel_consumed            %[kg] : Total fuel consumed by this
        thruster

```

[] Properties: Storage Variables

```

        store                        % Structure to store historical data

    end

```

Methods

```

    methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = True_SC_Chemical_Thruster(init_data, mission, i_SC,
i_MT)
    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
        obj.name = ['Chemical Thruster ', num2str(i_MT)];
    end
    obj.health = true;
    obj.temperature = 20;
    obj.instantaneous_power_consumption =
init_data.instantaneous_power_consumption; % Watts
    obj.instantaneous_power_consumed =
init_data.instantaneous_power_consumption; % Watts

    % Initialize specific power consumption settings
    if isfield(init_data, 'thruster_warm_up_power_consumed')
        obj.thruster_warm_up_power_consumed =
init_data.thruster_warm_up_power_consumed; % Watts
    else
        obj.thruster_warm_up_power_consumed =
obj.instantaneous_power_consumption; % Default to regular power

```

```

end

if isfield(init_data, 'command_actuation_power_consumed')
    obj.command_actuation_power_consumed =
init_data.command_actuation_power_consumed; % Watts
else
    obj.command_actuation_power_consumed = 3 *
obj.instantaneous_power_consumption; % Default to 3x regular power
end

obj.instantaneous_data_generated_per_sample =
init_data.instantaneous_data_generated_per_sample; % Kb
obj.thruster_noise = init_data.chemical_thruster_noise; % Noise
level
obj.command_wait_time = init_data.command_wait_time; % Seconds
between commands
obj.location = init_data.location; % Meters (body frame)
obj.orientation = init_data.orientation; % Unit vector (body
frame)

obj.isp = init_data.chemical_thruster_ISP; % sec
obj.force_inertial = zeros(1,3);

obj.minimum_thrust = init_data.minimum_thrust;
obj.maximum_thrust = init_data.maximum_thrust;

% Ensure thrust variables are properly initialized as scalars
obj.commanded_thrust = 0; % Initialize as scalar 0, not empty
array
obj.true_commanded_thrust = 0; % Initialize as scalar 0, not empty
array

obj.control_force_CT = zeros(1,3); % Ensure it's a 1x3 array
obj.control_torque_CT = zeros(1,3); % Ensure it's a 1x3 array

% Initialize warm-up related properties
obj.thruster_warm_up_time = 30; % Default warm-up time (30
seconds)
obj.accumulated_warm_up_time = 0;
obj.warm_up_start_time = 0;
obj.ready_state_start_time = 0;
obj.flag_warming_up = false;
obj.thruster_state = 'idle';

% Initialize command properties
obj.command_actuation = false;
obj.command_executed = false;
obj.command_time = 0;
obj.flag_executive = false;
obj.pending_fire = false;
obj.pending_thrust = 0;

% Initialize fuel consumption properties
obj.fuel_consumed_per_firing = 0;
obj.total_fuel_consumed = 0;

```

```

        % Initialize Storage Variables
        obj.store = [];
        obj.store.commanded_thrust =
zeros(mission.storage.num_storage_steps,1);
        obj.store.true_commanded_thrust =
zeros(mission.storage.num_storage_steps,1);
        obj.store.force_inertial =
zeros(mission.storage.num_storage_steps,3); % Changed from 1 to 3 columns
        obj.store.fuel_consumed_per_firing =
zeros(mission.storage.num_storage_steps,1);
        obj.store.total_fuel_consumed =
zeros(mission.storage.num_storage_steps,1);
        obj.store.thruster_state =
cell(mission.storage.num_storage_steps,1);
        obj.store.warm_up_progress =
zeros(mission.storage.num_storage_steps,1);
        obj.store.pending_fire =
zeros(mission.storage.num_storage_steps,1);
        obj.store.pending_thrust =
zeros(mission.storage.num_storage_steps,1);
        obj.store.control_torque_CT =
zeros(mission.storage.num_storage_steps,3); % Add storage

        % Update storage
        func_update_true_chemical_thruster_store(obj, mission);

        % Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

        % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);
end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_chemical_thruster_store(obj, mission)

    % Store values
    obj.store.commanded_thrust(mission.storage.k_storage,:) =
obj.commanded_thrust;
    obj.store.true_commanded_thrust(mission.storage.k_storage,:) =
obj.true_commanded_thrust;
    obj.store.force_inertial(mission.storage.k_storage,:) =
obj.force_inertial;
    obj.store.fuel_consumed_per_firing(mission.storage.k_storage,:) =
obj.fuel_consumed_per_firing;

```

```

        obj.store.total_fuel_consumed(mission.storage.k_storage,:) =
obj.total_fuel_consumed;
        obj.store.thruster_state{mission.storage.k_storage} =
obj.thruster_state;

        % Store pending fire information
        obj.store.pending_fire(mission.storage.k_storage) =
obj.pending_fire;
        obj.store.pending_thrust(mission.storage.k_storage) =
obj.pending_thrust;

        % Store control torque
        obj.store.control_torque_CT(mission.storage.k_storage,:) =
obj.control_torque_CT;

        % Calculate warm-up progress as a percentage
        if obj.thruster_warm_up_time > 0
            obj.store.warm_up_progress(mission.storage.k_storage) =
min(100, (obj.accumulated_warm_up_time / obj.thruster_warm_up_time) * 100);
        else
            obj.store.warm_up_progress(mission.storage.k_storage) = 100; %
No warm-up needed
        end
    end
end

```

[] Methods: Start Warm-Up

```

function obj = func_start_warm_up(obj, mission)
    % Start the thruster warm-up process
    if ~obj.flag_warming_up && strcmp(obj.thruster_state, 'idle') &&
obj.health
        obj.flag_warming_up = true;
        obj.thruster_state = 'warming_up';
        obj.warm_up_start_time = mission.true_time.time;
        obj.accumulated_warm_up_time = 0;
    end
end

```

[] Methods: Check Warm-Up Status

```

function is_ready = func_is_thruster_ready(obj)
    % Check if the thruster is ready to fire
    is_ready = strcmp(obj.thruster_state, 'ready') ||
strcmp(obj.thruster_state, 'firing');
end

```

[] Methods: Validate Thruster Properties

```

function obj = func_validate_thruster_properties(obj)
    % Safety function to ensure all properties are properly
initialized

```

```

% Check and fix scalar properties
if isempty(obj.commanded_thrust)
    obj.commanded_thrust = 0;
end

if isempty(obj.true_commanded_thrust)
    obj.true_commanded_thrust = 0;
end

if isempty(obj.instantaneous_power_consumption)
    obj.instantaneous_power_consumption = 0;
end

if isempty(obj.instantaneous_power_consumed)
    obj.instantaneous_power_consumed = 0;
end

% Check and fix vector properties
if isempty(obj.force_inertial) ||
~isequal(size(obj.force_inertial), [1,3])
    obj.force_inertial = zeros(1,3);
end

if isempty(obj.control_torque_CT) ||
~isequal(size(obj.control_torque_CT), [1,3])
    obj.control_torque_CT = zeros(1,3);
end

if isempty(obj.control_force_CT) ||
~isequal(size(obj.control_force_CT), [1,3])
    obj.control_force_CT = zeros(1,3);
end

% Check other critical properties
if isempty(obj.thruster_state)
    obj.thruster_state = 'idle';
end

if isempty(obj.ready_state_start_time)
    obj.ready_state_start_time = 0;
end

if isempty(obj.pending_fire)
    obj.pending_fire = false;
end

if isempty(obj.pending_thrust)
    obj.pending_thrust = 0;
end

if isempty(obj.instantaneous_data_generated_per_sample)
    obj.instantaneous_data_generated_per_sample = 0;
end

```

end

[] Methods: Main

```
function func_main_true_chemical_thruster(obj, mission, i_SC, ~)
    % Main function for True_SC_Chemical_Thruster
    % Controls thrust application, power consumption, and data
    generation.

    % Validate properties to ensure everything is properly initialized
    obj = func_validate_thruster_properties(obj);

    % Reset fuel consumed this firing (but NOT command_executed - that
needs    % to persist for one cycle so orbit control can see it)
    obj.fuel_consumed_per_firing = 0;

    % Initialize power consumption to idle value
    obj.instantaneous_power_consumption = 0;
    obj.instantaneous_power_consumed = 0;

    % Save a local copy of command_executed for this cycle's
processing    was_executed_last_cycle = obj.command_executed;

    % Check health status
    if obj.health == 0
        obj.thruster_state = 'idle';
        obj.flag_warming_up = false;
        obj.command_executed = false;
        return;
    end

    % State machine for thruster operation
    switch obj.thruster_state
        case 'idle'
            % Check if we need to start warming up
            if obj.flag_warming_up
                disp(['Thruster transitioning from idle to warming_up
at time ', num2str(mission.true_time.time), ' sec']);
                obj.thruster_state = 'warming_up';
                obj.accumulated_warm_up_time = 0;
            end

            % Minimal idle power consumption (fixed 0.1W in idle
state)
            obj.instantaneous_power_consumption = 0.1;

            case 'warming_up'
                % Update accumulated warm-up time
                obj.accumulated_warm_up_time =
obj.accumulated_warm_up_time + mission.true_time.time_step;
```

```

        % Check if warm-up is complete
        if obj.accumulated_warm_up_time >=
obj.thruster_warm_up_time
            disp(['Thruster completed warm-up and entering ready
state at time ', num2str(mission.true_time.time), ' sec']);
            obj.thruster_state = 'ready';
            obj.ready_state_start_time = mission.true_time.time; %
Set the start time of ready state
        end

        % Set warm-up power consumption
        obj.instantaneous_power_consumption =
obj.thruster_warm_up_power_consumed;

        case 'ready'
            % Thruster is ready to fire
            % Maintain warm-up power until firing or timeout
            obj.instantaneous_power_consumption =
obj.thruster_warm_up_power_consumed;

            % Check for command actuation
            if obj.flag_executive && obj.commanded_thrust > 0
                % Save the command for the next cycle
                obj.pending_fire = true;
                obj.pending_thrust = obj.commanded_thrust;

                disp(['Thruster transitioning from ready to firing at
time ', num2str(mission.true_time.time), ' sec']);
                disp(['  Commanded thrust: ',
num2str(obj.commanded_thrust), ' N']);
                obj.thruster_state = 'firing';
            end

            % Check for timeout (5 minutes idle in ready state)
            % Use the ready_state_start_time as reference to measure
timeout period
            if (mission.true_time.time - obj.ready_state_start_time) >
300
                disp(['Thruster timing out from ready state after ',
num2str(mission.true_time.time - obj.ready_state_start_time), ' seconds']);
                obj.thruster_state = 'idle';
                obj.flag_warming_up = false;
            end

            case 'firing'
                % Process thruster firing - use either current command or
pending command from previous cycle
                if (obj.flag_executive && obj.commanded_thrust > 0) ||
obj.pending_fire
                    try
                        % Use either active command or saved pending
command
                        if obj.flag_executive && obj.commanded_thrust > 0
                            thrust_to_use = obj.commanded_thrust;

```

```

        else
            thrust_to_use = obj.pending_thrust;
            disp(['Using pending thrust from previous
cycle: ', num2str(thrust_to_use), ' N']);
        end

        % Update thrust with noise
        obj.true_commanded_thrust = thrust_to_use +
obj.thruster_noise * (2*rand() - 1);

        % Ensure thrust remains within bounds
        obj.true_commanded_thrust =
max(min(obj.true_commanded_thrust, obj.maximum_thrust), obj.minimum_thrust);

        % Get current attitude matrix to transform from
body to inertial frame
        R =
quaternionToRotationMatrix(mission.true_SC{i_SC}.true_SC_adc.attitude);

        % Calculate force vector in body frame first
        force_body = obj.true_commanded_thrust *
obj.orientation;

        % Transform to inertial frame
        obj.force_inertial = R * force_body'; % Netwons

        % Log the thruster firing
        disp(['THRUSTER FIRING with thrust
of ', num2str(obj.true_commanded_thrust), ' N at time ',
num2str(mission.true_time.time), ' sec']);

        % Make sure that the control orbit verifies if
        % the deltaV has been performed correctly

mission.true_SC{i_SC}.software_SC_control_orbit.flag_executive = 1;

        % Add thrust on the SC (in inertial frame)

mission.true_SC{i_SC}.true_SC_navigation.control_force =
mission.true_SC{i_SC}.true_SC_navigation.control_force + obj.force_inertial';

        % Compute the disturbance torque
        r = obj.location -
mission.true_SC{i_SC}.true_SC_body.location_COM;
        obj.control_torque_CT = cross(r, force_body);

        % Apply torque to attitude system

mission.true_SC{i_SC}.true_SC_adc.disturbance_torque =
mission.true_SC{i_SC}.true_SC_adc.disturbance_torque + obj.control_torque_CT;

        % Update power consumption (warm-up + actuation)
        obj.instantaneous_power_consumption =
obj.thruster_warm_up_power_consumed + obj.command_actuation_power_consumed;

```

```

                                % Set command execution flag - this will persist
until next cycle                obj.command_executed = true;

                                % Calculate DeltaV applied and directly update
orbit control                   dt = mission.true_time.time_step;
                                sc_mass =
mission.true_SC{i_SC}.true_SC_body.total_mass;

                                % Calculate DeltaV applied (normalized direction *
magnitude)                     DeltaV_applied = (norm(obj.force_inertial) * dt /
                                sc_mass) * (obj.force_inertial / norm(obj.force_inertial));

                                % Update orbit control's total executed DeltaV
directly                        mission.true_SC{i_SC}.software_SC_control_orbit.total_DeltaV_executed =
                                mission.true_SC{i_SC}.software_SC_control_orbit.total_DeltaV_executed +
                                DeltaV_applied;

                                % Log the actuation
                                disp(['Applied DeltaV: ',
num2str(DeltaV_applied(1)), ', ', num2str(DeltaV_applied(2)), ', ',
num2str(DeltaV_applied(3)), ' m/s']);
                                disp(['Total DeltaV now: ',
num2str(mission.true_SC{i_SC}.software_SC_control_orbit.total_DeltaV_executed(1)), ',
', ...
num2str(mission.true_SC{i_SC}.software_SC_control_orbit.total_DeltaV_executed(2)), ',
', ...
num2str(mission.true_SC{i_SC}.software_SC_control_orbit.total_DeltaV_executed(3)), ' ]
m/s']);

                                % Calculate and display the remaining DeltaV to be
applied                         remaining_DeltaV =
                                mission.true_SC{i_SC}.software_SC_control_orbit.desired_control_DeltaV -
                                mission.true_SC{i_SC}.software_SC_control_orbit.total_DeltaV_executed;
                                disp(['Remaining DeltaV: ',
num2str(norm(remaining_DeltaV)), ' m/s']);

                                % Calculate fuel consumption
                                dt = mission.true_time.time_step;
                                g0 = 9.80665; % m/s^2
                                obj.fuel_consumed_per_firing =
                                (obj.true_commanded_thrust * dt) / (obj.isp * g0);
                                obj.total_fuel_consumed = obj.total_fuel_consumed
                                + obj.fuel_consumed_per_firing;

                                % Consume fuel from the tank if fuel tank exists

```

```

        if
isfield(mission.true_SC{i_SC}, 'true_SC_fuel_tank') && ...

mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_fuel_tank > 0

        % Find the assigned fuel tank for this
thruster (assuming the first one for now)
        i_tank = 1; % In a more complex
implementation, each thruster might have a specific tank assigned

        % Consume fuel from the tank

mission.true_SC{i_SC}.true_SC_fuel_tank{i_tank}.func_consume_fuel(obj.fuel_consumed_per_f
end

        % Clear pending fire flag after successful firing
obj.pending_fire = false;
obj.pending_thrust = 0;

        catch exception
            % Log error but continue execution
            %                                     warning('Error
during thruster firing: %s', exception.message);
            warning('Error during thruster firing');
            obj.thruster_state = 'ready';
            obj.command_executed = false;
            obj.pending_fire = false;
            obj.pending_thrust = 0;
        end
    else
        % No command to fire, go back to ready state
        if strcmp(obj.thruster_state, 'firing')
            disp(['Thruster returning to ready state from
firing at time ', num2str(mission.true_time.time), ' sec']);
        end
        obj.thruster_state = 'ready';
        % We don't reset command_executed here as it needs to
persist for one cycle
    end
end

        % Always update power consumed for power tracking
obj.instantaneous_power_consumed =
obj.instantaneous_power_consumption;

        % Update Power Consumed

func_update_instantaneous_power_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

        % Update Data Generated

func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

```

```
% Update storage
obj.func_update_true_chemical_thruster_store(mission);

% Reset executive flag and thrust command after processing
obj.flag_executive = false;
obj.commanded_thrust = 0;
obj.control_torque_CT = zeros(1,3);

cycle % Reset command_executed flag ONLY if it was set in the previous
      % (not the current one)
      if was_executed_last_cycle
          obj.command_executed = false;
      end

      obj.true_commanded_thrust = 0;
  end
end
end
```

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5.5 True_SC_Fuel_Tank

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Class: True_SC_Fuel_Tank

Tracks the fuel state of the spacecraft propellant tank

```
classdef True_SC_Fuel_Tank < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
name % [string] 'Fuel Tank i'

instantaneous_power_consumed % [Watts] Power consumed by the fuel
tank (e.g., heaters)

instantaneous_data_rate_generated % [kbps] Data rate generated during
current time step

maximum_capacity % [kg] Maximum fuel mass capacity

instantaneous_fuel_mass % [kg] Current fuel mass in the tank

fuel_density % [kg/m^3] Density of the propellant

location % [m] Location of the tank in the body frame

shape_model % Structure containing shape model information
```

[] Properties: Variables Computed Internally

```
health % [integer] Health of fuel tank (0: Off, 1:
On)

temperature % [deg C] Temperature of fuel tank
```

```
        flag_update_SC_body      % [Boolean] Flag to signal when SC body mass
needs to be updated
```

[] Properties: Storage Variables

```
        store                    % Structure to store historical data

    end
```

Methods

```
    methods
```

[] Methods: Constructor

Construct an instance of this class

```
function obj = True_SC_Fuel_Tank(init_data, mission, i_SC, i_HW)
    % Constructor for the fuel tank class

    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
        obj.name = ['Fuel Tank ', num2str(i_HW)];
    end

    obj.health = 1; % Default to healthy
    obj.temperature = 20; % Default temperature in Celsius

    % Power and data parameters
    obj.instantaneous_power_consumed =
init_data.instantaneous_power_consumed;
    obj.instantaneous_data_rate_generated =
init_data.instantaneous_data_rate_generated;

    % Fuel parameters
    obj.maximum_capacity = init_data.maximum_capacity;
    obj.instantaneous_fuel_mass = init_data.initial_fuel_mass;
    obj.fuel_density = init_data.fuel_density;

    % Physical parameters
    obj.location = init_data.location;

    % Shape model if provided
    if isfield(init_data, 'shape_model')
        obj.shape_model = init_data.shape_model;
    else
        obj.shape_model = [];
    end

    % Flag for body update
```

```

obj.flag_update_SC_body = 0;

% Initialize storage variables
obj.store = [];
obj.store.instantaneous_fuel_mass =
zeros(mission.storage.num_storage_steps, 1);
obj.store.instantaneous_power_consumed =
zeros(mission.storage.num_storage_steps, 1);

% Update storage
obj = func_update_true_SC_fuel_tank_store(obj, mission);

% Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

% Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);
end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_fuel_tank_store(obj, mission)
% Update storage variables for the fuel tank

if mission.storage.flag_store_this_time_step == 1

obj.store.instantaneous_fuel_mass(mission.storage.k_storage, :) =
obj.instantaneous_fuel_mass;

obj.store.instantaneous_power_consumed(mission.storage.k_storage, :) =
obj.instantaneous_power_consumed;
end
end

```

[] Methods: Consume Fuel

```

function obj = func_consume_fuel(obj, fuel_mass_consumed)
% Consume fuel from the tank

% Check if there's enough fuel
if fuel_mass_consumed > obj.instantaneous_fuel_mass
warning('Fuel tank %s: Attempted to consume more fuel than
available!', obj.name);
fuel_mass_consumed = obj.instantaneous_fuel_mass;
end

% Update fuel mass

```

```

        obj.instantaneous_fuel_mass = obj.instantaneous_fuel_mass -
fuel_mass_consumed;

        % Set flag to update SC body
        obj.flag_update_SC_body = 1;
    end

```

[] Methods: Main

```

function obj = func_main_true_SC_fuel_tank(obj, mission, i_SC)
    % Main function for the fuel tank

    % Update propellant mass in the spacecraft body
    if obj.flag_update_SC_body == 1
        % Instead of directly updating the mass, just set the flag for
the body to update
        % The body's func_update_SC_body_mass will grab the latest
fuel mass

mission.true_SC{i_SC}.true_SC_body.flag_update_SC_body_total_mass_COM_MI = 1;

        % Reset update flag
        obj.flag_update_SC_body = 0;
    end

    % Update power system with this tank's power consumption (heaters,
valves, etc.)

func_update_instantaneous_power_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

    % Update storage
    obj = func_update_true_SC_fuel_tank_store(obj, mission);
end

end

end

```

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5.6 True_SC_Generic_Sensor

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Class: True_SC_Generic_Sensor

Generic Sensor class

```
classdef True_SC_Generic_Sensor < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
instantaneous_power_consumed % [Watts] : Instantaneous power consumed

instantaneous_data_rate_generated % [kbps] : Data rate, in kilo bits
per sec (kbps)
```

[] Properties: Variables Computed Internally

```
name % [string] 'Generic Sensor i'

health % [integer] Health of sensor/actuator
% - 0. Switched off
% - 1. Switched on, works nominally

temperature % [deg C] : Temperature of sensor/actuator

flag_executive % [Boolean] Executive has told this sensor/actuator to
do its job

data % Other useful data
```

[] Properties: Storage Variables

```
store

end
```

Methods

methods

[] Methods: Constructor

Construct an instance of this class

```
function obj = True_SC_Generic_Sensor(init_data, mission, i_SC, i_HW)

    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
        obj.name = ['Generic Sensor ', num2str(i_HW)];
    end

    obj.health = 1;
    obj.temperature = 10; % [deg C]

    obj.instantaneous_power_consumed =
init_data.instantaneous_power_consumed; % [W]
    obj.instantaneous_data_rate_generated =
init_data.instantaneous_data_rate_generated; % [kbps]

    obj.flag_executive = 0;

    if isfield(init_data, 'data')
        obj.data = init_data.data;
    else
        obj.data = [];
    end

    % Initialize Variables to store: measurement_vector
    obj.store = [];
    obj.store.flag_executive =
zeros(mission.storage.num_storage_steps, length(obj.flag_executive));
    obj.store.instantaneous_data_rate_generated =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_data_rate_generated)); % [kbps]
    obj.store.instantaneous_power_consumed =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_power_consumed)); % [W]

    % Update Storage
    obj = func_update_true_SC_generic_sensor_store(obj, mission);

    % Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

    % Update SC Data Handling Class
```

```
func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,  
obj, mission);
```

```
end
```

[] Methods: Store

Update the store variable

```
function obj = func_update_true_SC_generic_sensor_store(obj, mission)  
  
    if mission.storage.flag_store_this_time_step == 1  
        obj.store.flag_executive(mission.storage.k_storage_attitude,:) =  
= obj.flag_executive; % [Boolean]  
  
        if obj.flag_executive == 1  
  
obj.store.instantaneous_data_rate_generated(mission.storage.k_storage,:) =  
obj.instantaneous_data_rate_generated; % [kbps]  
  
obj.store.instantaneous_power_consumed(mission.storage.k_storage,:) =  
obj.instantaneous_power_consumed; % [W]  
        end  
    end  
  
end
```

[] Methods: Main

Update Generic Sensor

```
function obj = func_main_true_SC_generic_sensor(obj, mission, i_SC)  
  
    if (obj.flag_executive == 1) && (obj.health == 1)  
        % Take measurement  
  
        if  
isfield(obj.data, 'instantaneous_power_consumed_per_SC_mode')  
            obj.instantaneous_power_consumed =  
obj.data.instantaneous_power_consumed_per_SC_mode(mission.true_SC{i_SC}.software_SC_execu  
[W]  
        end  
  
        % Update Power Consumed  
  
func_update_instantaneous_power_consumed(mission.true_SC{i_SC}.true_SC_power,  
obj, mission);  
  
        % Update Data Generated  
  
func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,  
obj, mission);
```

```
    else
        % Do nothing
    end

    % Update Storage
    obj = func_update_true_SC_generic_sensor_store(obj, mission);

    % Reset Variables
    obj.flag_executive = 0;

end

end

end
```

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5.7 True_SC_IMU

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[] Methods: Main	3
[] Methods: Truth	4
[] Methods: Simple	5

Class: True_SC_IMU

Tracks the IMU measurements

```
classdef True_SC_IMU < handle
```

Properties

properties

[] Properties: Initialized Variables

```
instantaneous_power_consumed % [Watts] : Instantaneous power consumed

instantaneous_data_generated_per_sample % [kb] : Data generated per
sample, in kilo bits (kb)

mode_true_sc_imu_selector % [string]
% - Truth
% - Simple

measurement_noise % [rad/sec] (1-sigma standard deviation)

measurement_wait_time % [sec]

location % [m] : Location of sensor, in body frame B

orientation % [unit vector] : Normal vector from location
```

[] Properties: Variables Computed Internally

```
name % [string] 'Sun Sensor i'

health % [integer] Health of sensor/actuator
% - 0. Switched off
```

```

    % - 1. Switched on, works nominally

    temperature % [deg C] : Temperature of sensor/actuator

    measurement_vector % [quaternion]

    measurement_time % [sec] SC time when this measurement was taken

    flag_executive % [Boolean] Executive has told this sensor/actuator to
do its job

    data % Other useful data

```

[] Properties: Storage Variables

```

store

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = True_SC_IMU(init_data, mission, i_SC, i_HW)

    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
        obj.name = ['IMU ', num2str(i_HW)];
    end

    obj.health = 1;
    obj.temperature = 10; % [deg C]

    obj.instantaneous_power_consumed =
init_data.instantaneous_power_consumed; % [W]
    obj.instantaneous_data_generated_per_sample =
init_data.instantaneous_data_generated_per_sample; % [kb]

    obj.mode_true_SC_imu_selector =
init_data.mode_true_SC_imu_selector; % [string]
    obj.measurement_wait_time = init_data.measurement_wait_time; %
[sec]
    obj.measurement_noise = init_data.measurement_noise; % [rad]

    obj.measurement_vector = zeros(1,3);

    obj.flag_executive = 1;

```

```

obj.measurement_time = -inf; % [sec]

obj.location = init_data.location; % [m]
obj.orientation = init_data.orientation; % [unit vector]

if isfield(init_data, 'data')
    obj.data = init_data.data;
else
    obj.data = [];
end

% Initialize Variables to store: measurement_vector
obj.store = [];
obj.store.measurement_vector =
zeros(mission.storage.num_storage_steps, length(obj.measurement_vector));

% Update Storage
obj = func_update_true_SC_imu_store(obj, mission);

% Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

% Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_imu_store(obj, mission)

    if mission.storage.flag_store_this_time_step_attitude == 1

obj.store.measurement_vector(mission.storage.k_storage_attitude,:) =
obj.measurement_vector; % [quaternion]
    end

end

```

[] Methods: Main

Update Camera

```

function obj = func_main_true_SC_imu(obj, mission, i_SC)

    if (obj.flag_executive == 1) && (obj.health == 1)

```

```

        % Take measurement

        if (mission.true_time.time_attitude - obj.measurement_time) >=
obj.measurement_wait_time

            % Sufficient time has elapsed for a new measurement
            obj.measurement_time = mission.true_time.time_attitude; %
[sec]

            switch obj.mode_true_SC_imu_selector

                case 'Truth'
                    obj = func_true_SC_imu_Truth(obj, mission, i_SC);

                case 'Simple'
                    obj = func_true_SC_imu_Simple(obj, mission, i_SC);

                otherwise
                    error('IMU mode not defined!')
            end

            % Update Data Generated

            func_update_instantaneous_data_generated_attitude(mission.true_SC{i_SC}.true_SC_data_hand
obj, mission);

        else
            % Data not generated in this time step

        end

        % Update Power Consumed

        func_update_instantaneous_power_consumed_attitude(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

    else
        % Do nothing

    end

    % Update Storage
    obj = func_update_true_SC_imu_store(obj, mission);

    % Reset Variables
    obj.flag_executive = 0;

end

```

[] Methods: Truth

IMU mode

```
function obj = func_true_SC_imu_Truth(obj, mission, i_SC)
    obj.measurement_vector =
mission.true_SC{i_SC}.true_SC_adc.angular_velocity;
end
```

[] Methods: Simple

IMU mode

```
function obj = func_true_SC_imu_Simple(obj, mission, i_SC)
    obj.measurement_vector =
mission.true_SC{i_SC}.true_SC_adc.angular_velocity +
obj.measurement_noise*randn(1,3) ;
end

end

end
```

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5.8 True_SC_Micro_Thruster

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[] Methods: Reset	5
[] Methods: Main	5

Class: True_SC_Micro_Thruster

Individual SC's micro thruster

```
classdef True_SC_Micro_Thruster < handle

    % True_SC_Micro_Thruster class represents a single micro-thruster
    % with various properties and methods for simulation and analysis.
```

Properties

properties

[] Properties: Initialized Variables

```
    instantaneous_power_consumption    %[Watts] : Instantaneous power
consumed by unit (if it is switched on)

    instantaneous_data_generated_per_sample    %[kb] : Data generated
during the current time step, in kilo bits

    mode_true_SC_micro_thruster_selector % Mode (Truth/Simple)

    thruster_noise                      %[N] : Added to every dimension of
commanded_thrust

    isp                                %[s] : Specific impulse of the
thruster

    maximum_thrust                     %[N]

    minimum_thrust                     %[N]

    command_wait_time                  %[sec] : Seconds betzeen commands
```

orientation	%[Unit vector] : Normal vector of
thrust in body frame B	
location	%[m] : Location of actuator, in body
frame B	

[] Properties: Variables Computed Internally

instantaneous_data_volume	% [kb]
instantaneous_power_consumed	%[Watts]
thruster_warm_up_power_consumed	%[Watts] : Power consumed during
warm-up time	
command_actuation_power_consumed	%[Watts] : Power consumed during
actuation	
name	% Name of the thruster
health	% Health of the thruster (0 : Not
working - 1 : Working)	
temperature	%[Celcius] Temerature of the thruster
control_force_MT	%[N] : Control force vector generated
by the unit that passes through Center of Mass of SC	
control_torque_MT	%[Nm] : Control torque about Center
of Mass of SC, generated by the unit	
thruster_warm_up_time	%[sec] : How much warm-up time is
needed?	
accumulated_warm_up_time	%[sec]
command_time	%[sec] : Time when latest Command was
actuated	
command_actuation	%[Boolean] : Command actuation
during this time step (after actuator has warmed up)	
command_executed	%[Boolean] : Command executed during
this time step	
commanded_thrust	%[N] : Comes from the SC's software
true_commanded_thrust	%[N] : Add thruster noise to
commanded_thrust. This is the actual thrust of this thruster, which the SC	
software doesn t know.	
% Fuel consumption properties	
fuel_consumed_per_firing	%[kg] : Amount of fuel consumed in
current firing	
total_fuel_consumed	%[kg] : Total fuel consumed by this
thruster	

[] Properties: Storage Variables

store

end

Methods

methods

[] Methods: Constructor

Construct an instance of this class

```
function obj = True_SC_Micro_Thruster(init_data, mission, i_SC, i_MT)
    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
        obj.name = ['Micro Thruster ', num2str(i_MT)];
    end
    obj.health = true;
    obj.temperature = 20;
    obj.instantaneous_power_consumption =
init_data.instantaneous_power_consumption; % Watts
    obj.instantaneous_power_consumed =
init_data.instantaneous_power_consumption; % Watts
    obj.instantaneous_data_generated_per_sample =
init_data.instantaneous_data_generated_per_sample; % Kb
    obj.mode_true_SC_micro_thruster_selector =
init_data.mode_true_SC_micro_thruster_selector; % Mode (Truth/Simple)
    obj.command_wait_time = init_data.command_wait_time; % Seconds
between commands
    obj.location = init_data.location; % Meters (body frame)

    obj.orientation = init_data.orientation; % Unit vector (body
frame)
    obj.orientation = obj.orientation / norm(obj.orientation); %
Normalize

    obj.thruster_noise = init_data.thruster_noise; % Noise level [N]
    obj.minimum_thrust = init_data.minimum_thrust;
    obj.maximum_thrust = init_data.maximum_thrust; % [N]

    % Set default values for warm-up parameters
    obj.thruster_warm_up_time = 0; % Default no warm-up
    obj.accumulated_warm_up_time = 0;
    obj.thruster_warm_up_power_consumed = 0;
    obj.command_actuation_power_consumed =
obj.instantaneous_power_consumption; % Default to regular consumption
    obj.instantaneous_data_volume =
obj.instantaneous_data_generated_per_sample; % [kb]

    % Initialize fuel consumption properties
    obj.isp = init_data.micro_thruster_ISP; % Get ISP from init data
    obj.fuel_consumed_per_firing = 0;
    obj.total_fuel_consumed = 0;
```

```

    % Reset all variables
    obj = func_reset_state(obj);

    % Initialize Storage Variables
    obj.store = [];
    obj.store.true_commanded_thrust =
zeros(mission.storage.num_storage_steps_attitude,1);
    obj.store.control_torque_MT =
zeros(mission.storage.num_storage_steps_attitude,
length(obj.control_torque_MT));
    obj.store.control_force_MT =
zeros(mission.storage.num_storage_steps_attitude,
length(obj.control_force_MT));
    obj.store.fuel_consumed_per_firing =
zeros(mission.storage.num_storage_steps_attitude,1);
    obj.store.total_fuel_consumed =
zeros(mission.storage.num_storage_steps_attitude,1);

    % Update storage
    func_update_true_SC_micro_thruster_store(obj, mission);

    % Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

    % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_micro_thruster_store(obj, mission)
    % Append new thrust data to the storage arrays

obj.store.true_commanded_thrust(mission.storage.k_storage_attitude,:) =
obj.true_commanded_thrust;
    obj.store.control_torque_MT(mission.storage.k_storage_attitude,:) =
obj.control_torque_MT;
    obj.store.control_force_MT(mission.storage.k_storage_attitude,:) =
obj.control_force_MT;

obj.store.fuel_consumed_per_firing(mission.storage.k_storage_attitude,:) =
obj.fuel_consumed_per_firing;

obj.store.total_fuel_consumed(mission.storage.k_storage_attitude,:) =
obj.total_fuel_consumed;
end

```

[] Methods: Reset

```
function obj = func_reset_state(obj)
    % Reset temporary state variables after each time step
    % This ensures clean state for the next time step

    % Reset actuation flags
    obj.command_actuation = false;
    obj.command_executed = false;

    % Reset thruster state for next time step
    obj.commanded_thrust = 0;
    obj.true_commanded_thrust = 0;
    obj.control_torque_MT = [0, 0, 0]; % [Nm]
    obj.control_force_MT = [0 0 0]; % [N]

    % Reset fuel consumption for this firing
    % Note: total_fuel_consumed is kept as it's cumulative
    obj.fuel_consumed_per_firing = 0;
end
```

[] Methods: Main

```
function func_main_true_SC_micro_thruster(obj, mission, i_SC, ~)
    % Main function for True_SC_Micro_Thruster
    % Controls thrust application, power consumption, and data
    generation.

    % Reset fuel consumed this firing
    obj.fuel_consumed_per_firing = 0;

    % Check if the thruster is healthy
    if obj.health == 0
        obj.commanded_thrust = 0; % Thruster is offline, no thrust can
        be applied
        obj.command_executed = false; % Mark as not executed
        obj.instantaneous_power_consumption = 0;
        obj.instantaneous_power_consumed = 0;
        return;
    end

    % Fire the thruster if the actuation flag is true
    % (should be set in the function optimize_thruster_dart in sw
    attitude control)
    if obj.command_actuation
        % Check warm-up time
        if obj.accumulated_warm_up_time < obj.thruster_warm_up_time
            % Thruster warming up
            obj.instantaneous_power_consumption =
            obj.thruster_warm_up_power_consumed;
            obj.instantaneous_power_consumed =
            obj.thruster_warm_up_power_consumed;
```

```

        obj.accumulated_warm_up_time =
obj.accumulated_warm_up_time + mission.time_step;
        obj.command_executed = false; % Not yet ready to fire
    else
        % Thruster ready to fire
        obj.instantaneous_power_consumption =
obj.command_actuation_power_consumed;
        obj.instantaneous_power_consumed =
obj.command_actuation_power_consumed;

        % Randomize noise
        current_thruster_noise = obj.thruster_noise * (2*rand() -
1); % Generates a number between 1.0e-04 and - 1.0e-04

        % Compute the true thrust with noise
        obj.true_commanded_thrust = obj.commanded_thrust +
current_thruster_noise;

        % Compute force vector
        obj.control_force_MT = obj.orientation *
obj.true_commanded_thrust;

        % Compute the torque generated by the thruster
        obj.control_torque_MT = cross(obj.location -
mission.true_SC{i_SC}.true_SC_body.location_COM, obj.control_force_MT);

        % Apply the generated torque to the spacecraft ADC
        mission.true_SC{i_SC}.true_SC_adc.control_torque = ...

mission.true_SC{i_SC}.true_SC_adc.control_torque + obj.control_torque_MT;

        % Apply the generated force to the spacecraft navigation
        mission.true_SC{i_SC}.true_SC_navigation.disturbance_force
= ...

mission.true_SC{i_SC}.true_SC_navigation.disturbance_force +
(obj.control_force_MT * mission.true_time.time_step_attitude /
mission.true_time.time_step ); % [N]

        % Calculate fuel consumption
        g0 = 9.80665; % m/s^2
        obj.fuel_consumed_per_firing = (obj.true_commanded_thrust
* mission.true_time.time_step_attitude) / (obj.isp * g0);
        obj.total_fuel_consumed = obj.total_fuel_consumed +
obj.fuel_consumed_per_firing;

        % Consume fuel from the tank if fuel tank exists
        if isfield(mission.true_SC{i_SC}, 'true_SC_fuel_tank')
&& ...

mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_fuel_tank > 0
            % Find the assigned fuel tank (assuming the first one
for now)
            i_tank = 1;

```

```

        % Consume fuel from the tank

mission.true_SC{i_SC}.true_SC_fuel_tank{i_tank}.func_consume_fuel(obj.fuel_consumed_per_f
end

        % Generate data for this actuation step
        obj.instantaneous_data_generated_per_sample =
obj.instantaneous_data_volume;

        % Mark as executed
        obj.command_executed = true;
end

else
    % Thruster not actuating
    obj.commanded_thrust = 0;
    obj.true_commanded_thrust = 0;
    obj.control_torque_MT = [0, 0, 0]; % No torque applied
    obj.command_executed = false;
    obj.instantaneous_power_consumption = 0; % No power used
    obj.instantaneous_power_consumed = 0;
    obj.instantaneous_data_generated_per_sample = 0; % No data
generated
end

    % Update Power Consumed

func_update_instantaneous_power_consumed_attitude(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

    % Update Data Generated

func_update_instantaneous_data_generated_attitude(mission.true_SC{i_SC}.true_SC_data_hand
obj, mission);

    % Update storage
    func_update_true_SC_micro_thruster_store(obj, mission);

    % Add this line to properly reset state after the time step is
complete
    % and all data has been stored
    func_reset_state(obj);
end

end

end
end

```

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5.9 True_SC_Onboard_Computer

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[] Properties: Storage Variables	1
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[] Methods: Constructor	2
[] Methods: Store	3
[] Methods: Main	3

Class: True_SC_Onboard_Computer

Onboard Computer class for spacecraft

```
classdef True_SC_Onboard_Computer < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
instantaneous_power_consumed % [Watts] : Instantaneous power consumed

instantaneous_data_rate_generated % [kbps] : Data rate, in kilo bits
per sec (kbps)

processor_utilization % [%] : CPU usage (0-100%)
```

[] Properties: Variables Computed Internally

```
name % [string] 'Onboard Computer i'

health % [integer] Health of computer
% - 0. Switched off
% - 1. Switched on, works nominally

temperature % [deg C] : Temperature of computer

flag_executive % [Boolean] Executive has told this computer to do its
job

data % Other useful data
```

[] Properties: Storage Variables

```
store
```

```
end
```

Methods

```
methods
```

[] Methods: Constructor

Construct an instance of this class

```
function obj = True_SC_Onboard_Computer(init_data, mission, i_SC,
i_HW)

    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
        obj.name = ['Onboard Computer ', num2str(i_HW)];
    end

    obj.health = 1;
    obj.temperature = 15; % [deg C]

    obj.instantaneous_power_consumed =
init_data.instantaneous_power_consumed; % [W]
    obj.instantaneous_data_rate_generated =
init_data.instantaneous_data_rate_generated; % [kbps]

    if isfield(init_data, 'processor_utilization')
        obj.processor_utilization = init_data.processor_utilization; %
[%]
    else
        obj.processor_utilization = 10; % [%] default utilization
    end

    obj.flag_executive = 0;

    if isfield(init_data, 'data')
        obj.data = init_data.data;
    else
        obj.data = [];
    end

    % Initialize Variables to store
    obj.store = [];
    obj.store.flag_executive =
zeros(mission.storage.num_storage_steps, length(obj.flag_executive));
    obj.store.instantaneous_data_rate_generated =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_data_rate_generated)); % [kbps]
    obj.store.instantaneous_power_consumed =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_power_consumed)); % [W]
```

```

        obj.store.processor_utilization =
zeros(mission.storage.num_storage_steps, 1); % [%]

        % Update Storage
        obj = func_update_true_SC_onboard_computer_store(obj, mission);

        % Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

        % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

    end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_onboard_computer_store(obj,
mission)

    if mission.storage.flag_store_this_time_step == 1
        obj.store.flag_executive(mission.storage.k_storage_attitude,:)
= obj.flag_executive; % [Boolean]

        if obj.flag_executive == 1

obj.store.instantaneous_data_rate_generated(mission.storage.k_storage,:) =
obj.instantaneous_data_rate_generated; % [kbps]

obj.store.instantaneous_power_consumed(mission.storage.k_storage,:) =
obj.instantaneous_power_consumed; % [W]

obj.store.processor_utilization(mission.storage.k_storage,:) =
obj.processor_utilization; % [%]
        end
    end

end

```

[] Methods: Main

Update Onboard Computer

```

function obj = func_main_true_SC_onboard_computer(obj, mission, i_SC)

    if (obj.flag_executive == 1) && (obj.health == 1)
        % Operate computer - constant power and data rate regardless
of processor utilization
    end

```

```
        % Update power consumed for spacecraft power budget

func_update_instantaneous_power_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

        % Update data generated for spacecraft data handling

func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

    else
        % Computer is off or malfunctioning
    end

    % Update Storage
    obj = func_update_true_SC_onboard_computer_store(obj, mission);

    % Do not reset flag_executive because computer is always on

end

end

end
```

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5.10 True_SC_Onboard_Clock

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[] Properties: Storage Variables	2
Methods	2
[] Methods: Constructor	2
[] Methods: Store	3
[] Methods: Main	3

Class: True_SC_Onboard_Clock

Tracks the time onboard the SC

```
classdef True_SC_Onboard_Clock < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
instantaneous_power_consumed % [Watts] : Instantaneous power consumed

instantaneous_data_rate_generated % [kbps] : Data rate generated
during current time step, in kilo bits (kb) per sec

mode_true_SC_onboard_clock_selector % [string]
% - Simple

measurement_noise % [sec] (1-sigma standard deviation) (Optional)

measurement_wait_time % [sec]
```

[] Properties: Variables Computed Internally

```
name % [string] 'Clock i'

health % [integer] Health of sensor/actuator
% - 0. Switched off
% - 1. Switched on, works nominally

temperature % [deg C] : Temperature of sensor/actuator

measurement_vector % [sec] [Time, Date]

measurement_time % [sec] SC time when this measurement was taken
```

```
        flag_executive % [Boolean] Executive has told this sensor/actuator to  
do its job
```

[] Properties: Storage Variables

```
        store  
  
    end
```

Methods

```
        methods
```

[] Methods: Constructor

Construct an instance of this class

```
function obj = True_SC_Onboard_Clock(init_data, mission, i_SC, i_HW)  
  
    if isfield(init_data, 'name')  
        obj.name = init_data.name;  
    else  
        obj.name = ['Clock ', num2str(i_HW)];  
    end  
  
    obj.health = 1;  
    obj.temperature = 10; % [deg C]  
  
    obj.instantaneous_power_consumed =  
init_data.instantaneous_power_consumed; % [W]  
    obj.instantaneous_data_rate_generated =  
init_data.instantaneous_data_rate_generated; % [kbps]  
  
    if isfield(init_data, 'measurement_noise')  
        obj.measurement_noise = init_data.measurement_noise; % [sec]  
    else  
        obj.measurement_noise = 0; % [sec]  
    end  
  
    obj.mode_true_SC_onboard_clock_selector =  
init_data.mode_true_SC_onboard_clock_selector; % [string]  
    obj.measurement_wait_time = init_data.measurement_wait_time; %  
[sec]  
  
    obj.flag_executive = 1;  
  
    this_measurement_noise = obj.measurement_noise*2*(rand-0.5); %  
[sec]  
    obj.measurement_vector = [(mission.true_time.time +  
this_measurement_noise) (mission.true_time.date + this_measurement_noise)]; %  
[sec] [Time, Date]  
    obj.measurement_time = obj.measurement_vector(1); % [sec]
```

```

        % Initialize Variables to store: measurement_vector
measurement_time
        obj.store = [];

        obj.store.measurement_vector =
zeros(mission.storage.num_storage_steps, length(obj.measurement_vector));
        obj.store.measurement_time =
zeros(mission.storage.num_storage_steps, length(obj.measurement_time));
        obj.store.measurement_noise = obj.measurement_noise; % [sec]

        % Update Storage
        obj = func_update_true_SC_onboard_clock_store(obj, mission);

        % Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

        % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_onboard_clock_store(obj, mission)

    if mission.storage.flag_store_this_time_step == 1
        obj.store.measurement_vector(mission.storage.k_storage,:) =
obj.measurement_vector; % [sec]
        obj.store.measurement_time(mission.storage.k_storage,:) =
obj.measurement_time; % [sec]
    end

end

```

[] Methods: Main

Update Clock Time

```

function obj = func_main_true_SC_onboard_clock(obj, mission, i_SC)

    if (obj.flag_executive == 1) && (obj.health == 1)
        % Take measurement

        if (mission.true_time.time - obj.measurement_time) >=
obj.measurement_wait_time

```

```

        % Sufficient time has elapsed for a new measurement

        switch obj.mode_true_SC_onboard_clock_selector

            case 'Simple'
                this_measurement_noise =
obj.measurement_noise*2*(rand-0.5); % [sec]
                obj.measurement_vector = [(mission.true_time.time
+ this_measurement_noise) (mission.true_time.date +
this_measurement_noise)]; % [sec]
                obj.measurement_time = mission.true_time.time; %
[sec]

            otherwise
                error('Clock mode not defined!')
            end

        end

        % Update Power Consumed

func_update_instantaneous_power_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

        % Update Data Generated

func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

    else
        % Do nothing

    end

    % Update Storage
    obj = func_update_true_SC_onboard_clock_store(obj, mission);

    % Reset Variables
    obj.flag_executive = 0;

end

end

end

```

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5.11 True_SC_Onboard_Memory

Table of Contents

Class: True_SC_Onboard_Memory	1
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[] Properties: Variables Computed Internally	1
[] Properties: Storage Variables	1
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[] Methods: Constructor	2
[] Methods: Store	3
[] Methods: Main	3

Class: True_SC_Onboard_Memory

Tracks the onboard Memory state

```
classdef True_SC_Onboard_Memory < handle
```

Properties

properties

[] Properties: Initialized Variables

```
instantaneous_power_consumed % [Watts] : Instantaneous power consumed

instantaneous_data_rate_generated % [kbps] : Data rate generated
during current time step, in kilo bits (kb) per sec

maximum_capacity % [kb] : Maximum data storage capacity of the Memeory
```

[] Properties: Variables Computed Internally

```
name % [string] 'Memory i'

health % [integer] Health of sensor/actuator
% - 0. Switched off
% - 1. Switched on, works nominally

temperature % [deg C] : Temperature of sensor/actuator

instantaneous_capacity % [kb] : Instantaneous capacity of Memeory

state_of_data_storage % [percentage] : SoDS is defined by = 100×
instantaneous_capacity / maximum_capacity
```

[] Properties: Storage Variables

store

end

Methods

methods

[] Methods: Constructor

Construct an instance of this class

```
function obj = True_SC_Onboard_Memory(init_data, mission, i_SC, i_HW)

    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
        obj.name = ['Memory ', num2str(i_HW)];
    end

    obj.health = 1;
    obj.temperature = 10; % [deg C]

    obj.instantaneous_power_consumed =
init_data.instantaneous_power_consumed; % [W]
    obj.instantaneous_data_rate_generated =
init_data.instantaneous_data_rate_generated; % [kbps]

    obj.maximum_capacity = init_data.maximum_capacity; % [kb]
    obj.instantaneous_capacity = 0; % [kb]
    obj.state_of_data_storage = 100*obj.instantaneous_capacity/
obj.maximum_capacity; % [percentage]

    % Initialize Variables to store: instantaneous_capacity
state_of_charge
    obj.store = [];

    obj.store.instantaneous_capacity =
zeros(mission.storage.num_storage_steps, length(obj.instantaneous_capacity));
    obj.store.state_of_data_storage =
zeros(mission.storage.num_storage_steps, length(obj.state_of_data_storage));
    obj.store.maximum_capacity = obj.maximum_capacity; % [kb]

    obj = func_update_true_SC_onboard_memory_store(obj, mission);

    % Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

    % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);
```

```
end
```

[] Methods: Store

Update the store variable

```
function obj = func_update_true_SC_onboard_memory_store(obj, mission)

    if mission.storage.flag_store_this_time_step == 1
        obj.store.instantaneous_capacity(mission.storage.k_storage,:)
= obj.instantaneous_capacity; % [kb]
        obj.store.state_of_data_storage(mission.storage.k_storage,:) =
obj.state_of_data_storage; % [percentage]
    end

end
```

[] Methods: Main

Update Memory SoDS

```
function obj = func_main_true_SC_onboard_memory(obj, mission, i_SC)

    %           if obj.instantaneous_capacity <= 0
    %           obj.instantaneous_capacity = 1e-3; % [kb]
    %           end

    obj.state_of_data_storage = 100*obj.instantaneous_capacity/
obj.maximum_capacity; % [percentage]

    obj = func_update_true_SC_onboard_memory_store(obj, mission);

    % Update Power Consumed

    func_update_instantaneous_power_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

    % Update Data Generated

    func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end

end

end
```

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5.12 True_SC_Radio_Antenna

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Class: True_SC_Radio_Antenna	1
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[] Properties: Storage Variables	2
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[] Methods: Constructor	2
[] Methods: Store	4
[] Methods: Main	5

Class: True_SC_Radio_Antenna

Tracks the Radio Antennas

```
classdef True_SC_Radio_Antenna < handle
```

Properties

properties

[] Properties: Initialized Variables

```
    antenna_type % [string]
    % - 'Dipole'
    % - 'High Gain'

    location % [m] : Location of sensor, in body frame B

    orientation % [unit vector] : Normal vector from location

    mode_true_sc_radio_antenna_selector % [string]
    % - TX
    % - RX

    TX_power_consumed % [Watts] : Power consumed during TX

    RX_power_consumed % [Watts] : Power consumed during RX

    base_data_rate_generated % [kbps] : Data rate, in kilo bits per sec
(kbps) due to Health Keeping

    % Optional (only for Link Margin Calculations)

    antenna_gain % [dB] gain of Earth receiver

    noise_temperature % [K] temperature noise
```

```
beamwidth % [MHz] receiver beamwidth

energy_bit_required % [dB] Minimum energy bit required

line_loss % [dB] Loss due to pointing or others

coding_gain % [dB] Coding gain
```

[] Properties: Variables Computed Internally

```
name % [string] 'Radio Antenna i'

health % [integer] Health of sensor/actuator
% - 0. Switched off
% - 1. Switched on, works nominally

temperature % [deg C] : Temperature of sensor/actuator

flag_executive % [Boolean] Executive has told this sensor/actuator to
do its job

instantaneous_power_consumed % [Watts] : Instantaneous power consumed

instantaneous_data_rate_generated % [kbps] : Data rate, in kilo bits
per sec (kbps) due to RX

instantaneous_data_rate_removed % [kbps] : Data rate, in kilo bits per
sec (kbps) due to TX

data % Other useful data

maximum_data_rate
```

[] Properties: Storage Variables

```
store

end
```

Methods

```
methods
```

[] Methods: Constructor

Construct an instance of this class

```
function obj = True_SC_Radio_Antenna(init_data, mission, i_SC, i_HW)

    if isfield(init_data, 'name')
```

```

        obj.name = init_data.name;
    else
        obj.name = ['Radio Antenna ', num2str(i_HW)];
    end

    obj.health = 1;
    obj.temperature = 10; % [deg C]
    obj.flag_executive = 0;
    %
    obj.antenna_type = init_data.antenna_type;
    %
    % obj.mode_true_SC_radio_antenna_selector =
init_data.mode_true_SC_radio_antenna_selector;
    %
    obj.TX_power_consumed = init_data.TX_power_consumed; % [Watts]
    obj.RX_power_consumed = init_data.RX_power_consumed; % [Watts]
    obj.instantaneous_power_consumed = obj.TX_power_consumed; %
[Watts] Will be modified dynamically but a value is needed to register

    obj.location = init_data.location; % [m]
    obj.orientation = init_data.orientation; % [unit vector]

    % switch obj.mode_true_SC_radio_antenna_selector
    %     case 'TX'
    %         obj.instantaneous_power_consumed =
obj.TX_power_consumed; % [Watts]
    %     case 'RX'
    %         obj.instantaneous_power_consumed =
obj.RX_power_consumed; % [Watts]
    %     otherwise
    %         error('Should not reach here!')
    % end

    if isfield(init_data, 'antenna_gain')

        obj.antenna_gain = init_data.antenna_gain; % [dB]
        obj.noise_temperature = init_data.noise_temperature; % [K]
        obj.beamwidth = init_data.beamwidth; % [MHz]
        obj.energy_bit_required = init_data.energy_bit_required; %
[dB]

        obj.coding_gain = init_data.coding_gain; % [dB]

    end
    %
    obj.base_data_rate_generated =
init_data.base_data_rate_generated; % [kbps]
    obj.instantaneous_data_rate_generated =
obj.base_data_rate_generated; % [kbps]
    obj.instantaneous_data_rate_removed = 0; % [kbps]
    obj.maximum_data_rate = obj.maximum_data_rate; % [kbps]

    % if isfield(init_data, 'data')
    %     obj.data = init_data.data;
    % else

```

```

        %      obj.data = [];
    % end
    %
    % Initialize Variables to store
    obj.store = [];

    obj.store.flag_executive =
zeros(mission.storage.num_storage_steps, length(obj.flag_executive)); %
[integer]
    obj.store.mode_TX_RX = zeros(mission.storage.num_storage_steps,
1); % [integer]
    obj.store.instantaneous_data_rate_generated =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_data_rate_generated)); % [kbps]
    obj.store.instantaneous_data_rate_removed =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_data_rate_removed)); % [kbps]
    obj.store.instantaneous_power_consumed =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_power_consumed)); % [W]

    % Update Storage
    obj = func_update_true_SC_radio_antenna_store(obj, mission);
    %
    % % Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);
    %
    % % Update SC Data Handling Class (Generated and Removed)

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

func_initialize_list_HW_data_removed(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_radio_antenna_store(obj, mission)

    if mission.storage.flag_store_this_time_step == 1
        obj.store.flag_executive(mission.storage.k_storage,:) =
obj.flag_executive; % [integer]

        if obj.flag_executive == 1

obj.store.instantaneous_data_rate_generated(mission.storage.k_storage,:) =
obj.instantaneous_data_rate_generated; % [kbps]

```

```

obj.store.instantaneous_data_rate_removed(mission.storage.k_storage,:) =
obj.instantaneous_data_rate_removed; % [kbps]

obj.store.instantaneous_power_consumed(mission.storage.k_storage,:) =
obj.instantaneous_power_consumed; % [W]

        switch obj.mode_true_SC_radio_antenna_selector
            case 'TX'
                obj.store.mode_TX_RX(mission.storage.k_storage,1)
= 1;
            case 'RX'
                obj.store.mode_TX_RX(mission.storage.k_storage,1)
= 2;
            otherwise
                error('[True_SC_Radio_Antenna] Should not reach
here!')
            end
        end
    end
end
end
end

```

[] Methods: Main

Update all variables

```

function obj = func_main_true_SC_radio_antenna(obj, mission, i_SC)

    if (obj.flag_executive == 1) && (obj.health == 1)

        switch obj.mode_true_SC_radio_antenna_selector
            case 'TX'
                obj.instantaneous_power_consumed =
obj.TX_power_consumed; % [Watts]
            case 'RX'
                obj.instantaneous_power_consumed =
obj.RX_power_consumed; % [Watts]
            otherwise
                error('[True_SC_Radio_Antenna] Should not reach
here!')
            end

        % Update SC Power Class

        func_update_instantaneous_power_consumed(mission.true_SC{i_SC}.true_SC_power,obj,
mission);

        func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);
    end
end

```

```

        % Update SC Data Handling Class (Generated and Removed)

func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

func_update_instantaneous_data_removed(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

    end

    % Update Storage
    obj = func_update_true_SC_radio_antenna_store(obj, mission);

    % Reset All Variables
    obj.flag_executive = 0;
    obj.instantaneous_data_rate_generated =
obj.base_data_rate_generated; % [kbps]
    obj.instantaneous_data_rate_removed = 0; % [kbps]

    end

end

end

```

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5.13 True_SC_Reaction_Wheel

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Class: True_SC_Reaction_Wheel

Represents a single reaction wheel for spacecraft attitude control

```
classdef True_SC_Reaction_Wheel < handle
```

Properties

properties

[] Properties: Initialized Variables

location	%[m] : Location of the reaction wheel in the body frame
orientation	%[Unit vector] : Axis of rotation in the body frame
max_torque	%[Nm] : Maximum torque the wheel can apply
max_angular_velocity	%[rad/s] : Maximum angular velocity
radius	%[m] radius of 1 RW
mass	%[kg] : Mass of the reaction wheel
power_consumed_angular_velocity_array	% [power_array ; velocity_array]
angular_velocity_noise	%[rad/s] : Random noise added to commanded torque
instantaneous_data_generated_per_sample	%[Kb] : Data generated during the current time step

[] Properties: Variables Computed Internally

name	% Name of the reaction wheel
health	% Health status (0: Not working, 1: Working)

```

        temperature                %[deg C]
        moment_of_inertia          %[kg·m^2] : Moment of inertia of the
wheel
        total_momentum             %[kg·m^2/s] : Total momentum of the wheel

        commanded_angular_acceleration % [rad/s] : Desired angular velocity of
the wheel
        actual_angular_acceleration % [rad/s] : Actual realised angular
velocity of the wheel
        min_acceleration           % [rad/s^2]
        angular_velocity            % [rad/s] : Current angular velocity of
the wheel

        actual_torque              % [Nm] : Actual torque considering
saturation and noise
        saturated                  % [Boolean] Is the wheel currently
saturated ?
        instantaneous_power_consumption %[Watts] : Power consumed during
operation
        instantaneous_power_consumed   %[Watts] : Alias for power tracking
system

        flag_executive             %[Bool] : Is the wheel currently
executing a command ?
        envelope_ratio              %[Ratio] : Ratio of the minimum distance
between wheels to the radius of the wheel
        maximum_torque              %[Nm] : Maximum torque the wheel can
apply
        momentum_capacity           %[kg·m^2/s] : Momentum capacity of the
wheel
        maximum_acceleration        %[rad/s^2] : Maximum acceleration the
wheel can apply

        instantaneous_data_volume    % [kb]

```

[] Properties: Storage Variables

```

        store                      %[Struct] : Store of the reaction wheel

    end

```

Methods

```

    methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = True_SC_Reaction_Wheel(init_data, mission, i_SC, i_RW)

```

```

obj.name = ['Reaction Wheel ', num2str(i_RW)];

obj.health = true;
obj.location = init_data.location;
obj.orientation = init_data.orientation;
obj.max_angular_velocity = init_data.max_angular_velocity;
obj.radius = init_data.radius;
obj.mass = init_data.mass;

obj.instantaneous_data_generated_per_sample =
init_data.instantaneous_data_generated_per_sample; % [kb]
obj.instantaneous_data_volume =
obj.instantaneous_data_generated_per_sample; % [kb]

% Calculate moment of inertia
% For a disk rotating around its center axis : 1/2*m*r^2
obj.moment_of_inertia = 0.5 * obj.mass * obj.radius^2;

obj.power_consumed_angular_velocity_array =
init_data.power_consumed_angular_velocity_array;

% Torque envelope
if isfield(init_data, 'max_torque')
    % Maximum Torque and Momentum Envelopes for Reaction Wheel
    Arrays
        % https://ntrs.nasa.gov/api/citations/20110015369/
        downloads/20110015369.pdf

assert(ismember(mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_reaction_wheel
[3 4 5 6]), 'Number of reaction wheel must be 3, 4, 5 or 6')
switch
mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_reaction_wheel
case 3
    d_min = 1; % d_12
case 4
    d_min = 1.633; % d_12 = d_13
case 5
    d_min = 5/8 * 2.667; % d_24 = d_42
case 6
    d_min = 2.667; % d_23
end
obj.envelope_ratio = d_min;
obj.maximum_torque = init_data.max_torque;

% Get maximum acceleration from init_data if provided,
otherwise calculate it
if isfield(init_data, 'maximum_acceleration')
    obj.maximum_acceleration = init_data.maximum_acceleration;
else
    obj.maximum_acceleration = obj.maximum_torque /
obj.moment_of_inertia; % rad/s^2
end
else

```

```

        obj.envelope_ratio = 1;
        obj.maximum_torque = Inf;
        obj.momentum_capacity = Inf;
        obj.maximum_acceleration = Inf;
    end

    obj.min_acceleration = 1; % rad/s^2

    obj.angular_velocity_noise = init_data.angular_velocity_noise;

    % Initialize dynamic state
    obj.angular_velocity = 0;
    obj.commanded_angular_acceleration = 0;
    obj.saturated = false;
    obj.flag_executive = false;
    obj.instantaneous_power_consumption = 0;
    obj.instantaneous_power_consumed = 0;

    obj.actual_torque = [0,0,0];

    % Initialize storage
    obj.total_momentum = 0;

    obj.store = [];
    obj.store.angular_velocity =
zeros(mission.storage.num_storage_steps_attitude, 1);
    obj.store.torque =
zeros(mission.storage.num_storage_steps_attitude, 1);
    obj.store.saturated =
zeros(mission.storage.num_storage_steps_attitude, 1);

    obj.store.commanded_angular_acceleration =
zeros(mission.storage.num_storage_steps_attitude, 1);
    obj.store.actual_angular_acceleration =
zeros(mission.storage.num_storage_steps_attitude, 1);
    obj.store.actual_torque =
zeros(mission.storage.num_storage_steps_attitude, 3);

    obj.store.max_angular_velocity = obj.max_angular_velocity;

    % Update storage
    func_update_reaction_wheel_store(obj, mission);

    % Update SC Power Class

    func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

    % Update SC Data Handling Class

    func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end

```

[] Methods: Store

Update the store variable

```
function obj = func_update_reaction_wheel_store(obj, mission)
    obj.store.angular_velocity(mission.storage.k_storage_attitude, :)
= obj.angular_velocity;
    obj.store.actual_torque(mission.storage.k_storage_attitude, :) =
obj.actual_torque;

obj.store.commanded_angular_acceleration(mission.storage.k_storage_attitude, :)
= obj.commanded_angular_acceleration;
    obj.store.saturated(mission.storage.k_storage_attitude, :) =
obj.saturated;
end
```

[] Methods: Main

Update Reaction Wheel

```
function func_main_true_reaction_wheel(obj, mission, i_SC, ~)
    % Main function that runs the reaction wheel simulation
    if ~obj.health
        obj.commanded_angular_acceleration = 0;
        obj.angular_velocity = 0;
        obj.instantaneous_power_consumption = 0;
        obj.instantaneous_power_consumed = 0;
        obj.instantaneous_data_generated_per_sample = 0;
        obj.actual_torque = [0,0,0];
        obj.actual_angular_acceleration = 0;
        return;
    end

    if(obj.flag_executive && abs(obj.commanded_angular_acceleration) >
0)

        % Limit commanded acceleration
        if abs(obj.commanded_angular_acceleration) >
obj.maximum_acceleration
            obj.commanded_angular_acceleration =
sign(obj.commanded_angular_acceleration) * obj.maximum_acceleration;
        end

        % Calculate torque directly from acceleration (# = I*#)
        torque_magnitude = obj.moment_of_inertia *
obj.commanded_angular_acceleration;
        obj.actual_torque = torque_magnitude * obj.orientation;

        % Update velocity with noise and limits
        if obj.commanded_angular_acceleration ~= 0
            % Add noise only during active commands
            current_vel_noise = obj.angular_velocity_noise * (2*rand()
- 1);
```

```

        else
            current_vel_noise = 0; % No noise when idle
        end

        % Calculate the new velocity without limits
        unconstrained_velocity = obj.angular_velocity +
obj.commanded_angular_acceleration * mission.true_time.time_step_attitude +
current_vel_noise;

        % Apply rate limiting to prevent dramatic velocity changes in
a single step
        % Maximum allowed change in velocity per time step (10% of max
velocity is a reasonable value)
        max_velocity_change = 0.1 * obj.max_angular_velocity;

        % ENHANCED SAFETY: Add more conservative limits for direction
reversals
        % Detect potential reversal (wheel going one way, command
pushing it the complete other way)
        if sign(unconstrained_velocity) ~= sign(obj.angular_velocity)
&& abs(obj.angular_velocity) > 0.3 * obj.max_angular_velocity
            % This is a potential direction reversal and the wheel is
at significant speed
            % Reduce maximum allowed change dramatically for safer
deceleration
            max_velocity_change = 0.02 * obj.max_angular_velocity;

            % Log this event to help debugging
            disp(['REACTION WHEEL SAFETY: Detected potential rapid
direction reversal for ', obj.name]);
            disp(['Current velocity: ',
num2str(obj.angular_velocity), ' rad/s']);
            disp(['Commanded acceleration: ',
num2str(obj.commanded_angular_acceleration), ' rad/s^2']);
            disp(['Limiting velocity change to ',
num2str(max_velocity_change), ' rad/s per time step']);
        end

        % Limit the velocity change
        if abs(unconstrained_velocity - obj.angular_velocity) >
max_velocity_change
            limited_velocity = obj.angular_velocity +
sign(unconstrained_velocity - obj.angular_velocity) * max_velocity_change;
        else
            limited_velocity = unconstrained_velocity;
        end

        % Apply absolute velocity limits (don't exceed max angular
velocity)
        new_velocity = max(min(limited_velocity,
obj.max_angular_velocity), -obj.max_angular_velocity);

        % If the velocity didn't change much, leave it as is to avoid
numerical issues

```

```

        velocity_tolerance = 1e-4;
        if abs(new_velocity - obj.angular_velocity) <
velocity_tolerance
            new_velocity = obj.angular_velocity; % Clamp near-zero
velocities
        end

        % Calculate the actual acceleration that occurred (for
telemetry)
        obj.actual_angular_acceleration = (new_velocity -
obj.angular_velocity) / mission.true_time.time_step_attitude;

        % Update the angular velocity
        obj.angular_velocity = new_velocity;

        % Check for saturation
        % > If reaches 80% of max angular velocity
        obj.saturated = (abs(obj.angular_velocity) >=
obj.max_angular_velocity * 0.80);

        % Update spacecraft torque directly
        mission.true_SC{i_SC}.true_SC_adc.control_torque = ...
            mission.true_SC{i_SC}.true_SC_adc.control_torque +
obj.actual_torque;

        % Update power and data
        obj.instantaneous_power_consumption = abs(obj.actual_torque *
obj.angular_velocity);

        % Calculate individual wheel momentum: h = I * # * direction
        % The wheel momentum is a vector along the wheel's spin axis
(orientation)
        momentum_magnitude = obj.moment_of_inertia *
obj.angular_velocity;
        obj.total_momentum = momentum_magnitude * obj.orientation;

        % Update power and data
        power_consumptions =
obj.power_consumed_angular_velocity_array(1, :);
        angular_velocities =
obj.power_consumed_angular_velocity_array(2, :);

        % Ensure the array is sorted by angular velocity
        [angular_velocities, sortIdx] = sort(angular_velocities);
        power_consumptions = power_consumptions(sortIdx);

        % Interpolate to find the power consumption for the current
angular velocity
        if obj.angular_velocity < min(angular_velocities)
            obj.instantaneous_power_consumption =
power_consumptions(1);
        elseif obj.angular_velocity > max(angular_velocities)

```

```

        obj.instantaneous_power_consumption =
power_consumptions(end);
    else
        obj.instantaneous_power_consumption
= interp1(angular_velocities, power_consumptions,
obj.angular_velocity, 'linear');
    end
    % Set property for power tracking system
    obj.instantaneous_power_consumed =
obj.instantaneous_power_consumption;

    % Update the data generated
    obj.instantaneous_data_generated_per_sample =
obj.instantaneous_data_volume; % [kb]

else
    obj.commanded_angular_acceleration = 0;
    obj.instantaneous_power_consumption = 0;
    obj.instantaneous_power_consumed = 0;
    obj.instantaneous_data_generated_per_sample = 0;
end

% Update Power Consumed

func_update_instantaneous_power_consumed_attitude(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

% Update Data Generated

func_update_instantaneous_data_generated_attitude(mission.true_SC{i_SC}.true_SC_data_hand
obj, mission);

% Update storage
func_update_reaction_wheel_store(obj, mission);

% CRITICAL FIX: Reset command flags at the end of each cycle
% This prevents commands from persisting indefinitely between
cycles
    obj.flag_executive = false;
    obj.commanded_angular_acceleration = 0;
end
end
end

```

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5.14 True_SC_Science_Processor

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Class: True_SC_Science_Processor

Tracks the Science Processor

```
classdef True_SC_Science_Processor < handle
```

Properties

properties

[] Properties: Initialized Variables

```
instantaneous_power_consumed % [Watts] : Instantaneous power consumed

instantaneous_data_rate_generated % [kbps] : Data rate, in kilo bits
per sec (kbps)

instantaneous_data_removed_per_sample % [kb] : Data in kilo bits (kb)

flag_show_science_processor_plot % [Boolean] : 1 = Shows the Science
Processor plot

mode_true_sc_science_processor_selector % [string] Select which Mode
to run
```

[] Properties: Variables Computed Internally

```
name % [string] 'Generic Sensor i'

health % [integer] Health of sensor/actuator
% - 0. Switched off
% - 1. Switched on, works nominally

temperature % [deg C] : Temperature of sensor/actuator
```

```
        flag_executive % [Boolean] Executive has told this sensor/actuator to  
do its job
```

```
        data % Other useful data
```

[] Properties: Storage Variables

```
        store  
  
    end
```

Methods

```
    methods
```

[] Methods: Constructor

Construct an instance of this class

```
function obj = True_SC_Science_Processor(init_data, mission, i_SC,  
i_HW)  
  
    if isfield(init_data, 'name')  
        obj.name = init_data.name;  
    else  
        obj.name = ['Science Processor ', num2str(i_HW)];  
    end  
  
    obj.health = 1;  
    obj.temperature = 10; % [deg C]  
  
    obj.instantaneous_power_consumed =  
init_data.instantaneous_power_consumed; % [W]  
    obj.instantaneous_data_rate_generated =  
init_data.instantaneous_data_rate_generated; % [kbps]  
    obj.instantaneous_data_removed_per_sample =  
init_data.instantaneous_data_removed_per_sample; % [kb]  
    obj.flag_show_science_processor_plot =  
init_data.flag_show_science_processor_plot; % [Boolean]  
    obj.mode_true_SC_science_processor_selector =  
init_data.mode_true_SC_science_processor_selector; % [string]  
  
    obj.flag_executive = 0;  
  
    if isfield(init_data, 'data')  
        obj.data = init_data.data;  
    else  
        obj.data = [];  
    end  
  
    % Initialize Variables to store: measurement_vector  
    obj.store = [];
```

```

        obj.store.flag_executive =
zeros(mission.storage.num_storage_steps, length(obj.flag_executive));
        obj.store.instantaneous_data_rate_generated =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_data_rate_generated)); % [kbps]
        obj.store.instantaneous_data_removed_per_sample =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_data_removed_per_sample)); % [kb]
        obj.store.instantaneous_power_consumed =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_power_consumed)); % [W]

        % Additional Science Processor Variables
        switch obj.mode_true_SC_science_processor_selector

            case 'Nightingale'
                obj =
func_true_SC_science_processor_Nightingale_constructor(obj, mission, i_SC);

            otherwise
                % Do nothing!
        end

        % Update Storage
        obj = func_update_true_SC_science_processor_store(obj, mission);

        % Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

        % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

func_initialize_list_HW_data_removed(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

    end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_science_processor_store(obj,
mission)

    if mission.storage.flag_store_this_time_step == 1
        obj.store.flag_executive(mission.storage.k_storage_attitude,:)
= obj.flag_executive; % [Boolean]

        if obj.flag_executive == 1

```

```

obj.store.instantaneous_data_rate_generated(mission.storage.k_storage,:) =
obj.instantaneous_data_rate_generated; % [kbps]

obj.store.instantaneous_data_removed_per_sample(mission.storage.k_storage,:)
= obj.instantaneous_data_removed_per_sample; % [kb]

obj.store.instantaneous_power_consumed(mission.storage.k_storage,:) =
obj.instantaneous_power_consumed; % [W]
    end
end
end

```

[] Methods: Main

Update Science Processor

```

function obj = func_main_true_SC_science_processor(obj, mission, i_SC)

    if (obj.flag_executive == 1) && (obj.health == 1)
        % Take measurement

        if
isfield(obj.data, 'instantaneous_power_consumed_per_SC_mode')
            obj.instantaneous_power_consumed =
obj.data.instantaneous_power_consumed_per_SC_mode(mission.true_SC{i_SC}.software_SC_execu
[W]
        end

        switch obj.mode_true_SC_science_processor_selector

            case 'Nightingale'
                obj = func_true_SC_science_processor_Nightingale(obj,
mission, i_SC);

            otherwise
                error('Should not reach here!')
            end

        % Update Power Consumed

func_update_instantaneous_power_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

        % Update Data Handling

func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

func_update_instantaneous_data_removed(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

```

```

        else
            % If not active, set power to a low standby value
            obj.instantaneous_power_consumed =
obj.instantaneous_power_consumed * 0.1; % 10% of normal power when in standby

            % Still update power system even when in standby

func_update_instantaneous_power_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);
        end

        % Update Storage
obj = func_update_true_SC_science_processor_store(obj, mission);

        % Reset Variables
obj.flag_executive = 0;

    end

end

end

```

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5.15 True_SC_Science_Radar

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Class: True_SC_Science_Radar

Tracks the onboard Radar measurements

```
classdef True_SC_Science_Radar < handle
```

Properties

properties

[] Properties: Initialized Variables

```
instantaneous_power_consumed % [Watts] : Instantaneous power consumed

instantaneous_data_rate_generated % [kbps] : Data rate, in kilo bits
per sec (kbps)

mode_true_SC_science_radar_selector % [string]
% - DROID

measurement_wait_time % [sec]

location % [m] : Location of sensor, in body frame B

orientation % [unit vector] : Normal vector from location

field_of_view % [deg] : Field of view (FOV) of the radar in deg
% Set to 0 to select the closest point

flag_show_radar_plot % [Boolean] : 1 = Shows the radar plot
wait_time_visualize_SC_radar_coverage_during_sim % [sec] (Optional)

num_points % [integer] Number of points in mesh
```

[] Properties: Variables Computed Internally

```
name % [string] 'Radar i'
```

```

health % [integer] Health of sensor/actuator
% - 0. Switched off
% - 1. Switched on, works nominally

temperature % [deg C] : Temperature of sensor/actuator

measurement_vector % [Image]

measurement_time % [sec] SC time when this measurement was taken

flag_executive % [Boolean] Executive has told this sensor/actuator to
do its job

pos_points % [unit vector] Location of points in mesh

spherical_points % [unit vector] Location of points in Sphere

monostatic_observed_point % [array] Monostatic: which point is
observed how many times

monostatic_num_point_observed % [integer] Monostatic: total number of
points observed

prev_time_visualize_SC_radar_coverage_during_sim % [sec]

data % Other useful data

```

[] Properties: Storage Variables

```

store

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = True_SC_Science_Radar(init_data, mission, i_SC, i_HW)

    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
        obj.name = ['Radar ', num2str(i_HW)];
    end

    obj.health = 1;
    obj.temperature = 10; % [deg C]

```

```

        obj.instantaneous_power_consumed =
init_data.instantaneous_power_consumed; % [W]
        obj.mode_true_SC_science_radar_selector =
init_data.mode_true_SC_science_radar_selector; % [string]
        obj.instantaneous_data_rate_generated =
init_data.instantaneous_data_rate_generated; % [kbps]

        obj.measurement_wait_time = init_data.measurement_wait_time; %
[sec]
        obj.measurement_time = -inf; % [sec]

        obj.flag_executive = 0;

        obj.location = init_data.location; % [m]
        obj.orientation = init_data.orientation; % [unit vector]

        obj.field_of_view = init_data.field_of_view; % [deg]

        obj.flag_show_radar_plot = init_data.flag_show_radar_plot; %
[Boolean]

        if
isfield(init_data, 'wait_time_visualize_SC_radar_coverage_during_sim')
            obj.wait_time_visualize_SC_radar_coverage_during_sim =
init_data.wait_time_visualize_SC_radar_coverage_during_sim;
        else
            obj.wait_time_visualize_SC_radar_coverage_during_sim = 0; %
[sec]
        end
        obj.prev_time_visualize_SC_radar_coverage_during_sim = -inf;

        if isfield(init_data, 'data')
            obj.data = init_data.data;
        else
            obj.data = [];
        end

        % load the science points
        obj.num_points = init_data.num_points; % [integer]
        obj.pos_points = func_load_science_points_v2(obj.num_points);

        obj.spherical_points = zeros(obj.num_points, 2);
        for i = 1:1:obj.num_points

            %           sph =
Cartesian2Spherical(obj.pos_points(i,:)); % [r, theta, phi] in radians
            %           longitude = rad2deg(sph(3)); % [deg]
            %           latitude = rad2deg(sph(2)); % [deg]
            %           latitude = latitude - 90; % [deg]

            [radius, lon, lat] = cspice_reclat(obj.pos_points(i,:)); %
[radius, longitude [rad], latitude [rad] ]

            obj.spherical_points(i,:) = [rad2deg(lon), rad2deg(lat)];

```

```

end

% monostatic data
obj.monostatic_observed_point = zeros(1,obj.num_points);
obj.monostatic_num_point_observed = 0;

% Initialize Variables to store: monostatic_num_point_observed
obj.store = [];

obj.store.monostatic_num_point_observed =
zeros(mission.storage.num_storage_steps,
length(obj.monostatic_num_point_observed));
obj.store.flag_executive =
zeros(mission.storage.num_storage_steps, length(obj.flag_executive));
obj.store.instantaneous_data_rate_generated =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_data_rate_generated)); % [kbps]
obj.store.instantaneous_power_consumed =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_power_consumed)); % [W]

% Update Storage
obj = func_update_true_SC_science_radar_store(obj, mission);

% Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

% Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

% Store video of func_visualize_SC_orbit_during_sim
if (mission.storage.plot_parameters.flag_save_video == 1) &&
(obj.flag_show_radar_plot == 1)
    obj.data.video_filename = [mission.storage.output_folder,
mission.name, '_SC', num2str(i_SC), '_Radar', num2str(i_HW), '.mp4'];
    obj.data.myVideo =
VideoWriter(obj.data.video_filename, 'MPEG-4');
    obj.data.myVideo.FrameRate = 30; % Default 30
    obj.data.myVideo.Quality = 100; % Default 75
    open(obj.data.myVideo);
end
end

```

[] Methods: Store

Update the store variable

```
function obj = func_update_true_SC_science_radar_store(obj, mission)
```

```

        if mission.storage.flag_store_this_time_step == 1

obj.store.monostatic_num_point_observed(mission.storage.k_storage,:) =
obj.monostatic_num_point_observed; % [integer]
        obj.store.flag_executive(mission.storage.k_storage,:) =
obj.flag_executive; % [integer]

        if obj.flag_executive == 1

obj.store.instantaneous_data_rate_generated(mission.storage.k_storage,:) =
obj.instantaneous_data_rate_generated; % [kbps]

obj.store.instantaneous_power_consumed(mission.storage.k_storage,:) =
obj.instantaneous_power_consumed; % [W]
        end

    end

end

```

[] Methods: Main

Update Radar

```

function obj = func_main_true_SC_science_radar(obj, mission, i_SC,
i_HW)

    if (obj.flag_executive == 1) && (obj.health == 1)
        % Take measurement

        if (mission.true_time.time - obj.measurement_time) >=
obj.measurement_wait_time

            % Sufficient time has elapsed for a new measurement
obj.measurement_time = mission.true_time.time; % [sec]

            switch obj.mode_true_SC_science_radar_selector

                case 'DROID'
                    obj = func_true_SC_science_radar_DROID(obj,
mission, i_SC);

                case 'Nightingale'
                    obj = func_true_SC_science_radar_Nightingale(obj,
mission, i_SC);

                otherwise
                    error('Radar mode not defined!')
            end

            obj.prev_time_visualize_SC_radar_coverage_during_sim = -
inf;

```

```

        else
            % Data not generated in this time step
            % Data is only generated when a radar measurement is
performed

        end

        if
isfield(obj.data, 'instantaneous_power_consumed_per_SC_mode')
            obj.instantaneous_power_consumed =
obj.data.instantaneous_power_consumed_per_SC_mode(mission.true_SC{i_SC}.software_SC_execu
[W]
        end

        % Update Power Consumed

func_update_instantaneous_power_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

        else
            % Do nothing

        end

        % Plot Radar Coverage
        if (obj.flag_show_radar_plot == 1) &&
(mission.true_SC{i_SC}.software_SC_executive.time -
obj.prev_time_visualize_SC_radar_coverage_during_sim >=
obj.wait_time_visualize_SC_radar_coverage_during_sim )
            obj = func_visualize_SC_radar_coverage_during_sim(obj,
mission, i_SC, i_HW);
        end

        % Update Storage
        obj = func_update_true_SC_science_radar_store(obj, mission);

        % Reset Variables
        obj.flag_executive = 0;

    end

```

[] Methods: Visualize Radar Coverage

Visualize all SC attitude orbit during simulation

```

function obj = func_visualize_SC_radar_coverage_during_sim(obj,
mission, i_SC, i_HW)

    obj.prev_time_visualize_SC_radar_coverage_during_sim =
mission.true_SC{i_SC}.software_SC_executive.time; % [sec]

    % (20*i_SC) + i_HW

```

```

        plot_handle = figure('Name',[ 'SC ',num2str(i_SC), ' Radar
',num2str(i_HW), ' Coverage']);
        clf
        set(plot_handle,'Color',[1 1 1]);
        set(plot_handle,'units','normalized','outerposition',[0 0 1 1])
        set(plot_handle,'PaperPositionMode','auto');

        time_sim_elapsed = seconds(mission.true_time.time -
mission.true_time.t_initial);
        time_sim_elapsed.Format = 'dd:hh:mm:ss';

        sgtitle(['SC ',num2str(i_SC),', Radar ',num2str(i_HW),'
Coverage = ',num2str(round(100 * obj.monostatic_num_point_observed /
obj.num_points,1)),' %, Simulation Time =
',char(time_sim_elapsed)],'FontSize',mission.storage.plot_parameters.title_font_size,'Fon

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%
% % 3D Radar Vizualization % %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%

        subplot(1,2,1)
        hold on

        for i_SC = 1:1:mission.num_SC

plot3(mission.true_SC{i_SC}.true_SC_navigation.position_relative_target(1),
mission.true_SC{i_SC}.true_SC_navigation.position_relative_target(2),
mission.true_SC{i_SC}.true_SC_navigation.position_relative_target(3), 's','MarkerSize',15

            if (obj.flag_executive == 1)
                % Plot Radar Orientation
                this_location =
mission.true_SC{i_SC}.true_SC_navigation.position_relative_target;
                this_orientation =
(mission.true_SC{i_SC}.true_SC_adc.rotation_matrix * obj.orientation)';

                quiver3(this_location(1), this_location(2),
this_location(3), this_orientation(1), this_orientation(2),
this_orientation(3), ...

                'LineWidth',3,'DisplayName',obj.name,'Color',rgb('Orange'),'AutoScaleFactor',200*missio
                end

            end

            i_target =
mission.true_SC{i_SC}.true_SC_navigation.index_relative_target;
            func_plot_target_shape(i_target, mission);

```

```

        this_pos_points = mission.true_target{i_target}.radius *
(mission.true_target{i_target}.rotation_matrix * obj.pos_points'); % [km]

        % Define a colormap
        cmap = jet(max(obj.monostatic_observed_point)+1); % Use a colormap
with max(obj.monostatic_observed_point)+1 colors

        % Map the values to colors
        colors = cmap(1+obj.monostatic_observed_point', :);

        scatter3(this_pos_points(:,1), this_pos_points(:,2),
this_pos_points(:,3), 10, colors, 'filled', 'DisplayName', 'Radar Points'); %
50 is the size of the markers

        grid on

        axis equal
        legend('Location', 'southwest')
        xlabel('X axis [km]')
        ylabel('Y axis [km]')
        zlabel('Z axis [km]')

set(gca, 'FontSize', mission.storage.plot_parameters.standard_font_size, 'FontName', mission
        title('3D Radar Coverage in Target-centered Rotating
Frame', 'FontSize', mission.storage.plot_parameters.standard_font_size)

        %               view(3)
        view(-40, -30)
        axis equal

        hold off

        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
        % % 2D Radar Vizualization % %
        %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

        subplot(1,2,2)
        hold on

        scatter(obj.spherical_points(:,2), obj.spherical_points(:,1), 10,
colors, 'filled');

        for i_SC = 1:1:mission.num_SC

                %               sph =
Cartesian2Spherical(mission.true_target{i_target}.rotation_matrix' *
mission.true_SC{i_SC}.true_SC_navigation.position_relative_target'); % [r,
theta, phi] in radians
                %               longitude = rad2deg(sph(3)); % [deg]
                %               latitude = rad2deg(sph(2)); % [deg]
                %               latitude = latitude - 90; % [deg]

```

```

        [radius, lon, lat] =
cspice_reclat(mission.true_target{i_target}.rotation_matrix' *
mission.true_SC{i_SC}.true_SC_navigation.position_relative_target'); %
[radius, longitude [rad], latitude [rad] ]
        plot(rad2deg(lat),
rad2deg(lon), 's', 'MarkerSize',15, 'MarkerFaceColor',rgb('Gray'), 'DisplayName',mission.t
        end

        % Add colorbar to show mapping
        colorbar;
        caxis([0 max(obj.monostatic_observed_point)+1]);

        axis equal
        ylabel('Longitude [deg]')
        xlabel('Latitude [deg]')

set(gca, 'FontSize',mission.storage.plot_parameters.standard_font_size,'FontName',mission
        title('2D Radar Coverage in Target-centered Static
Frame','FontSize',mission.storage.plot_parameters.standard_font_size)

        drawnow limitrate

        if (mission.storage.plot_parameters.flag_save_video == 1) &&
(mission.flag_stop_sim == 0)
            open(obj.data.myVideo);
            writeVideo(obj.data.myVideo, getframe(plot_handle));
        end

        if (mission.storage.plot_parameters.flag_save_plots == 1) &&
(mission.flag_stop_sim == 1)
            saveas(plot_handle,[mission.storage.output_folder,
mission.name,'_SC',num2str(i_SC),'_Radar',num2str(i_HW),'.png'])
        end

    end

end

end
end

```

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5.16 True_SC_Solar_Panel

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Class: True_SC_Solar_Panel

SC's Solar Panels

```
classdef True_SC_Solar_Panel < handle
```

Properties

properties

[] Properties: Initialized Variables

```
instantaneous_power_consumed % [Watts] : Instantaneous power consumed  
(irrespective of whether it is generating power or not)
```

```
instantaneous_data_rate_generated % [kbps] : Data rate generated  
during current time step, in kilo bits (kb) per sec
```

```
mass % [kg] : Mass of ith solar panel
```

```
shape_model % : Shape model of Solar Panel  
% - Vertices [m] : Position of vertices in body frame B  
% - Faces : Triplet of vertex indices define a face  
% - Face_reflectance_factor_solar_cell_side : # [0, 1] for ith face  
(used for SRP)  
% - Face_reflectance_factor_opposite_side : # [0, 1] for ith face  
(used for SRP)  
% - Face_orientation_solar_cell_side [unit vector] : Normal vector in  
body frame B  
% - # Face_center [m] : Center of this Face  
% - # Face_area [m^2]  
% - type [string] : Type of shape is used for MI and volume  
calculations
```

```
type % [string] : Solar panel type
```

```

        % 'body_mounted' : Stuck to SC side (only solar cell side is used for
SRP)
        % 'passive_deployed' : Passively deployed (orientation in body frame B
does not change, i.e. it is static)
        % 'active_deployed_gimballed' : Actively gimballed (orientation in
body frame B changes)

        packing_fraction % [float] # [0, 1] Packing fraction of solar cells in
solar panel

        solar_cell_efficiency % [float] # [0, 1] Efficiency of each solar cell

```

[] Properties: Variables Computed Internally

```

name % [string] 'SP i_SP'

health % [integer] Health of sensor/actuator
% - 0. Switched off
% - 1. Switched on, works nominally

temperature % [deg C] : Temperature of sensor/actuator

instantaneous_power_generated % [Watts] : Instantaneous power produced
by ith solar panel

maximum_power % [Watts] : Maximum power that could have been produced
by ith solar panel is the Sun was exactly along SP's orientation

Sun_incidence_angle % [deg] : Angle between Sun vector and
Face_orientation_solar_cell_side

```

[] Properties: Storage Variables

```

store

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = True_SC_Solar_Panel(init_data, mission, i_SC, i_HW)

    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else

```

```

        obj.name = ['Solar Panel ', num2str(i_HW)];
    end

    obj.health = 1;
    obj.temperature = 10; % [deg C]

    obj.instantaneous_power_consumed =
init_data.instantaneous_power_consumed; % [W]
    obj.instantaneous_data_rate_generated =
init_data.instantaneous_data_rate_generated; % [kbps]

    % Initialize Shape
    obj.shape_model = init_data.shape_model;

    Face_center = zeros(size(obj.shape_model.Faces));
    for i=1:size(obj.shape_model.Faces,1)
        % face center : [(V1x+V2x+V3x)/3 ; (V1y+V2y+V3y)/3 : (V1z+V2z
+V3z)/3 ]
        Face_center(i,:) = [
            (obj.shape_model.Vertices(obj.shape_model.Faces(i,1),1)
+ obj.shape_model.Vertices(obj.shape_model.Faces(i,2),1) +
obj.shape_model.Vertices(obj.shape_model.Faces(i,3),1))/3;
            (obj.shape_model.Vertices(obj.shape_model.Faces(i,1),2)
+ obj.shape_model.Vertices(obj.shape_model.Faces(i,2),2) +
obj.shape_model.Vertices(obj.shape_model.Faces(i,3),2))/3;
            (obj.shape_model.Vertices(obj.shape_model.Faces(i,1),3)
+ obj.shape_model.Vertices(obj.shape_model.Faces(i,2),3) +
obj.shape_model.Vertices(obj.shape_model.Faces(i,3),3))/3];
    end
    obj.shape_model.Face_center = Face_center;

    % SP area from vertices
    area = 0; % [m^2]
    for f=1:size(obj.shape_model.Faces,1)
        vertex_index = obj.shape_model.Faces(f,:); % index of
vertices for this face
        a = norm(obj.shape_model.Vertices(vertex_index(1),:) -
obj.shape_model.Vertices(vertex_index(2),:));
        b = norm(obj.shape_model.Vertices(vertex_index(2),:) -
obj.shape_model.Vertices(vertex_index(3),:));
        c = norm(obj.shape_model.Vertices(vertex_index(3),:) -
obj.shape_model.Vertices(vertex_index(1),:));
        s = (a+b+c)/2; % semi perimeter
        area = area + sqrt(s*(s-a)*(s-b)*(s-c)); % Heron formula
    end

    obj.shape_model.Face_area = area;

    % Center of mass
    obj.shape_model.r_CM = mean(obj.shape_model.Vertices, 1); % [m]

    switch obj.shape_model.type

        case 'cuboid'

```

```

        % Inertia matrix (assume cuboid)
        L = max(obj.shape_model.Vertices(:,1)) -
min(obj.shape_model.Vertices(:,1)); % [m]
        W = max(obj.shape_model.Vertices(:,2)) -
min(obj.shape_model.Vertices(:,2)); % [m]
        H = max(obj.shape_model.Vertices(:,3)) -
min(obj.shape_model.Vertices(:,3)); % [m]
        obj.shape_model.I_through_r_CM = diag([1/12*(W^2+H^2),
1/12*(L^2+H^2), 1/12*(L^2+W^2)]); % [m^2]

        % Volume
        obj.shape_model.volume = L*W*H; % [m^3]

    otherwise
        error('Havent written yet!')

end

obj.mass = init_data.mass; % [kg]

obj.packing_fraction = init_data.packing_fraction;

obj.type = init_data.type;

obj.solar_cell_efficiency = init_data.solar_cell_efficiency;

obj.instantaneous_power_generated = 0; % [W]

obj.maximum_power = 0; % [W]

obj.Sun_incidence_angle = 180; % [deg]

obj = func_update_SP_instantaneous_power_generated(obj, mission,
i_SC);

    % Initialize Variables to store: instantaneous_power_generated
maximum_power Sun_incidence_angle
    obj.store = [];

    obj.store.instantaneous_power_generated =
zeros(mission.storage.num_storage_steps,
length(obj.instantaneous_power_generated));
    obj.store.maximum_power = zeros(mission.storage.num_storage_steps,
length(obj.maximum_power));
    obj.store.Sun_incidence_angle =
zeros(mission.storage.num_storage_steps, length(obj.Sun_incidence_angle));

    obj = func_update_true_SC_SP_store(obj, mission);

    % Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

```

```
func_initialize_list_HW_energy_generated(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

    % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end
```

[] Methods: Store

Update the store variable

```
function obj = func_update_true_SC_SP_store(obj, mission)

    if mission.storage.flag_store_this_time_step == 1

obj.store.instantaneous_power_generated(mission.storage.k_storage,:) =
obj.instantaneous_power_generated; % [W]
        obj.store.maximum_power(mission.storage.k_storage,:) =
obj.maximum_power; % [W]
        obj.store.Sun_incidence_angle(mission.storage.k_storage,:) =
obj.Sun_incidence_angle; % [deg]
    end

end
```

[] Methods: Main

Update SP's instantaneous_power_generated

```
function obj = func_main_true_SC_solar_panel(obj, mission, i_SC)

    obj = func_update_SP_instantaneous_power_generated(obj, mission,
i_SC);

    obj = func_update_true_SC_SP_store(obj, mission);

    % Update Power Generated Consumed

func_update_instantaneous_power_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

func_update_instantaneous_power_generated(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

    % Update Data Generated

func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);
```

end

[] Methods: Instantaneous Power Generated

Update SP's instantaneous_power_generated

```
function obj = func_update_SP_instantaneous_power_generated(obj,
mission, i_SC)

    if (obj.health == 1) &&
(mission.true_SC{i_SC}.true_SC_navigation.flag_visible_Sun == 1)

        Sun_vector =
mission.true_solar_system.SS_body{mission.true_solar_system.index_Sun}.position
- mission.true_SC{i_SC}.true_SC_navigation.position; % [km]

        Sun_vector_normalized = func_normalize_vec(Sun_vector); %
[unit vector]

        obj.Sun_incidence_angle =
real(acosd(dot(Sun_vector_normalized',
mission.true_SC{i_SC}.true_SC_adc.rotation_matrix *
obj.shape_model.Face_orientation_solar_cell_side'))); % [deg]

        obj.maximum_power =
mission.true_solar_system.solar_constant_AU *
(mission.true_solar_system.AU_distance/norm(Sun_vector))^2
* obj.shape_model.Face_area * obj.packing_fraction *
obj.solar_cell_efficiency; % [W]

        if obj.Sun_incidence_angle <= 90 % [deg]

            obj.instantaneous_power_generated = obj.maximum_power *
cosd(obj.Sun_incidence_angle); % [W]

        else

            % No power generated
            obj.instantaneous_power_generated = 0; % [W]

        end

    else

        % Unhealthy Solar Panel

        obj.maximum_power = 0; % [W]

        obj.instantaneous_power_generated = 0; % [W]

        obj.Sun_incidence_angle = inf; % [deg]

    end

end

end
```

```
end
end
```

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5.17 True_SC_Star_Tracker

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Class: True_SC_Star_Tracker

Tracks the Star Tracker measurements

```
classdef True_SC_Star_Tracker < handle
```

Properties

properties

[] Properties: Initialized Variables

```
instantaneous_power_consumed % [Watts] : Instantaneous power consumed

instantaneous_data_generated_per_sample % [kb] : Data generated per
sample, in kilo bits (kb)

mode_true_SC_star_tracker_selector % [string]
% - Truth
% - Simple
% - Simple with Sun outside FOV

measurement_noise % [rad] (1-sigma standard deviation) (Optional)

measurement_wait_time % [sec]

location % [m] : Location of sensor, in body frame B

orientation % [unit vector] : Normal vector from location

field_of_view % [deg] : Field of view (FOV) of the camera in deg (No
measurement if Sun is within this FOV)
```

[] Properties: Variables Computed Internally

```
name % [string] 'Sun Sensor i'
```

```

health % [integer] Health of sensor/actuator
% - 0. Switched off
% - 1. Switched on, works nominally

temperature % [deg C] : Temperature of sensor/actuator

measurement_vector % [quaternion]

measurement_time % [sec] SC time when this measurement was taken

flag_executive % [Boolean] Executive has told this sensor/actuator to
do its job

data % Other useful data

```

[] Properties: Storage Variables

```

store

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = True_SC_Star_Tracker(init_data, mission, i_SC, i_HW)

    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
        obj.name = ['Star Tracker ', num2str(i_HW)];
    end

    obj.health = 1;
    obj.temperature = 10; % [deg C]

    obj.instantaneous_power_consumed =
init_data.instantaneous_power_consumed; % [W]
    obj.instantaneous_data_generated_per_sample =
init_data.instantaneous_data_generated_per_sample; % [kb]

    obj.mode_true_SC_star_tracker_selector =
init_data.mode_true_SC_star_tracker_selector; % [string]
    obj.measurement_wait_time = init_data.measurement_wait_time; %
[sec]
    obj.measurement_noise = init_data.measurement_noise; % [rad]

```

```

obj.measurement_vector = zeros(1,4);

obj.flag_executive = 1;

obj.measurement_time = -inf; % [sec]

obj.location = init_data.location; % [m]
obj.orientation = init_data.orientation; % [unit vector]
obj.field_of_view = init_data.field_of_view; % [deg]

if isfield(init_data, 'data')
    obj.data = init_data.data;
else
    obj.data = [];
end

% Initialize Variables to store: measurement_vector
obj.store = [];
obj.store.measurement_vector =
zeros(mission.storage.num_storage_steps, length(obj.measurement_vector));

% Update Storage
obj = func_update_true_SC_star_tracker_store(obj, mission);

% Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

% Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_star_tracker_store(obj, mission)

    if mission.storage.flag_store_this_time_step_attitude == 1

obj.store.measurement_vector(mission.storage.k_storage_attitude,:) =
obj.measurement_vector; % [quaternion]
        end

    end

```

[] Methods: Main

Update Camera

```

function obj = func_main_true_SC_star_tracker(obj, mission, i_SC)

    if (obj.flag_executive == 1) && (obj.health == 1)
        % Take measurement

        if (mission.true_time.time_attitude - obj.measurement_time) >=
obj.measurement_wait_time

            % Sufficient time has elapsed for a new measurement
            obj.measurement_time = mission.true_time.time_attitude; %
[sec]

            switch obj.mode_true_SC_star_tracker_selector

                case 'Truth'
                    obj = func_true_SC_star_tracker_Truth(obj,
mission, i_SC);

                case 'Simple'
                    obj = func_true_SC_star_tracker_Simple(obj,
mission, i_SC);

                case 'Simple with Sun outside FOV'

                    this_orientation =
(mission.true_SC{i_SC}.true_SC_adc.rotation_matrix * obj.orientation)'; %
[unit vector]

                    Sun_vector =
mission.true_solar_system.SS_body{mission.true_solar_system.index_Sun}.position
- mission.true_SC{i_SC}.true_SC_navigation.position; % [km]
                    Sun_vector_normalized =
func_normalize_vec(Sun_vector); % [unit vector]

                    if func_angle_between_vectors(this_orientation,
Sun_vector_normalized) >= deg2rad(obj.field_of_view)
                        obj = func_true_SC_star_tracker_Simple(obj,
mission, i_SC);
                    else
                        % Measurement doesn't exist
                        obj.measurement_vector = nan(1,4);
                    end

                    otherwise
                        error('Star Tracker mode not defined!')
                    end

                % Update Data Generated

            func_update_instantaneous_data_generated_attitude(mission.true_SC{i_SC}.true_SC_data_hand
obj, mission);

            else
                % Data not generated in this time step

```

```

        end

        % Update Power Consumed

func_update_instantaneous_power_consumed_attitude(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

    else
        % Do nothing

    end

    % Update Storage
obj = func_update_true_SC_star_tracker_store(obj, mission);

    % Reset Variables
obj.flag_executive = 0;

end

```

[] Methods: Truth

Star Tracker mode

```

function obj = func_true_SC_star_tracker_Truth(obj, mission, i_SC)
    obj.measurement_vector =
func_quaternion_properize( mission.true_SC{i_SC}.true_SC_adc.attitude);
end

```

[] Methods: Simple

Star Tracker mode

```

function obj = func_true_SC_star_tracker_Simple(obj, mission, i_SC)
    % OLD Incorrect Method
    % obj.measurement_vector =
func_quaternion_properize( mission.true_SC{i_SC}.true_SC_adc.attitude +
obj.measurement_noise*randn(1,4) );

    % New Correct Method

    % Define the error quaternion (small rotation) in axis-angle
format
    error_angle = obj.measurement_noise; % [rad]
    error_axis = randn(1,3);
    error_axis = error_axis/norm(error_axis); % [unit vector]

    % Convert axis-angle to quaternion
    error_quaternion = [sin(error_angle/2) * error_axis,
cos(error_angle/2)];
    error_quaternion = func_quaternion_properize(error_quaternion);

```

```
        % Apply the error by quaternion multiplication (Hamilton product)
        obj.measurement_vector =
func_quaternion_multiply(mission.true_SC{i_SC}.true_SC_adc.attitude,
error_quaternion);
        obj.measurement_vector =
func_quaternion_properize(obj.measurement_vector);

    end

end

end
```

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5.18 True_SC_Sun_Sensor

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[] Methods: Simple	5

Class: True_SC_Sun_Sensor

Tracks the Sun Sensor measurements

```
classdef True_SC_Sun_Sensor < handle
```

Properties

properties

[] Properties: Initialized Variables

```
instantaneous_power_consumed % [Watts] : Instantaneous power consumed

instantaneous_data_generated_per_sample % [kb] : Data generated per
sample, in kilo bits (kb)

mode_true_SC_sun_sensor_selector % [string]
% - Truth
% - Simple
% - Simple with Sun in FOV

measurement_noise % [rad] (1-sigma standard deviation)

measurement_wait_time % [sec]

location % [m] : Location of sensor, in body frame B

orientation % [unit vector] : Normal vector from location

field_of_view % [deg] : Field of view (FOV) of the camera in deg (No
measurement if Sun is outside this FOV)
```

[] Properties: Variables Computed Internally

```
name % [string] 'Sun Sensor i'
```

```

health % [integer] Health of sensor/actuator
% - 0. Switched off
% - 1. Switched on, works nominally

temperature % [deg C] : Temperature of sensor/actuator

measurement_vector % [quaternion]

measurement_time % [sec] SC time when this measurement was taken

flag_executive % [Boolean] Executive has told this sensor/actuator to
do its job

data % Other useful data

```

[] Properties: Storage Variables

```

store

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = True_SC_Sun_Sensor(init_data, mission, i_SC, i_HW)

    if isfield(init_data, 'name')
        obj.name = init_data.name;
    else
        obj.name = ['Sun Sensor ', num2str(i_HW)];
    end

    obj.health = 1;
    obj.temperature = 10; % [deg C]

    obj.instantaneous_power_consumed =
init_data.instantaneous_power_consumed; % [W]
    obj.instantaneous_data_generated_per_sample =
init_data.instantaneous_data_generated_per_sample; % [kb]

    obj.mode_true_SC_sun_sensor_selector =
init_data.mode_true_SC_sun_sensor_selector; % [string]
    obj.measurement_wait_time = init_data.measurement_wait_time; %
[sec]
    obj.measurement_noise = init_data.measurement_noise; % [rad]

```

```

obj.measurement_vector = zeros(1,4);

obj.flag_executive = 1;

obj.measurement_time = -inf; % [sec]

obj.location = init_data.location; % [m]
obj.orientation = init_data.orientation; % [unit vector]
obj.field_of_view = init_data.field_of_view; % [deg]

if isfield(init_data, 'data')
    obj.data = init_data.data;
else
    obj.data = [];
end

% Initialize Variables to store: measurement_vector
obj.store = [];
obj.store.measurement_vector =
zeros(mission.storage.num_storage_steps, length(obj.measurement_vector));

% Update Storage
obj = func_update_true_SC_sun_sensor_store(obj, mission);

% Update SC Power Class

func_initialize_list_HW_energy_consumed(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

% Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_true_SC_sun_sensor_store(obj, mission)

    if mission.storage.flag_store_this_time_step_attitude == 1

obj.store.measurement_vector(mission.storage.k_storage_attitude,:) =
obj.measurement_vector; % [quaternion]
    end

end

```

[] Methods: Main

Update Camera

```

function obj = func_main_true_SC_sun_sensor(obj, mission, i_SC)

    if (obj.flag_executive == 1) && (obj.health == 1)
        % Take measurement

        if (mission.true_time.time_attitude - obj.measurement_time) >=
obj.measurement_wait_time

            % Sufficient time has elapsed for a new measurement
            obj.measurement_time = mission.true_time.time_attitude; %
[sec]

            switch obj.mode_true_SC_sun_sensor_selector

                case 'Truth'
                    obj = func_true_SC_sun_sensor_Truth(obj, mission,
i_SC);

                case 'Simple'
                    obj = func_true_SC_sun_sensor_Simple(obj, mission,
i_SC);

                case 'Simple with Sun in FOV'

                    this_orientation =
(mission.true_SC{i_SC}.true_SC_adc.rotation_matrix * obj.orientation)'; %
[unit vector]

                    Sun_vector =
mission.true_solar_system.SS_body{mission.true_solar_system.index_Sun}.position
- mission.true_SC{i_SC}.true_SC_navigation.position; % [km]
                    Sun_vector_normalized =
func_normalize_vec(Sun_vector); % [unit vector]

                    if func_angle_between_vectors(this_orientation,
Sun_vector_normalized) <= deg2rad(obj.field_of_view)
                        obj = func_true_SC_sun_sensor_Simple(obj,
mission, i_SC);
                    else
                        % Measurement doesn't exist
                        obj.measurement_vector = nan(1,4);
                    end

                    otherwise
                        error('Sun Sensor mode not defined!')
                    end

                    % Update Data Generated

func_update_instantaneous_data_generated_attitude(mission.true_SC{i_SC}.true_SC_data_hand
obj, mission);

                else
                    % Data not generated in this time step

```

```

        end

        % Update Power Consumed

func_update_instantaneous_power_consumed_attitude(mission.true_SC{i_SC}.true_SC_power,
obj, mission);

    else
        % Do nothing

    end

    % Update Storage
    obj = func_update_true_SC_sun_sensor_store(obj, mission);

    % Reset Variables
    obj.flag_executive = 0;

end

```

[] Methods: Truth

Sun Sensor mode

```

function obj = func_true_SC_sun_sensor_Truth(obj, mission, i_SC)
    obj.measurement_vector =
func_quaternion_properize( mission.true_SC{i_SC}.true_SC_adc.attitude);
end

```

[] Methods: Simple

Sun Sensor mode

```

function obj = func_true_SC_sun_sensor_Simple(obj, mission, i_SC)
    % OLD Incorrect Method
    % obj.measurement_vector =
func_quaternion_properize( mission.true_SC{i_SC}.true_SC_adc.attitude +
obj.measurement_noise*randn(1,4) );

    % New Correct Method

    % Define the error quaternion (small rotation) in axis-angle
format
    error_angle = obj.measurement_noise; % [rad]
    error_axis = rand(1,3) - 0.5;
    error_axis = error_axis/norm(error_axis); % [unit vector]

    % Convert axis-angle to quaternion
    error_quaternion = [sin(error_angle/2) * error_axis,
cos(error_angle/2)];
    error_quaternion = func_quaternion_properize(error_quaternion);

```

```
        % Apply the error by quaternion multiplication (Hamilton product)
        obj.measurement_vector =
func_quaternion_multiply(mission.true_SC{i_SC}.true_SC_adc.attitude,
error_quaternion);
        obj.measurement_vector =
func_quaternion_properize(obj.measurement_vector);

    end

end

end
```

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Chapter 6

SC System-Level and Functional-Level Autonomy Software Layer Classes

6.1 Software_SC_Communication

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Class: Software_SC_Communication

Tracks the Communication Links of the Spacecraft

```
classdef Software_SC_Communication < handle
```

Properties

properties

[] Properties: Initialized Variables

```
instantaneous_data_generated_per_sample % [kb] : Data generated per
sample, in kilo bits (kb)

mode_software_SC_communication_selector % [string] Different
communication modes
% - 'DART'
% - 'Nightingale'

attitude_error_threshold % [rad]
```

[] Properties: Variables Computed Internally

```
name % [string] = SC j for jth SC + SW Communication

flag_executive % [Boolean] Executive has told this sensor/actuator to
do its job

this_attitude_error % [rad] current attitude error

data % Other useful data

last_communication_time % [sec]
wait_time_comm_dte % [sec] time to wait for communicating info to
earth
```

[] Properties: Storage Variables

```
store  
  
end
```

Methods

```
methods
```

[] Methods: Constructor

Construct an instance of this class

```
function obj = Software_SC_Communication(init_data, mission, i_SC)  
  
    obj.name = [mission.true_SC{i_SC}.true_SC_body.name, ' SW  
Communication']; % [string]  
    obj.flag_executive = 0;  
  
    obj.instantaneous_data_generated_per_sample =  
init_data.instantaneous_data_generated_per_sample; % [kb]  
    obj.mode_software_SC_communication_selector =  
init_data.mode_software_SC_communication_selector; % [string]  
  
    obj.attitude_error_threshold =  
deg2rad(init_data.attitude_error_threshold_deg); % [rad]  
  
    obj.this_attitude_error = inf;  
  
    if isfield(init_data, 'data')  
        obj.data = init_data.data;  
    else  
        obj.data = [];  
    end  
  
    % Initialize communication time tracker  
    if isfield(init_data, 'last_communication_time')  
        obj.last_communication_time =  
init_data.last_communication_time;  
    else  
        obj.last_communication_time = 0; % Start at 0 so first check  
will attempt communication  
    end  
  
    % Initialize wait time for DTE communications if provided  
    if isfield(init_data, 'wait_time_comm_dte')  
        obj.wait_time_comm_dte = init_data.wait_time_comm_dte;  
    else  
        obj.wait_time_comm_dte = 3600; % Default to 1 hour (3600  
seconds)  
    end
```

```

    % Initialize Variables to store
    obj.store = [];

    obj.data.transmission_complete = false;

    obj.store.flag_executive =
zeros(mission.storage.num_storage_steps, length(obj.flag_executive));
    obj.store.this_attitude_error =
zeros(mission.storage.num_storage_steps, length(obj.this_attitude_error));

    % Update Storage
    obj = func_update_software_SC_communication_store(obj, mission);

    % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end

```

[] Methods: Store

Update the store variables

```

function obj = func_update_software_SC_communication_store(obj,
mission)

    if mission.storage.flag_store_this_time_step == 1
        obj.store.flag_executive(mission.storage.k_storage,:) =
obj.flag_executive; % [Boolean]
        obj.store.this_attitude_error(mission.storage.k_storage,:) =
obj.this_attitude_error; % [rad]
    end

end

```

[] Methods: Main

Main Function

```

function obj = func_main_software_SC_communication(obj, mission, i_SC)

    if (obj.flag_executive == 1)

        switch obj.mode_software_SC_communication_selector

            case 'DART'
                obj = func_update_software_SC_communication_Dart(obj,
mission, i_SC);

            case 'Nightingale'

```

```

        obj =
func_update_software_SC_communication_Nightingale(obj, mission, i_SC);

        otherwise
            disp('Communication mode not defined!')
        end

        % Update Data Generated

func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

    end

    % Update Storage
    obj = func_update_software_SC_communication_store(obj, mission);

    % Reset Variables
    obj.flag_executive = 0;
    obj.this_attitude_error = inf;

end

end

end

```

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6.2 Software_SC_Control_Attitude

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Class: Software_SC_Control_Attitude	1
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[] Properties: Storage Variables	2
Methods	2
[] Methods: Constructor	2
[] Methods: Store	4
[] Methods: Main	5

Class: Software_SC_Control_Attitude

Control the Attitude of the Spacecraft

```
classdef Software_SC_Control_Attitude < handle
```

Properties

properties

[] Properties: Initialized Variables

```
instantaneous_data_generated_per_sample % [kb] : Data generated per
sample, in kilo bits (kb)

mode_software_SC_control_attitude_selector % [string] Different
attitude control modes
% - 'DART Oracle' : Directly change True_SC_ADC.attitude values for
DART mission
% - 'Nightingale Oracle' : Directly change True_SC_ADC.attitude values
for Nightingale mission
% - 'Oracle with Control' : Use True_SC_ADC values + Noise
```

[] Properties: Variables Computed Internally

```
name % [string] = SC j for jth SC + SW Control Attitude

flag_executive % [Boolean] Executive has told this sensor/actuator to
do its job

desired_attitude % [quaternion] : Orientation of inertial frame I
with respect to the body frame B

error_angle_desired_attitude % [radians] : Angle error between
desired_attitude and true attitude
```

```

    desired_angular_velocity % [rad/sec] : Angular velocity of inertial
    frame I with respect to the body frame B

    desired_control_torque % [Nm] : Desired control torque

    data % Other useful data

    desaturation_procedure % [Bool] - Is the procedure started ?
    thruster_contribution_matix % thruster contribution
    pinv_reaction_wheel_contribution_matrix % reaction wheel contribution
matrix
    reaction_wheel_attitude_control_threshold % [rad] Angle from which
wheels can take over the correction
    optim_data

    max_thrust % [N] : Maximum thrust of the thruster
    min_thrust % [N] : Minimum thrust of the thruster

    % Cached torque capabilities
    max_rw_torque % [Nm] : Maximum torque capability of reaction wheels
    max_mt_torque % [Nm] : Maximum torque capability of micro thrusters

```

[] Properties: Storage Variables

```

store

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = Software_SC_Control_Attitude(init_data, mission, i_SC)

    obj.name = [mission.true_SC{i_SC}.true_SC_body.name, ' SW Control
Attitude']; % [string]
    obj.flag_executive = 1;

    obj.instantaneous_data_generated_per_sample = 0; % [kb]
    obj.mode_software_SC_control_attitude_selector =
init_data.mode_software_SC_control_attitude_selector; % [string]

    if isfield(init_data, 'data')
        obj.data = init_data.data;
    else
        obj.data = [];
    end
end

```

```

        % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

        % Initialization of thruster and RW optimization data
func_initialize_optimization_data(obj, mission, i_SC);

        % Initialize matrices and hardware data
if
mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_micro_thruster > 0
    obj = func_initialize_micro_thruster_contribution(obj,
mission, i_SC);
end

if
mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_reaction_wheel > 0
    obj = func_initialize_reaction_wheel_contribution(obj,
mission, i_SC);
end

        % Calculate and cache max torque capabilities
obj.max_rw_torque = func_calculate_max_reaction_wheel_torque(obj,
mission, i_SC);
obj.max_mt_torque = func_calculate_max_thruster_torque(obj,
mission, i_SC);

        % All the zeros
obj.desaturation_procedure = 0;
obj.desired_attitude = zeros(1,4); % [quaternion]
obj.error_angle_desired_attitude = 0; % [rad]
obj.desired_control_torque = zeros(1,3); % [Toraue Vector Nm]
obj.desired_angular_velocity = zeros(1,3); % [rad/sec]
obj.data.integral_error = zeros(3,1); % Initialize as 3x1 vector
for X/Y/Z axes

        % Initialize control gains
if isfield(init_data, 'control_gain')
    obj.data.control_gain = init_data.control_gain;
else
    obj.data.control_gain = [0.1 1]; % [Kr ; Lambda_r] for RWA/
MT control
end
obj.data.prev_desired_attitude = zeros(1,4); % [quaternion]
obj.data.num_prev_desired_attitude = 60;

        % Initialize Variables to store
obj.store = [];

obj.store.flag_executive =
zeros(mission.storage.num_storage_steps_attitude,
length(obj.flag_executive));

```

```

        obj.store.desaturation_procedure =
zeros(mission.storage.num_storage_steps_attitude,
length(obj.desaturation_procedure));
        obj.store.desired_attitude =
zeros(mission.storage.num_storage_steps_attitude,
length(obj.desired_attitude));
        obj.store.desired_angular_velocity =
zeros(mission.storage.num_storage_steps_attitude,
length(obj.desired_angular_velocity));
        obj.store.desired_control_torque =
zeros(mission.storage.num_storage_steps_attitude,
length(obj.desired_control_torque));
        obj.store.error_angle_desired_attitude
= zeros(mission.storage.num_storage_steps_attitude,
length(obj.error_angle_desired_attitude));

        % Update Storage
        obj = func_update_software_SC_control_attitude_store(obj,
mission);

        if isfield(init_data, 'reaction_wheel_attitude_control_threshold')
            obj.reaction_wheel_attitude_control_threshold =
init_data.reaction_wheel_attitude_control_threshold;
        else
            obj.reaction_wheel_attitude_control_threshold = 0.1; % [Rad]-
Nominal is 0.05
        end

        % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_software_SC_control_attitude_store(obj,
mission)
    if mission.storage.flag_store_this_time_step_attitude == 1
        obj.store.flag_executive(mission.storage.k_storage_attitude,:)
= obj.flag_executive;

        obj.store.desaturation_procedure(mission.storage.k_storage_attitude,:) =
obj.desaturation_procedure; % [quaternion]

        obj.store.desired_attitude(mission.storage.k_storage_attitude,:) =
obj.desired_attitude; % [quaternion]

```

```

obj.store.desired_angular_velocity(mission.storage.k_storage_attitude,:) =
obj.desired_angular_velocity; % [rad/sec]

obj.store.desired_control_torque(mission.storage.k_storage_attitude,:) =
obj.desired_control_torque; % [Nm]

obj.store.error_angle_desired_attitude(mission.storage.k_storage_attitude,:)
= obj.error_angle_desired_attitude; % [rad]
    end
end

```

[] Methods: Main

Main Function

```

function obj = func_main_software_SC_control_attitude(obj, mission,
i_SC)

    if (obj.flag_executive == 1)

        switch obj.mode_software_SC_control_attitude_selector

            case {'DART Oracle', 'DART Control Asymptotically Stable
send to ADC directly', 'DART Control PD', 'DART Control Asymptotically Stable
send to actuators', 'DART Control Asymptotically Stable send to thrusters'}
                obj =
func_update_software_SC_control_attitude_DART(obj, mission, i_SC);

            case {'Nightingale Oracle', 'Nightingale Control
Asymptotically Stable send to ADC directly', 'Nightingale Control PD send
to ADC directly', 'Nightingale Control PD send to thrusters', 'Nightingale
Control PD send to actuators', 'Nightingale Control Asymptotically Stable
send to actuators', 'Nightingale Control Asymptotically Stable send to
rwa', 'Nightingale Control Asymptotically Stable send to thrusters'}
                obj =
func_update_software_SC_control_attitude_Nightingale_v2(obj, mission, i_SC);

            otherwise
                error('Attitude Control mode not defined!')
            end

            % Update Data Generated

func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);
        end

        % Compute Error Angle between desired_attitude and estimated
attitude
    end
end

```

```
        obj.error_angle_desired_attitude =  
func_error_angle_between_quaternions(obj.desired_attitude,  
mission.true_SC{i_SC}.software_SC_estimate_attitude.attitude); % [rad]  
  
        % Update Storage  
        obj = func_update_software_SC_control_attitude_store(obj,  
mission);  
  
        % DO NOT SWITCH OFF FUNCTIONS USING flag_executive INSIDE Attitude  
Dynamics Loop (ADL)  
    end  
  
end  
  
end
```

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6.3 `Software_SC_Control_Orbit`

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[] Methods: Constructor	3
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[] Methods: Main	5

Class: Software_SC_Control_Orbit

Control the Orbit of the Spacecraft

```
classdef Software_SC_Control_Orbit < handle

    % Software_SC_Control_Orbit: Manages spacecraft control parameters for
    % orbiting small bodies.
    % Includes functionalities for trajectory calculations, intercept
    % predictions,
    % and delta-V computations tailored for spacecraft mission scenarios.
```

Properties

properties

[] Properties: Initialized Variables

```
    mode_software_sc_control_orbit_selector % [string] Different orbit
    control modes
    % - 'DART'

    max_time_before_control % [s]
```

[] Properties: Variables Computed Internally

```
    name % [string] = SC j for jth SC + SW Control Orbit

    instantaneous_data_generated_per_sample % [kb] : Data generated per
    sample, in kilo bits (kb)

    data % Other useful data

    last_time_control % [s]
    flag_executive % [bool]
```

```

% Maneuver tracking
maneuver_start_time % [s] Time when current maneuver began execution
thruster_fired_successfully % [bool] Flag to track if thruster
actually fired

% Delta-V control parameters
desired_control_DeltaV % [m/s]: Desired Delta-V vector
desired_control_DeltaV_units % [string]: Units for Delta-V
total_DeltaV_executed % [m/s]: Accumulated executed Delta-V

burn_duration % [s]

% Thrust control parameters
desired_control_thrust % [N]: Desired thrust for trajectory control
desired_control_thrust_units % [string]: Units for thrust (e.g., N,
kN)

% Time horizons and intercept data
time_horizon % [sec]: Time horizon for trajectory planning
time_intercept % [sec]: Time of intercept with target
time_horizon_DeltaV % [sec]: Time horizon for Delta-V execution
time_DeltaV % [sec]: Time of Delta-V execution
time_horizon_data_cutoff % [sec]: Time cutoff for data integration
time_data_cutoff % [sec]: Data cutoff time

% Intercept and trajectory details
intercept_SB_position % [km]: Intercept position relative to small
body
intercept_SB_velocity % [km/s]: Intercept velocity relative to small
body
intercept_distance % [km]: Distance at intercept
desired_intercept_distance % [km]: Desired distance at intercept

% Options for numerical integrations
options % [struct]: Options for ODE solvers

% Flags and execution controls
desired_DeltaV_needs_to_be_executed % [boolean]: Whether Delta-V needs
execution
desired_DeltaV_computed % [boolean]: Whether Delta-V is computed
desired_attitude_for_DeltaV_achieved % [boolean]: Attitude flag for
Delta-V execution
desired_DeltaV_achieved % [boolean]: Whether Delta-V has been achieved

% Desired trajectory details
desired_time_array % [sec]: Array of planned trajectory times
desired_SC_pos_vel_current_SBcentered % [km, km/s]: Desired spacecraft
state in small body frame
flag_position_velocity_burn % [int]: Indicator for position or
velocity-based burns
desired_control_DeltaV_position_burn % [m/s]: Position-based Delta-V
time_DeltaV_position_burn % [sec]: Time for position-based burn
desired_control_DeltaV_velocity_burn % [m/s]: Velocity-based Delta-V
time_DeltaV_velocity_burn % [sec]: Time for velocity-based burn

```

```

        threshold_minimum_deltaV % [m/s] - the minimum deltaV that is worth
        executing, usually 0.001 m/s

        % Fuel management properties
        min_fuel_threshold % [kg]: Minimum fuel threshold to allow maneuvers
        estimated_fuel_required % [kg]: Estimated fuel required for maneuver
        flag_insufficient_fuel % [boolean]: Flag indicating insufficient fuel

```

[] Properties: Storage Variables

```

        store % Structure to store historical data

    end

```

Methods

```

    methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = Software_SC_Control_Orbit(init_data, mission, i_SC)
    % Initialize the spacecraft control orbit class

    obj.name = [mission.true_SC{i_SC}.true_SC_body.name, ' SW Control
Orbit']; % [string]

    obj.mode_software_SC_control_orbit_selector =
init_data.mode_software_SC_control_orbit_selector;
    obj.max_time_before_control = init_data.max_time_before_control;

    obj.flag_executive = 0;
    obj.last_time_control = 0;

    obj.instantaneous_data_generated_per_sample = 0; % [kb]

    obj.desired_control_thrust = 0; % Initialize thrust to zero
    obj.options = odeset('RelTol', 1e-14, 'AbsTol', 1e-14);

    obj.time_DeltaV = 0; % Initialize Delta-V time
    obj.time_horizon = 10 * 24 * 60 * 60; % Default planning horizon
(10 days)

    obj.desired_DeltaV_needs_to_be_executed = false;
    obj.desired_DeltaV_computed = false;
    obj.desired_attitude_for_DeltaV_achieved = 0;

    obj.intercept_distance = 0; % Initialize intercept distance
    obj.desired_intercept_distance = 0; % Initialize desired intercept
distance

```

```

        obj.desired_control_DeltaV = zeros(3, 1); % Initialize Delta-V
vector
        obj.desired_DeltaV_achieved = false;

        obj.total_DeltaV_executed = zeros(3, 1); % Initialize Delta-V
vector

        obj.time_horizon_DeltaV = 30 * 60; % Default Delta-V planning
horizon (30 minutes)
        obj.time_horizon_data_cutoff = 0; % No data cutoff initially

        obj.threshold_minimum_deltaV = 0.01;

        % Initialize fuel management properties
        obj.min_fuel_threshold = 0.1; % Minimum fuel threshold in kg
        obj.estimated_fuel_required = 0; % Estimated fuel required for
maneuver
        obj.flag_insufficient_fuel = false; % Flag indicating insufficient
fuel

        % Initialize Storage Variables
        obj.store = [];
        obj.store.intercept_distance =
zeros(mission.storage.num_storage_steps_attitude,1); % Initialize as empty
numeric array
        obj.store.desired_DeltaV_computed =
zeros(mission.storage.num_storage_steps_attitude,1);
        obj.store.desired_attitude_for_DeltaV_achieved =
zeros(mission.storage.num_storage_steps_attitude,1);

        obj.store.desired_control_DeltaV =
zeros(mission.storage.num_storage_steps_attitude, 3);
        obj.store.total_DeltaV_executed =
zeros(mission.storage.num_storage_steps_attitude, 3);
        obj.store.attitude_error =
zeros(mission.storage.num_storage_steps_attitude, 3); % Euler angles error
        obj.store.deltaV_magnitude_desired =
zeros(mission.storage.num_storage_steps_attitude, 1);
        obj.store.deltaV_magnitude_executed =
zeros(mission.storage.num_storage_steps_attitude, 1);
        obj.store.flag_insufficient_fuel =
zeros(mission.storage.num_storage_steps_attitude, 1);
        obj.store.estimated_fuel_required =
zeros(mission.storage.num_storage_steps_attitude, 1);

        obj.desired_DeltaV_achieved = 0;
        obj.total_DeltaV_executed = [0 0 0]'; % [m/sec]
        obj.desired_attitude_for_DeltaV_achieved = 0;

        % Initialize maneuver tracking properties
        obj.maneuver_start_time = 0;
        obj.thruster_fired_successfully = false;

```

```

        % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);
end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_software_SC_Control_Orbit_store(obj,
mission)
    obj.store.intercept_distance(mission.storage.k_storage,:) =
obj.intercept_distance;
    obj.store.desired_DeltaV_computed(mission.storage.k_storage,:) =
obj.desired_DeltaV_computed;

obj.store.desired_attitude_for_DeltaV_achieved(mission.storage.k_storage,:) =
obj.desired_attitude_for_DeltaV_achieved;

    % New variables
    obj.store.desired_control_DeltaV(mission.storage.k_storage, :) =
obj.desired_control_DeltaV;
    obj.store.total_DeltaV_executed(mission.storage.k_storage, :) =
obj.total_DeltaV_executed;

    % % Compute attitude error
    % actual_quat =
mission.true_SC{i_SC}.software_SC_estimate_attitude.attitude;
    % desired_quat =
mission.true_SC{i_SC}.software_SC_control_attitude.desired_attitude;
    % error_quat = quatmultiply(quatconj(actual_quat), desired_quat);
    % euler_error = quat2eul(error_quat, 'ZYX'); % Convert to Euler
angles (rad)
    % obj.store.attitude_error(mission.storage.k_storage, :) =
euler_error;

    % DeltaV magnitudes
    obj.store.deltaV_magnitude_desired(mission.storage.k_storage) =
norm(obj.desired_control_DeltaV);
    obj.store.deltaV_magnitude_executed(mission.storage.k_storage) =
norm(obj.total_DeltaV_executed);

    % Fuel management data
    obj.store.flag_insufficient_fuel(mission.storage.k_storage) =
obj.flag_insufficient_fuel;
    obj.store.estimated_fuel_required(mission.storage.k_storage) =
obj.estimated_fuel_required;
end

```

[] Methods: Main

Main Function

```
function func_main_software_SC_control_orbit(obj, mission, i_SC)

    if (obj.flag_executive == 1)

        switch obj.mode_software_SC_control_orbit_selector

            case 'DART'
                obj = func_update_software_SC_control_orbit_DART(obj,
mission, i_SC);

            case 'Inactive'
                % Do nothing!

            otherwise
                error('Orbit Control mode not defined!')
            end

            % Update Data Generated

func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

        end

        % Update Storage
        obj.func_update_software_SC_Control_Orbit_store(mission);

        % Reset Variables
        obj.flag_executive = 0;

    end

end

end
```

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6.4 Software_SC_Data_Handling

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[] Properties: Variables Computed Internally	1
[] Properties: Storage Variables	1
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[] Methods: Constructor	2
[] Methods: Store	3
[] Methods: Main	3

Class: Software_SC_Data_Handling

Track the data_handling status onboard the spacecraft

```
classdef Software_SC_Data_Handling < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
instantaneous_data_generated_per_sample % [kb] : Data generated per  
sample, in kilo bits (kb)
```

```
mode_software_SC_data_handling_selector % [string] Different Data  
Handling modes  
% - 'Generic'
```

[] Properties: Variables Computed Internally

```
name % [string] = SC j for jth SC + SW Data Handling
```

```
flag_executive % [Boolean] Executive has told this sensor/actuator to  
do its job
```

```
total_data_storage % [kb] : Total data in all memories
```

```
mean_state_of_data_storage % [percentage] : SoDS is defined by = 100×  
Sum (instantaneous_capacity) / Sum (maximum_capacity)
```

```
data % Other useful data
```

[] Properties: Storage Variables

```
store
```

end

Methods

methods

[] Methods: Constructor

Construct an instance of this class

```
function obj = Software_SC_Data_Handling(init_data, mission, i_SC)

    obj.name = [mission.true_SC{i_SC}.true_SC_body.name, ' SW Data
Handling']; % [string]
    obj.flag_executive = 0;

    obj.instantaneous_data_generated_per_sample =
init_data.instantaneous_data_generated_per_sample; % [kb]

    obj.mode_software_SC_data_handling_selector =
init_data.mode_software_SC_data_handling_selector;

    obj.mode_software_SC_data_handling_selector = 'Generic';

    if isfield(init_data, 'data')
        obj.data = init_data.data;
    else
        obj.data = [];
    end

    % Update Mean SoC
    obj = func_update_mean_state_of_data_storage(obj, mission, i_SC);

    obj.mean_state_of_data_storage = 0;

    % Initialize Variables to store
    obj.store = [];

    obj.store.flag_executive =
zeros(mission.storage.num_storage_steps, length(obj.flag_executive));
    obj.store.mean_state_of_data_storage =
zeros(mission.storage.num_storage_steps,
length(obj.mean_state_of_data_storage));
    obj.store.total_data_storage =
zeros(mission.storage.num_storage_steps, length(obj.total_data_storage));

    % Update Storage
    obj = func_update_software_SC_data_handling_store(obj, mission);

    % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);
```

```
end
```

[] Methods: Store

Update the store variables

```
function obj = func_update_software_SC_data_handling_store(obj, mission)

    if mission.storage.flag_store_this_time_step == 1
        obj.store.flag_executive(mission.storage.k_storage,:) = obj.flag_executive; % [Boolean]

    obj.store.mean_state_of_data_storage(mission.storage.k_storage,:) = obj.mean_state_of_data_storage; % [percentage]
        obj.store.total_data_storage(mission.storage.k_storage,:) = obj.total_data_storage; % [kb]
    end

end
```

[] Methods: Main

Main Function

```
function obj = func_main_software_SC_data_handling(obj, mission, i_SC)

    switch obj.mode_software_SC_data_handling_selector

        case 'Generic'
            % Update Mean SoC
            obj = func_update_mean_state_of_data_storage(obj, mission, i_SC);

        case 'Nightingale'
            % Update Mean SoC for (num_onboard_memory-1) only
            obj = func_update_mean_state_of_data_storage_Nightingale(obj, mission, i_SC);

        otherwise
            error('Data Handling mode not defined!')
        end

        % Update Data Generated

    func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling, obj, mission);

    % Update Storage
    obj = func_update_software_SC_data_handling_store(obj, mission);
```

```
        % Reset Variables
        obj.flag_executive = 0;

    end

end

end
```

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6.5 Software_SC_Estimate_Attitude

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[] Properties: Storage Variables	2
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[] Methods: Constructor	2
[] Methods: Store	3
[] Methods: Main	4

Class: Software_SC_Estimate_Attitude

Estimates the Attitude of the Spacecraft

```
classdef Software_SC_Estimate_Attitude < handle
```

Properties

properties

[] Properties: Initialized Variables

```
instantaneous_data_generated_per_sample % [kb] : Data generated per
sample, in kilo bits (kb)

mode_software_SC_estimate_attitude_selector % [string] Different
attitude estimation modes
% - 'Truth' : Use True_SC_ADC values
% - 'Truth with Noise' : Use True_SC_ADC values + Noise
% - 'KF' : Use Kalman Filter
```

[] Properties: Variables Computed Internally

```
name % [string] = SC j for jth SC + SW Estimate Attitude

flag_executive % [Boolean] Executive has told this sensor/actuator to
do its job

attitude % [quaternion] : Orientation of inertial frame I with respect
to the body frame B

angular_velocity % [rad/sec] : Angular velocity of inertial frame I
with respect to the body frame B

dot_angular_velocity % [rad/sec^2] : Time derivative of
angular_velocity (needed by RWA)
```

```
attitude_uncertainty % [error in quaternion]

angular_velocity_uncertainty % [rad/sec]

dot_angular_velocity_uncertainty % [rad/sec^2]

data % Other useful data
```

[] Properties: Storage Variables

```
store

end
```

Methods

```
methods
```

[] Methods: Constructor

Construct an instance of this class

```
function obj = Software_SC_Estimate_Attitude(init_data, mission, i_SC)

    obj.name = [mission.true_SC{i_SC}.true_SC_body.name, ' SW Estimate
Attitude']; % [string]
    obj.flag_executive = 1;

    obj.instantaneous_data_generated_per_sample = 0; % [kb]
    obj.mode_software_SC_estimate_attitude_selector =
init_data.mode_software_SC_estimate_attitude_selector; % [string]

    if isfield(init_data, 'data')
        obj.data = init_data.data;
    else
        obj.data = [];
    end

    obj = func_update_software_SC_estimate_attitude_Truth(obj,
mission, i_SC);

    % Initialize Variables to store: attitude angular_velocity
dot_angular_velocity and uncertainties
    obj.store = [];

    obj.store.flag_executive =
zeros(mission.storage.num_storage_steps_attitude,
length(obj.flag_executive));

    obj.store.attitude =
zeros(mission.storage.num_storage_steps_attitude, length(obj.attitude));
```

```

        obj.store.attitude_uncertainty =
zeros(mission.storage.num_storage_steps_attitude,
length(obj.attitude_uncertainty));

        obj.store.angular_velocity =
zeros(mission.storage.num_storage_steps_attitude,
length(obj.angular_velocity));
        obj.store.angular_velocity_uncertainty
= zeros(mission.storage.num_storage_steps_attitude,
length(obj.angular_velocity_uncertainty));

        obj.store.dot_angular_velocity =
zeros(mission.storage.num_storage_steps_attitude,
length(obj.dot_angular_velocity));
        obj.store.dot_angular_velocity_uncertainty
= zeros(mission.storage.num_storage_steps_attitude,
length(obj.dot_angular_velocity_uncertainty));

        % Update Storage
        obj = func_update_software_SC_estimate_attitude_store(obj,
mission);

        % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_software_SC_estimate_attitude_store(obj,
mission)

    if mission.storage.flag_store_this_time_step_attitude == 1
        obj.store.flag_executive(mission.storage.k_storage_attitude,:)
= obj.flag_executive;

        obj.store.attitude(mission.storage.k_storage_attitude,:) =
obj.attitude; % [quaternion]

        obj.store.attitude_uncertainty(mission.storage.k_storage_attitude,:) =
obj.attitude_uncertainty;

        obj.store.angular_velocity(mission.storage.k_storage_attitude,:) =
obj.angular_velocity; % [rad/sec]

        obj.store.angular_velocity_uncertainty(mission.storage.k_storage_attitude,:)
= obj.angular_velocity_uncertainty;

```

```

obj.store.dot_angular_velocity(mission.storage.k_storage_attitude,:) =
obj.dot_angular_velocity; % [rad/sec^2]

obj.store.dot_angular_velocity_uncertainty(mission.storage.k_storage_attitude,:)
= obj.dot_angular_velocity_uncertainty;
    end

end

```

[] Methods: Main

Main Function

```

function obj = func_main_software_SC_estimate_attitude(obj, mission,
i_SC)

    if (obj.flag_executive == 1)

        switch obj.mode_software_SC_estimate_attitude_selector

            case 'Truth'
                obj =
func_update_software_SC_estimate_attitude_Truth(obj, mission, i_SC);

            case 'KF'
                obj =
func_update_software_SC_estimate_attitude_KF(obj, mission, i_SC);

            otherwise
                error('Attitude Estimation mode not defined!')
            end

            % Update Data Generated

func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

        end

        % Update Storage
obj = func_update_software_SC_estimate_attitude_store(obj,
mission);

        % Reset Variables
if abs(mission.true_time.time - mission.true_time.time_attitude)
<= 1e-6
    obj.flag_executive = 0;
else
    % DONOT SWITCH OFF FUNCTIONS USING flag_executive INSIDE
Attitude Dynamics Loop (ADL)
end

```

```
        end
    end
end
```

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6.6 Software_SC_Estimate_Orbit

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[] Methods: Store	4
[] Methods: Main	5

Class: Software_SC_Estimate_Orbit

Estimates the Orbits of the Spacecraft and Target

```
classdef Software_SC_Estimate_Orbit < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
instantaneous_data_generated_per_sample % [kb] : Data generated per
sample, in kilo bits (kb)

mode_software_SC_estimate_orbit_selector % [string] Different attitude
dynamics modes
% - 'Truth' : Use True values
% - 'Truth with Noise' : Use True values + Noise
% - 'TruthWithErrorGrowth' : Use True values with error growth when
target is not visible

compute_wait_time % [sec]
```

[] Properties: Variables Computed Internally

```
name % [string] = SC j for jth SC + SW Estimate Orbit

flag_executive % [Boolean] Executive has told this sensor/actuator to
do its job

position % [km] : Current position of SC in inertial frame I
position_uncertainty % [km]

velocity % [km/sec] : Current velocity of SC in inertial frame I
velocity_uncertainty % [km/sec]
```

```

        position_relative_target % [km] : Current position of SC relative to
        SB-center J2000 inertial frame
        position_relative_target_uncertainty % [km]

        velocity_relative_target % [km/sec] : Current velocity of SC relative
        to SB-center J2000 inertial frame
        velocity_relative_target_uncertainty % [km/sec]

        name_relative_target % [string] : Name of the target, relative to
        which position and velocity are specified
        index_relative_target % [integer] : Index of the target, relative to
        which position and velocity are specified

        position_target % [km] Current position of Target wrt Sun-centered
        J2000
        position_target_uncertainty % [km]

        velocity_target % [km/sec] Current velocity of Target wrt Sun-centered
        J2000
        velocity_target_uncertainty % [km/sec]

        compute_time % [sec] SC time when this measurement was taken

        data % Other useful data

```

[] Properties: Storage Variables

```

store

end

```

Methods

```

methods

```

[] Methods: Constructor

Construct an instance of this class

```

function obj = Software_SC_Estimate_Orbit(init_data, mission, i_SC)

    obj.name = [mission.true_SC{i_SC}.true_SC_body.name, ' SW Estimate
Orbit']; % [string]
    obj.flag_executive = 1;

    obj.instantaneous_data_generated_per_sample = 0; % [kb]
    obj.mode_software_SC_estimate_orbit_selector =
init_data.mode_software_SC_estimate_orbit_selector; % [string]

    obj.name_relative_target =
mission.true_SC{i_SC}.true_SC_navigation.name_relative_target; % [string]
    obj.index_relative_target =
mission.true_SC{i_SC}.true_SC_navigation.index_relative_target; % [integer]

```

```

        if isfield(init_data, 'data')
            obj.data = init_data.data;
        else
            obj.data = [];
        end

        % Initialize data fields for error growth mode
        if
strcmp(obj.mode_software_SC_estimate_orbit_selector, 'TruthWithErrorGrowth')
            obj.data.last_target_visible_time = -inf; % [sec] Initialize
to a value that ensures we start with uncertainty
            obj.data.position_error_growth_rate = 0.01; % [km/sec] Rate at
which position uncertainty grows
            obj.data.velocity_error_growth_rate = 0.001; % [km/sec^2] Rate
at which velocity uncertainty grows
        end

        if isfield(init_data, 'compute_wait_time')
            obj.compute_wait_time = init_data.compute_wait_time; % [sec]
        else
            obj.compute_wait_time = 0; % [sec]
        end

        obj.compute_time = -inf; % [sec]

        obj = func_update_software_SC_estimate_orbit_Truth(obj, mission,
i_SC);

        % Initialize Variables to store: position velocity of SC and
Target
        obj.store = [];

        obj.store.position = zeros(mission.storage.num_storage_steps,
length(obj.position));
        obj.store.position_uncertainty =
zeros(mission.storage.num_storage_steps, length(obj.position_uncertainty));

        obj.store.velocity = zeros(mission.storage.num_storage_steps,
length(obj.velocity));
        obj.store.velocity_uncertainty =
zeros(mission.storage.num_storage_steps, length(obj.velocity_uncertainty));

        obj.store.position_relative_target =
zeros(mission.storage.num_storage_steps, length(obj.position));
        obj.store.position_relative_target_uncertainty =
zeros(mission.storage.num_storage_steps,
length(obj.position_relative_target_uncertainty));

        obj.store.velocity_relative_target =
zeros(mission.storage.num_storage_steps, length(obj.velocity));
        obj.store.velocity_relative_target_uncertainty =
zeros(mission.storage.num_storage_steps,
length(obj.velocity_relative_target_uncertainty));

```

```

        obj.store.position_target =
zeros(mission.storage.num_storage_steps, length(obj.position_target));
        obj.store.position_target_uncertainty =
zeros(mission.storage.num_storage_steps,
length(obj.position_target_uncertainty));

        obj.store.velocity_target =
zeros(mission.storage.num_storage_steps, length(obj.velocity_target));
        obj.store.velocity_target_uncertainty =
zeros(mission.storage.num_storage_steps,
length(obj.velocity_target_uncertainty));

        % Update Storage
        obj = func_update_software_SC_estimate_orbit_store(obj, mission);

        % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_software_SC_estimate_orbit_store(obj,
mission)

    if mission.storage.flag_store_this_time_step == 1
        obj.store.position(mission.storage.k_storage,:) =
obj.position; % [km]
        obj.store.position_uncertainty(mission.storage.k_storage,:) =
obj.position_uncertainty;

        obj.store.velocity(mission.storage.k_storage,:) =
obj.velocity; % [km/sec]
        obj.store.velocity_uncertainty(mission.storage.k_storage,:) =
obj.velocity_uncertainty;

obj.store.position_relative_target(mission.storage.k_storage,:) =
obj.position_relative_target; % [km]

obj.store.position_relative_target_uncertainty(mission.storage.k_storage,:) =
obj.position_relative_target_uncertainty;

obj.store.velocity_relative_target(mission.storage.k_storage,:) =
obj.velocity_relative_target; % [km/sec]

```

```

obj.store.velocity_relative_target_uncertainty(mission.storage.k_storage,:) =
obj.velocity_relative_target_uncertainty;

                obj.store.position_target(mission.storage.k_storage,:) =
obj.position_target; % [km]

obj.store.position_target_uncertainty(mission.storage.k_storage,:) =
obj.position_target_uncertainty;

                obj.store.velocity_target(mission.storage.k_storage,:) =
obj.velocity_target; % [km/sec]

obj.store.velocity_target_uncertainty(mission.storage.k_storage,:) =
obj.velocity_target_uncertainty;

        end

    end

```

[] Methods: Main

Main Function

```

function obj = func_main_software_SC_estimate_orbit(obj, mission,
i_SC)

    if (obj.flag_executive == 1)

        switch obj.mode_software_SC_estimate_orbit_selector

            case 'Truth'
                obj =
func_update_software_SC_estimate_orbit_Truth(obj, mission, i_SC);

            case 'TruthWithErrorGrowth'
                obj =
func_update_software_SC_estimate_orbit_TruthWithErrorGrowth(obj, mission,
i_SC);

            otherwise
                error('Orbit Estimation mode not defined!')
            end

            % Update Data Generated

func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

        end

        % Update Storage
        obj = func_update_software_SC_estimate_orbit_store(obj, mission);

```

```
        % Reset Variables
        obj.flag_executive = 0;

    end

end

end
```

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6.7 Software_SC_Executive

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Class: Software_SC_Executive

Tracks the tasks performed by Executive

```
classdef Software_SC_Executive < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
    sc_modes % [Cells of strings] All Spacecraft Modes

    mode_software_SC_executive_selector % [string] Select which Executive
to run

    instantaneous_data_generated_per_sample % [kb] : Data generated per
sample, in kilo bits (kb)

    compute_wait_time % [sec]
```

[] Properties: Variables Computed Internally

```
    name % [string] = SC j for jth SC + SW Executive

    time % [sec] : Current SC time
    date % [sec from J2000] : Current SC date

    this_sc_mode % [string] : Current SC mode
    this_sc_mode_value % [integer] : Current SC mode

    data % Other useful data
```

[] Properties: Storage Variables

```
store
```

end

Methods

methods

[] Methods: Constructor

Construct an instance of this class

```
function obj = Software_SC_Executive(init_data, mission, i_SC)

    obj.name = [mission.true_SC{i_SC}.true_SC_body.name, ' SW
Executive']; % [string]
    obj.time = mission.true_time.time; % [sec]
    obj.date = mission.true_time.date; % [sec from J2000]

    obj.sc_modes = init_data.sc_modes;
    obj.mode_software_SC_executive_selector =
init_data.mode_software_SC_executive_selector;
    obj.instantaneous_data_generated_per_sample = 0; % [kb]

    obj.this_sc_mode = obj.sc_modes{1};
    obj.this_sc_mode_value = func_find_this_sc_mode_value(obj,
obj.this_sc_mode);

    if isfield(init_data, 'data')
        obj.data = init_data.data;
    else
        obj.data = [];
    end

    if isfield(init_data, 'compute_wait_time')
        obj.compute_wait_time = init_data.compute_wait_time; % [sec]
    else
        obj.compute_wait_time = 0; % [sec]
    end

    % Initialize Variables to store: this_sc_mode_value time date data
    obj.store = [];

    obj.store.this_sc_mode_value =
zeros(mission.storage.num_storage_steps, length(obj.this_sc_mode_value));
    obj.store.time = zeros(mission.storage.num_storage_steps,
length(obj.time));
    obj.store.date = zeros(mission.storage.num_storage_steps,
length(obj.date));
    obj.store.sc_modes = obj.sc_modes; % [sec]

    % Additional Executive Variables
    switch obj.mode_software_SC_executive_selector

        case 'DART'
```

```

        obj = func_software_SC_executive_Dart_constructor(obj,
mission, i_SC);

        case 'Nightingale'
            obj =
func_software_SC_executive_Nightingale_constructor(obj, mission, i_SC);

        otherwise
            % Do nothing!
            disp('Using only DART Executive variables!')
        end

        % Update Storage
        obj = func_update_software_SC_executive_store(obj, mission);

        % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end

```

[] Methods: Store

Update the store variable

```

function obj = func_update_software_SC_executive_store(obj, mission)
    if mission.storage.flag_store_this_time_step == 1
        obj.store.this_sc_mode_value(mission.storage.k_storage,:) =
obj.this_sc_mode_value; % [integer]
        obj.store.time(mission.storage.k_storage,:) = obj.time; %
[sec]
        obj.store.date(mission.storage.k_storage,:) = obj.date; %
[sec]

        % Additional Storage Variables
        switch obj.mode_software_SC_executive_selector
            case 'Nightingale'
                obj =
func_update_software_SC_executive_store_Nightingale(obj, mission);

            otherwise
                % Do nothing!
            end
        end
    end
end

```

[] Methods: Main

Main Function

```

function obj = func_main_software_SC_executive(obj, mission, i_SC)

```

```

        % Update Time
        for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_onboard_clock

mission.true_SC{i_SC}.true_SC_onboard_clock{i_HW}.flag_executive = 1; % Make
sure time is measured
            obj.time =
mission.true_SC{i_SC}.true_SC_onboard_clock{i_HW}.measurement_vector(1); %
[sec]
            obj.date =
mission.true_SC{i_SC}.true_SC_onboard_clock{i_HW}.measurement_vector(2); %
[sec from J2000]
        end

        switch obj.mode_software_SC_executive_selector

            case 'DART'
                obj = func_software_SC_executive_DART(obj, mission, i_SC);
                obj.this_sc_mode_value = func_find_this_sc_mode_value(obj,
obj.this_sc_mode);

            case 'Nightingale'
                obj = func_software_SC_executive_Nightingale(obj, mission,
i_SC);

            otherwise
                error('Executive mode not defined!')
            end

        % Update Data Generated

func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

        % Update Storage
        obj = func_update_software_SC_executive_store(obj, mission);

    end

end

end

```

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6.8 Software_SC_Power

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Class: Software_SC_Power

Track the power status onboard the spacecraft

```
classdef Software_SC_Power < handle
```

Properties

```
properties
```

[] Properties: Initialized Variables

```
instantaneous_data_generated_per_sample % [kb] : Data generated per  
sample, in kilo bits (kb)
```

```
mode_software_SC_power_selector % [string] Different power modes  
% - 'Generic'
```

[] Properties: Variables Computed Internally

```
name % [string] = SC j for jth SC + SW Power  
  
flag_executive % [Boolean] Executive has told this sensor/actuator to  
do its job  
  
mean_state_of_charge % [percentage] : Mean SoC is defined by = 100×  
Sum (instantaneous_capacity) / Sum(maximum_capacity)  
  
data % Other useful data
```

[] Properties: Storage Variables

```
store  
  
end
```

Methods

methods

[] Methods: Constructor

Construct an instance of this class

```
function obj = Software_SC_Power(init_data, mission, i_SC)

    obj.name = [mission.true_SC{i_SC}.true_SC_body.name, ' SW
Power']; % [string]
    obj.flag_executive = 0;

    obj.instantaneous_data_generated_per_sample =
init_data.instantaneous_data_generated_per_sample; % [kb]

    obj.mode_software_SC_power_selector =
init_data.mode_software_SC_power_selector;

    if isfield(init_data, 'data')
        obj.data = init_data.data;
    else
        obj.data = [];
    end

    % Update Mean SoC
    obj = func_update_mean_state_of_charge(obj, mission, i_SC);

    % Initialize Variables to store
    obj.store = [];

    obj.store.flag_executive =
zeros(mission.storage.num_storage_steps, length(obj.flag_executive));
    obj.store.mean_state_of_charge =
zeros(mission.storage.num_storage_steps, length(obj.mean_state_of_charge));

    % Update Storage
    obj = func_update_software_SC_power_store(obj, mission);

    % Update SC Data Handling Class

func_initialize_list_HW_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

end
```

[] Methods: Store

Update the store variables

```
function obj = func_update_software_SC_power_store(obj, mission)
```

```

        if mission.storage.flag_store_this_time_step == 1
            obj.store.flag_executive(mission.storage.k_storage,:) =
obj.flag_executive; % [Boolean]
            obj.store.mean_state_of_charge(mission.storage.k_storage,:) =
obj.mean_state_of_charge; % [percentage]
        end

    end
end

```

[] Methods: Main

Main Function

```

function obj = func_main_software_SC_power(obj, mission, i_SC)

    if (obj.flag_executive == 1)

        switch obj.mode_software_SC_power_selector

            case 'Generic'

                % Update Mean SoC
                obj = func_update_mean_state_of_charge(obj, mission,
i_SC);

            case 'Nightingale'
                % obj =
func_update_software_SC_power_Nightingale(obj,mission,i_SC);

                % Update Mean SoC
                obj = func_update_mean_state_of_charge(obj, mission,
i_SC);

            otherwise
                error('Power mode not defined!')
            end

            % Update Data Generated

            func_update_instantaneous_data_generated(mission.true_SC{i_SC}.true_SC_data_handling,
obj, mission);

        end

        % Update Storage
        obj = func_update_software_SC_power_store(obj, mission);

        % Reset Variables
        obj.flag_executive = 0;

    end

end

```

end

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Chapter 7

Main File

7.1 main_v3

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main_v3

This is the main time loop that runs everything!

tic

Time Loop

```
disp('Starting Main Time Loop')
for k = 1:1:mission.true_time.num_time_steps
```

Update Time, Date

```
    func_update_true_time_date(mission.true_time, k);
```

Update Storage

```
    func_update_storage_flag(mission.storage, mission);
    func_update_time_store(mission.true_time, mission);
```

Update Solar System

```
    func_main_true_solar_system(mission.true_solar_system, mission);
```

Update Target Position Velocity

```
    for i_target = 1:1:mission.num_target
        func_main_true_target(mission.true_target{i_target}, mission);
    end
```

For Each Spacecraft

```
    for i_SC = 1:1:mission.num_SC
```

[] Update Solar Radiation Pressure

```
        func_main_true_SC_SRP(mission.true_SC{i_SC}.true_SC_SRP, mission,
i_SC);
```

[] Update Gravity Gradient

```
        func_main_true_SC_gravity_gradient(mission.true_SC{i_SC}.true_SC_gravity_gradient,
mission, i_SC);
```

[] Update SC Body

```
func_main_true_SC_body(mission.true_SC{i_SC}.true_SC_body, mission,
i_SC);
```

[] Update SC Position Velocity

```
func_main_true_SC_navigation(mission.true_SC{i_SC}.true_SC_navigation,
mission, i_SC);
```

[] Update SC Onbaord Clock

```
for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_onboard_clock

func_main_true_SC_onboard_clock(mission.true_SC{i_SC}.true_SC_onboard_clock{i_HW},
mission, i_SC);
end
```

[] Update SC Onboard Computer

```
for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_onboard_computer

func_main_true_SC_onboard_computer(mission.true_SC{i_SC}.true_SC_onboard_computer{i_HW},
mission, i_SC);
end
```

[] Update Software SC Executive

```
func_main_software_SC_executive(mission.true_SC{i_SC}.software_SC_executive,
mission, i_SC);
```

[] Update SC Camera

```
for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_camera

func_main_true_SC_camera(mission.true_SC{i_SC}.true_SC_camera{i_HW}, mission,
i_SC, i_HW);
end

end
```

Attitude Dynamics Loop (ADL)

```
for k_attitude = 1:1:mission.true_time.num_time_steps_attitude
```

[] Update Time in ADL

```
func_update_true_time_attitude(mission.true_time, k_attitude);
```

[] Update Storage in ADL

```
func_update_storage_flag_attitude(mission.storage, mission);  
func_update_time_store_attitude(mission.true_time, mission);
```

[] For Each Spacecraft

```
for i_SC = 1:1:mission.num_SC
```

[] [] Update SC Attitude in ADL

```
    func_main_true_SC_attitude(mission.true_SC{i_SC}.true_SC_adc,  
mission, i_SC);
```

[] [] Update SC Sun Sensor in ADL

```
        for i_HW =  
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_sun_sensor  
  
    func_main_true_SC_sun_sensor(mission.true_SC{i_SC}.true_SC_sun_sensor{i_HW},  
mission, i_SC);  
        end
```

[] [] Update SC Star Tracker in ADL

```
        for i_HW =  
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_star_tracker  
  
    func_main_true_SC_star_tracker(mission.true_SC{i_SC}.true_SC_star_tracker{i_HW},  
mission, i_SC);  
        end
```

[] [] Update SC IMU in ADL

```
        for i_HW =  
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_imu  
            func_main_true_SC_imu(mission.true_SC{i_SC}.true_SC_imu{i_HW},  
mission, i_SC);  
        end
```

[] [] Update Software SC Attitude Estimation in ADL

```
func_main_software_SC_estimate_attitude(mission.true_SC{i_SC}.software_SC_estimate_attitude, mission, i_SC);
```

[] [] Update Software SC Attitude Control

```
func_main_software_SC_control_attitude(mission.true_SC{i_SC}.software_SC_control_attitude, mission, i_SC);
```

[] Update Micro Thrusters

```
for i_HW =  
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_micro_thruster  
  
func_main_true_SC_micro_thruster(mission.true_SC{i_SC}.true_SC_micro_thruster{i_HW},  
mission, i_SC, i_HW);  
end
```

[] Update Reaction wheels

```
for i_HW =  
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_reaction_wheel  
  
func_main_true_reaction_wheel(mission.true_SC{i_SC}.true_SC_reaction_wheel{i_HW},  
mission, i_SC, i_HW);  
end  
  
end  
  
end
```

For Each Spacecraft

```
for i_SC = 1:1:mission.num_SC
```

[] Update SC Science Radar

```
for i_HW =  
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_science_radar  
  
func_main_true_SC_science_radar(mission.true_SC{i_SC}.true_SC_science_radar{i_HW},  
mission, i_SC, i_HW);  
end
```

[] Update SC Science Processor

```
    for i_HW =  
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_science_processor  
  
func_main_true_SC_science_processor(mission.true_SC{i_SC}.true_SC_science_processor{i_HW},  
mission, i_SC);  
    end
```

[] Update Software SC Communication

```
func_main_software_SC_communication(mission.true_SC{i_SC}.software_SC_communication,  
mission, i_SC);
```

[] Update SC Communication Link

```
    for i_HW =  
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_communication_link  
  
func_main_true_SC_communication_link(mission.true_SC{i_SC}.true_SC_communication_link{i_HW},  
mission, i_SC);  
    end
```

[] Update SC Radio Antenna

```
    for i_HW =  
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_radio_antenna  
  
func_main_true_SC_radio_antenna(mission.true_SC{i_SC}.true_SC_radio_antenna{i_HW},  
mission, i_SC);  
    end
```

[] Update SC Generic Sensor

```
    for i_HW =  
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_generic_sensor  
  
func_main_true_SC_generic_sensor(mission.true_SC{i_SC}.true_SC_generic_sensor{i_HW},  
mission, i_SC);  
    end
```

[] Update SC Solar Panels

```
    for i_HW =  
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_solar_panel  
  
func_main_true_SC_solar_panel(mission.true_SC{i_SC}.true_SC_solar_panel{i_HW},  
mission, i_SC);  
    end
```

[] Update Software SC Orbit Estimation in ADL

```
func_main_software_SC_estimate_orbit(mission.true_SC{i_SC}.software_SC_estimate_orbit,  
mission, i_SC);
```

[] Update Software SC Orbit Control in ADL

```
func_main_software_SC_control_orbit(mission.true_SC{i_SC}.software_SC_control_orbit,  
mission, i_SC);
```

[] Update Chemical Thruster

```
    for i_HW =  
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_chemical_thruster  
  
func_main_true_chemical_thruster(mission.true_SC{i_SC}.true_SC_chemical_thruster{i_HW},  
mission, i_SC, i_HW);  
    end
```

[] Update Fuel Tanks

```
    for i_HW =  
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_fuel_tank  
  
func_main_true_SC_fuel_tank(mission.true_SC{i_SC}.true_SC_fuel_tank{i_HW},  
mission, i_SC);  
    end
```

[] Update SC Battery

```
    for i_HW =  
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_battery  
  
func_main_true_SC_battery(mission.true_SC{i_SC}.true_SC_battery{i_HW},  
mission, i_SC);  
    end
```

[] Update Software SC Power

```
func_main_software_SC_power(mission.true_SC{i_SC}.software_SC_power,  
mission, i_SC);
```

[] Update SC Data Handling

```
func_main_true_SC_data_handling(mission.true_SC{i_SC}.true_SC_data_handling,  
mission, i_SC);
```

[] Update SC Onboard Memory

```
    for i_HW =  
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_onboard_memory  
  
func_main_true_SC_onboard_memory(mission.true_SC{i_SC}.true_SC_onboard_memory{i_HW},  
mission, i_SC);  
    end
```

[] Update Software SC Data Handling

```
func_main_software_SC_data_handling(mission.true_SC{i_SC}.software_SC_data_handling,  
mission, i_SC);
```

[] Update SC Power

```
    func_main_true_SC_power(mission.true_SC{i_SC}.true_SC_power, mission,  
i_SC);  
  
    end
```

Update Ground Stations's Radio Antenna

```
    for i_HW = 1:1:mission.true_ground_station.num_GS_radio_antenna  
        func_main_true_GS_radio_antenna(mission.true_GS_radio_antenna{i_HW},  
mission);  
    end
```

Update Ground Station

```
func_main_true_ground_station(mission.true_ground_station, mission, i_SC);
```

Fix Warnings

```
w = warning('query', 'last');  
if ~isempty(w)  
    warning('off', w.identifier);  
end
```

Update real-time visualization

```
func_update_realtime_plot(mission.storage, mission);
```

Stop Sim

```
if mission.storage.flag_stop_sim == 1  
    disp('Stopping Sim!')
```

```
        break
    end
end
```

Close all SPICE files

```
cspice_kclear
```

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Chapter 8

Mission Classes

8.1 Mission_DART

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DART Mission

Initialization File for DART (Double Asteroid Redirection Test) mission simulation

```

% Clear workspace
clear
close all
clc

% Change workspace folder to this file location
mfile_name      = mfilename('fullpath');
[pathstr,name,ext] = fileparts(mfile_name);
cd(pathstr);
clear mfile_name pathstr name ext

% Add required paths
addpath(genpath('.././MuSCAT_Supporting_Files'))
addpath(genpath('.././'))

```

Mission Definition

```

mission = [];
mission.name = 'DART';           % Name of the Mission
mission.num_SC = 1;             % Number of Spacecraft
mission.num_target = 1;         % Number of Target bodies
mission.frame = 'Absolute';      % Frame type: 'Absolute', 'Relative', or
                                % 'Combined'
mission.flag_stop_sim = 0;       % Boolean flag to stop simulation if needed

```

Time Configuration

```

init_data = [];
init_data.t_initial = 0;         % [sec] Initial
                                % time
init_data.t_final = 200000;      % [sec] Final time
init_data.time_step = 5;         % [sec] Simulation
                                % time step
init_data.t_initial_date_string = '02-NOV-2018 00:00:00'; % Format = [DD-
MMM-YYYY HH:MM:SS]
init_data.time_step_attitude = 0.1; % [sec] Time step
                                % for attitude dynamics
mission.true_time = True_Time(init_data);

```

Storage Configuration

```

init_data = [];
init_data.time_step_storage = 0;
init_data.time_step_storage_attitude = 0;
init_data.flag_visualize_SC_attitude_orbit_during_sim = 0; % [Boolean] Show
                                % attitude during sim
init_data.flag_realtime_plotting = 1; % [Boolean] Show mission data and
                                % attitude during sim
init_data.flag_save_plots = 1; % [Boolean] 1: Save them (takes
                                % little time), 0: Doesnt save them
init_data.flag_save_video = 0; % [Boolean] 1: Save them (takes
                                % more time), 0: Doesnt save them

```

```
mission.storage = Storage(init_data, mission);

% Set font size for plots
mission.storage.plot_parameters.standard_font_size = 15;

% Initialize time storage
func_initialize_time_store(mission.true_time, mission);
```

Star Catalog Configuration

```
mission.true_stars = True_Stars(mission);
mission.true_stars.maximum_magnitude = 10; % Maximum star magnitude to
include
```

Solar System Configuration

```
init_data = [];
init_data.SS_body_names = ["Sun", "Earth"]; % Solar system bodies to include
mission.true_solar_system = True_Solar_System(init_data, mission);
```

Target Body Configuration

```
for i_target = 1:1:mission.num_target
    init_data = [];
    init_data.target_name = 'Bennu'; % Target asteroid name
    mission.true_target{i_target} = True_Target_SPICE(init_data, mission);
end
```

Ground Station Configuration

```
init_data = [];
init_data.num_GS_radio_antenna = 1; % Number of ground station
antennas
mission.true_ground_station = True_Ground_Station(init_data, mission);
```

Ground Station Radio Antenna Configuration

```
for i_HW = 1:1:mission.true_ground_station.num_GS_radio_antenna
    init_data = [];
    init_data.antenna_type = 'High Gain';
    init_data.mode_true_GS_radio_antenna_selector = 'RX';

    % Link Margin Calculation Parameters
    init_data.antenna_gain = 90; % [dB]
    init_data.noise_temperature = 100; % [K]
    init_data.beamwidth = 0.1; % [MHz]
    init_data.energy_bit_required = 4.2; % [dB]
    init_data.line_loss = 0; % [dB]
    init_data.coding_gain = 7.3; % [dB]
```

```
mission.true_GS_radio_antenna{i_HW} = True_GS_Radio_Antenna(init_data,  
mission, i_HW);  
end
```

Spacecraft Initialization

```
for i_SC = 1:1:mission.num_SC  
mission.true_SC{i_SC} = [];  
end
```

Spacecraft Body Configuration

```
i_SC = 1; % First spacecraft  
  
init_data = [];  
init_data.i_SC = i_SC;  
  
% Body shape model  
init_data.shape_model{1} = [];  
init_data.shape_model{1}.Vertices = [0 0 0;  
0.3 0 0;  
0.3 0 0.1;  
0 0 0.1;  
0 0.2 0;  
0.3 0.2 0;  
0.3 0.2 0.1;  
0 0.2 0.1]; % [m]  
init_data.shape_model{1}.Faces = [1 2 3;  
1 4 3;  
2 3 7;  
2 6 7;  
3 4 8;  
3 7 8;  
1 4 8;  
1 5 8;  
1 2 6;  
1 5 6;  
5 6 7;  
5 8 7];  
  
init_data.shape_model{1}.Face_reflectance_factor =  
0.6*ones(size(init_data.shape_model{1}.Faces,1),1);  
init_data.shape_model{1}.type = 'cuboid';  
init_data.shape_model{1}.mass = 11; % [kg] Dry mass  
  
% Additional mass components  
init_data.mass.supplement{1}.mass = 0.5; % [kg]  
init_data.mass.supplement{1}.location = [0.1 0 0]; % [m]  
init_data.mass.supplement{1}.MI_over_m = zeros(3,3); % [m^2]  
  
init_data.mass.supplement{2}.mass = 0.5; % [kg]  
init_data.mass.supplement{2}.location = [0 0 0.1]; % [m]  
init_data.mass.supplement{2}.MI_over_m = zeros(3,3); % [m^2]
```

```

init_data.mode_COM_selector = 'update'; % Compute Center of Mass dynamically
init_data.mode_MI_selector = 'update'; % Compute Moment of Inertia
    dynamically

% Initialize hardware configuration
run init_num_hardware_exists
init_data.num_hardware_exists = num_hardware_exists;
clear num_hardware_exists

% Define hardware complement
init_data.num_hardware_exists.num_onboard_clock = 1;
init_data.num_hardware_exists.num_camera = 1;
init_data.num_hardware_exists.num_solar_panel = 3;
init_data.num_hardware_exists.num_battery = 2;
init_data.num_hardware_exists.num_onboard_memory = 2;
init_data.num_hardware_exists.num_sun_sensor = 6;
init_data.num_hardware_exists.num_star_tracker = 3;
init_data.num_hardware_exists.num_imu = 1;
init_data.num_hardware_exists.num_micro_thruster = 12;
init_data.num_hardware_exists.num_chemical_thruster = 1;
init_data.num_hardware_exists.num_reaction_wheel = 3;
init_data.num_hardware_exists.num_communication_link = 2;
init_data.num_hardware_exists.num_radio_antenna = 1;
init_data.num_hardware_exists.num_fuel_tank = 1;
init_data.num_hardware_exists.num_onboard_computer = 2;

mission.true_SC{i_SC}.true_SC_body = True_SC_Body(init_data, mission);

```

Initialize First Spacecraft's Position and Velocity

```

init_data = [];
init_data.spice_filename = '../MuSCAT_Supporting_Files/SC_data/DART/
traj_daresim_simple.bsp'; % [string] : SC's SPICE FileName
cspice_furnsh(init_data.spice_filename)

% bandyopa@MT-319257 exe % ./brief ../MuSCAT_Supporting_Files/SC_data/traj_daresim_simple.bsp
%
% BRIEF -- Version 4.0.0, September 8, 2010 -- Toolkit Version N0066
%
%
% Summary for: ../MuSCAT_Supporting_Files/SC_data/traj_daresim_simple.bsp
%
% Body: -110
%      Start of Interval (ET)                End of Interval (ET)
%      -----
%      2018 OCT 27 21:36:30.000                2018 NOV 03 21:36:00.000

init_data.spice_name = '-110'; % [string] : SC's SPICE Name

% Sun centered - J2000 frame (inertial)

```

```
init_data.SC_pos_vel =
    cspice_spkezr(init_data.spice_name,mission.true_time.date,'J2000','NONE','SUN');
init_data.position = init_data.SC_pos_vel(1:3)'; % [km]
init_data.velocity = init_data.SC_pos_vel(4:6)'; % [km/sec]

init_data.mode_true_SC_navigation_dynamics_selector = 'Absolute Dynamics';

mission.true_SC{i_SC}.true_SC_navigation = True_SC_Navigation(init_data,
    mission);
```

Initialize First Spacecraft's Attitude

```
init_data = [];
init_data.SC_MRP_init = [0.1 0.2 0.3]; % MRP
init_data.SC_omega_init = [0 0 0.001]; % [rad/sec]

init_data.SC_e_init = init_data.SC_MRP_init/norm(init_data.SC_MRP_init);
init_data.SC_Phi_init = 4*atand(init_data.SC_MRP_init(1)/
    init_data.SC_e_init(1)); % [deg]
init_data.SC_beta_v_init = init_data.SC_e_init *
    sind(init_data.SC_Phi_init/2);
init_data.SC_beta_4_init = cosd(init_data.SC_Phi_init/2);

init_data.attitude = [init_data.SC_beta_v_init, init_data.SC_beta_4_init]; %
    [quaternion]
init_data.attitude = func_quaternion_properize(init_data.attitude); %
    [quaternion] properized
init_data.angular_velocity = init_data.SC_omega_init;

init_data.mode_true_SC_attitude_dynamics_selector = 'Rigid';

mission.true_SC{i_SC}.true_SC_adc = True_SC_ADC(init_data, mission);
```

Initialize First Spacecraft's Power

```
init_data = [];
init_data.power_loss_rate = 0.05; % [float] 5% power loss in distribution and
    conversion
mission.true_SC{i_SC}.true_SC_power = True_SC_Power(init_data, mission);
```

Initialize First Spacecraft's Data

```
init_data = [];
init_data.mode_true_SC_data_handling_selector = 'Generic';
mission.true_SC{i_SC}.true_SC_data_handling = True_SC_Data_Handling(init_data,
    mission);
```

Initialize First Spacecraft's Radio Antenna

```
for i_HW =
    1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_radio_antenna
```

```

init_data = [];
init_data.location = [0 1 0]; % [unit vector] antenna physical axis in
Body frame
init_data.orientation = [0 0 1]; % [unit vector] antenna pointing
direction for nominal gain in Body frame

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Antennas
init_data.antenna_type = "dipole"; % antenna type
init_data.antenna_gain = 28.1; % [dB] Gain of DTE antenna SC
init_data.antenna_axis = [0 1 0]; % [unit vector] antenna physical
axis in Body frame
init_data.antenna_pointing = [0 0 1]; % [unit vector] antenna pointing
direction for nominal gain in Body frame
init_data.antenna_frequency = 8450; % [MHz]
init_data.tx_line_loss = 1; % [dB]
init_data.noise_temperature = 100; % [K]
init_data.energy_bit_required = 4.2; % [dB]
init_data.coding_gain = 7.3; % [dB]
init_data.beamwidth = 0.1; % [MHz]

init_data.maximum_data_rate = 1000; % [kbps]
init_data.base_data_rate_generated = 10; % [kbps]

init_data.TX_power_consumed = 50; % [W] Based on 50 W RF output and 50%
efficiency
init_data.RX_power_consumed = 25; % [W] Typical for spacecraft receivers

mission.true_SC{i_SC}.true_SC_radio_antenna{i_HW} =
True_SC_Radio_Antenna(init_data, mission, i_SC, i_HW);
end

```

Spacecraft Fuel Tank Configuration

```

for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_fuel_tank
init_data = [];

% Basic properties
init_data.name = ['Fuel Tank ', num2str(i_HW)];
init_data.instantaneous_power_consumed = 2.0; % [W] for heaters,
valves, etc.
init_data.instantaneous_data_rate_generated = 0.1; % [kbps] for telemetry

% Fuel properties
init_data.maximum_capacity = 5.0; % [kg] total fuel capacity
init_data.initial_fuel_mass = 5.0; % [kg] initial fuel mass (full tank)
init_data.fuel_density = 1000; % [kg/m^3] typical hydrazine density

% Physical properties
init_data.location = [0.15, 0.1, 0.05]; % [m] tank location in body frame

```

```

% Shape model - simplified cuboid
init_data.shape_model = [];
init_data.shape_model.Vertices = [
    0.1, 0.05, 0.0;
    0.2, 0.05, 0.0;
    0.2, 0.15, 0.0;
    0.1, 0.15, 0.0;
    0.1, 0.05, 0.1;
    0.2, 0.05, 0.1;
    0.2, 0.15, 0.1;
    0.1, 0.15, 0.1
];
init_data.shape_model.Faces = [
    1, 2, 3;
    1, 3, 4;
    5, 6, 7;
    5, 7, 8;
    1, 2, 6;
    1, 6, 5;
    2, 3, 7;
    2, 7, 6;
    3, 4, 8;
    3, 8, 7;
    4, 1, 5;
    4, 5, 8
];
init_data.shape_model.type = 'cuboid';

% Create fuel tank object
mission.true_SC{i_SC}.true_SC_fuel_tank{i_HW} =
True_SC_Fuel_Tank(init_data, mission, i_SC, i_HW);

% Update spacecraft body with fuel mass properties
mission.true_SC{i_SC}.true_SC_body.mass.propellant{i_HW}.mass =
init_data.initial_fuel_mass;
mission.true_SC{i_SC}.true_SC_body.mass.propellant{i_HW}.location =
init_data.location;
mission.true_SC{i_SC}.true_SC_body.mass.propellant{i_HW}.MI_over_m =
zeros(3,3); % Simple approximation

% Trigger mass properties update
mission.true_SC{i_SC}.true_SC_body.flag_update_SC_body_total_mass_COM_MI =
1;
end

```

Initialize First Spacecraft's Solar Panels

```

for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_solar_panel

    init_data = [];
    init_data.instantaneous_power_consumed = 0.01; % [W] (irrespective of
whether it is generating power or not)

```

```

init_data.instantaneous_data_rate_generated = (1e-3)*8; % [kbps] i.e. 1
Byte per sec

init_data.shape_model = [];
init_data.shape_model.Vertices = [0 0 0; 0.2 0 0; 0.2 0 -0.6; 0 0 -0.6];
    % [m] vertices
init_data.shape_model.Faces = [1 2 3; 1 4 3];
    % faces
init_data.shape_model.Face_reflectance_factor_solar_cell_side = [0.01;
0.01]; % reflectance factor of solar cell side
init_data.shape_model.Face_reflectance_factor_opposite_side = [0.5; 0.5];
    % reflectance factor of solar cell side
init_data.shape_model.Face_orientation_solar_cell_side = [0 -1 0];
    % orientation normal vector of solar cell side
init_data.shape_model.type = 'cuboid';

init_data.mass = 0.24; % [kg] ~ 2 kg/m^2

init_data.type = 'passive_deployed';
% 'body_mounted' : Stuck to SC side (only solar cell side is used for SRP)
% 'passive_deployed' : Passively deployed (orientation in body frame B
does not change, i.e. it is static)
% 'active_deployed_gimballed' : Actively gimballed (orientation in body
frame B changes)

init_data.packing_fraction = 0.74; % Packing fraction of solar cells in
solar panel
init_data.solar_cell_efficiency = 0.28; % Efficiency of each solar cell

if i_HW == 2
    init_data.shape_model.Vertices = [0 0 0.1; 0.2 0 0.1; 0.2 0 0.7; 0 0
0.7]; % [m] vertices
end

if i_HW == 3
    init_data.shape_model.Vertices =
mission.true_SC{i_SC}.true_SC_body.shape_model{1}.Vertices;
    init_data.shape_model.Faces =
mission.true_SC{i_SC}.true_SC_body.shape_model{1}.Faces(1:2,:);
    init_data.type = 'body_mounted';
end

mission.true_SC{i_SC}.true_SC_solar_panel{i_HW} =
True_SC_Solar_Panel(init_data, mission, i_SC, i_HW);

end

```

Initialize First Spacecraft's Battery

```

for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_battery

```

```

init_data = [];
init_data.maximum_capacity = 40; % [W hr]
init_data.charging_efficiency = 0.96; % [float <= 1]
init_data.discharging_efficiency = 0.96; % [float <= 1]
init_data.instantaneous_power_consumed = 1e-4; % [W]
init_data.instantaneous_data_rate_generated = (1e-3)*8; % [kbps] i.e. 1
Byte per sec

mission.true_SC{i_SC}.true_SC_battery{i_HW} = True_SC_Battery(init_data,
mission, i_SC, i_HW);

end

```

Initialize First Spacecraft's Onboard Memory

```

for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_onboard_memory

    init_data = [];
    init_data.maximum_capacity = 1e6; % [kb]
    init_data.instantaneous_power_consumed = 1; % [W]
    init_data.instantaneous_data_rate_generated = (1e-3)*8; % [kbps] i.e. 1
    Byte per sec

    mission.true_SC{i_SC}.true_SC_onboard_memory{i_HW} =
    True_SC_Onboard_Memory(init_data, mission, i_SC, i_HW);

end

```

Initialize First Spacecraft's Onboard Clock

```

for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_onboard_clock

    init_data = [];
    init_data.instantaneous_power_consumed = 0.1; % [W]
    init_data.instantaneous_data_rate_generated = (1e-3)*16; % [kbps] i.e. 2
    Bytes per sec
    init_data.mode_true_SC_onboard_clock_selector = 'Simple';
    init_data.measurement_wait_time = 0; % [sec]

    mission.true_SC{i_SC}.true_SC_onboard_clock{i_HW} =
    True_SC_Onboard_Clock(init_data, mission, i_SC, i_HW);

end

```

Initialize First Spacecraft's Cameras

```

for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_camera

```

```

init_data = [];
init_data.instantaneous_power_consumed = 10; % [W] https://
dragonflyaerospace.com/products/caiman/
init_data.mode_true_SC_camera_selector = 'Simple';
init_data.measurement_wait_time = 60; % [sec] -> This was 10x60 but in the
v1 is 60 only and that is how switch mode is implemented

init_data.location = [0.3 0.1 0.05]; % [m]
init_data.orientation = [1 0 0]; % [unit vector]
init_data.orientation_up = [0 0 1]; % [unit vector]

init_data.resolution = [512 512]; % [x y] pixel
init_data.field_of_view = 10; % [deg]
init_data.flag_show_camera_plot = 0;
init_data.flag_show_stars = 1;

init_data.instantaneous_data_generated_per_pixel = (1e-3)* 8; % [kb]

mission.true_SC{i_SC}.true_SC_camera{i_HW} = True_SC_Camera(init_data,
mission, i_SC, i_HW);

end

```

Initialize First Spacecraft's Sun Sensors

```

for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_sun_sensor

    init_data = [];
    init_data.instantaneous_power_consumed = 36e-3; % [W] https://
www.cubesatshop.com/wp-content/uploads/2016/06/SSOCA60-Technical-
Specifications.pdf
    init_data.instantaneous_data_generated_per_sample = (4 + 1)*16e-3; %
[kb] : 4 quaternion + 1 time vector, each of 16-bit depth
    init_data.mode_true_SC_sun_sensor_selector = 'Simple with Sun in FOV';
    init_data.measurement_wait_time = 0.1; % [sec]
    init_data.measurement_noise = deg2rad(0.5); % [rad] 0.5 degrees
    init_data.field_of_view = 60; % [deg]

    switch i_HW

        case 1
            init_data.location = [0.3 0.05 0.05]; % [m]
            init_data.orientation = [1 0 0]; % [unit vector]

        case 2
            init_data.location = [0 0.05 0.05]; % [m]
            init_data.orientation = [-1 0 0]; % [unit vector]

        case 3
            init_data.location = [0.15 0.2 0.05]; % [m]
            init_data.orientation = [0 1 0]; % [unit vector]
    end
end

```

```

    case 4
        init_data.location = [0.15 0 0.05]; % [m]
        init_data.orientation = [0 -1 0]; % [unit vector]

    case 5
        init_data.location = [0.15 0.1 0.1]; % [m]
        init_data.orientation = [0 0 1]; % [unit vector]

    case 6
        init_data.location = [0.15 0.1 0]; % [m]
        init_data.orientation = [0 0 -1]; % [unit vector]

    otherwise
        error('Should not reach here!')
    end

    mission.true_SC{i_SC}.true_SC_sun_sensor{i_HW} =
    True_SC_Sun_Sensor(init_data, mission, i_SC, i_HW);
end

```

Initialize First Spacecraft's Star Tracker

```

for i_HW =
    1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_star_tracker

    init_data = [];

    init_data.instantaneous_power_consumed = 1.5; %
    [W] https://www.bluecanyontech.com/static/datasheet/
    BCT_DataSheet_Components_StarTrackers.pdf
    init_data.instantaneous_data_generated_per_sample = (4 + 1)*16e-3; %
    [kb] : 4 quaternion + 1 time vector, each of 16-bit depth
    init_data.mode_true_SC_star_tracker_selector = 'Simple with Sun outside
    FOV';
    init_data.measurement_wait_time = 0.1; % [sec]
    init_data.measurement_noise = 2e-4; % [rad]
    init_data.field_of_view = 90; % [deg]

    switch i_HW

        case 1
            init_data.location = [0.3 0.15 0.05]; % [m]
            init_data.orientation = [1 0 0]; % [unit vector]

        case 2
            init_data.location = [0 0.15 0.05]; % [m]
            init_data.orientation = [-1 0 0]; % [unit vector]

        case 3
            init_data.location = [0.10 0.2 0.05]; % [m]
            init_data.orientation = [0 1 0]; % [unit vector]

```

```

        otherwise
            error('Should not reach here!')
        end

        mission.true_SC{i_SC}.true_SC_star_tracker{i_HW} =
        True_SC_Star_Tracker(init_data, mission, i_SC, i_HW);

end

```

Initialize First Spacecraft's IMU

```

for i_HW = 1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_imu

    init_data = [];

    init_data.instantaneous_power_consumed = 0.6; % [W] https://www.micro-a.net/imu-tmpl.html
    init_data.instantaneous_data_generated_per_sample = (3 + 1)*16e-3; %
    [kb] : 3 angular velocity + 1 time vector, each of 16-bit depth
    init_data.mode_true_SC_imu_selector = 'Simple';
    init_data.measurement_wait_time = 0.1; % [sec]
    init_data.measurement_noise = 9.7e-5; % [rad/sec]

    init_data.location = [0 0 0]; % [m]
    init_data.orientation = [1 0 0]; % [unit vector]

    mission.true_SC{i_SC}.true_SC_imu{i_HW} = True_SC_IMU(init_data, mission,
    i_SC, i_HW);

end

```

Initialize First Spacecraft's Micro Thrusters

```

for i_HW =
    1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_micro_thruster

    init_data = [];

    init_data.instantaneous_power_consumption = 10; % Watts
    init_data.instantaneous_data_generated_per_sample = (3)*16e-3; % [kb] :
    thrust + health + temperature, each of 16-bit depth
    init_data.mode_true_SC_micro_thruster_selector = 'Simple'; % Mode (Truth/
    Simple)
    init_data.thruster_noise = 100*(1e-6); % Noise level [N](unit depends on
    implementation)

    init_data.micro_thruster_ISP = 700; % [sec]

    init_data.minimum_thrust = 0.001; % [N]
    init_data.maximum_thrust = 10*(1e-2); % [N]

    init_data.command_wait_time = 0.5; % Seconds between commands

end

```

```
switch i_HW
case 1
    init_data.location = [0.3 0.1 0.05]; % [m]
    init_data.orientation = [0 1 0]; % [unit vector]

case 2
    init_data.location = [0.3 0.1 0.05]; % [m]
    init_data.orientation = [0 -1 0]; % [unit vector]

case 3
    init_data.location = [0.3 0.1 0.05]; % [m]
    init_data.orientation = [0 0 1]; % [unit vector]

case 4
    init_data.location = [0.3 0.1 0.05]; % [m]
    init_data.orientation = [0 0 -1]; % [unit vector]

case 5
    init_data.location = [0 0.1 0.05]; % [m]
    init_data.orientation = [0 1 0]; % [unit vector]

case 6
    init_data.location = [0 0.1 0.05]; % [m]
    init_data.orientation = [0 -1 0]; % [unit vector]

case 7
    init_data.location = [0 0.1 0.05]; % [m]
    init_data.orientation = [0 0 1]; % [unit vector]

case 8
    init_data.location = [0 0.1 0.05]; % [m]
    init_data.orientation = [0 0 -1]; % [unit vector]

case 9
    init_data.location = [0.15 0.2 0.05]; % [m]
    init_data.orientation = [0 0 1]; % [unit vector]

case 10
    init_data.location = [0.15 0.2 0.05]; % [m]
    init_data.orientation = [0 0 -1]; % [unit vector]

case 11
    init_data.location = [0.15 0 0.05]; % [m]
    init_data.orientation = [0 0 1]; % [unit vector]

case 12
    init_data.location = [0.15 0 0.05]; % [m]
    init_data.orientation = [0 0 -1]; % [unit vector]

otherwise
    error('Should not reach here!')
end
```

```

    mission.true_SC{i_SC}.true_SC_micro_thruster{i_HW} =
    True_SC_Micro_Thruster(init_data, mission, i_SC, i_HW);

```

```

end

```

Initialize the Reaction Wheels

Dart can be simulated using 3 or 4 wheels as an example !

```

for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_reaction_wheel

    init_data = [];
    init_data.location = [0,0,0];
    init_data.radius = (43e-3)/2; % [m] radius of 1 RW
    init_data.mass = 0.137; % [kg] mass of 1 RW
    init_data.max_angular_velocity = 6500*2*pi/60; % [rad/s] 6500 RPM
    init_data.angular_velocity_noise = 0.001*2*pi/60; % [rad/s] velocity
noise (reduced from 0.01)
    init_data.instantaneous_data_generated_per_sample = (3)*16e-3; % [kb] :
thrust + health + temperature, each of 16-bit depth
    init_data.max_torque = 3.2*1e-3; % Nm

    % Calculate and set maximum acceleration
    % This is redundant with the calculation in the True_SC_Reaction_Wheel
constructor,
    % but makes it explicit and easier to adjust
    moment_of_inertia = 0.5 * init_data.mass * init_data.radius^2;
    init_data.maximum_acceleration = init_data.max_torque /
moment_of_inertia; % rad/s^2

    init_data.power_consumed_angular_velocity_array = [1e-3*[180 600
6000]; [0 1000*2*pi/60 init_data.max_angular_velocity]]; % [power_array ;
velocity_array]

    % 3 wheel configuration

    if(mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_reaction_wheel
== 3)
        switch i_HW
            case 1
                init_data.orientation = [1, 0, 0]; % X-axis
            case 2
                init_data.orientation = [0, 1, 0]; % Y-axis
            case 3
                init_data.orientation = [0, 0, 1]; % Z-axis
        end
    end

    % 4 wheel configuration

    if(mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_reaction_wheel
== 4)

```

```

        switch i_HW
        case 1
            init_data.orientation = [1, 1, 0]/sqrt(2); % Diagonal in XY-
plane
        case 2
            init_data.orientation = [1, -1, 0]/sqrt(2); % Diagonal in XY-
plane
        case 3
            init_data.orientation = [0, 1, 1]/sqrt(2); % Diagonal in YZ-
plane
        case 4
            init_data.orientation = [0, 1, -1]/sqrt(2); % Diagonal in YZ-
plane
        end
    end

    mission.true_SC{i_SC}.true_SC_reaction_wheel{i_HW} =
    True_SC_Reaction_Wheel(init_data, mission, i_SC, i_HW);

end

```

Chemical Thruster Configuration

```

for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_chemical_thruster

    init_data = [];

    % Power and data parameters
    init_data.instantaneous_power_consumption = 2.0; % [W] Base power
draw (standby)
    init_data.thruster_warm_up_power_consumed = 5.0; % [W] Power during
warm-up phase
    init_data.command_actuation_power_consumed = 15.0; % [W] Power during
active thrust
    init_data.instantaneous_data_generated_per_sample = 10; % [kb] per sample
    init_data.chemical_thruster_noise = 10e-4; % [N] Thrust noise
level

    % Thruster properties
    init_data.chemical_thruster_ISP = 200; % [s] Specific
impulse
    init_data.command_wait_time = 1; % [s] Minimum time
between commands
    init_data.location = [0.3, 0.2/2, 0.1/2]; % [m] Thruster
location in body frame
    init_data.orientation = [-1, 0, 0]; % Thrust direction
(unit vector)

    init_data.maximum_thrust = 1; % [N] Maximum
thrust level
    init_data.minimum_thrust = 0.01; % [N] Minimum
thrust level

```

```

    % Create chemical thruster object
    mission.true_SC{i_SC}.true_SC_chemical_thruster{i_HW} =
    True_SC_Chemical_Thruster(init_data, mission, i_SC, i_HW);
end

```

Onboard Computer Configuration

```

for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_onboard_computer
    init_data = [];

    % Basic properties
    init_data.name = ['Onboard Computer ', num2str(i_HW)];

    % Set different properties for primary and backup computers
    if i_HW == 1
        % Primary computer
        init_data.instantaneous_power_consumed = 8.0;      % [W] Main flight
computer
        init_data.instantaneous_data_rate_generated = 2.0; % [kbps] for
telemetry and logs
        init_data.processor_utilization = 25;              % [%] Fixed CPU
usage
    else
        % Backup computer
        init_data.instantaneous_power_consumed = 4.0;      % [W] Backup in
standby mode
        init_data.instantaneous_data_rate_generated = 0.5; % [kbps] minimal
telemetry
        init_data.processor_utilization = 5;              % [%] Fixed low
utilization in standby
    end

    % Create onboard computer object
    mission.true_SC{i_SC}.true_SC_onboard_computer{i_HW} =
    True_SC_Onboard_Computer(init_data, mission, i_SC, i_HW);
end

```

Spacecraft Communication Links Configuration

```

for i_HW =
1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_communication_link
    init_data = [];

    % Configure appropriate link based on index
    if i_HW == 1
        % Downlink: Spacecraft to Earth
        init_data.TX_spacecraft = i_SC;          % Transmitter is this
spacecraft
    end
end

```

```

        init_data.TX_spacecraft_Radio_HW = 1;           % Using antenna 1

        init_data.RX_spacecraft = 0;                   % Receiver is Ground
Station (0)
        init_data.RX_spacecraft_Radio_HW = 1;           % Using GS antenna 1

        init_data.flag_compute_data_rate = 0;           % Use given data rate
instead of computing
        init_data.given_data_rate = 360;                % [kbps] Downlink data
rate
    else
        % Uplink: Earth to Spacecraft
        init_data.TX_spacecraft = 0;                   % Transmitter is Ground
Station (0)
        init_data.TX_spacecraft_Radio_HW = 1;           % Using GS antenna 1

        init_data.RX_spacecraft = i_SC;                 % Receiver is this
spacecraft
        init_data.RX_spacecraft_Radio_HW = 1;           % Using antenna 1

        init_data.flag_compute_data_rate = 0;           % Use given data rate
instead of computing
        init_data.given_data_rate = 0;                 % [kbps] Set low to avoid
overfilling memory
    end

    % Create communication link object
    mission.true_SC{i_SC}.true_SC_communication_link{i_HW} =
True_SC_Communication_Link(init_data, mission, i_SC, i_HW);
end

```

Initialize Solar Radiation Pressure

```

init_data = [];
init_data.enable_SRP = 1; % Enable SRP calculations

mission.true_SC{i_SC}.true_SC_SRP = True_SC_SRP(init_data, mission, i_SC);

```

Initialize Gravity Gradient for Earth

```

init_data = [];
init_data.enable_G2 = 0; % Disable gravity gradient because Dart is an
interceptor

mission.true_SC{i_SC}.true_SC_gravity_gradient =
True_SC_Gravity_Gradient(init_data, mission, i_SC);

```

Spacecraft Software: Executive Configuration

```

init_data = [];
init_data.sc_modes = {'Point camera to Target', 'Maximize SP Power', 'Point
Thruster along DeltaV direction', 'DTE Comm'};

```

```
init_data.mode_software_SC_executive_selector = 'DART';
```

```
mission.true_SC{i_SC}.software_SC_executive = Software_SC_Executive(init_data,  
    mission, i_SC);
```

Spacecraft Software: Attitude Estimation Configuration

```
init_data = [];  
init_data.mode_software_SC_estimate_attitude_selector = 'Truth'; % Use true  
    attitude values
```

```
mission.true_SC{i_SC}.software_SC_estimate_attitude =  
    Software_SC_Estimate_Attitude(init_data, mission, i_SC);
```

Spacecraft Software: Orbit Estimation Configuration

```
init_data = [];  
init_data.mode_software_SC_estimate_orbit_selector = 'TruthWithErrorGrowth';  
    % Use true orbit values with error growth when target not visible
```

```
mission.true_SC{i_SC}.software_SC_estimate_orbit =  
    Software_SC_Estimate_Orbit(init_data, mission, i_SC);
```

Spacecraft Software: Orbit Control Configuration

```
init_data = [];  
init_data.max_time_before_control = 0.5*60*60 + 900; % 45 minutes  
init_data.mode_software_SC_control_orbit_selector = 'DART';
```

```
mission.true_SC{i_SC}.software_SC_control_orbit =  
    Software_SC_Control_Orbit(init_data, mission, i_SC);
```

Spacecraft Software: Attitude Control Configuration

```
init_data = [];  
init_data.mode_software_SC_control_attitude_selector = 'DART Control  
    Asymptotically Stable send to actuators';  
init_data.control_gain = [1 0.2]; % Controller gain parameters
```

```
mission.true_SC{i_SC}.software_SC_control_attitude =  
    Software_SC_Control_Attitude(init_data, mission, i_SC);
```

Spacecraft Software: Communication Configuration

```
init_data = [];  
init_data.mode_software_SC_communication_selector = 'DART';  
init_data.instantaneous_data_generated_per_sample = (1e-3)*8*2; % [kb] 2  
    Bytes per sample  
init_data.attitude_error_threshold_deg = 1; % [deg] Max attitude error for  
    communication  
  
init_data.data = [];  
init_data.data.last_communication_time = 0;  
init_data.data.wait_time_comm_dte = 0.7*60*60; % [sec] 42 minutes between DTE  
    comms  
  
mission.true_SC{i_SC}.software_SC_communication =  
    Software_SC_Communication(init_data, mission, i_SC);
```

Spacecraft Software: Power Management Configuration

```
init_data = [];  
init_data.mode_software_SC_power_selector = 'Generic';  
init_data.instantaneous_data_generated_per_sample = (1e-3)*8*2; % [kb] 2  
    Bytes per sample  
  
mission.true_SC{i_SC}.software_SC_power = Software_SC_Power(init_data,  
    mission, i_SC);
```

Spacecraft Software: Data Handling Configuration

```
init_data = [];  
init_data.mode_software_SC_data_handling_selector = 'Generic';  
init_data.instantaneous_data_generated_per_sample = (1e-3)*8*2; % [kb] 2  
    Bytes per sample  
  
mission.true_SC{i_SC}.software_SC_data_handling =  
    Software_SC_Data_Handling(init_data, mission, i_SC);
```

Final Things to Do Before Running the Simulation

```
% Initialize mass, COM, MI  
func_update_SC_body_total_mass_COM_MI(mission.true_SC{i_SC}.true_SC_body);  
  
% Initialize store of Power
```

```

func_initialize_store_HW_power_consumed_generated(mission.true_SC{i_SC}.true_SC_power,
mission);

% Initialize store of Data Handling
func_initialize_store_HW_data_generated_removed(mission.true_SC{i_SC}.true_SC_data_handling,
mission);

% Initialize onboard computers
for i_HW =
    1:1:mission.true_SC{i_SC}.true_SC_body.num_hardware_exists.num_onboard_computer
        mission.true_SC{i_SC}.true_SC_onboard_computer{i_HW}.flag_executive = 1; %
        Start active
    end
end

```

Save All Data

```

clear init_data i_SC i_HW i_target

% Visualise the SC in 3D + Dashboard
func_visualize_SC(mission.storage, mission, true);
save([mission.storage.output_folder, 'all_data.mat'], '-v7.3')

```

Execute Main File

```
run main_v3.m
```

Save All Data

```

close all
disp('-----')
disp('Simulation Over. Starting saving data to disk...');

save([mission.storage.output_folder, 'all_data.mat'], '-v7.3')

disp(['Finished writing to file "all_data.mat" in folder : ',
mission.storage.output_folder])
disp('-----')

```

Plots

Use our memory-optimized visualization

```

fprintf('Starting memory-optimized visualization...');
memoryInfo = evalc('dispmemory()');
disp(['Current memory before visualisation - ', memoryInfo(1:end-1), ])

func_visualize_simulation_data(mission.storage, mission);

memoryInfo = evalc('dispmemory()');
fprintf('Visualization complete. ');
disp(['Current memory after visualisation - ', memoryInfo(1:end-1), ])

```

```
disp ( '-----' )
```

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Bibliography

- [1] S. Bandyopadhyay, Y. K. Nakka, L. Fesq, and S. Ardito, “Design and development of MuSCAT: Multi-spacecraft concept and autonomy tool,” in *AIAA ASCEND Autonomous Operations in Space*, Las Vegas, NV, 2024.