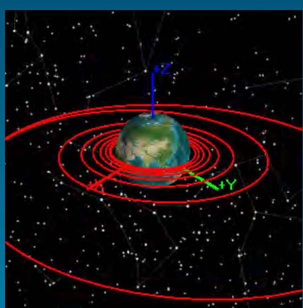
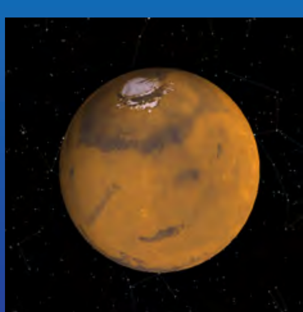
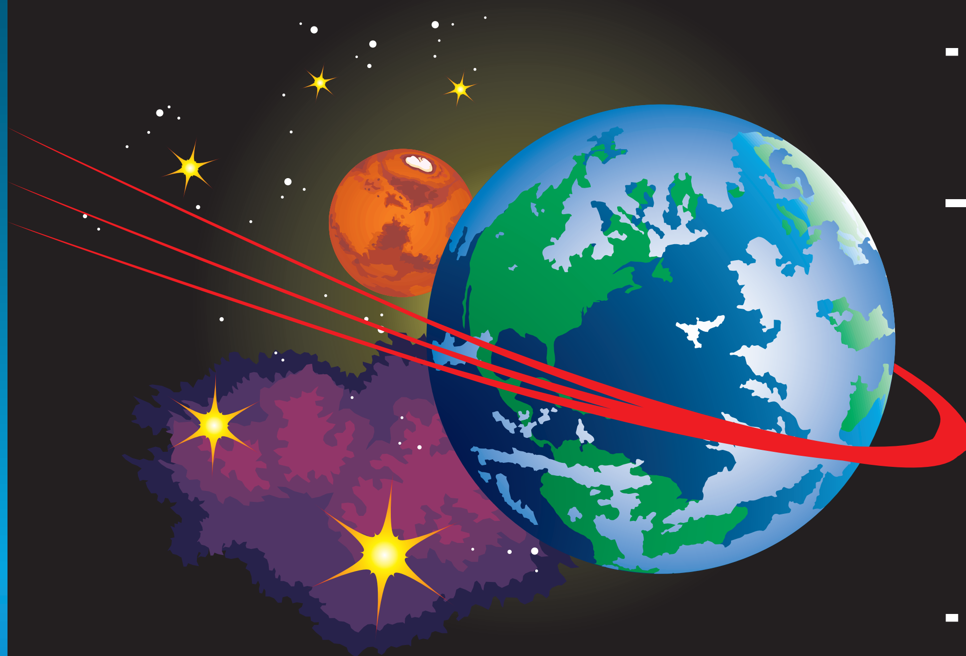
National Aeronautics and Space Administration







GMAT
User Guide
R2014a

general mission analysis tool

www.nasa.gov

General Mission Analysis Tool (GMAT)

User Guide

The GMAT Development Team

R2014a

General Mission Analysis Tool (GMAT): User Guide

Table of Contents

Documentation Overview

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

Using GMAT

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

The *Using GMAT* section provides general information on GMAT and how to use the software.

The *Welcome to GMAT* contains a brief project and software overview, including project status, licensing, and contributors.

The *Getting Started* section describes how to get and install GMAT, how to run the provided samples, and where to turn for further help.

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

> **Note**
>
> We consider the *User Interfaces Overview* section to be essential reading, as it describes some fundamental aspects of how GMAT works.

Tutorials

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

Here is a summary of selected Tutorials. For a complete list of tutorials see the *Tutorials* chapter.

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

The *Mars B-Plane Targeting* tutorial shows how to use GMAT to design a Mars transfer trajectory by targeting desired B-plane conditions at Mars.

The *Target Finite Burn to Raise Apogee* tutorial shows how to raise orbit apogee using finite maneuver targeting.

Reference Guide

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

The *Resources* section provides general information on GMAT Resources such as **Spacecraft**, **Propagators**, **Coordinate Systems**, and **EphemerisFiles** to name just a few. Go here for details regarding syntax, options, variable ranges and data types, defaults, and expected behavior. Each section contains detailed, copy-and-paste ready examples.

The *Commands* section provides general information on GMAT Commands such as **Maneuver**, **Assignment**, **Optimize**, and **Propagate** to name just a few. Go here for details regarding syntax, options, variable ranges and data types, defaults, and expected behavior. Each section contains detailed, copy-and-paste ready examples.

The *System* section provides information on system configuration, external interfaces, the script language, and the command line interface.

Note

This document uses two typographical conventions throughout:

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

Using GMAT

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> **Note**
>
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Welcome to GMAT

Do you want to go Mars but don't know when to leave or how much to bring? Do you want to study Earth protection by planning a mission to a near-Earth asteroid? The General Mission Analysis Tool (GMAT) is an open-source space mission design tool to answer just those types of questions. GMAT is designed to model and optimize spacecraft trajectories in flight regimes ranging from low Earth orbit to lunar, libration point , and deep space missions. GMAT is developed by a team of NASA, private industry, public, and private contributors and is used for real-world engineering studies, as a tool for education and public engagement, and as of R2013b released in Nov. 2013, to fly operational spacecraft.

Features Overview

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

Dynamics and Environment Modelling

- High fidelity dynamics models including harmonic gravity, drag, tides, and relativistic corrections
- High fidelity spacecraft modeling
- Formations and constellations
- Impulsive and finite maneuver modeling and optimization
- Propulsion system modeling including tanks and thrusters
- Solar System modeling including high fidelity ephemerides, custom celestial bodies, libration points, and barycenters
- Rich set of coordinate system including J2000, ICRF, fixed, rotating, topocentric, and many others
- SPICE kernel propagation
- Propagators that naturally synchronize epochs of multiple vehicles and avoid fixed step integration and interpolation

Plotting, Reporting and Product Generation

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

Optimization and Targeting

- Boundary value targeters
- Nonlinear, constrained optimization
- Custom, scriptable cost functions
- Custom, scriptable nonlinear equality and inequality constraint functions
- Custom targeter controls and constraints

Programming Infrastructure

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

Interfaces

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

Licensing

GMAT is licensed under the Apache License 2.0.

Platform Support

GMAT has been rigorously tested on the Windows 7 platform and we perform nightly regression tests running almost 12,000 test cases for the script engine and over 4000 test cases for the GUI interface.

While the system is routinely built on Mac and Linux, we consider the software to be in alpha form on those plaforms. For release R2014a, we have only addressed issues on Mac and Linux that also occur on the Windows 7 platform. Part of our planning effort for the next release will be to assess the future of GMAT on Mac and Linux.

Contributors

The Navigation and Mission Design Branch at NASA's Goddard Space Flight Center performs project management activities and is involved in most phases of the development process including requirements, algorithms, design, and testing. The Ground Software Systems Branch performs design, implementation, and integration testing. External particpants contribute to design, implementation, testing and documentation. External participants for R2014a include:

- Thinking Systems, Inc. (system architecture and all aspects of development)
- a.i. solutions (testing)
- Korean Aerospace Research Institute
- Chonbuk National University, South Korea
- Korea Advanced Institute of Science and Technology
- Yonsei University, South Korea

Past commercial and external contributors to GMAT include:

- Air Force Research Lab (all aspects of development)
- Boeing (algorithms and testing)

- The Schafer Corporation (all aspects of development)
- Honeywell Technology Solutions (testing)
- Computer Sciences Corporation (requirements)

The NASA Jet Propulsion Laboratory (JPL) has provided funding for integration of the SPICE toolkit into GMAT. Additionally, the European Space Agency's (ESA) Advanced Concepts team has developed optimizer plug-ins for the Non-Linear Programming (NLP) solvers SNOPT (Sparse Nonlinear OPTimizer) and IPOPT (Interior Point OPTimizer).

Getting Started

Installation

Installers and application bundles are available on the GMAT SourceForge project page, located at `https://sourceforge.net/projects/gmat`.

The following packages are available for the major platforms:

	Installer	Binary bundle	Source code
Windows (XP, Vista, 7)	✔	✔	✔
Mac OS X			✔
Linux			✔

Installer

To use the Windows installer, download the appropriate `gmat-winInstaller-*.exe` file from the SourceForge download page and run it. You'll be asked a series of questions, and GMAT will be installed to your local user account.

By default, GMAT installs to the `%LOCALAPPDATA%` folder in your user directory, and does not require elevated privileges to install. On Windows Vista and Windows 7, this generally corresponds to the `C:\Users\`*`username`*`\AppData\Local` folder. You are free to choose another install location during the installation process, but elevated privileges may be required to do so.

Binary Bundle

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

Source Code

GMAT is available as a platform-independent source code bundle. Note that all testing is performed on Windows, so on other platforms it is considered a beta release. See the GMAT Wiki for compiling instructions.

Rather than compiling from the source bundle, however, we generally recommend checking out a snapshot from the Subversion repository:

```
svn://svn.code.sf.net/p/gmat/code
```

There are tags available for reach release.

Running GMAT

Starting GMAT

On Microsoft Windows platforms there are several ways to start a GMAT session. If you used the GMAT installer, you can click the **GMAT R2014a** item in the **Start** menu. If you installed

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

To start GMAT from the command line, run `GMAT.exe`. Various command-line parameters are available; see Command-Line Usage for details.

Exiting GMAT

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

Sample Missions

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

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

To run optimization missions, you will need MATLAB and the MATLAB Optimization Toolbox or the internal `libVF13Optimizer` plugin. These are proprietary libraries and are not distributed with GMAT. MATLAB connectivity is not yet fully supported in the Mac and Linux, and therefore you cannot run optimization missions that use MATLAB's **fmincon** optimizer on those platforms. See MATLAB Interface for details on configuring the MATLAB optimizer.

Getting Help

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

- Homepage: `http://gmat.gsfc.nasa.gov`
- Wiki: `http://gmatcentral.org`
- User forums: `http://forums.gmatcentral.org`
- Downloads and source code: `http://sourceforge.net/projects/gmat`
- Submit bug reports and feature requests: `http://bugs.gmatcentral.org`
- Official contact: `<gmat@gsfc.nasa.gov>`

Tour of GMAT

User Interfaces Overview

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

GUI Overview

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

Windows GUI

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

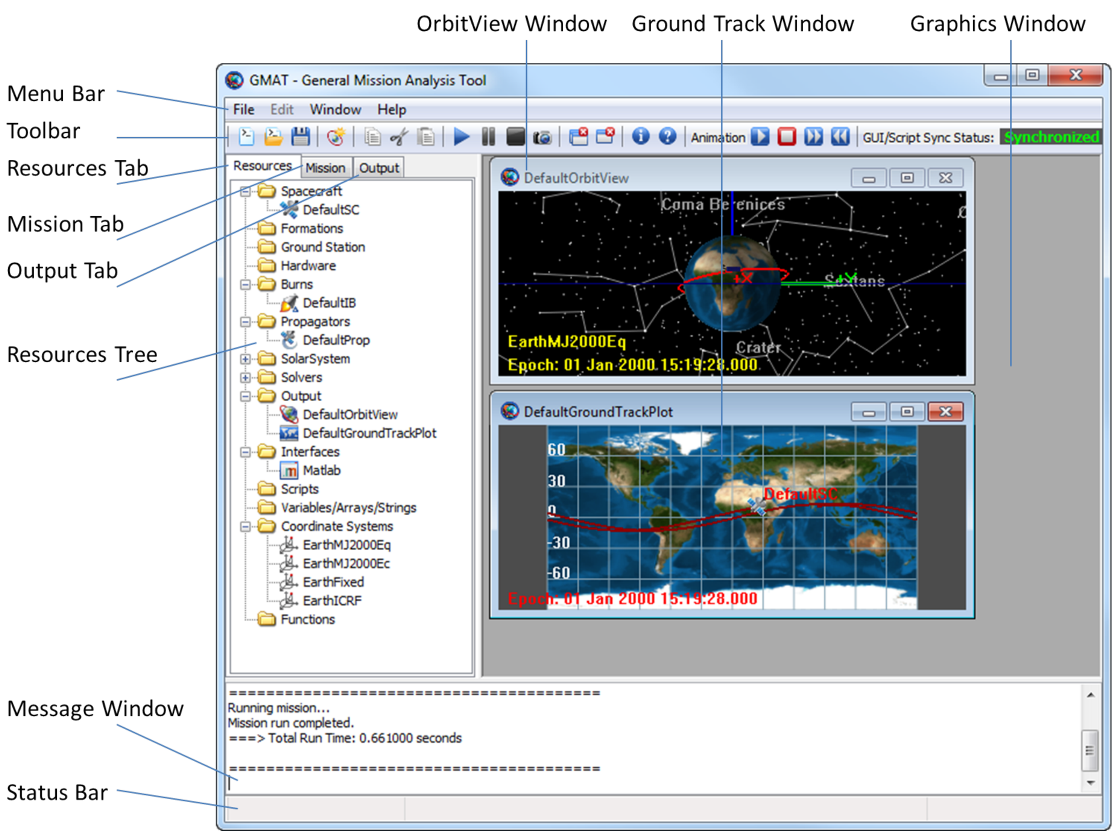


Figure 1. GMAT Desktop (Windows)

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

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

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

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

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

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

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

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

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

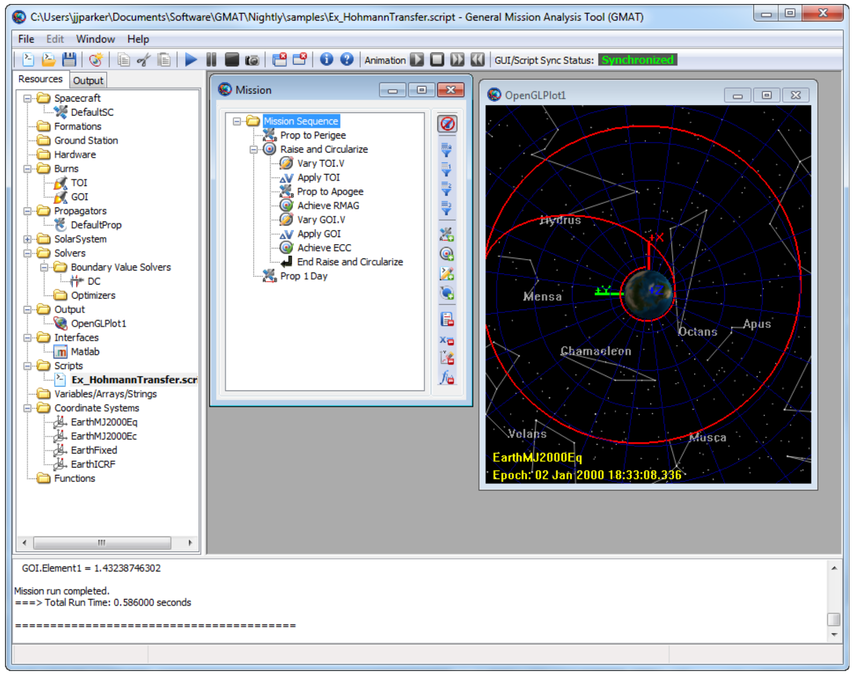


Figure 2. Undocked Mission Tree

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

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

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

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

Script Interface Overview

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

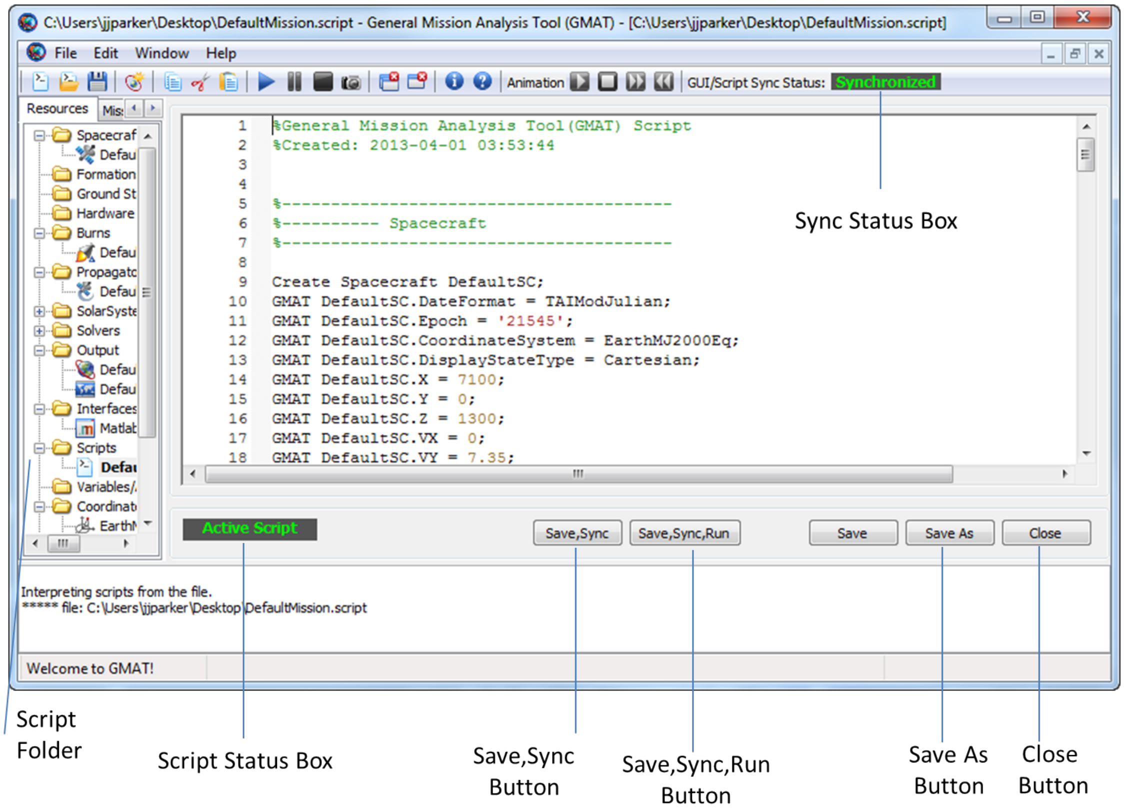


Figure 3. GMAT Script Editor

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

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

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

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

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

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

GUI/Script Interface Interactions and Rules

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

GUI/Script Interactions and Synchronization

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

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

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

How the GUI Maps to a Script

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

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

How the Script Maps to the GUI

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

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

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

Basic Script Syntax Rules

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

  For a more complete discussion of GMAT's script language, see the Script Language documentation.

Resources Tree

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

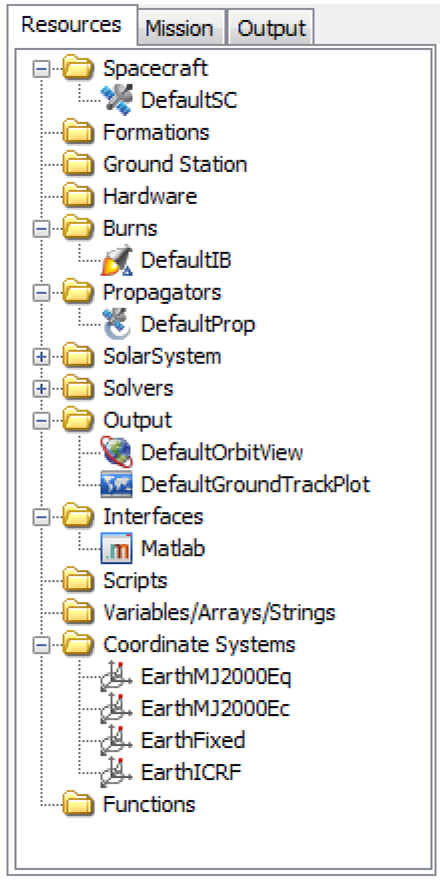


Figure 4. Default Resources tree

Organization

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

Folder Menus

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

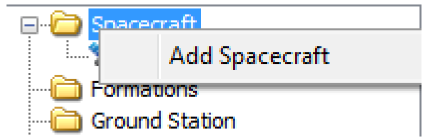


Figure 5. Folder menu for Spacecraft

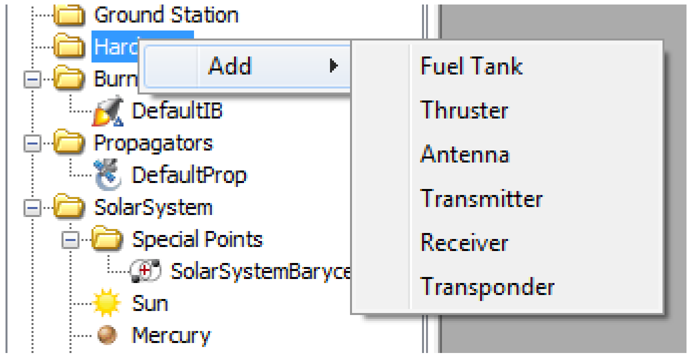


Figure 6. Folder menu for Hardware

Resource Menus

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

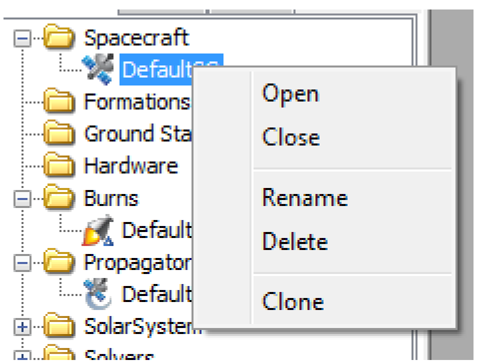


Figure 7. Resource menu

Open/Close

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

Rename

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

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

Delete

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

- Default coordinate systems
  - **EarthMJ2000Eq**
  - **EarthMJ2000Ec**
  - **EarthFixed**
  - **EarthICRF**
- Default planetary bodies
  - **Sun**
  - **Mercury**
  - **Venus**
  - **Earth**
  - **Luna**
  - **Mars**
  - **Jupiter**
  - **Saturn**
  - **Uranus**
  - **Neptune**
  - **Pluto**

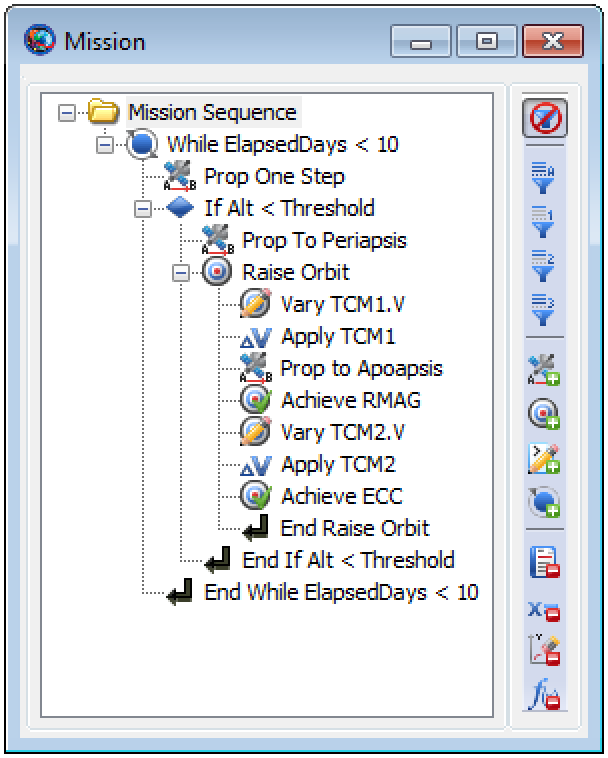
Clone

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

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

Mission Tree

The Mission Tree is an ordered, hierarchical, display of your GMAT script command mission sequence (everything after the **BeginMissionSequence** in your script). It represents the ordered list of commands to be executed to model your mission. The hierarchical grouping in the mission tree represent commands that are executed inside a control logic command, e.g., **If**, **For**, **While**, etc. The mission tree allows you to add, edit, delete and rename commands. It allows you to configure or filter the display of the commands in the Mission Tree to make the command execution easier to understand or modify. An example Mission Tree screenshot is below. The Mission Tree window is made up of 2 elements: the Mission Sequence on the left and the view filters toolbar on the right.



Warning

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

Mission Tree Display

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

In general, commands are executed only once. However, child commands grouped under the loop commands (e.g. **For** and **While**) may execute multiple times. These commands will execute for each time the loop command evaluates to true. Commands under the **If** commands are only executed if the **If** condition evaluates to true; otherwise, they are skipped. For the **If-Else** command, child commands grouped under the **If** portion of the command execute if the conditional statement evaluates to true; otherwise, the child commands grouped under the **Else** portion of the command execute.

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

View Filters Toolbar

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

- Filter by branch level
- Filter by command types (inclusive)
- Filter by command types (exclusive)

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

> **Note**
>
> Note that all parents of a viewable command are displayed, even if the parent command is not part of the viewable command set.
>
> Also note that the Mission Tree automatically reconfigures to show all commands when the user Appends or Inserts a new command.

Filter by Branch Level

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

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

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

Filter by Command Types

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

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

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

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

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

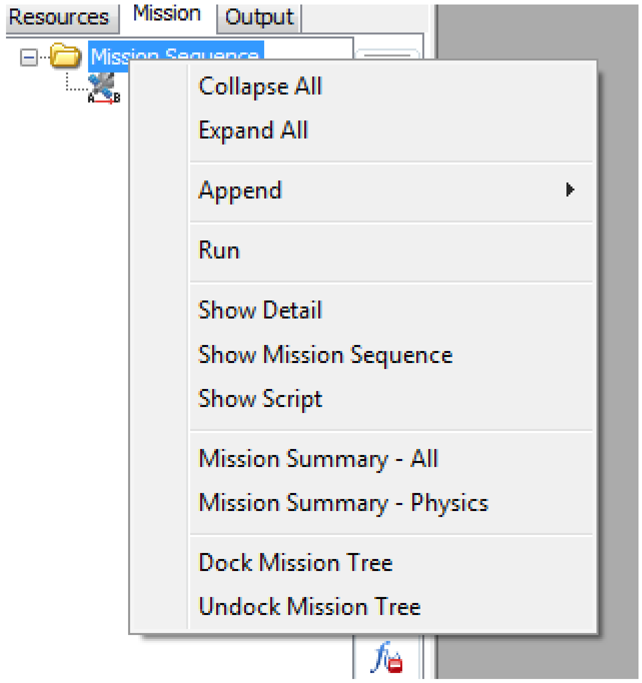
- **Report**
- **Equation**
- Output-related (**Report**, **Toggle**, **PenUp**, **PenDown**, **MarkPoint**, and **ClearPlot**)
- Function calls (**CallMatlabFunction**)

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

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

Mission Sequence Menu

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



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

Mission Sequence Menu Options:

Collapse All

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

Expand All

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

Append

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

Run

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

Show Detail

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

Show Mission Sequence

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

Show Script

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

Mission Summary - All

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

Mission Summary - Physics

The **Mission Summary - Physics** menu option displays a mission simulation summary for physics related commands in the mission sequence. This summary information includes spacecraft state information, spacecraft physical properties, time information, planetodetic properties, and other orbit data for each command. This information is only available after a mission simulation is run and the data shows state information after the execution of the command. Note that if you have physics-based commands such as **Propagate** or **Maneuver** inside a **ScriptEvent** command, then summary information for those commands, are not displayed. Showing Mission Summary data for a **ScriptEvent** is equivalent to showing summary data for the last command in that **ScriptEvent**. If commands are nested in control flow or solver branches, the summary data that is displayed is for the last pass through the sequence. This menu option is always available.

Dock Mission Tree

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

Undock Mission Tree

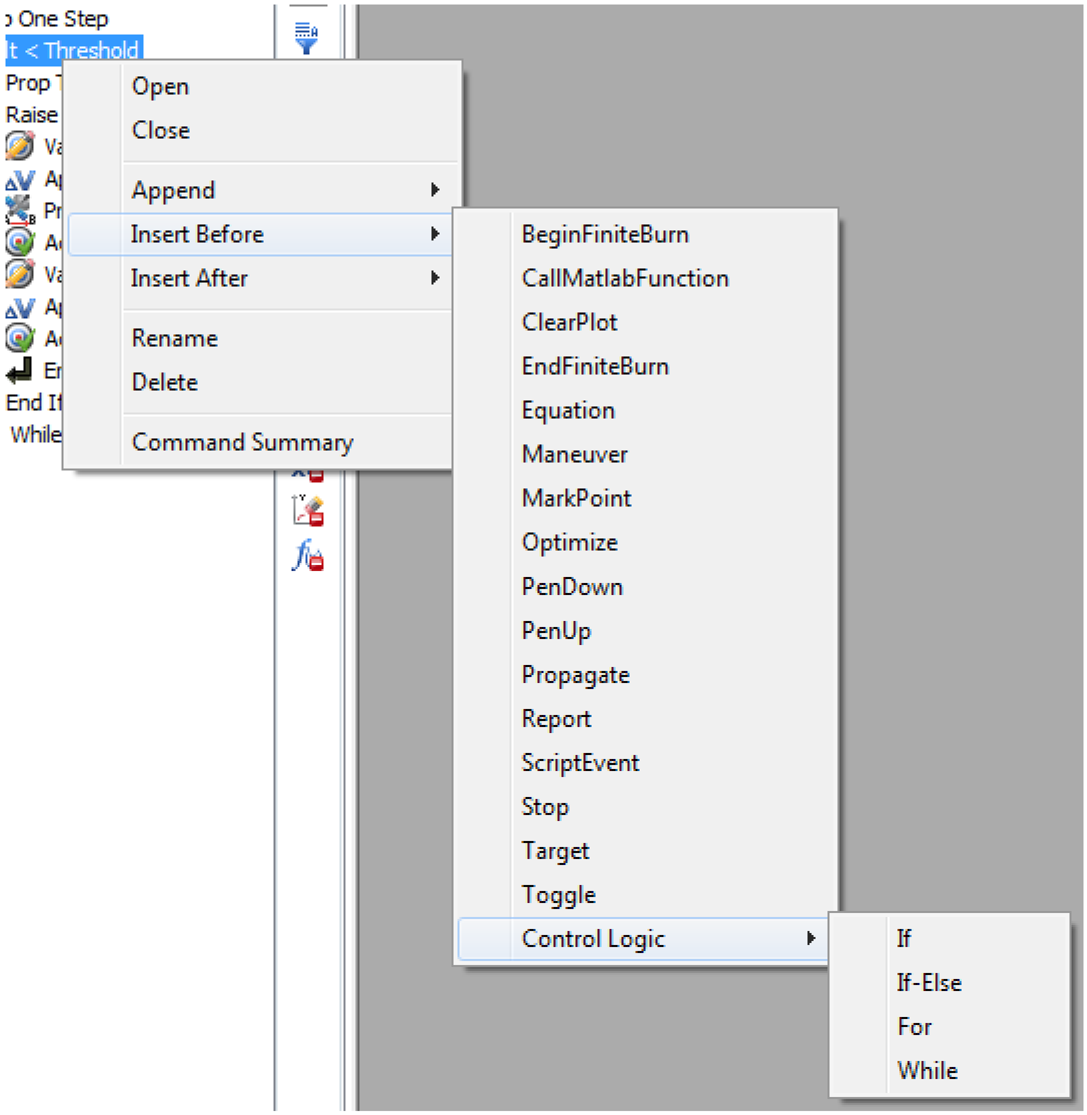
The **Undock Mission Tree** menu option undocks, or makes floating, the Mission Tree window from the Resources tree and Output tree. The undocked Mission Tree window may be resized, moved, maximized, minimized, and restored. This option is only selectable if the Mission Tree is currently docked. Please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

Command Menu

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

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

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



Command Menu Options

Open

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

Close

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

Append

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

Insert After

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

Insert Before

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

Rename

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

Delete

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

Command Summary

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

Docking/Undocking/Placement

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

To undock the Mission Tree Display, either:

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

To dock the Mission Tree display, either:

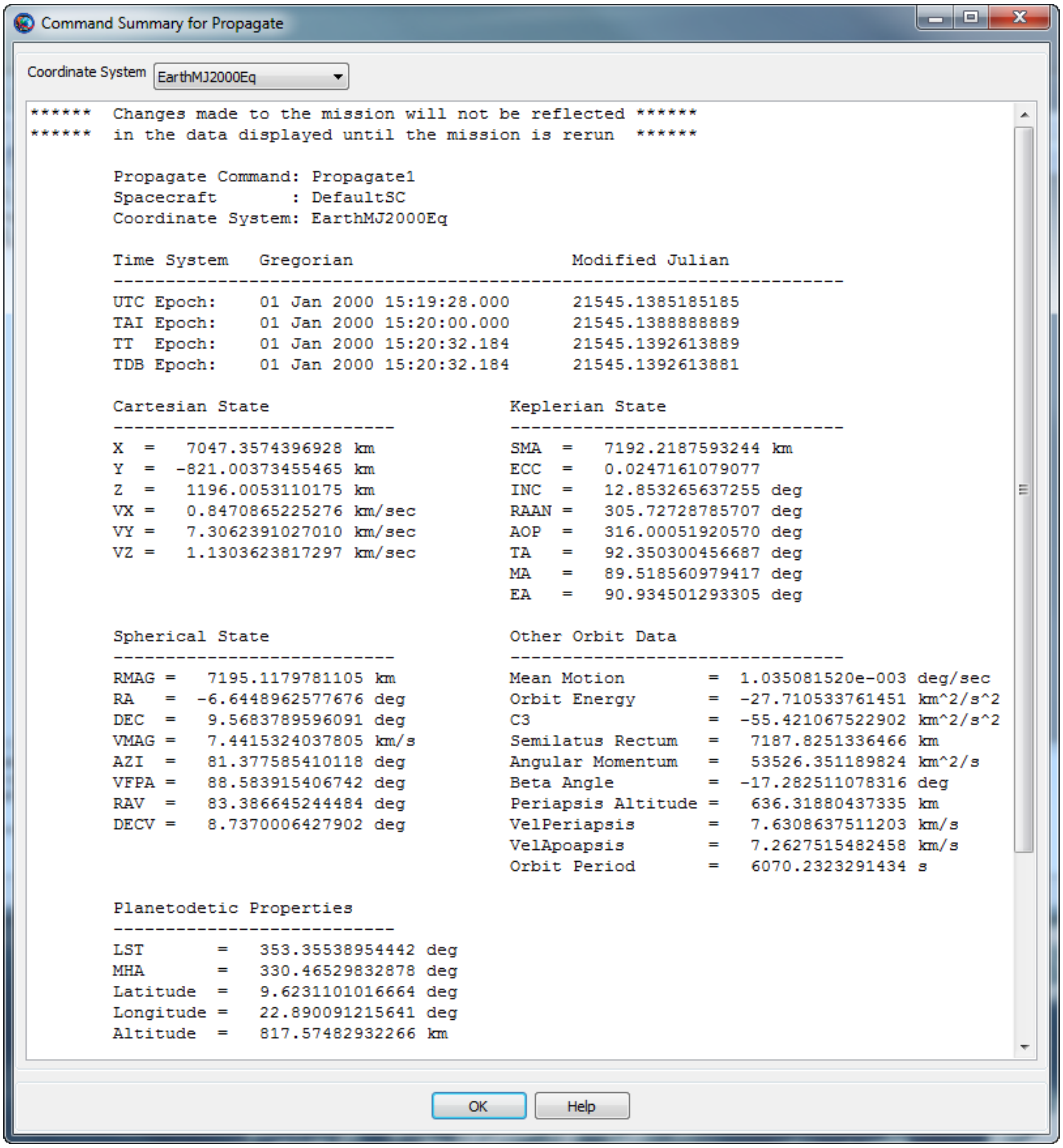
- Left click the close button (**x**) of the undocked Mission Tree window.
- RIght click the **Mission Sequence** home item and select **Dock Mission Tree**.

Command Summary

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

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

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



Data Availability

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

Data Contents

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

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

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

Supported Commands

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

Coordinate Systems

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

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

```
Propagate Command: Propagate1
        Spacecraft       : DefaultSC
        Coordinate System: EarthMJ2000Eq

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

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

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

```
        Dry mass                =    850.00000000000 kg
        Total mass              =    850.00000000000 kg
```

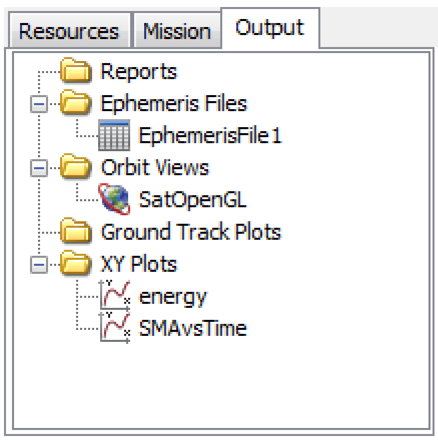
Output Tree

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

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

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

A populated Output tree is shown in the following figure.



Script Editor

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

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

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

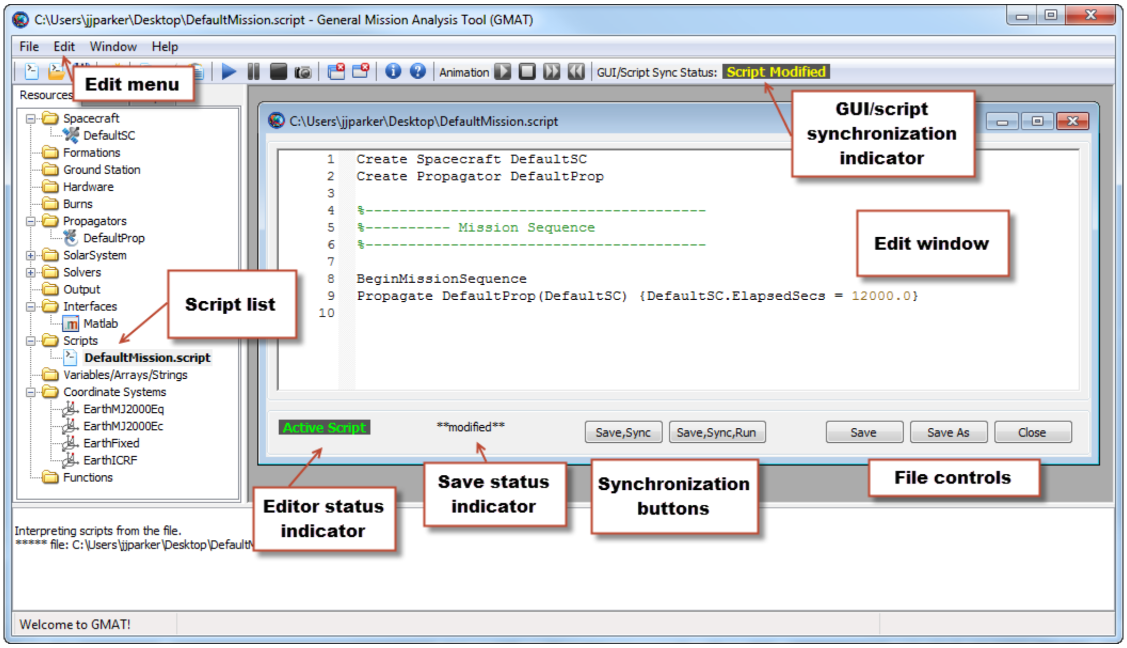


Figure 8. Parts of the script editor

Active Script

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

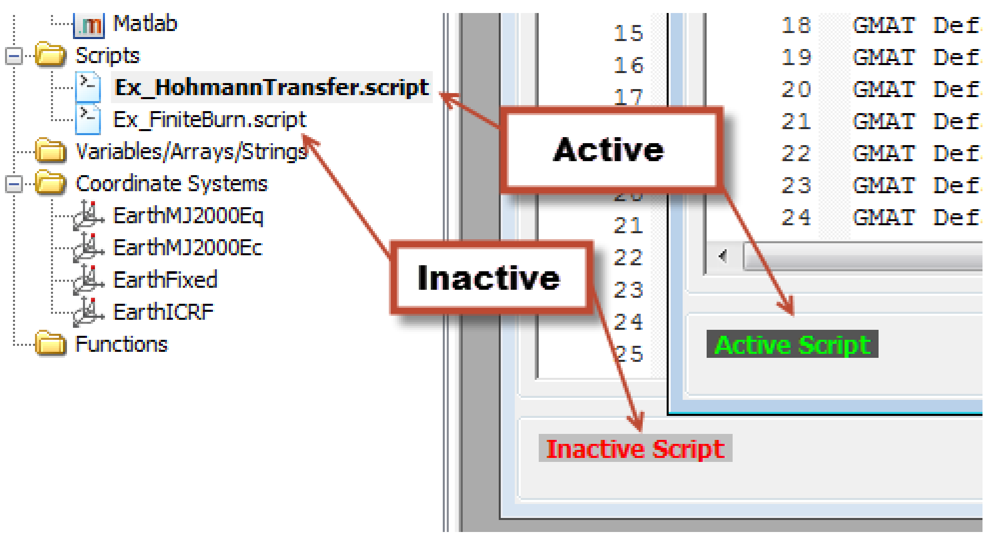


Figure 9. Active script indicators

To synchronize with the GUI, you must make an inactive script active by clicking either of the synchronization buttons (described in the next section). This will change the current script to active, synchronize the GUI, and change the the previously active script to inactive. Alternately, you can right-click the script name in the resources tree and click Build.

GUI/Script Synchronization

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

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

Warning

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

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

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

1. Saves any modifications to the script
2. Closes all open windows (except the script editor itself)
3. Validates the script file

4. Refreshes the GUI by loading the saved script
5. Sets **GUI/Script Sync Status** to **Synchronized**.

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

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

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

Scripts List

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

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

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

Edit Window

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

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

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

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

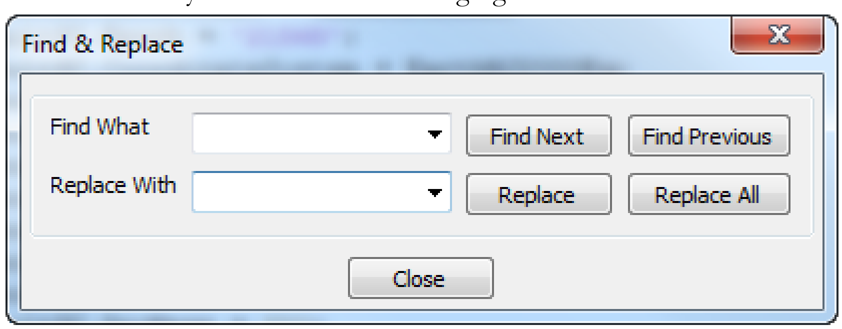
When the script editor is active in the GMAT GUI, the Edit menu is also available with the following options:

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

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

Find and Replace

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



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

File Controls

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

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

Save Status Indicator

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

Configuring GMAT

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

File Structure

The default directory structure for GMAT is broken into eight main subdirectories, as shown in Figure 10. These directories organize the files and data used to run GMAT, including binary libraries, data files, texture maps, and 3D models. The only two files in the GMAT root directory are `license.txt`, which contains the text of the Apache License 2.0, and `README.txt`, which contains user information for the current GMAT release. A summary of the contents of each subdirectory is provided in the sections below.

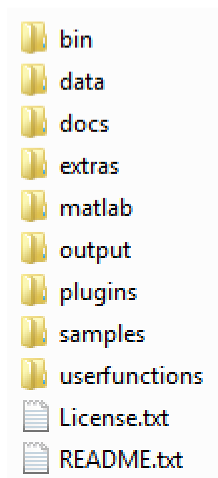


Figure 10. GMAT Root Directory Structure

bin

The `bin` directory contains all binary files required for the core functionality of GMAT. These libraries include the executable file (`GMAT.exe` on Windows, `GMAT.app` on the Mac, and `GMAT` on Linux) and platform-specific support libraries. The `bin` directory also contains two text files: `gmat_startup_file.txt` and `gmat.ini`. The startup file is discussed in detail in a separate section below. The `gmat.ini` file is used to configure some GUI panels, set paths to external web links, and define GUI tooltip messages.

data

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

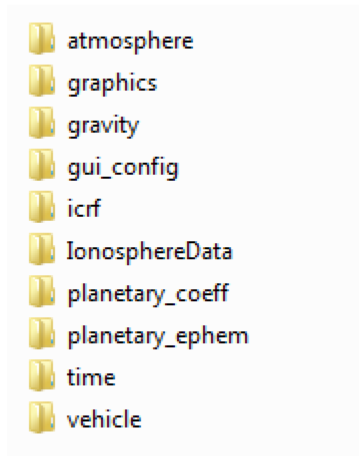


Figure 11. GMAT Data Directory Structure

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

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

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

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

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

The `time` directory contains the JPL leap second kernel `naif0010.tls` and the GMAT leap second file `tai-utc.dat`.

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

docs

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

extras

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

matlab

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

output

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

plugins

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

samples

The `samples` directory contains over 45 sample missions, ranging from a Hohmann transfer to libration point station-keeping to Mars B-plane targeting. Example files begin with "Ex_" and files that corresponde to GMAT tutorials begin with "Tut_". These files are intended to demonstrate GMAT's capabilities and to provide you with a potential starting point for building common mission types for your application and flight regime. Samples with specific requirements are located in subdirectories such as `NeedMatlab` and `NeedVF13ad`.

userfunctions

The `userfunctions` directory contains MATLAB functions that are included in the GMAT distribution. You can also store your own custom MATLAB functions in this folders.

Configuring Data Files

You can configure the data files GMAT loads at run time by editing the `gmat_startup_file.txt` file located in the `bin` directory. The startup file contains path information for data files such as ephemeris, Earth orientation parameters and graphics files. By editing the startup file, you can customize which files are loaded and used during a GMAT session. Below we describe the customization features available in the startup file. The order of lines in the startup file does not matter.

For all details, see the Startup File reference.

Leap Second and EOP files

GMAT reads several files that are used for high fidelity modelling of time and coordinate systems: the leap second files and the Earth orientation parameters (EOP) provided by the IERS. The EOP file is updated daily by the IERS. To update your local file with the latest data, simply replace the file `eopc04_08.62-now` in the `data/planetary_coeff` directory. Updated versions of this file are available from the IERS.

There are two leap second files provided with GMAT in the `data/time` directory. The `naif0010.tls` file is used by the JPL SPICE libraries when computing ephemerides. When a new leap second is added, you can replace this file with the new file from NAIF. GMAT reads the `tai-utc.dat` file for all time computations requiring leap seconds that are not performed by the SPICE utilities. When a new leap second is added, you can replace this file with the new file from the US Naval Observatory. In addtion, you can modify the file if a new leap second is added by simply duplicating the last row and updating it with the correct information for the new leap second. For example, if a new leapsecond were added on 01 Jul 2013, you would add the following line to the bottom of `tai-utc.dat`:

```
2013 JUL 1 =JD 2456474.5 TAI-UTC= 35.0 S + (MJD - 41317.) X 0.0
```

Loading Custom Plugins

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

Configuring the MATLAB Inteface

GMAT contains an interface to MATLAB. See the MATLAB Interface reference to configure the MATLAB interface.

User-defined Function Paths

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

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

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

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

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

Tutorials

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

Here is a summary of selected Tutorials. For a complete list of tutorials see the *Tutorials* chapter.

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

The *Mars B-Plane Targeting* tutorial shows how to use GMAT to design a Mars transfer trajectory by targeting desired B-plane conditions at Mars.

The *Target Finite Burn to Raise Apogee* tutorial shows how to raise orbit apogee using finite maneuver targeting.

Simulating an Orbit

Audience	Beginner
Length	30 minutes
Prerequisites	None
Script File	`Tut_SimulatingAnOrbit.script`

Objective and Overview

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

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

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

Configure the Spacecraft

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

Rename the Spacecraft

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

Set the Spacecraft Epoch

1. In the **Resources** tree, double-click **Sat**. Click the **Orbit** tab if it is not already selected.
2. In the **Epoch Format** list, select **UTCGregorian**. You'll see the value in the **Epoch** field change to the UTC Gregorian epoch format.
3. In in the **Epoch** box, type **`22 Jul 2014 11:29:10.811`**. This field is case-sensitive, and must be entered in the exact format shown.
4. Click **Apply** or press the **ENTER** key to save these changes.

Set the Keplerian Orbital Elements

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

Table 1. Sat Orbit State Settings

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

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

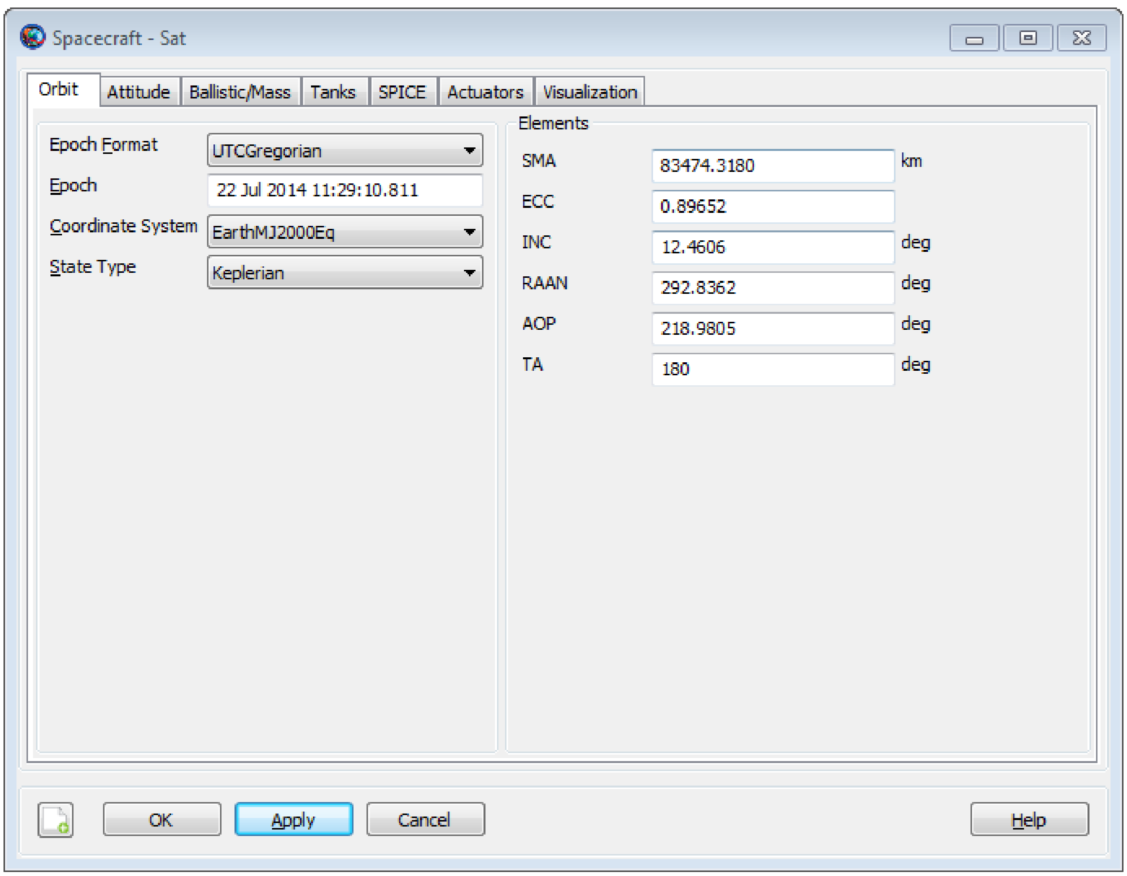


Figure 12. Spacecraft State Setup

Configure the Propagator

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

Rename the Propagator

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

Configure the Force Model

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

1. In the **Resources** tree, double-click **LowEarthProp**.
2. Under **Gravity**, in the **Degree** box, type **`10`**.
3. In the **Order** box, type **`10`**.
4. In **Atmosphere Model** list, click **JacchiaRoberts**.
5. Click the **Select** button next to the **Point Masses** box. This opens the **CelesBodySelectDialog** window.
6. In the **Available Bodies** list, click **Sun**, then click **->** to add **Sun** to the **Selected Bodies** list.
7. Add the moon (named **Luna** in GMAT) in the same way.
8. Click **OK** to close the **CelesBodySelectDialog**.
9. Select **Use Solar Radiation Pressure** to toggle it on. Your screen should now match Figure 13.
10. Click **OK**.

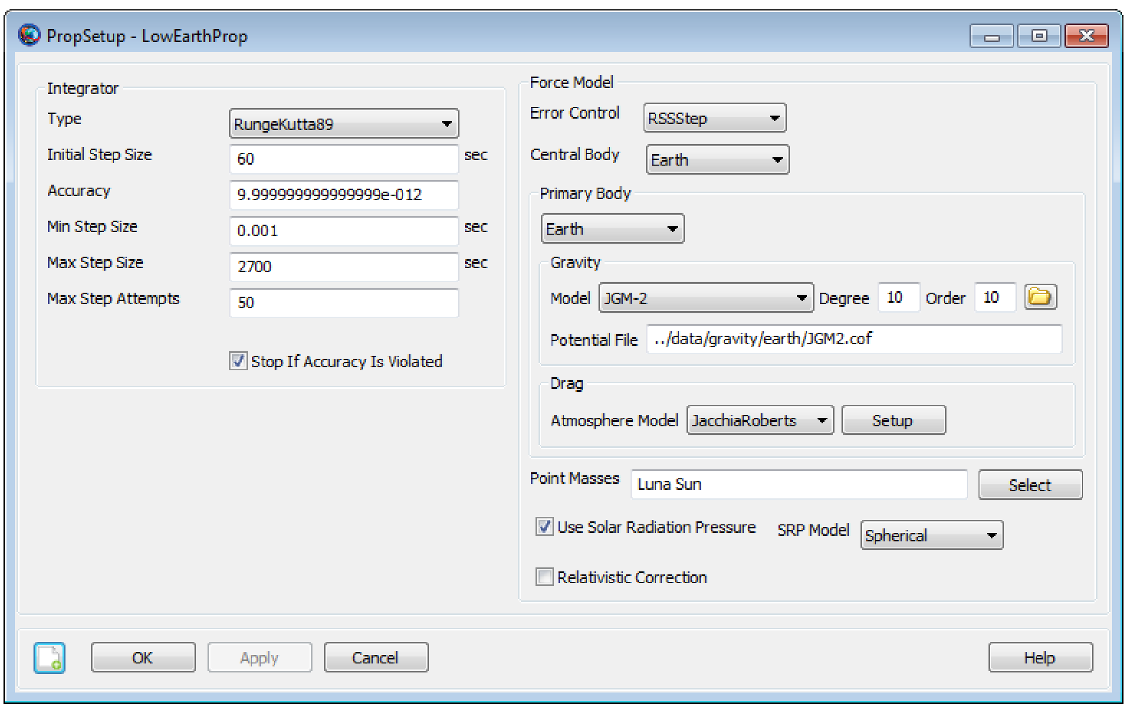


Figure 13. Force Model Configuration

Configuring the Orbit View Plot

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

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

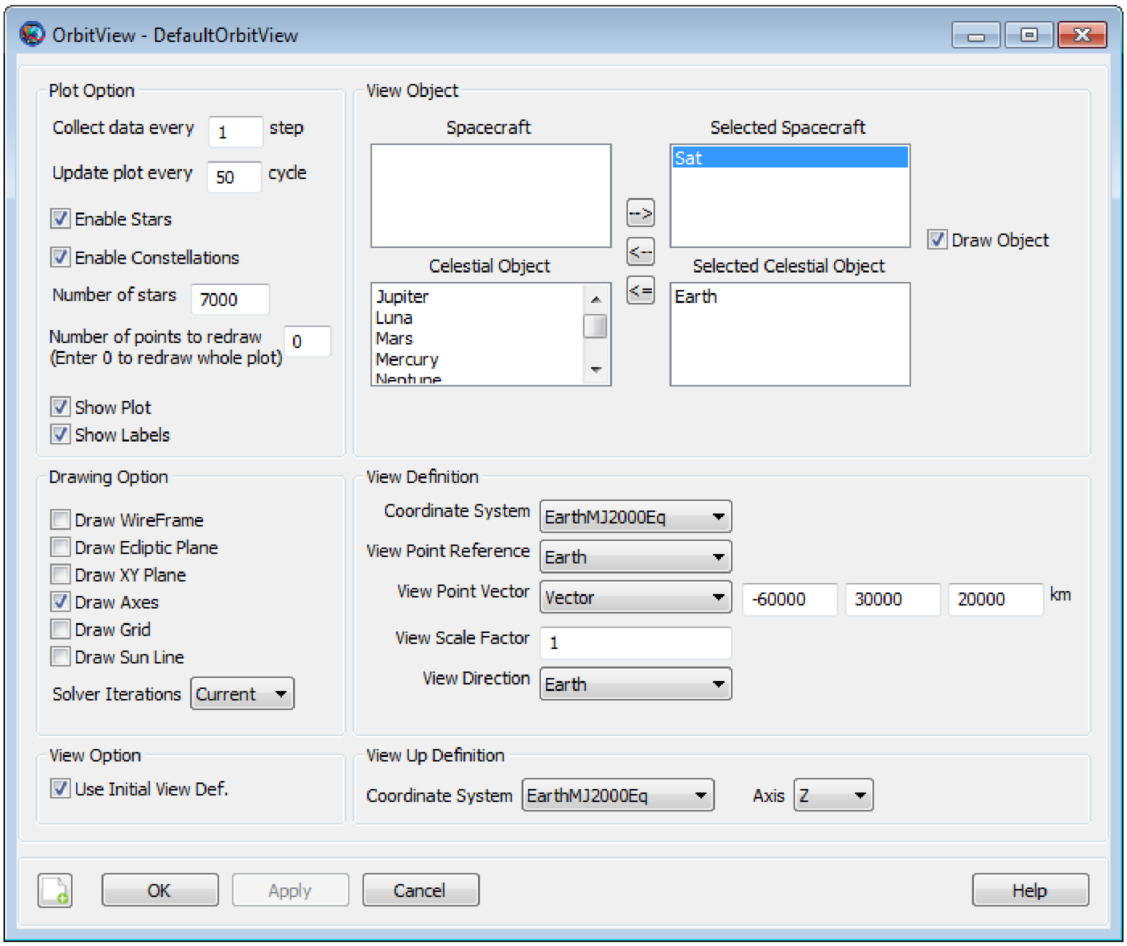


Figure 14. DefaultOrbitView Configuration

Configure the Propagate Command

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

1. Click the **Mission** tab to display the **Mission** tree.

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

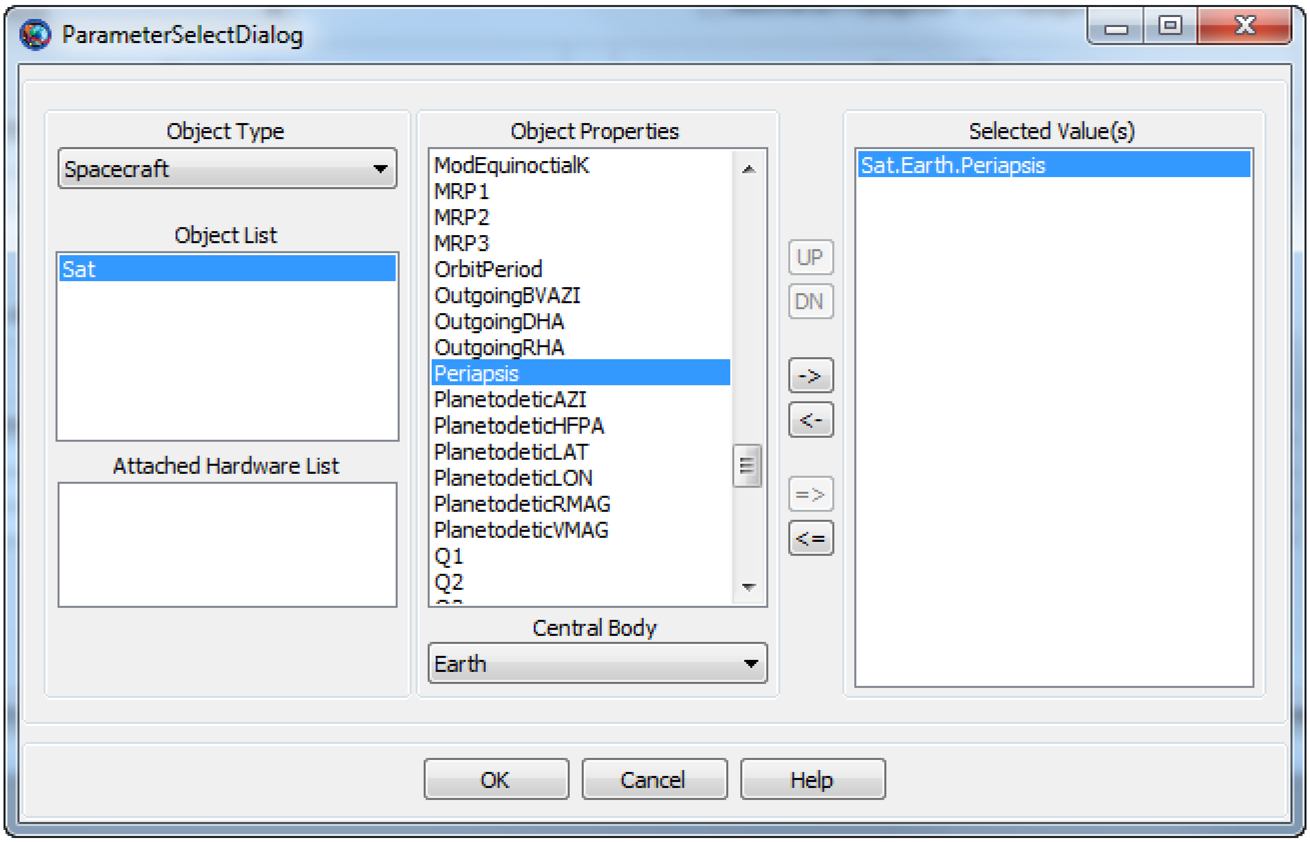


Figure 15. Propagate Command ParameterSelectDialog Configuration

6. Click **OK**. Your screen should now match Figure 16.
7. Click **OK**.

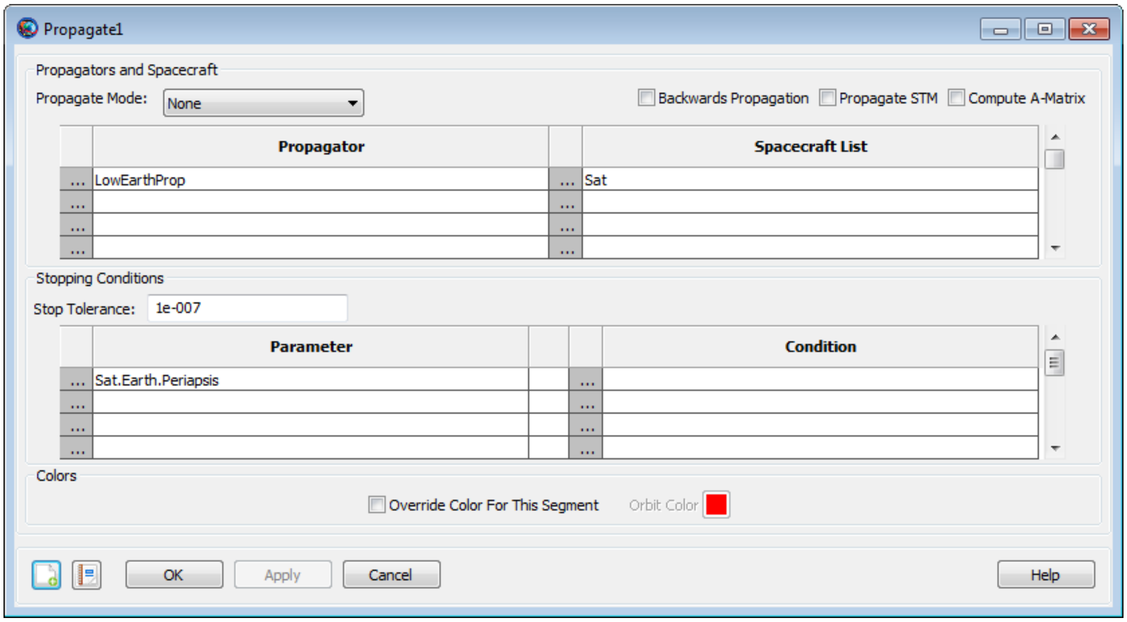


Figure 16. Propagate Command Configuration

Run and Analyze the Results

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

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

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

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

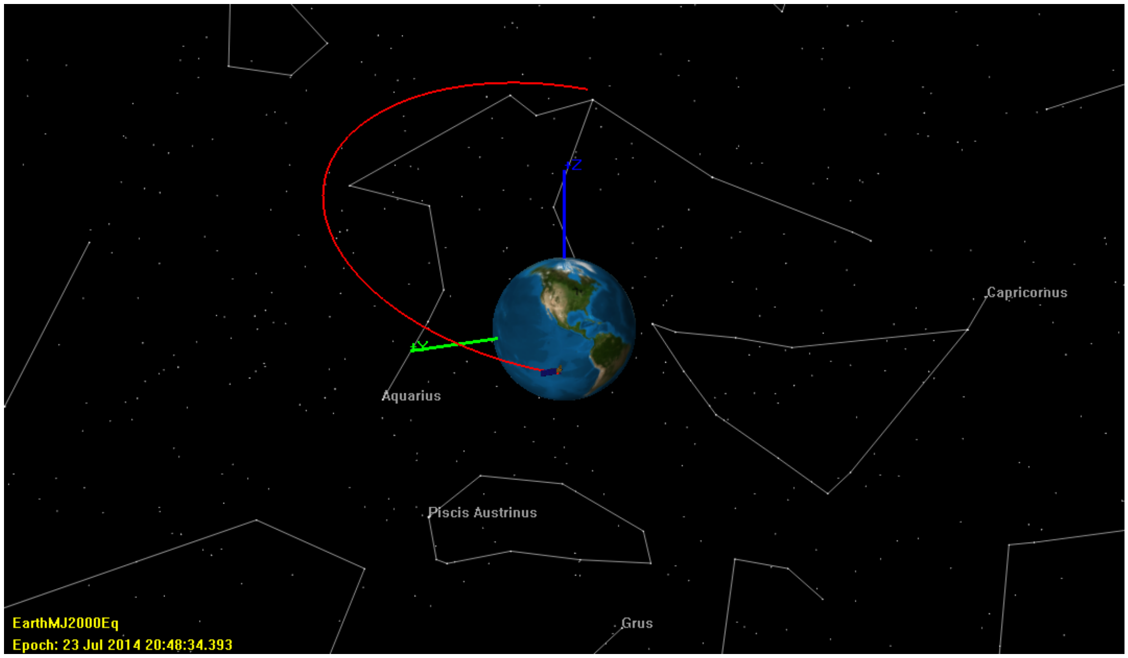


Figure 17. Orbit View Plot after Mission Run

Simple Orbit Transfer

Audience	Beginner
Length	30 minutes
Prerequisites	Complete *Simulating an Orbit*
Script File	`Tut_SimpleOrbitTransfer.script`

Objective and Overview

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

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

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

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

Configure Maneuvers, Differential Corrector, and Graphics

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

Create the Differential Corrector

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

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

Modify the Default Orbit View

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

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

Table 2. DefaultOrbitView settings

Field	Value
Solver Iterations, under **Drawing Option**	**Current**
Axis, under **View Up Defintion**	**X**
View Point Vector boxes, under **View Definition**	`0`, `0`, and `120000` respectively

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

Create the Maneuvers.

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

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

Configure the Mission Sequence

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

Configure the Initial Propagate Command

1. Click on the **Mission** tab to show the **Mission** tree.

2. Configure **Propagate1** to propagate to `DefaultSC.Earth.Periapsis`.
3. Rename **Propagate1** to `Prop To Periapsis`.

Create the Target Sequence

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

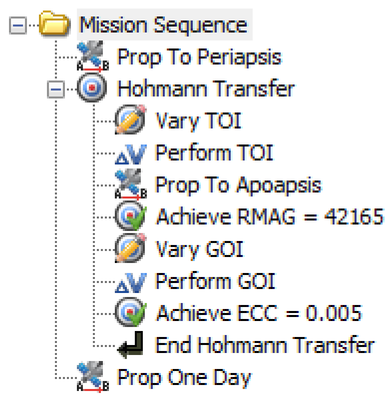


Figure 18. Final Mission Sequence for the Hohmann Transfer

To create the **Target** sequence:

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

Table 3. Additional Target Sequence Commands

Command	Name
Maneuver	`Perform TOI`
Propagate	`Prop To Apoapsis`
Achieve	`Achieve RMAG = 42165`
Vary	`Vary GOI`
Maneuver	`Perform GOI`
Achieve	`Achieve ECC = 0.005`

Note

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

Create the Final Propagate Command

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

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

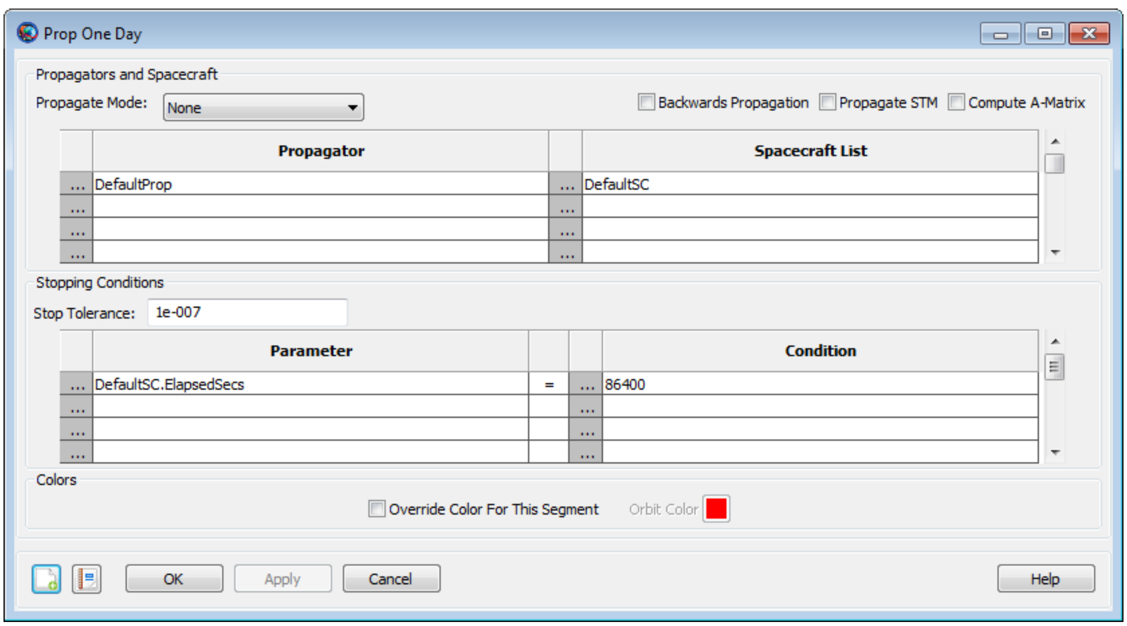


Figure 19. Prop One Day Command Configuration

Configure the Target Sequence

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

Configure the Vary TOI Command

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

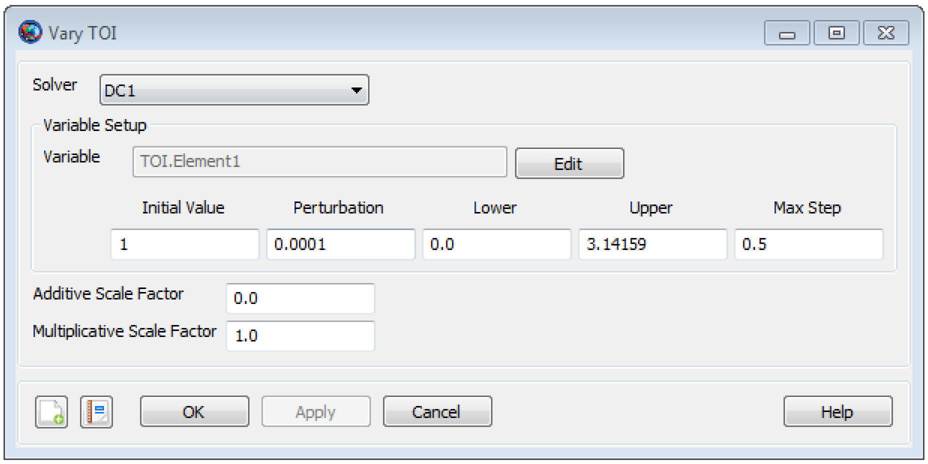


Figure 20. Vary TOI Command Configuration

Configure the Perform TOI Command

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

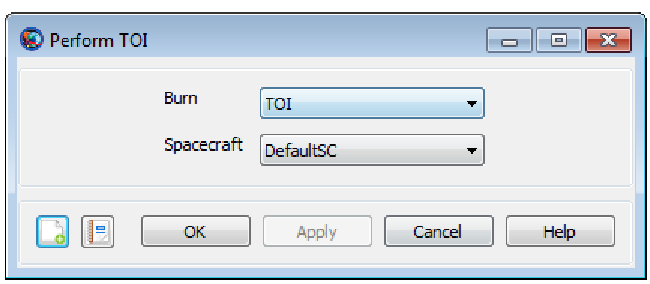


Figure 21. Perform TOI Command Configuration

Configure the Prop to Apoapsis Command

1. Double-click **Prop to Apoapsis** to edit its properties.

2. Under **Parameter**, replace **`DefaultSC.ElapsedSecs`** with **`DefaultSC.Earth.Apoapsis`**.
3. Click **OK** to save these changes.

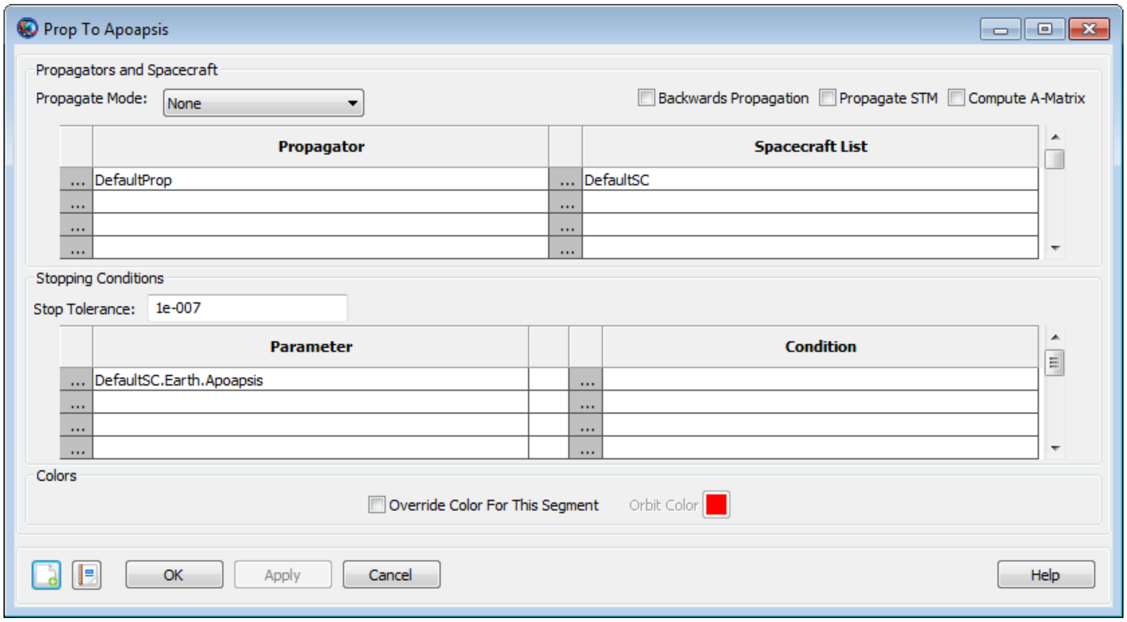


Figure 22. Prop to Apoapsis Command Configuration

Configure the Achieve RMAG = 42165 Command

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

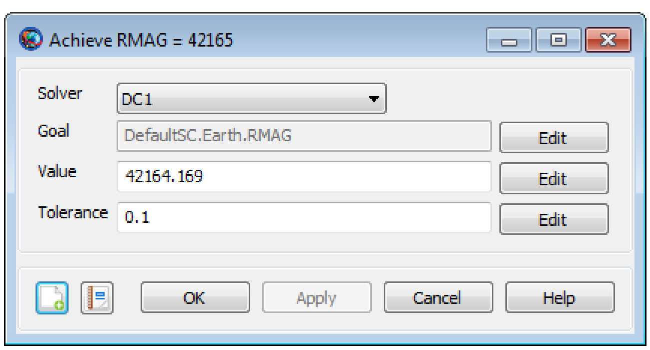


Figure 23. Achieve RMAG = 42165 Command Configuration

Configure the Vary GOI Command

1. Double-click **Vary GOI** to edit its properties.
2. Next to **Variable**, click the **Edit** button.

3. Under **Object List**, click **GOI**.
4. In the **Object Properties** list, double-click **Element1** to move it to the **Selected Value(s)** list. See the image below for results.

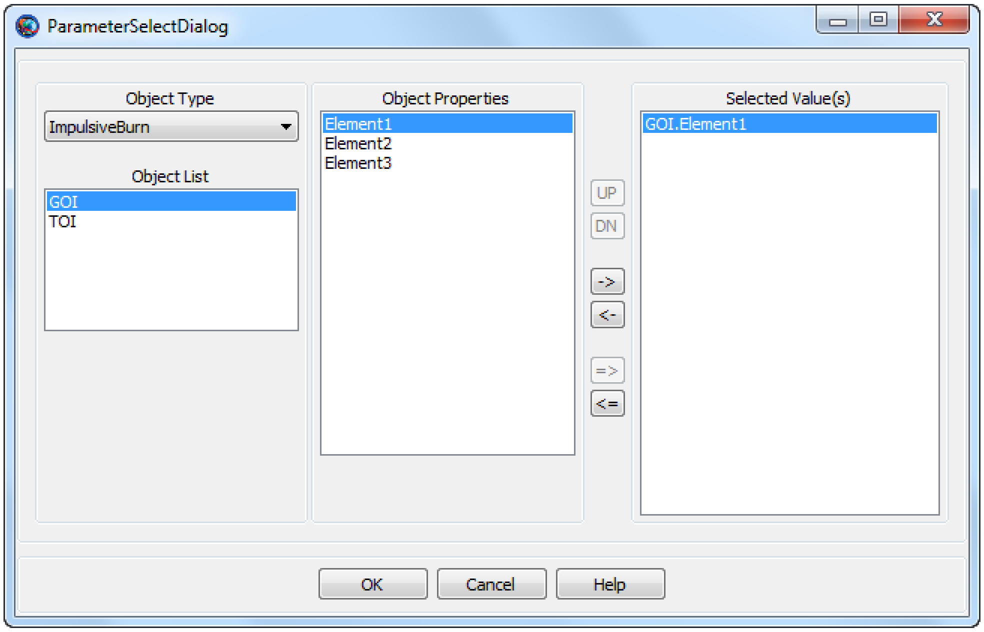


Figure 24. Vary GOI Parameter Selection

5. Click **OK** to close the **ParameterSelectDialog** window.
6. In the **Initial Value** box, type **`1.0`**.
7. In the **MaxStep** text box, type **`0.2`**.
8. Click **OK** to save these changes.

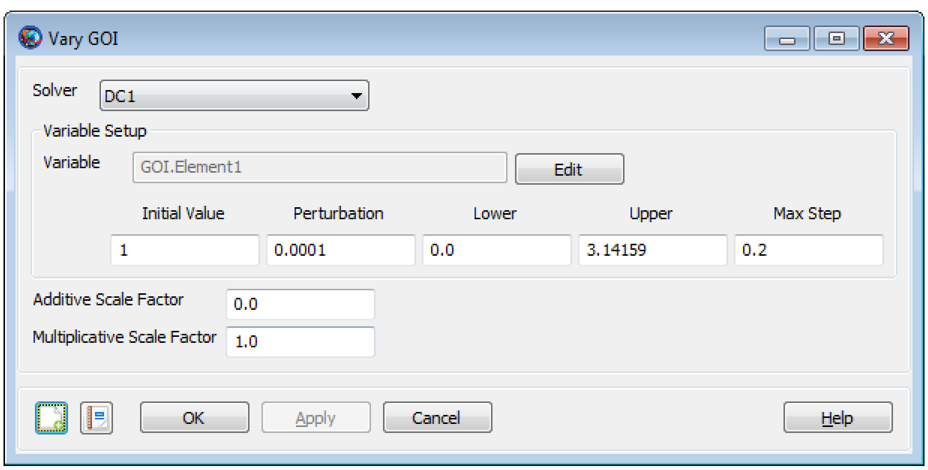


Figure 25. Vary GOI Command Configuration

Configure the Perform GOI Command

1. Double-click **Perform GOI** to edit its properties.

2. In the **Burn** list, click **GOI**.
3. Click **OK** to save these changes.

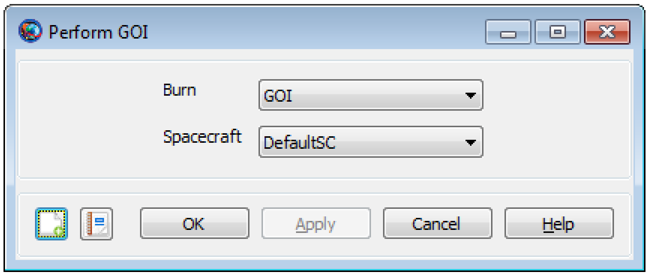


Figure 26. Perform GOI Command Configuration

Configure the Achieve ECC = 0.005 Command

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

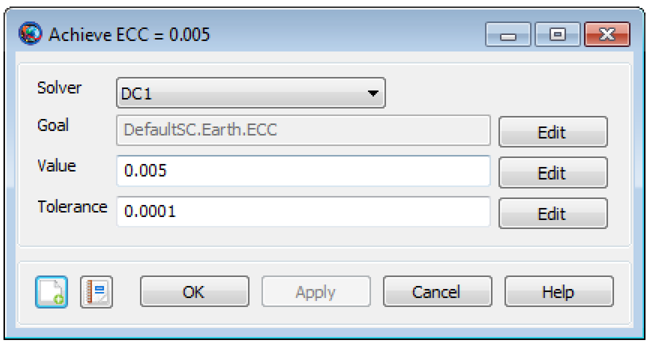


Figure 27. Achieve ECC = 0.005 Command Configuration

Run the Mission

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

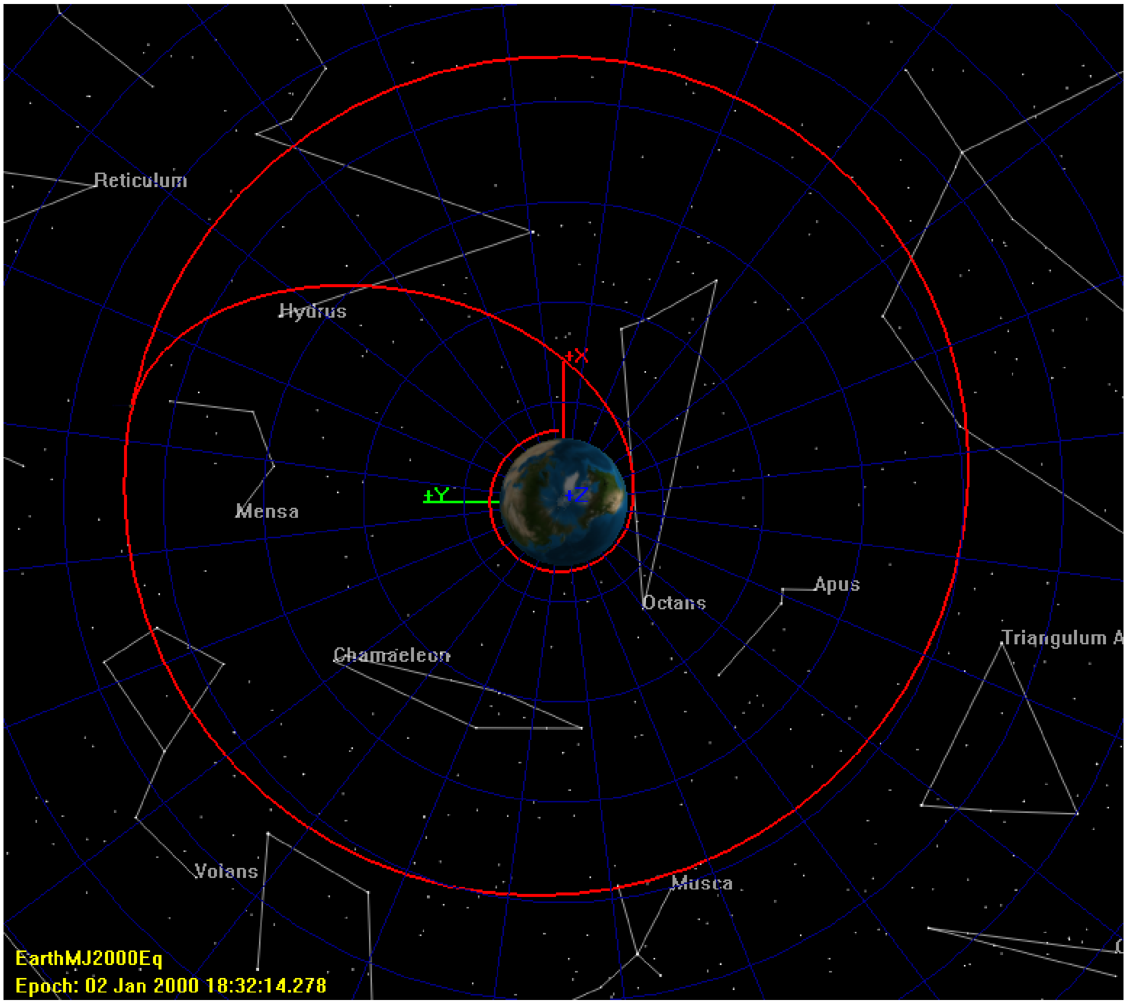


Figure 28. 3D View of Hohmann Transfer

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

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

Target Finite Burn to Raise Apogee

Audience	Intermediate level
Length	45 minutes
Prerequisites	Complete Simulating an Orbit and Simple Orbit Transfer
Script File	`Tut_Target_Finite_Burn_to_Raise_Apogee.script`

Objective and Overview

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

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

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

The basic steps of this tutorial are:

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

Create and Configure Spacecraft Hardware and Finite Burn

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

Create a Thruster and a Fuel Tank

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

1. In the **Resources** tree, right-click on the **Hardware** folder, point to **Add**, and click **Thruster**. A resource named **Thruster1** will be created.
2. In the **Resources** tree, right-click on the **Hardware** folder, point to **Add**, and click **FuelTank**. A resource named **FuelTank1** will be created.
3. Double-click **Thruster1** to edit its properties.
4. Select the **Decrement Mass** box so that GMAT will model fuel use associated with a finite burn.
5. Use the drop down menu to the right of the **Tank** field to select **FuelTank1** as the fuel source for **Thruster1**. Click **OK**.

Figure 29 below shows the default **FuelTank1** configuration that we will use and Figure 30 shows the finished **Thruster1** configuration.

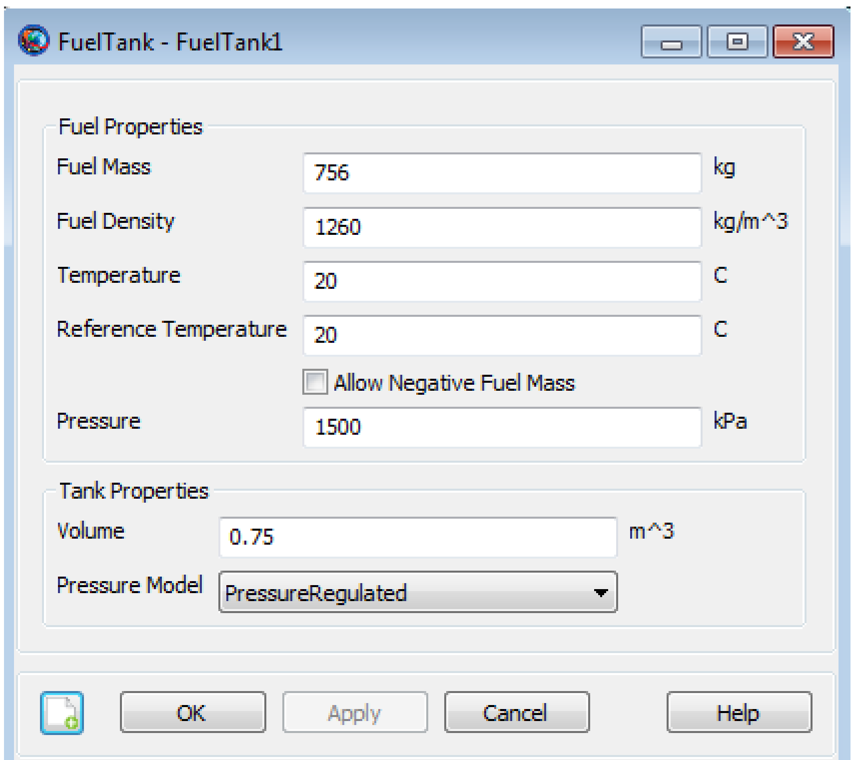


Figure 29. FuelTank1 Configuration

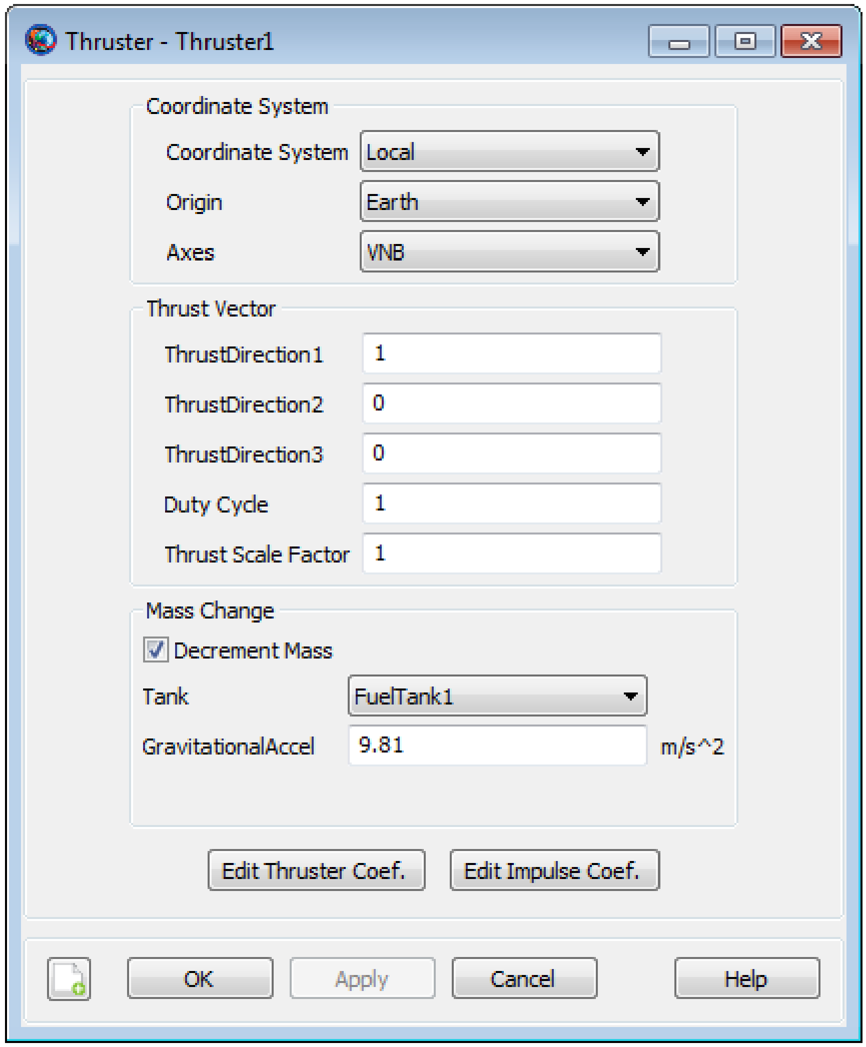


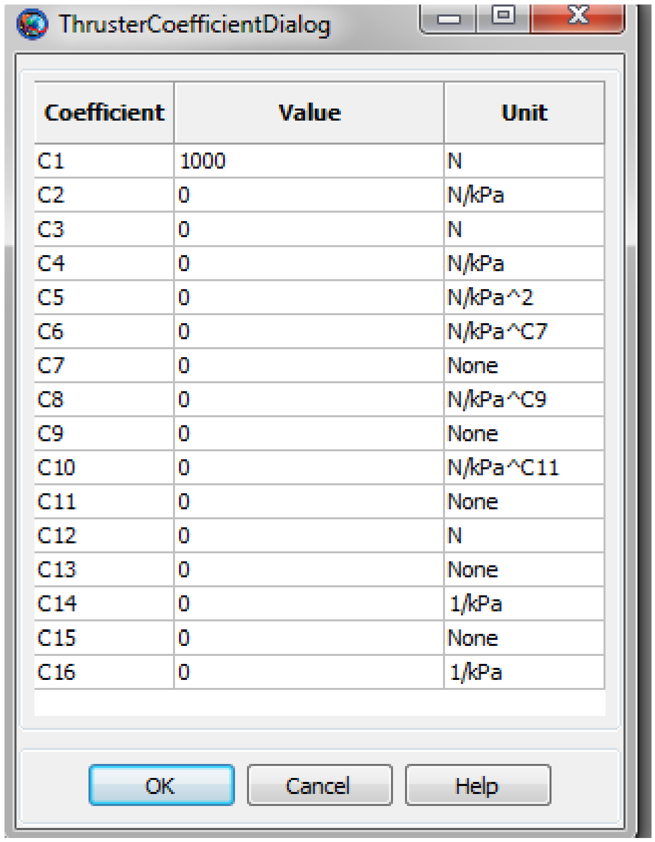
Figure 30. Thruster1 Configuration

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

For a general finite burn, if desired, we can specify how both the thrust and the fuel use depend upon fuel tank pressure. The user does this by inputting coefficients of certain pre-defined polynomials. To view the values for the thrust coefficients, click the **Edit Thruster Coef.** button and to view the ISP coefficients which determine fuel use, click the **Edit Impulse Coef.** button. For this tutorial, we will use the default ISP polynomial coefficient values but we will change the **Thruster1** polynomial coefficients as follows.

Modify Thruster1 Thrust Coefficients

1. In the **Resources** tree, double-click **Thruster1** to edit its properties
2. Click the **Edit Thruster Coef.** button to bring up the **ThrusterCoefficientDialog** box, shown in Figure 31. Replace the default **C1** coefficient value of `10` with `1000`. Click **OK**.



ThrusterCoefficientDialog

Coefficient	Value	Unit
C1	1000	N
C2	0	N/kPa
C3	0	N
C4	0	N/kPa
C5	0	N/kPa^2
C6	0	N/kPa^C7
C7	0	None
C8	0	N/kPa^C9
C9	0	None
C10	0	N/kPa^C11
C11	0	None
C12	0	N
C13	0	None
C14	0	1/kPa
C15	0	None
C16	0	1/kPa

OK Cancel Help

Figure 31. Thruster1 Thrust Coefficients

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

Thrust = 1000 (Newtons)

ISP = 300 (seconds)

Attach FuelTank1 and Thruster1 to DefaultSC

1. In the **Resources** tree, double-click **DefaultSC** to edit its properties.
2. Select the **Tanks** tab. In the **Available Tanks** column, select **FuelTank1**. Then click the right arrow button to add **FuelTank1** to the **SelectedTanks** list. Click **Apply**.
3. Select the **Actuators** tab. In the **Available Thrusters** column, select **Thruster1**. Then click the right arrow button to add **Thruster1** to the **SelectedThrusters** list. Click **OK**.

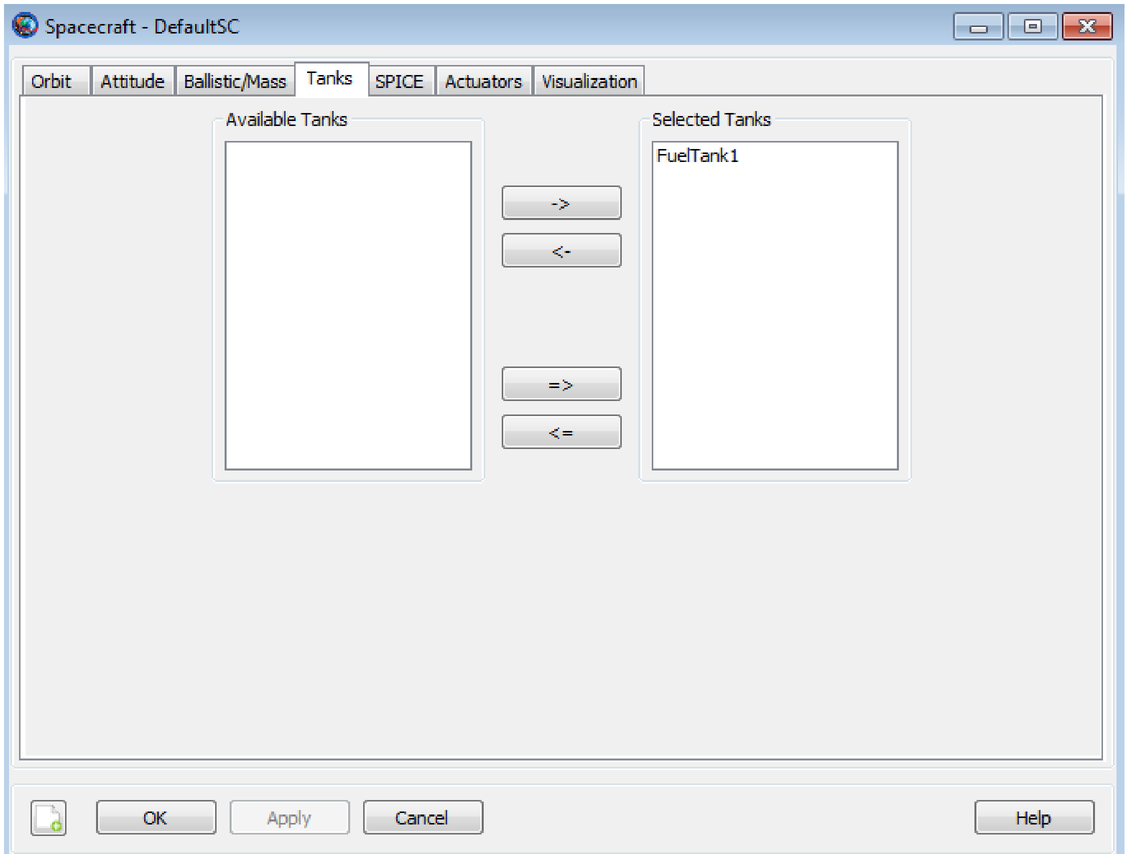


Figure 32. Attach FuelTank1 to DefaultSC

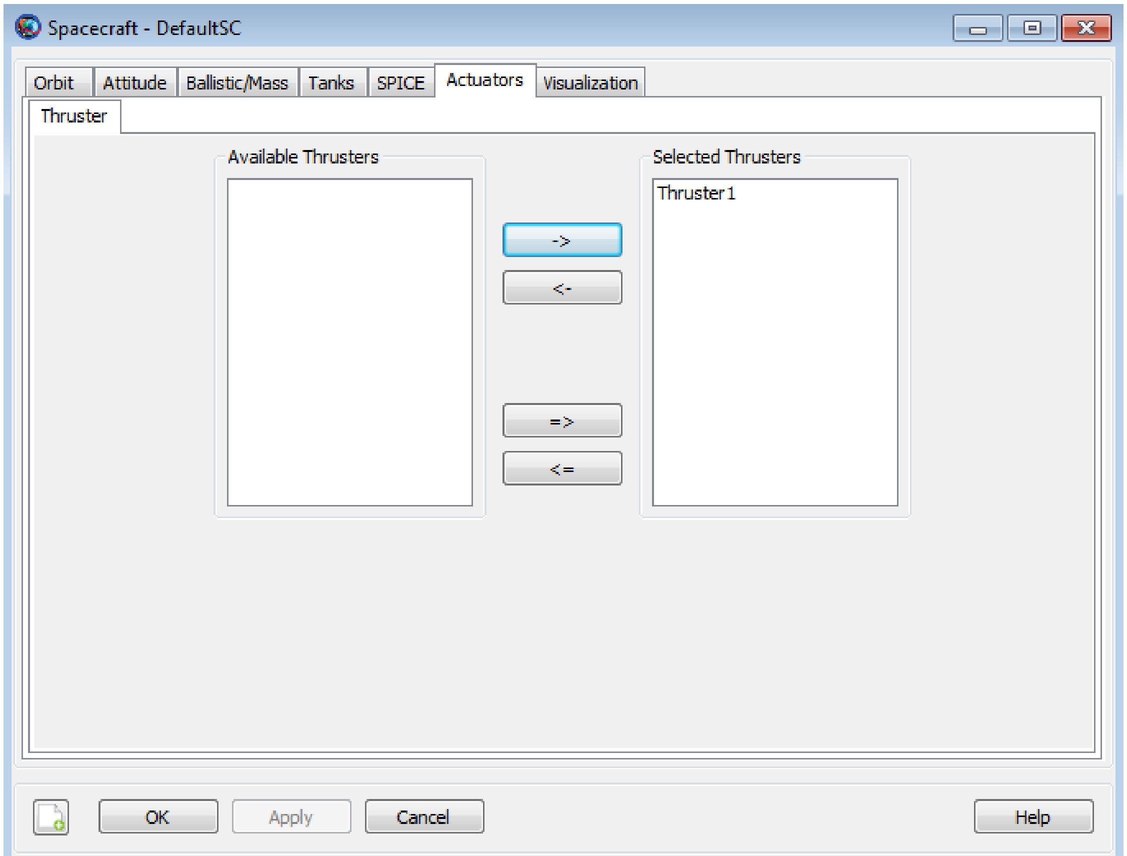


Figure 33. Attach Thruster1 to DefaultSC

Create the Finite Burn Maneuver

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

1. In the **Resources** tree, right-click the **Burns** folder and add a **FiniteBurn**. A resource named **FiniteBurn1** will be created.
2. Double-click **FiniteBurn1** to edit its properties.
3. Use the menu to the right of the **Thruster** field to select **Thruster1** as the thruster associated with **FiniteBurn1**. Click **OK**.

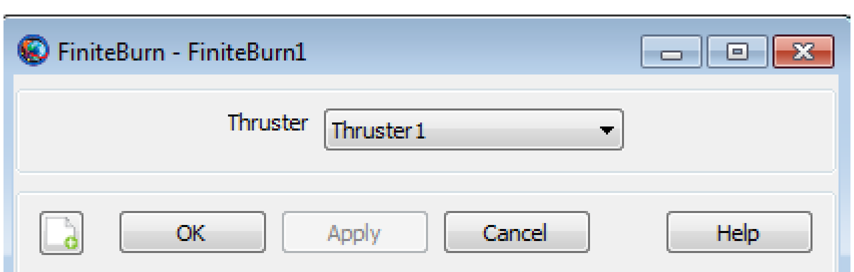


Figure 34. Creation of FiniteBurn Resource FiniteBurn1

Create the Differential Corrector and Target Control Variable

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

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

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

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

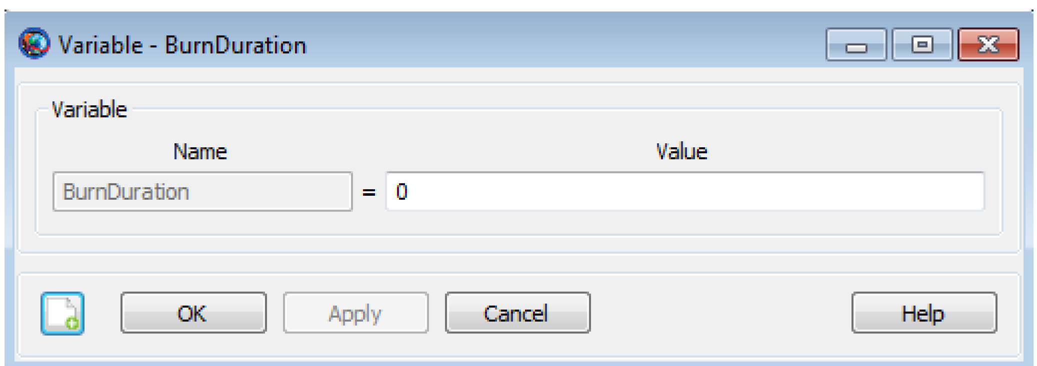


Figure 35. Creation of Variable Resource, BurnDuration

Configure the Mission Sequence

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

Configure the Initial Propagate Command

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

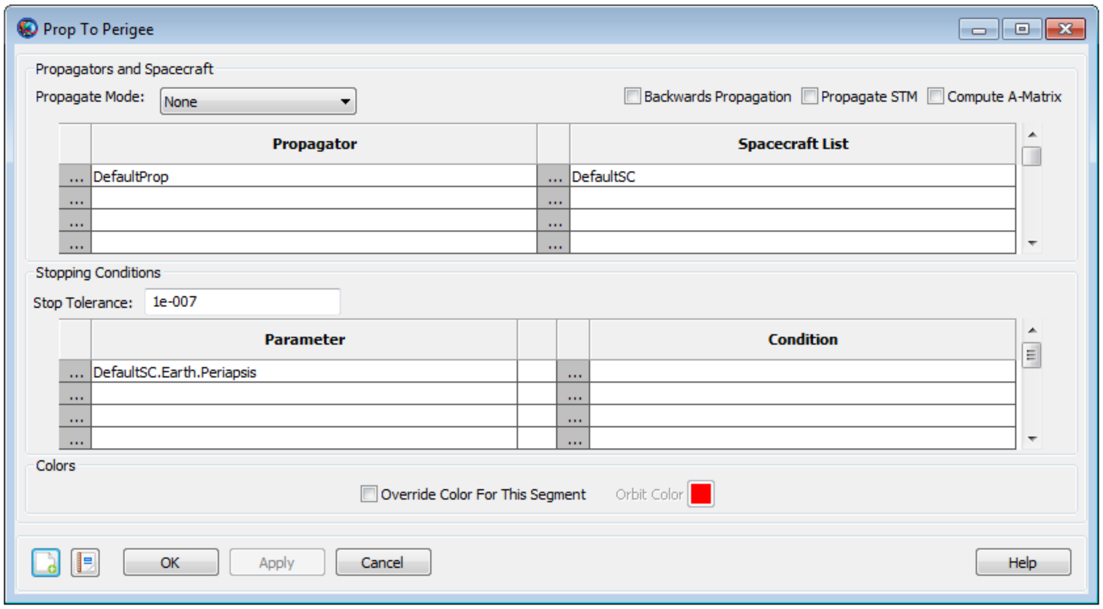


Figure 36. Prop To Perigee Command Configuration

Create the Target Sequence

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

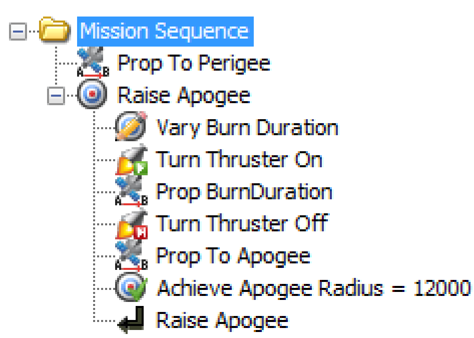


Figure 37. Final Mission Sequence

To create the **Target** sequence:

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

5. Complete the **Target** sequence by inserting the commands shown in Table 4.

Table 4. Additional Target Sequence Commands

Command	Name
Propagate	`Prop BurnDuration`
EndFiniteBurn	`Turn Thruster Off`
Propagate	`Prop To Apogee`
Achieve	`Achieve Apogee Radius = 12000`

Configure the Target Sequence

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

Configure the Raise Apogee Command

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

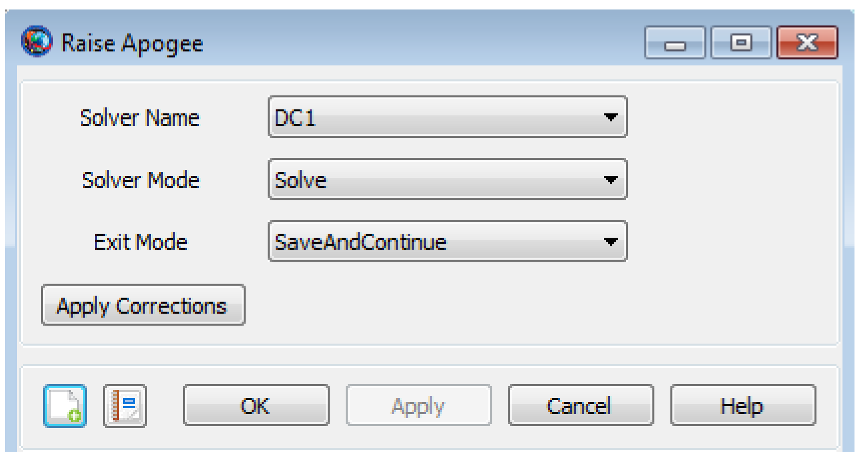


Figure 38. Raise Apogee Command Configuration

Configure the Vary Burn Duration Command

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

3. In the **Upper** box, type `10000`
4. In the **Max Step** box, type `100`.
5. Click **OK** to save these changes.

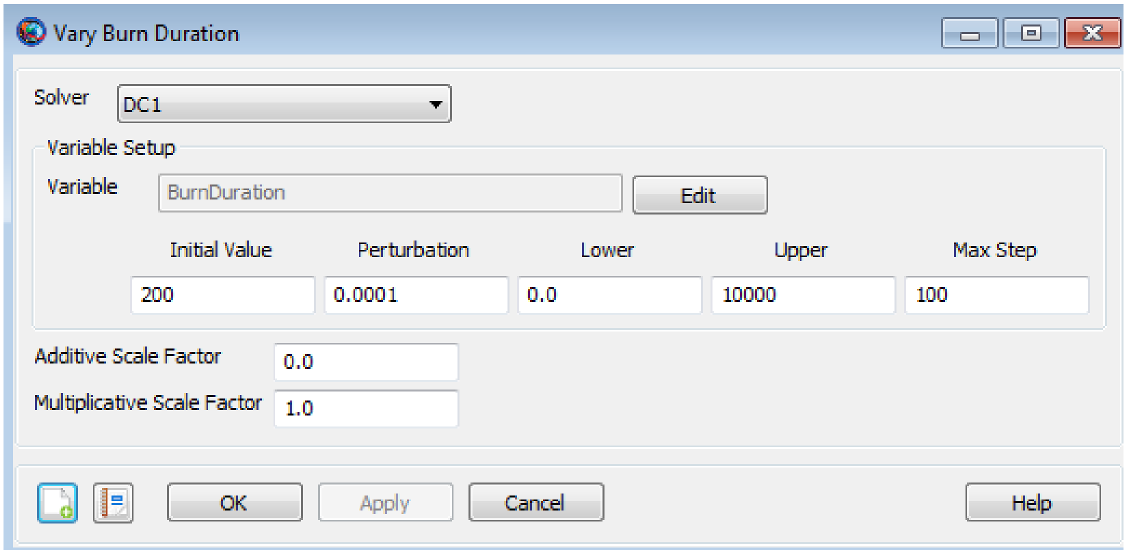


Figure 39. Vary Burn Duration Command Configuration

Configure the Turn Thruster On Command

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

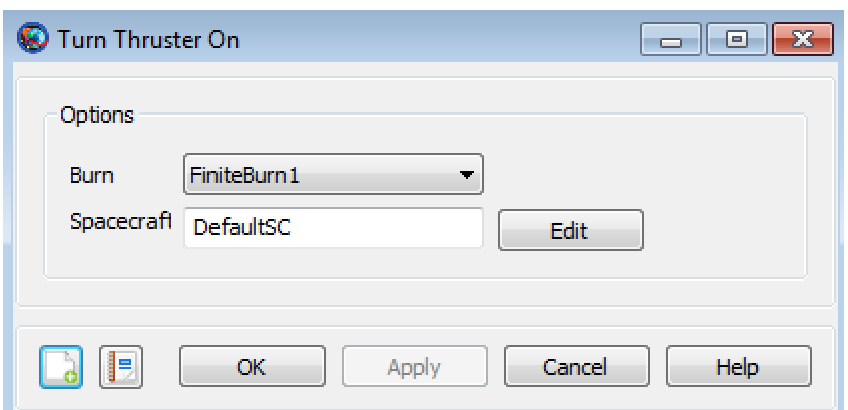


Figure 40. Turn Thruster On Command Configuration

Configure the Prop BurnDuration Command

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

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

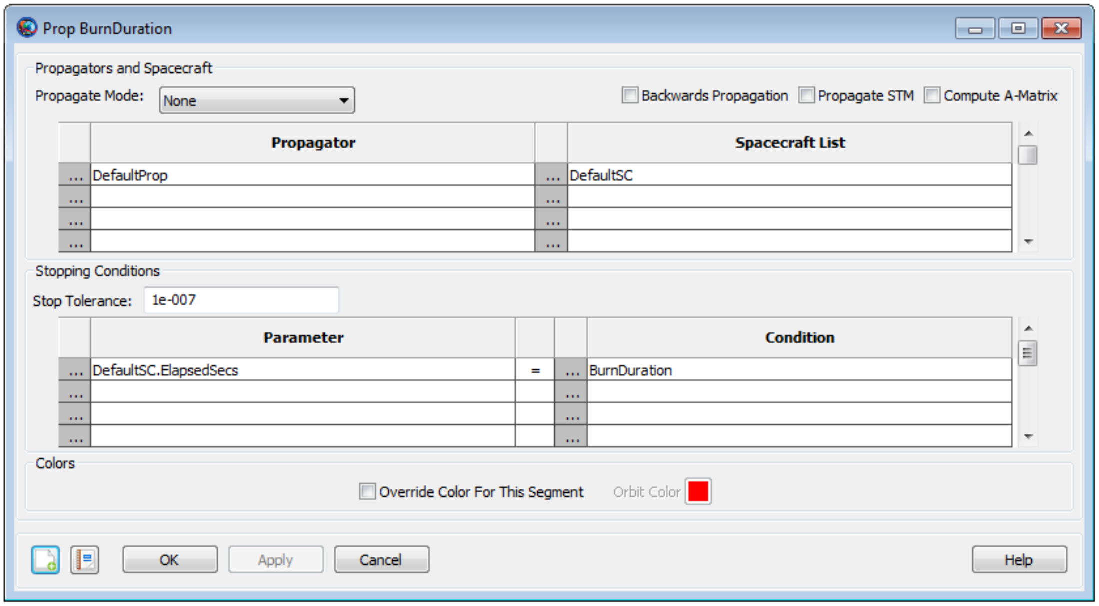


Figure 41. Prop BurnDuration Command Configuration

Configure the Turn Thruster Off Command

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

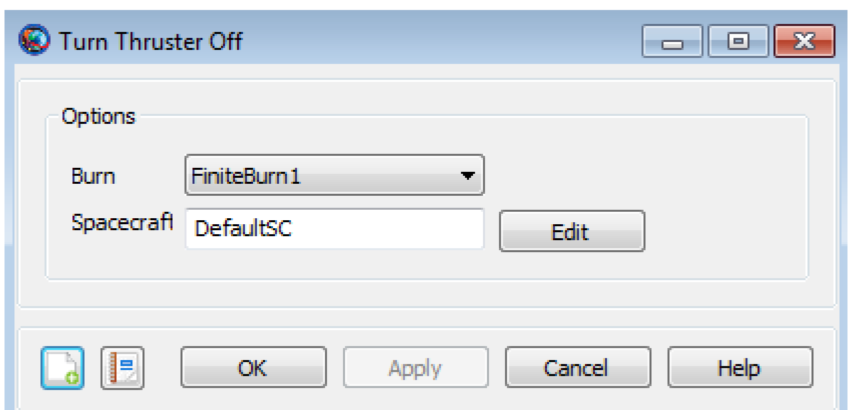


Figure 42. Turn Thruster Off Command Configuration

Configure the Prop To Apogee Command

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

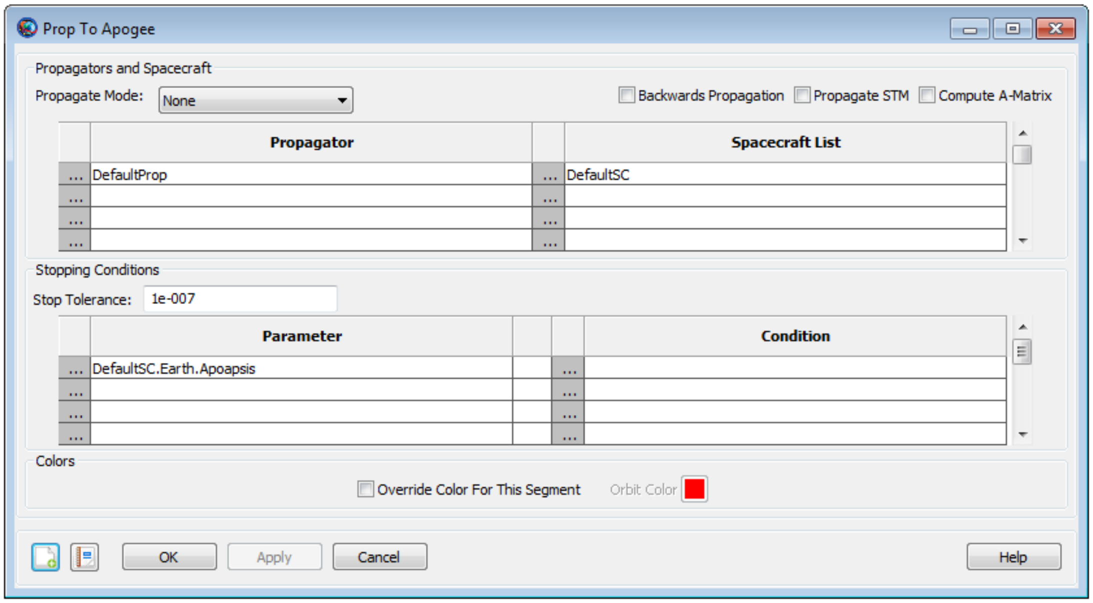


Figure 43. Prop To Apogee Command Configuration

Configure the Achieve Apogee Radius = 12000 Command

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

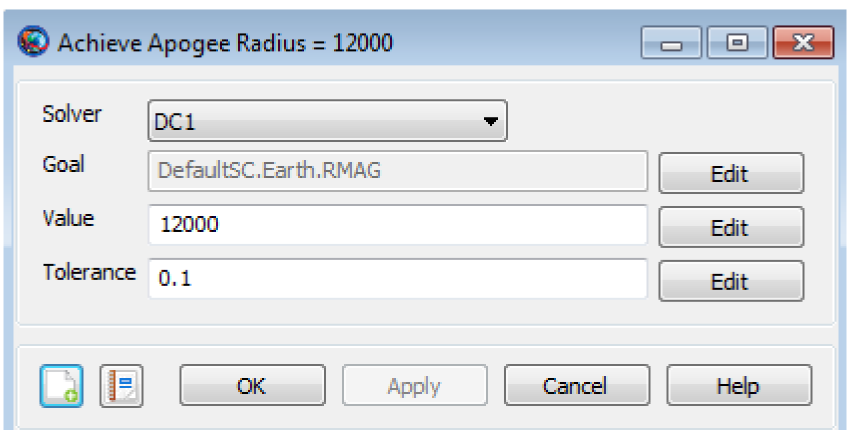


Figure 44. Achieve Apogee Radius = 12000 Command Configuration

Run the Mission

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

Inspect Orbit View and Message Window

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

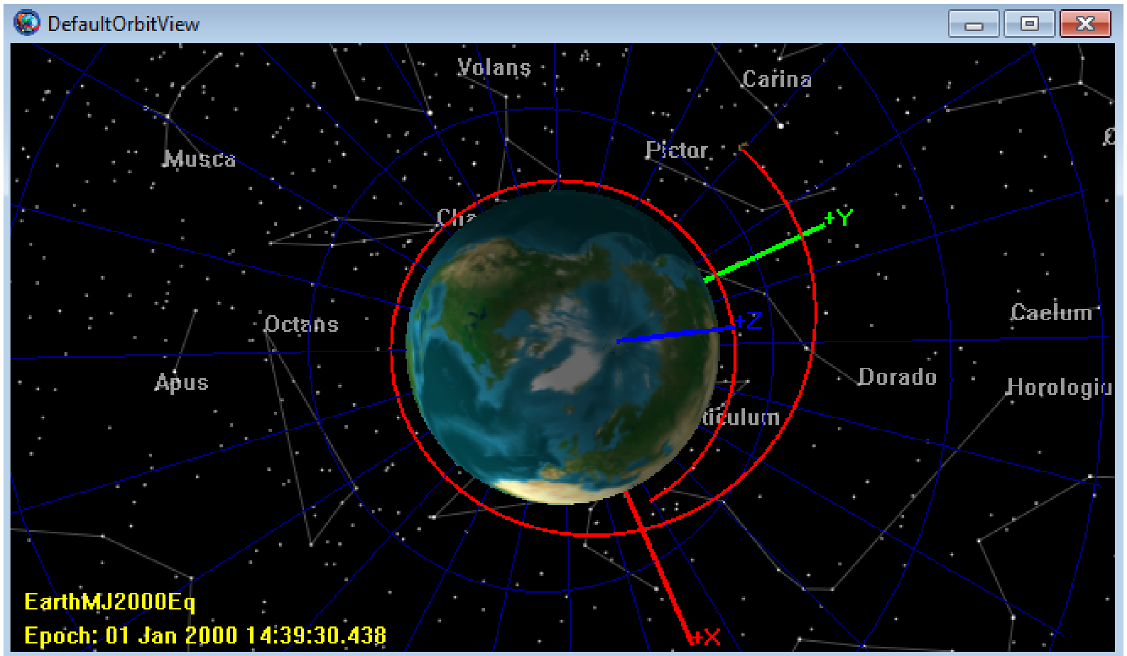


Figure 45. 3D View of Finite Burn to Raise Apogee

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

```
*** Targeting Completed in 13 iterations

    Final Variable values:

    BurnDuration = 1213.19316329
```

Explore the Command Summary Reports

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

1. In the **Mission** tree, select **Prop To Perigee**, then right-click to open the associated **Command Summary** which describes the state of **DefaultSC** after the **Prop To Perigee** command has been performed. We verify perigee has indeed been achieved by finding the mean anomaly value of **DefaultSC**. To do this, we look at the value of **MA** under the Keplerian State. As expected, the mean anomaly is zero.

2. View the **Turn Thruster On** command summary. Note that, as expected, prior to the start of the maneuver, the fuel mass is `756` kg.
3. View the **Turn Thruster Off** command summary.

   a. Note that the mean anomaly at the end of the maneuver is `25.13` degrees. Thus, as the burn occurred, the mean anomaly increased from `0` to `25.13` degrees. By orbital theory, we know that an apogee raising burn is best performed at perigee. Thus, we may be able to achieve our orbital goal using less fuel if we "center" the burn. For example, we could try starting our burn at a mean anomaly of `-(25.13/2)` instead of `0` degrees.
   b. Note that, at the end of the maneuver, the fuel mass is `343.76990815648` kg. Thus, this finite burn used approximately `756 - 343.8` = `412.2` kg of fuel.
4. View the **Prop To Apogee** command summary.

   a. We note that the mean anomaly is `180` degrees which proves that we are indeed at apogee.
   b. We note that the orbital radius (RMAG) is `11999.999998192` km which proves that we have achieved our desired `12000` km apogee radius to within our desired tolerance of `0.1` km.

Mars B-Plane Targeting

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

Objective and Overview

Note

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

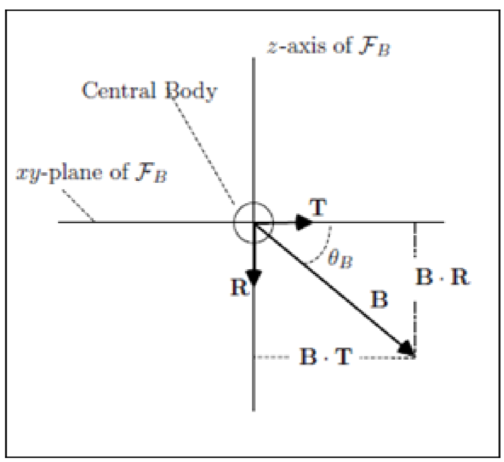


Figure 46. Geometry of the B-Plane as seen from a viewpoint perpendicular to the B-Plane

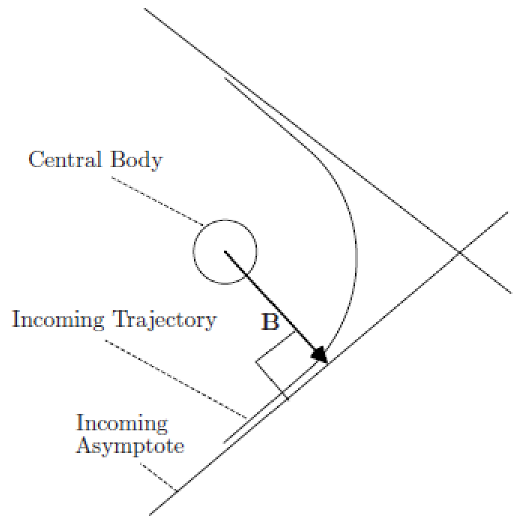


Figure 47. The B-vector as seen from a viewpoint perpendicular to orbit plane

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

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

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

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

8. Create first **Target** sequence to target BdotT and BdotR components of the B-vector.
9. Create second **Target** sequence to implement MOI by targeting position magnitude at apoapsis.
10. Run the mission and analyze the results.

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

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

Create Fuel Tank

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

1. In the **Resources** tree, right-click the **Hardware** folder, point to **Add** and click **Fuel Tank**. A new resource called **FuelTank1** will be created.
2. Right-click**FuelTank1** and click **Rename**.
3. In the**Rename** box, type **MainTank** and click **OK**.
4. Double click on**MainTank** to edit its properties.
5. Set the values shown in the table below.

Table 5. MainTank settings

Field	Value
Fuel Mass	`1718`
Fuel Density	`1000`
Pressure	`5000`
Volume	`2`

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

Modify the DefaultSC Resource

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

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

Table 6. MAVEN settings

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

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

Create the Maneuvers

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

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

Create the Propagators

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

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

Table 7. NearEarth settings

Field	Value
Initial Step Size under **Integrator**	`600`
Accuracy under **Integrator**	`1e-013`
Min Step Size under **Integrator**	`0`
Max Step Size under **Integrator**	`600`
Model under **Gravity**	**JGM-2**
Degree under **Gravity**	`8`
Order under **Gravity**	`8`
Atmosphere Model under **Drag**	**None**
Point Masses under **Force Model**	Add **Luna** and **Sun**
Use Solar Radiation Pressure under **Force Model**	**Check this field**

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

Table 8. DeepSpace settings

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

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

Table 9. NearMars settings

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

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

Create the Differential Corrector

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

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

Create the Coordinate Systems

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

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

Create the Orbit Views

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

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

Table 10. EarthView settings

Field	Value
View Scale Factor under **View Definition**	`4`
View Point Vector boxes, under **View Definition**	`0, 0, 30000`

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

Table 11. SolarSystemView settings

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

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

Table 12. MarsView settings

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

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

Configure the Mission Sequence

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

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

Create the First Target Sequence

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

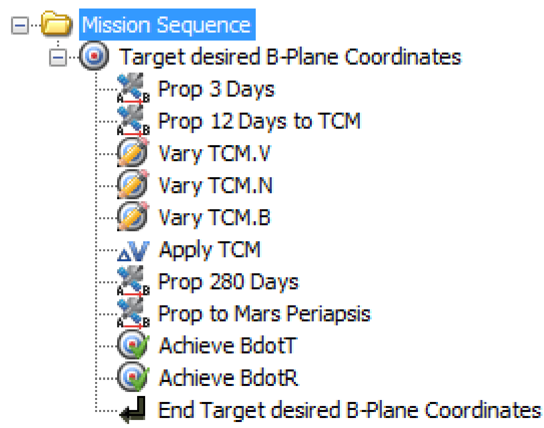


Figure 48. Mission Sequence for the First Target sequence

To create the first **Target** sequence:

1. Click on the **Mission** tab to show the **Mission** tree.
2. You'll see that there already exists a **Propagate1** command. We need to delete this command
3. Right-click on **Propagate1** command and click **Delete**.
4. Right-click on **Mission Sequence** folder, point to **Append**, and click **Target**. This will insert two separate commands: **Target1** and **EndTarget1**.
5. Right-click **Target1** and click **Rename**.
6. Type **Target desired B-plane Coordinates** and click **OK**.
7. Right-click **Target desired B-plane Coordinates**, point to **Append**, and click **Propagate**. A new command called **Propagate1** will be created.
8. Right-click **Propagate1** and click **Rename**.
9. In the **Rename** box, type **Prop 3 Days** and click **OK**.
10. Complete the **Target** sequence by appending the commands in Table 13.

Table 13. Additional First Target Sequence Commands

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

Note

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

Configure the First Target Sequence

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

Configure the Target desired B-plane Coordinates Command

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

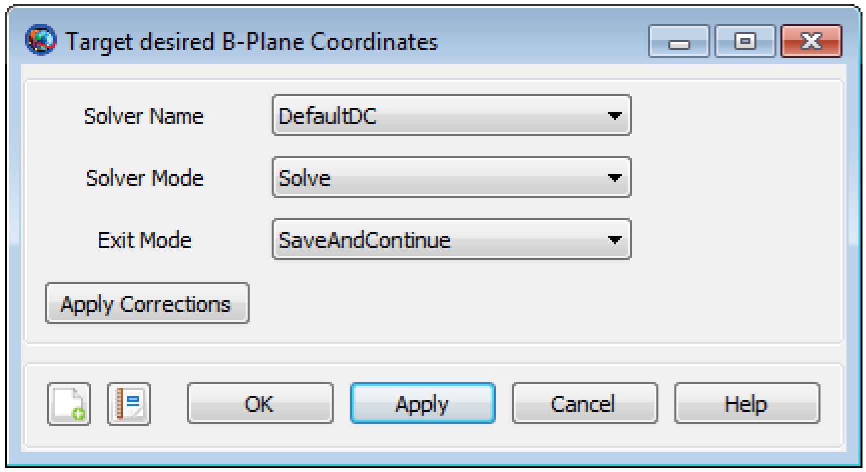


Figure 49. Target desired B-plane Coordinates Command Configuration

Configure the Prop 3 Days Command

1. Double-click **Prop 3 Days** to edit its properties.
2. Under **Propagator**, make sure that **NearEarth** is selected
3. Under **Parameter**, replace **MAVEN.ElapsedSeconds** with **MAVEN.ElapsedDays**.
4. Under **Condition**, replace **0.0** with **3**.
5. Click **OK** to save these changes.

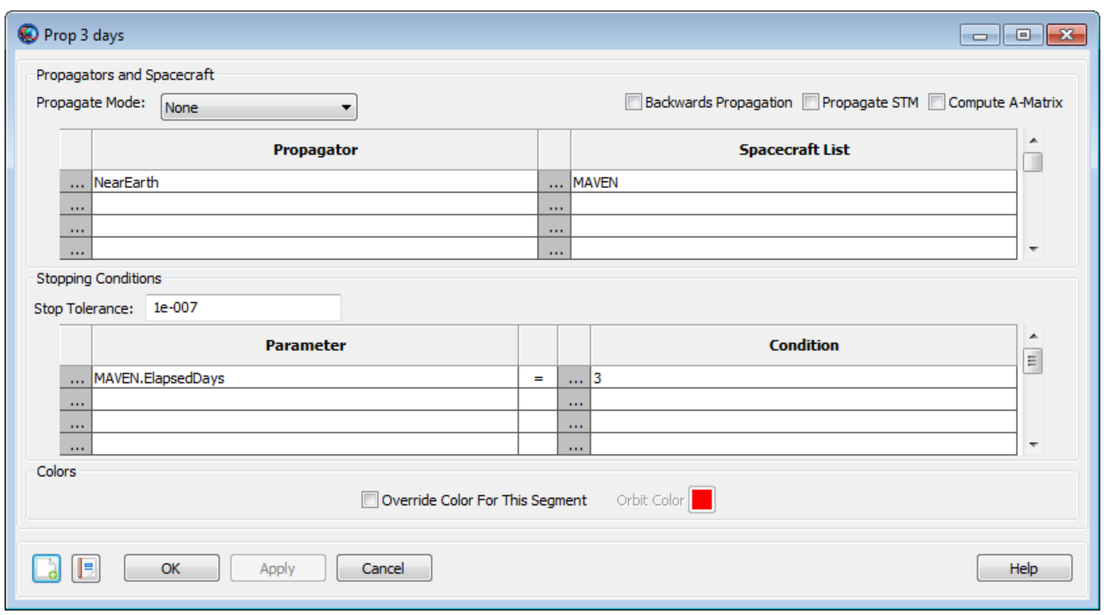


Figure 50. Prop 3 Days Command Configuration

Configure the Prop 12 Days to TCM Command

1. Double-click **Prop 12 Days to TCM** to edit its properties.

2. Under **Propagator**, replace **NearEarth** with **DeepSpace**.
3. Under **Parameter**, replace **MAVEN.ElapsedSeconds** with **MAVEN.ElapsedDays**.
4. Under **Condition**, replace **0.0** with **12**.
5. Click **OK** to save these changes.

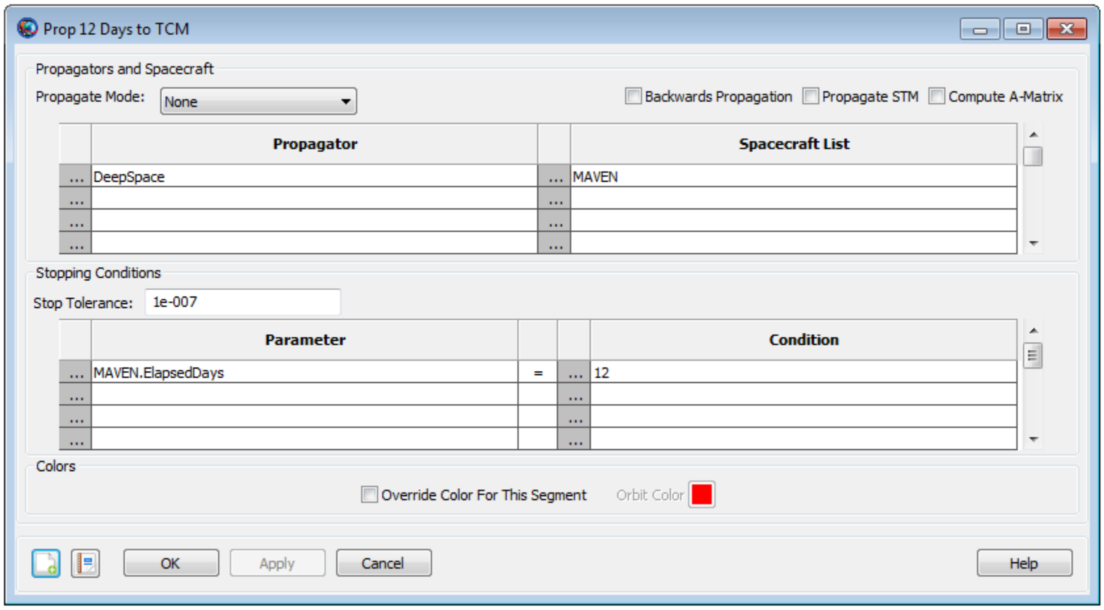


Figure 51. Prop 12 Days to TCM Command Configuration

Configure the Vary TCM.V Command

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

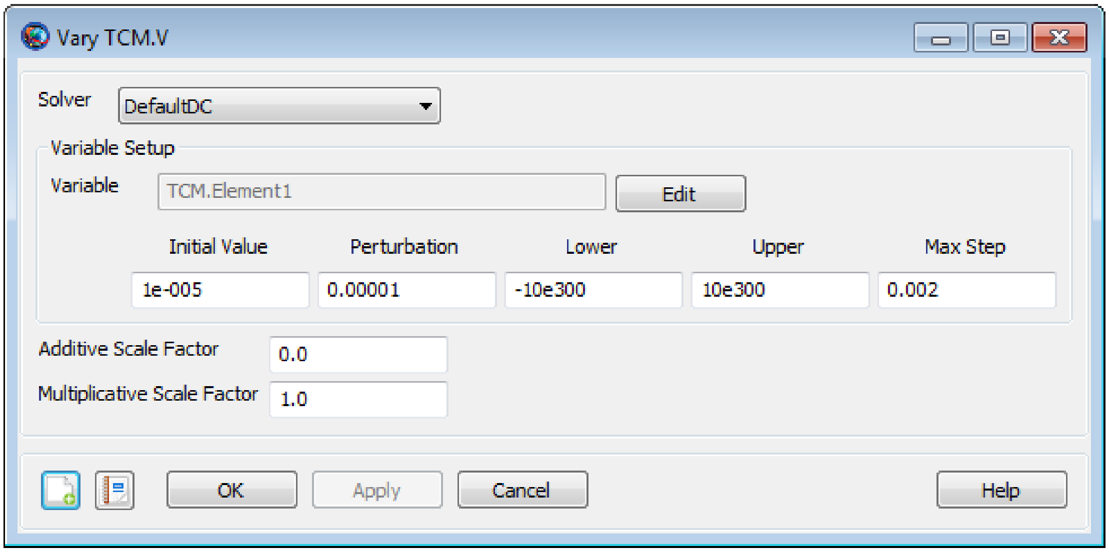


Figure 52. Vary TCM.V Command Configuration

Configure the Vary TCM.N Command

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

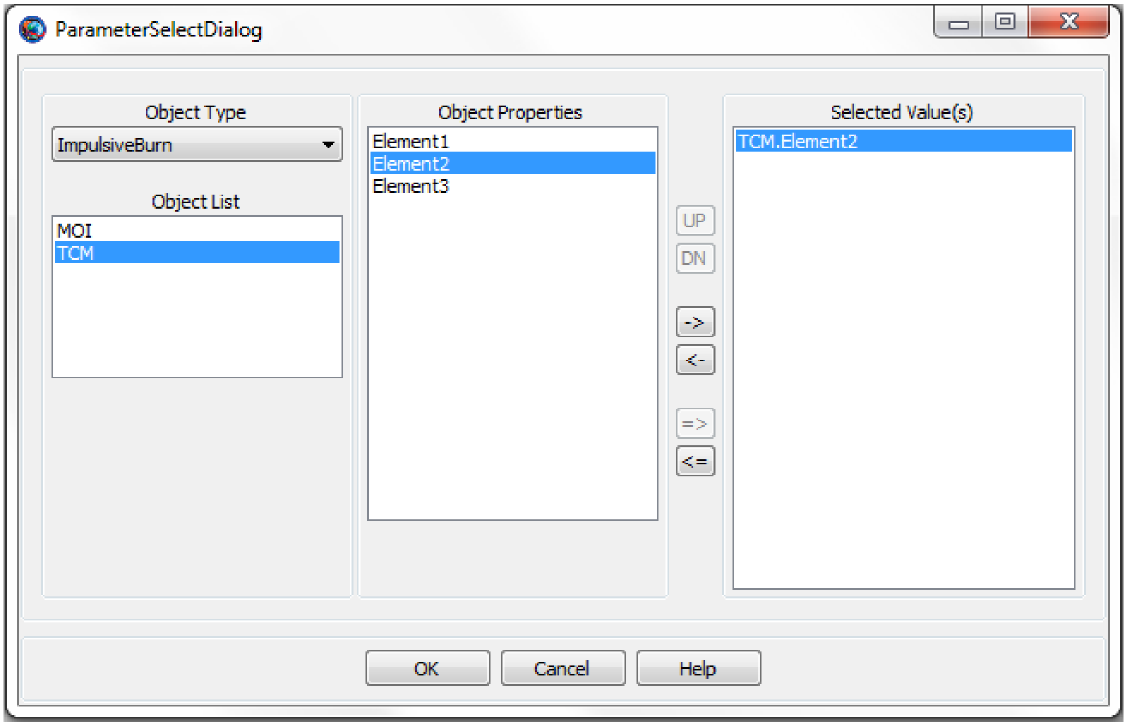


Figure 53. Vary TCM.N Parameter Selection

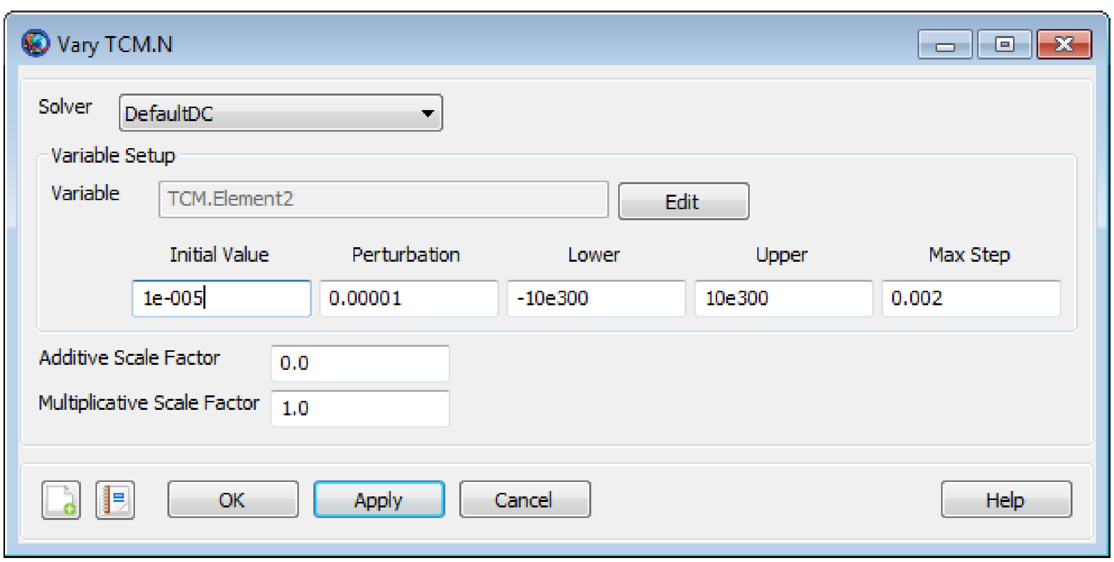


Figure 54. Vary TCM.N Command Configuration

Configure the Vary TCM.B Command

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

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

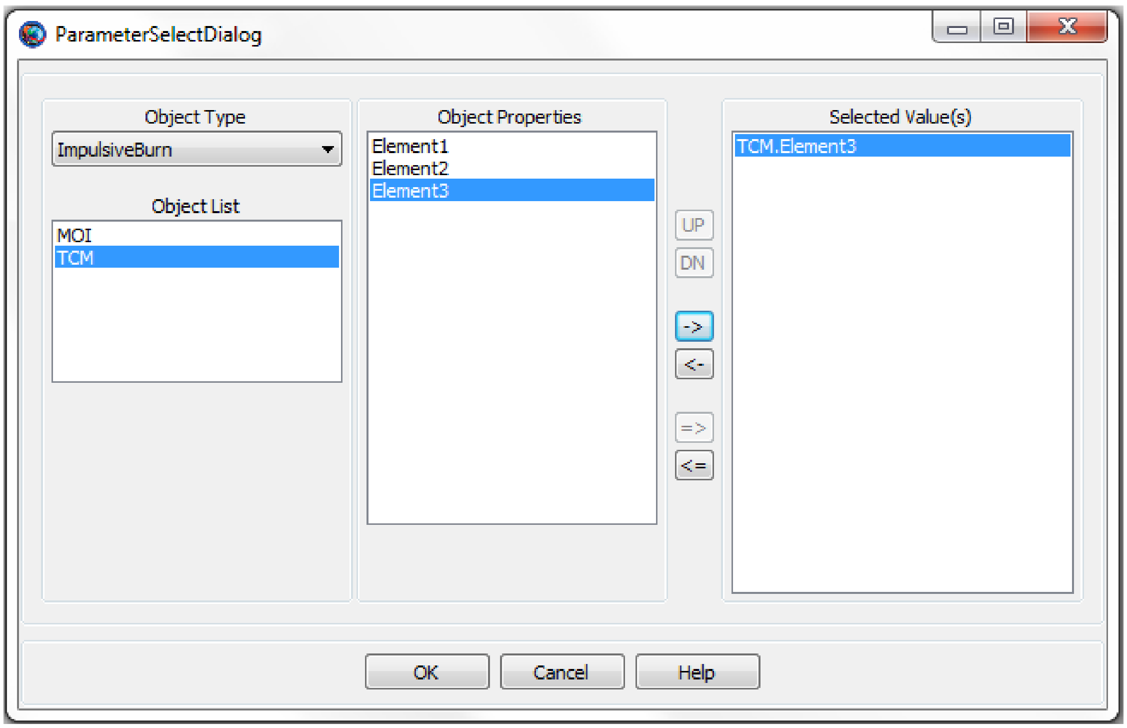


Figure 55. Vary TCM.B Parameter Selection

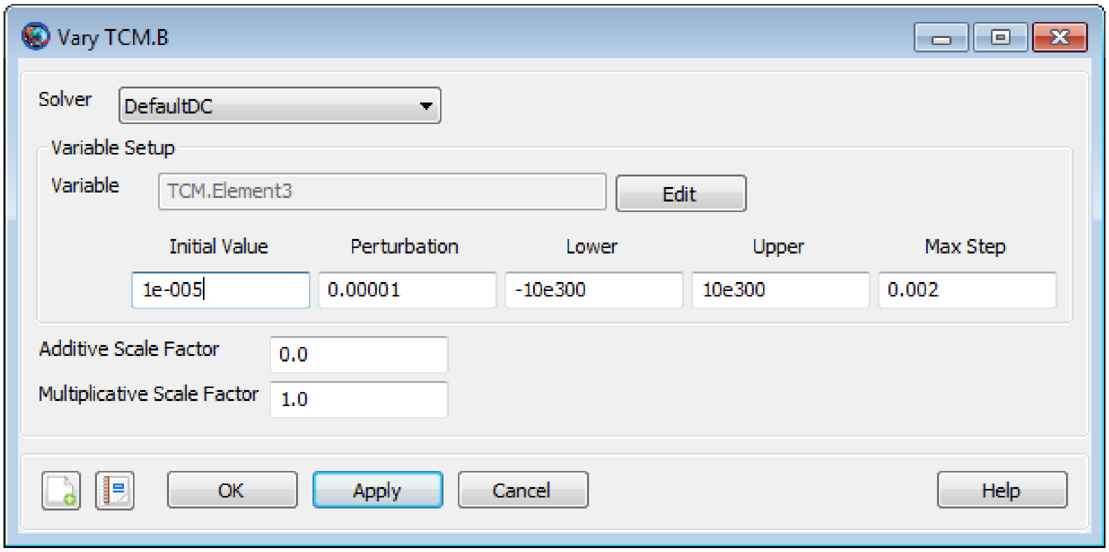


Figure 56. Vary TCM.N Command Configuration

Configure the Apply TCM Command

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

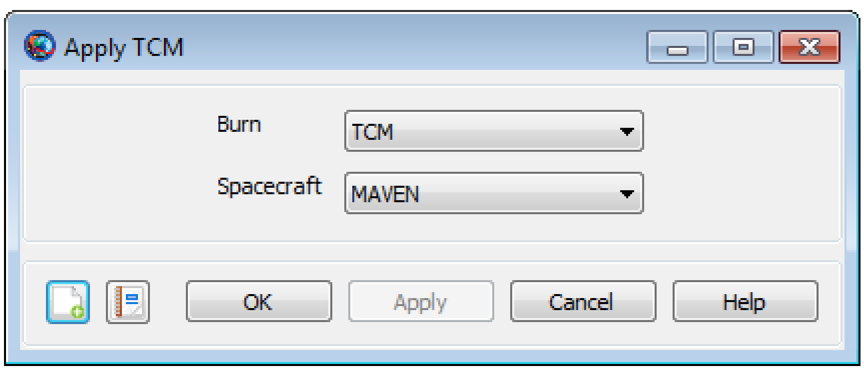


Figure 57. Apply TCM Command Configuration

Configure the Prop 280 Days Command

1. Double-click **Prop 280 Days** to edit its properties.
2. Under **Propagator**, replace **NearEarth** with **DeepSpace**.
3. Under **Parameter**, replace **MAVEN.ElapsedSeconds** with **MAVEN.ElapsedDays**.
4. Under **Condition**, replace **0.0** with **280**.
5. Click **OK** to save these changes.

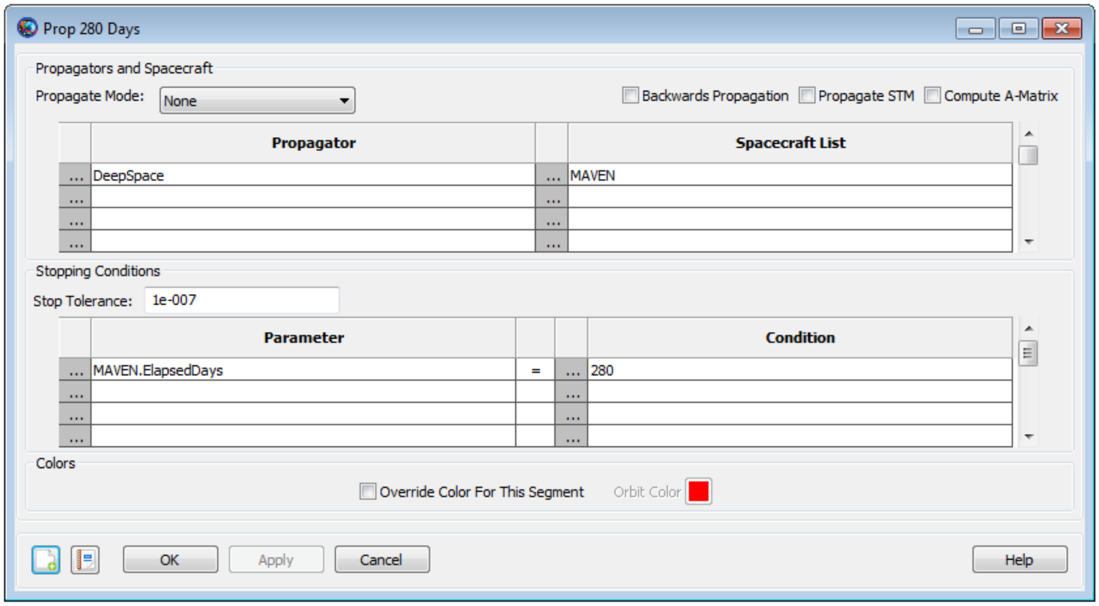


Figure 58. Prop 280 Days Command Configuration

Configure the Prop to Mars Periapsis Command

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

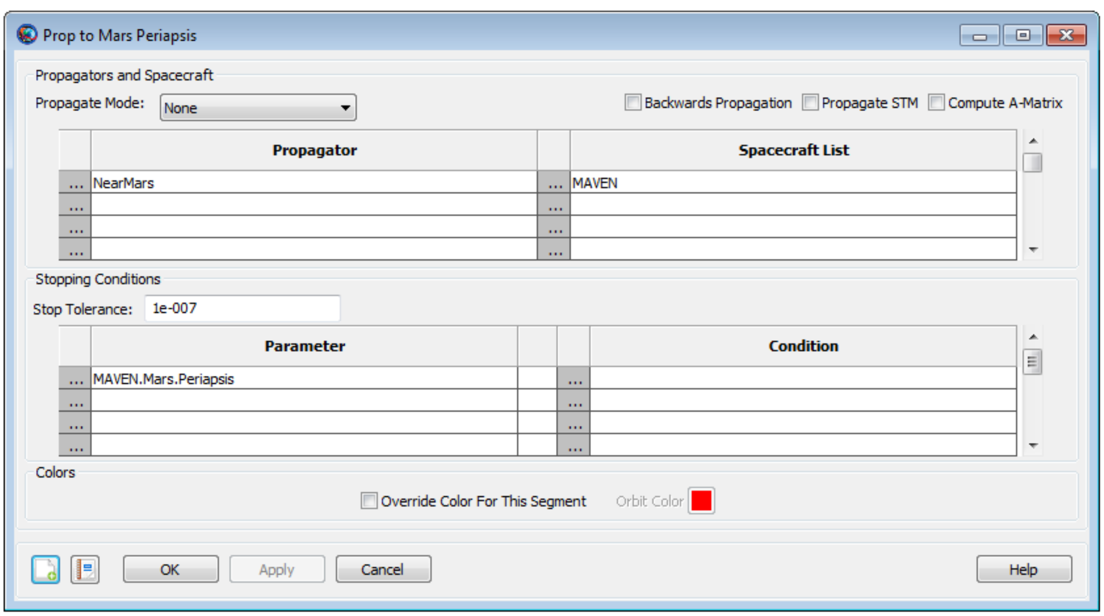


Figure 59. Prop to Mars Periapsis Command Configuration

Configure the Achieve BdotT Command

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

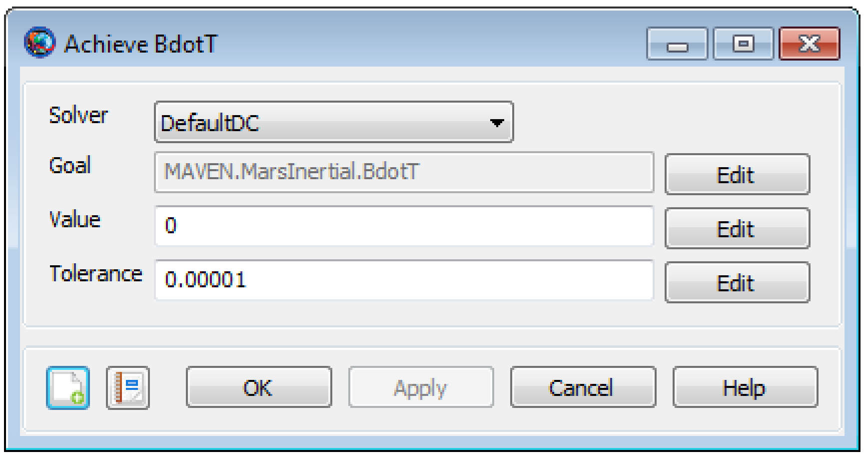


Figure 60. Achieve BdotT Command Configuration

Configure the Achieve BdotR Command

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

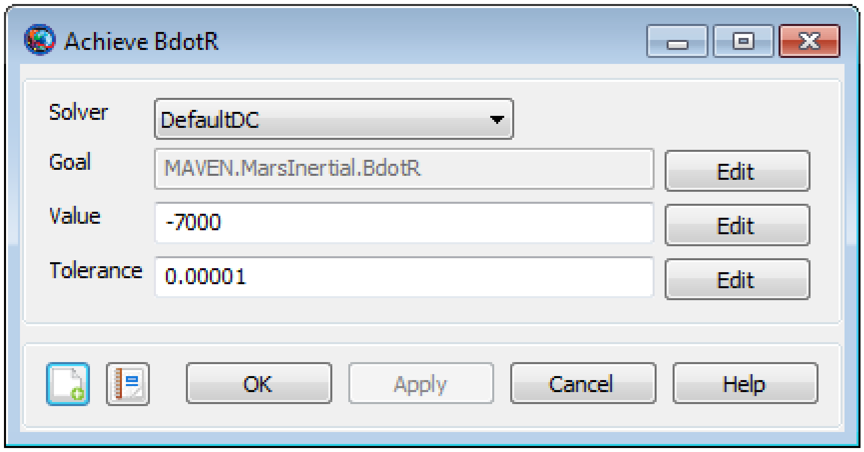


Figure 61. Achieve BdotR Command Configuration

Run the Mission with first Target Sequence

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

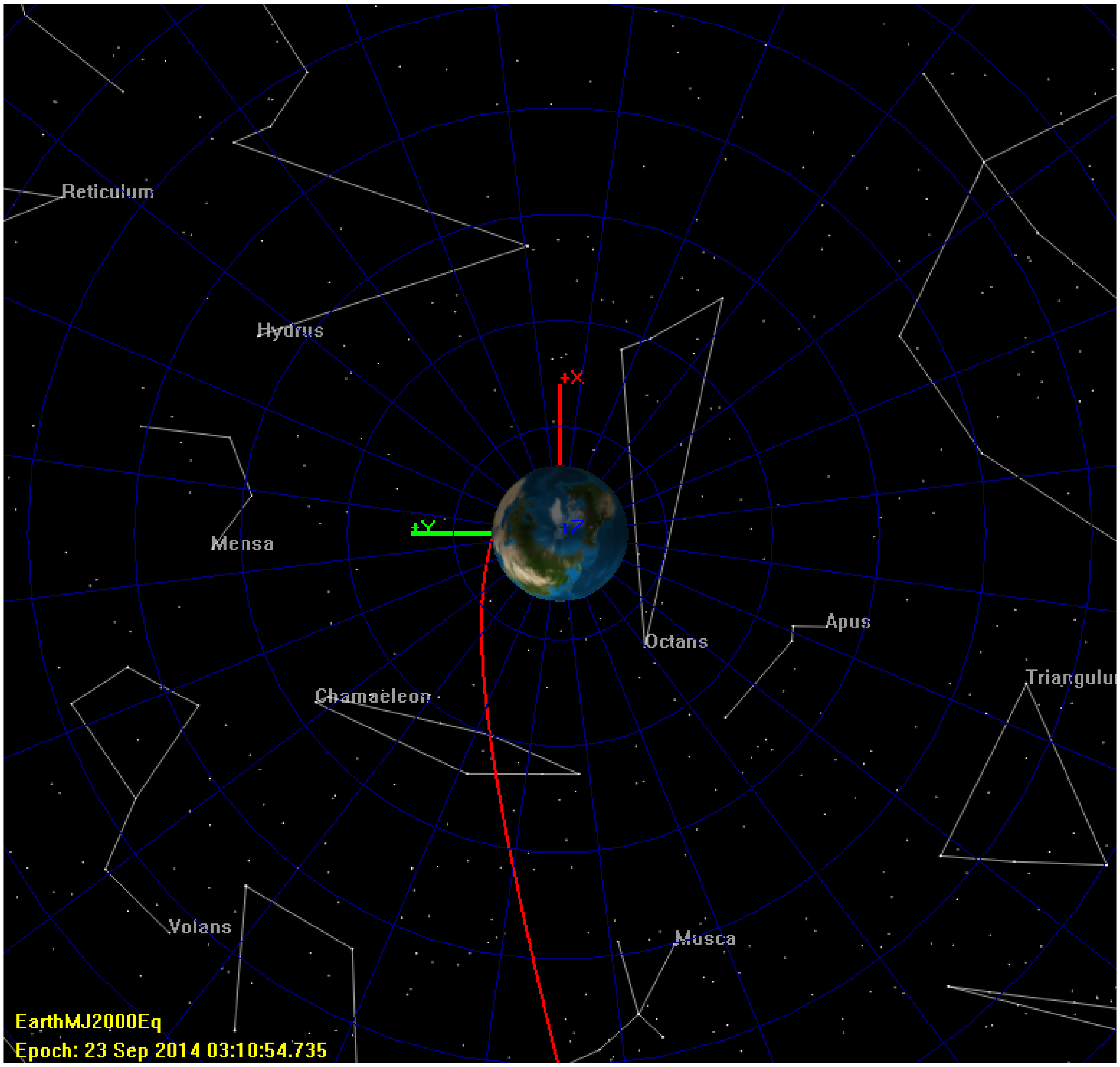


Figure 62. 3D View of departure hyperbolic trajectory (EarthView)

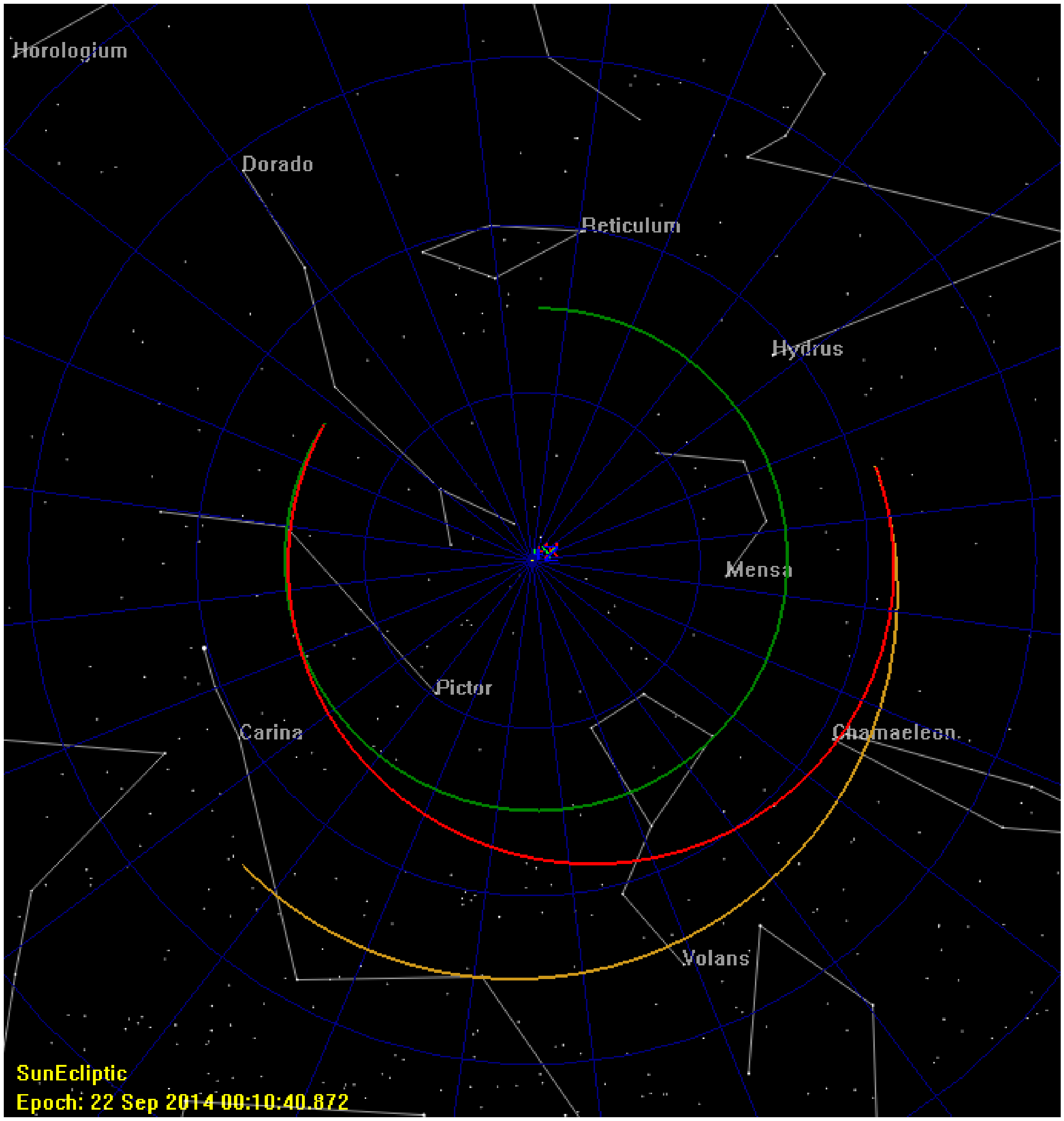


Figure 63. 3D View of heliocentric transfer trajectory (SolarSystemView)

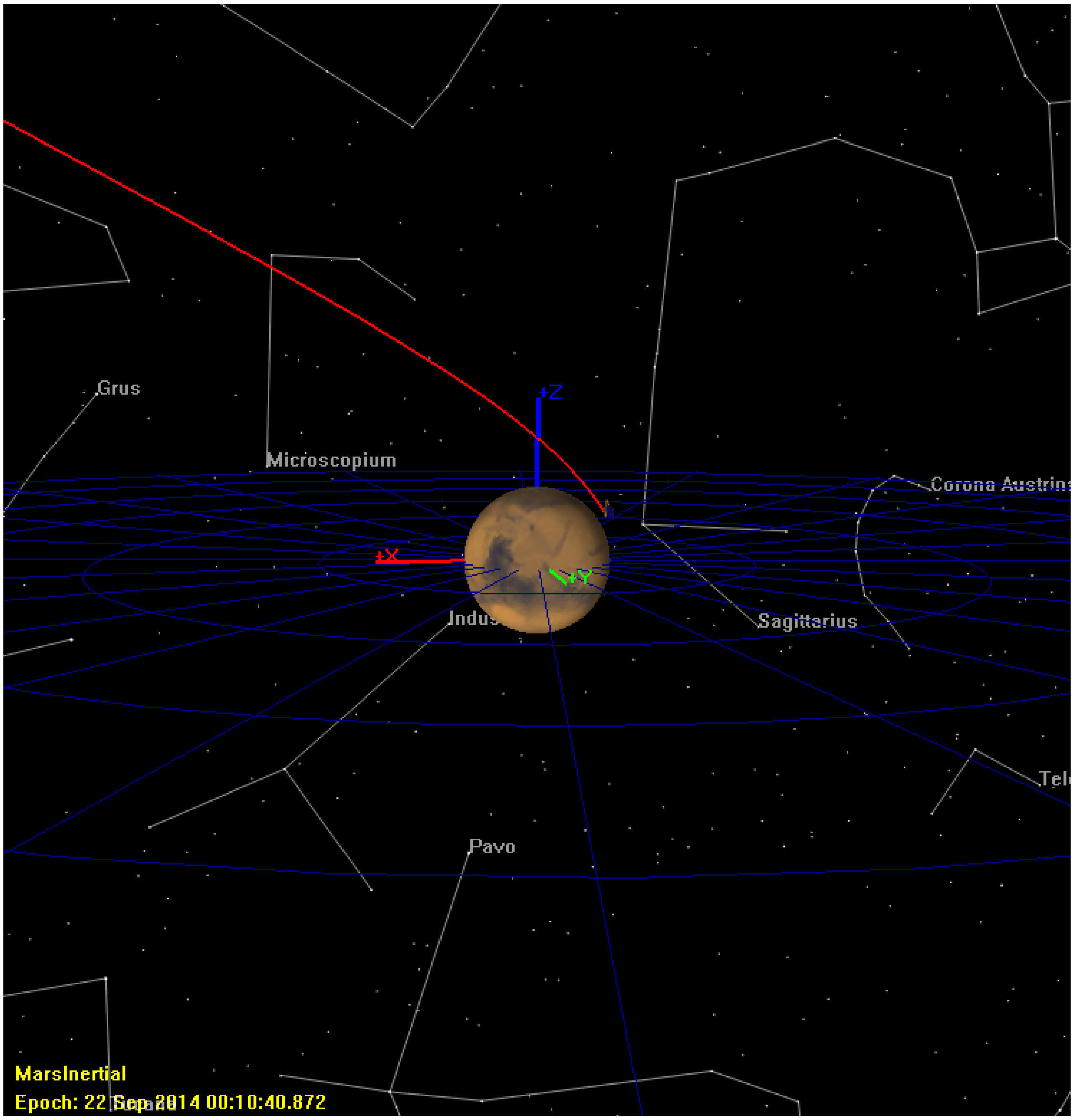


Figure 64. 3D View of approach hyperbolic trajectory. MAVEN stopped at periapsis (MarsView)

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

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

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

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

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

   ```
   Delta V Vector:

   Element 1: 0.0039376963731 km/s

   Element 2: 0.0060423170483 km/s

   Element 3: -0.0006747125434 km/s
   ```
3. Scroll down and under `Mass depletion from MainTank` heading, `Delta V` and `Mass Change` tells you TCM maneuver's magnitude and how much fuel was used for the maneuver:

   ```
   Delta V: 0.0072436375569 km/s

   Mass change: -6.3128738639690 kg
   ```
4. Click **OK** to close **Command Summary** window.

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

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

   ```
   BdotT = -0.0000053320678 km

   BdotR = -7000.0000019398 km

   INC = 90.000000039301 deg
   ```

Create the Second Target Sequence

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

Now let's create the commands necessary to perform the second **Target** sequence. Figure 65 illustrates the configuration of the **Mission** tree after you have completed the steps in this section. Notice that in Figure 65, the second **Target** sequence is created after the first **Target** sequence. We'll discuss the second **Target** sequence after it has been created.

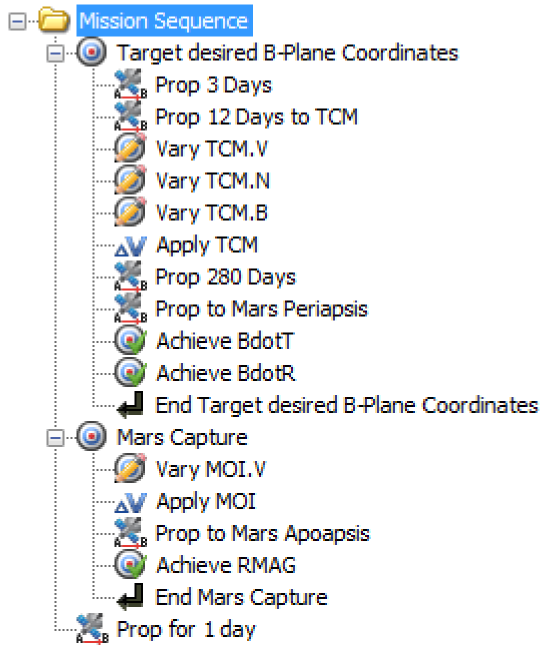


Figure 65. Mission Sequence showing first and second Target sequences

To create the second **Target** sequence:

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

Table 14. Additional Second Target Sequence Commands

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

Note

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

Create the Final Propagate Command

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

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

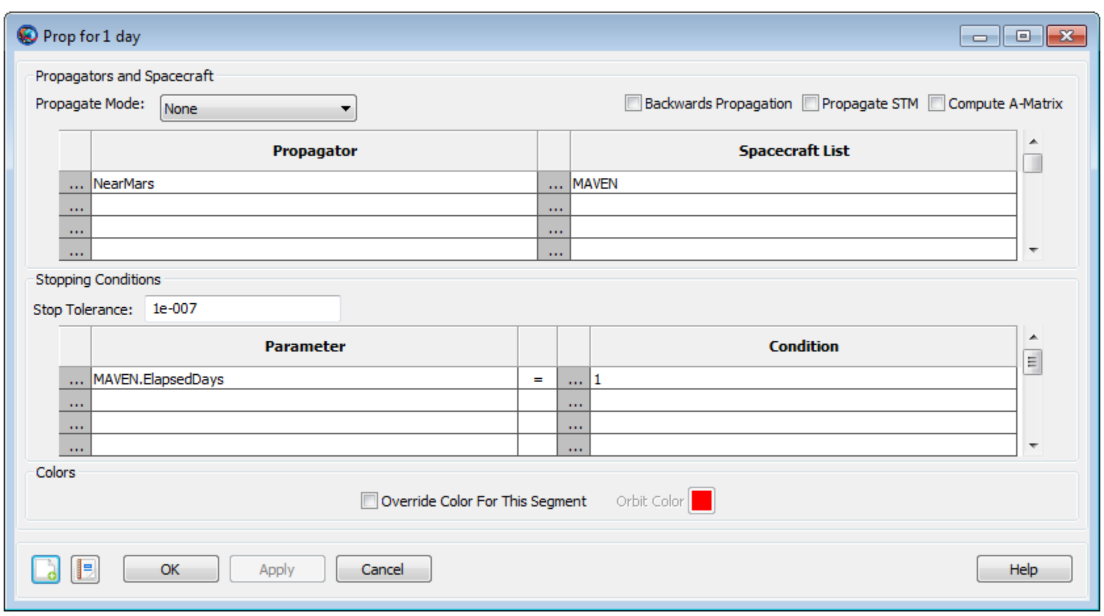


Figure 66. Prop for 1 day Command Configuration

Configure the second Target Sequence

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

Configure the Mars Capture Command

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

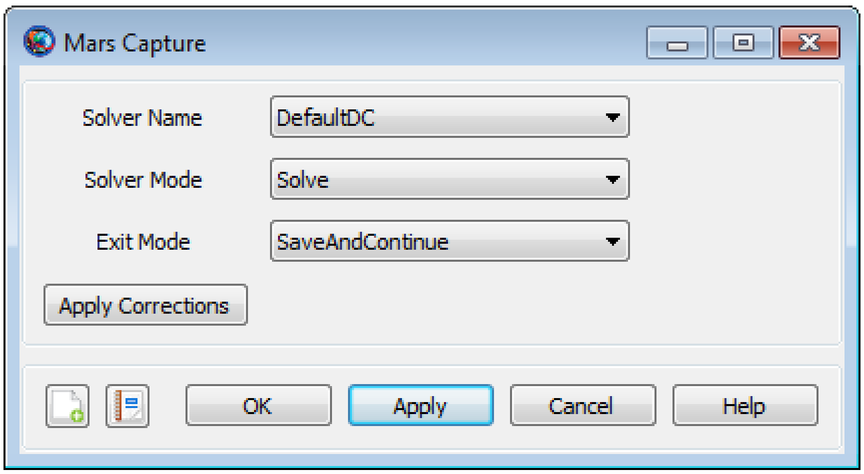


Figure 67. Mars Capture Command Configuration

Configure the Vary MOI.V Command

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

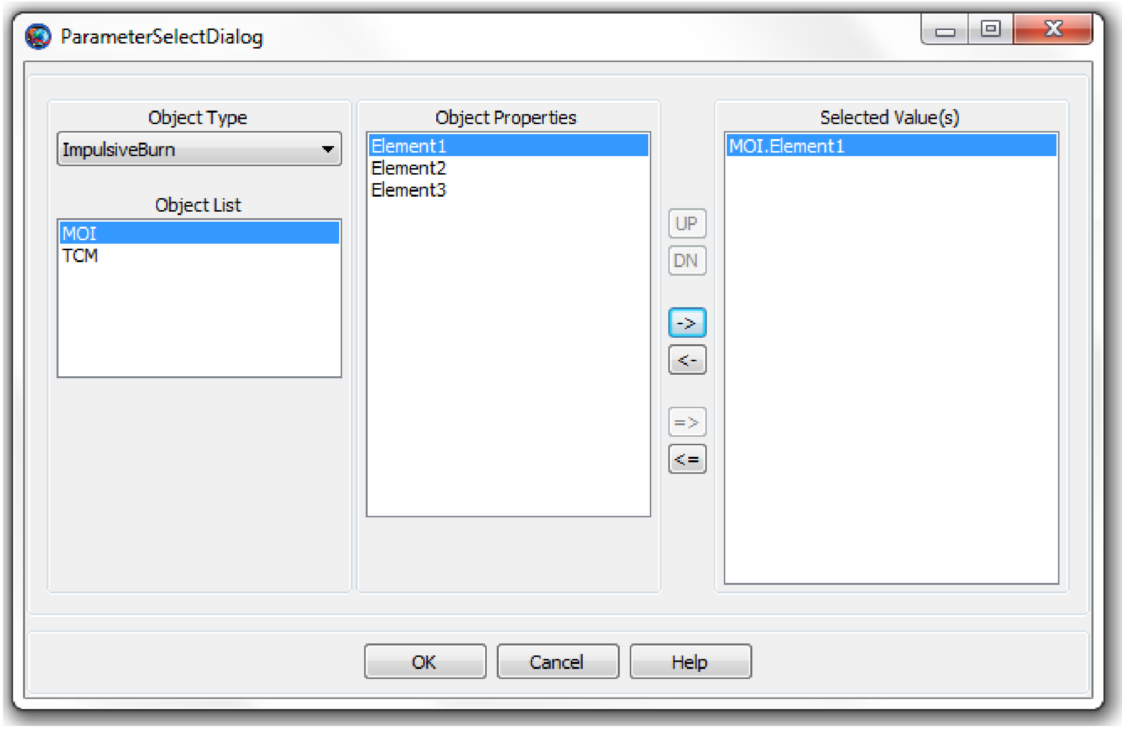


Figure 68. Vary MOI Parameter Selection

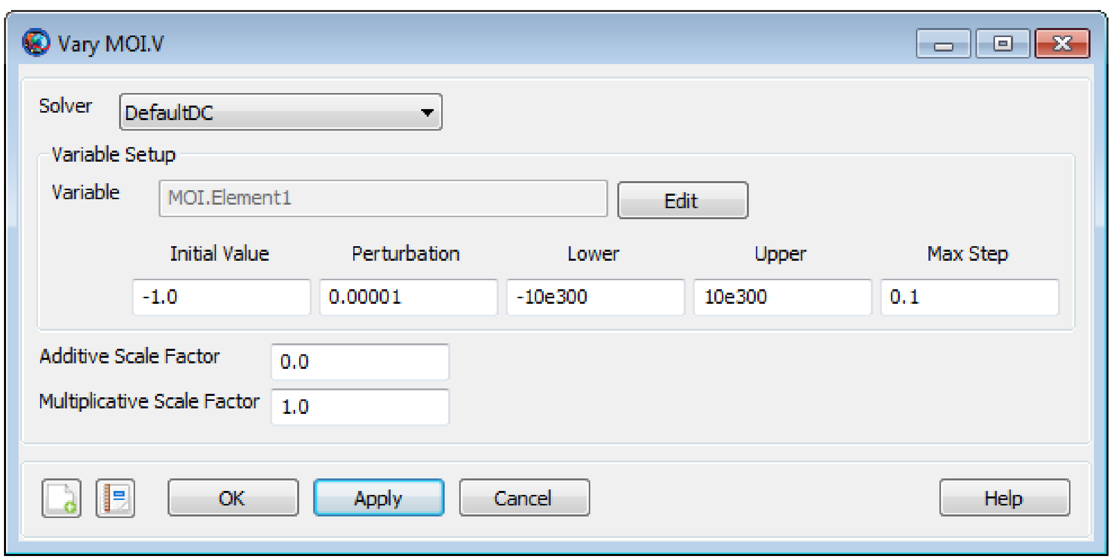


Figure 69. Vary MOI Command Configuration

Configure the Apply MOI Command

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

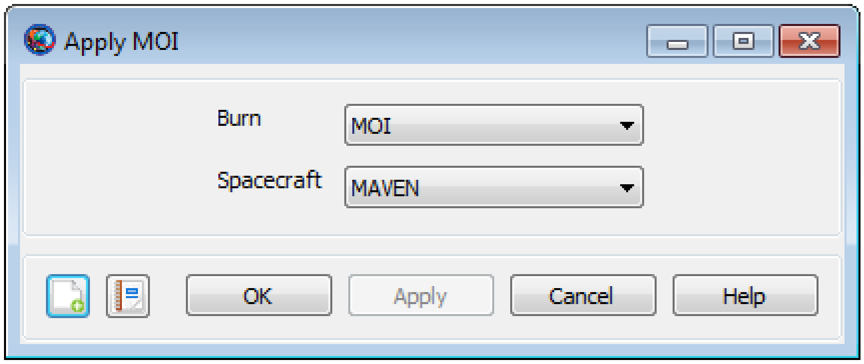


Figure 70. Apply MOI Command Configuration

Configure the Prop to Mars Apoapsis Command

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

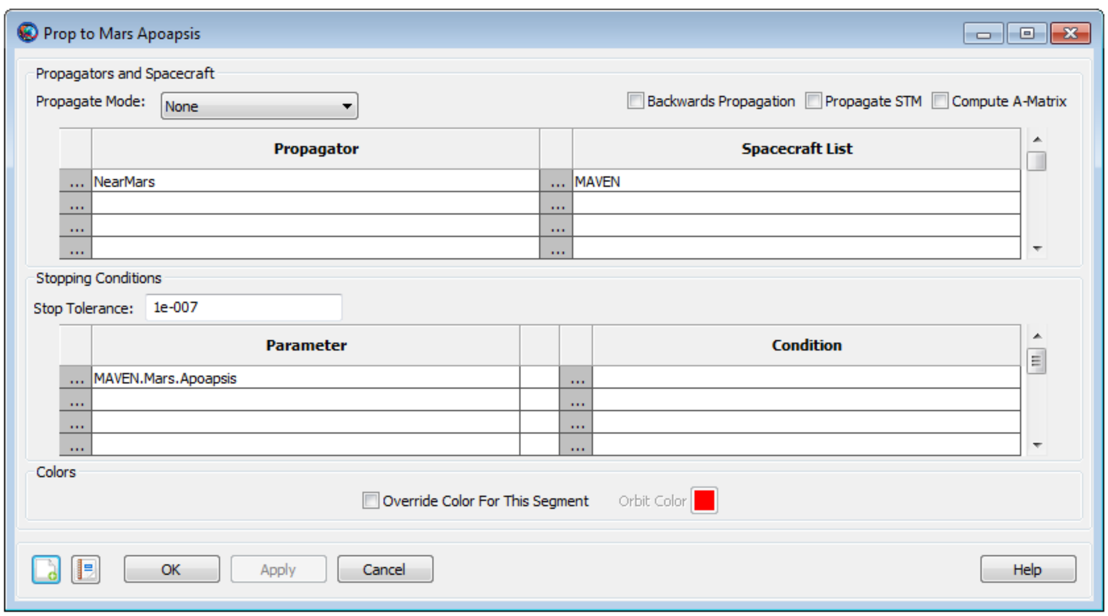


Figure 71. Prop to Mars Apoapsis Command Configuration

Configure the Achieve RMAG Command

1. Double-click **Achieve RMAG** to edit its properties.
2. Next to **Goal**, click the **Edit** button.
3. In the **Object Properties** list, click **RMAG**.
4. Under **Central Body**, select **Mars** and double-click on **RMAG**.

5. Click **OK** to close the **ParameterSelectDialog** window.
6. In the **Value** box, type **12000**.
7. Click **OK** to save these changes.

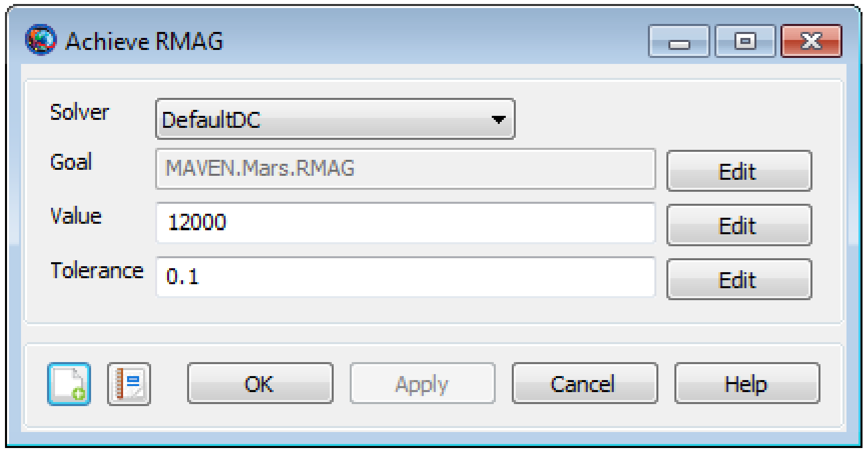


Figure 72. Achieve RMAG Command Configuration

Run the Mission with first and second Target Sequences

Before running the mission, click **Save** (💾). This will save the additional changes that we implemented in the **Mission** tree. Now click **Run** (▶). The first **Target** sequence will converge in one-iteration. This is because earlier, we stored the solution as the initial conditions. The second **Target** sequence may converge after 10 to11 iterations.

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

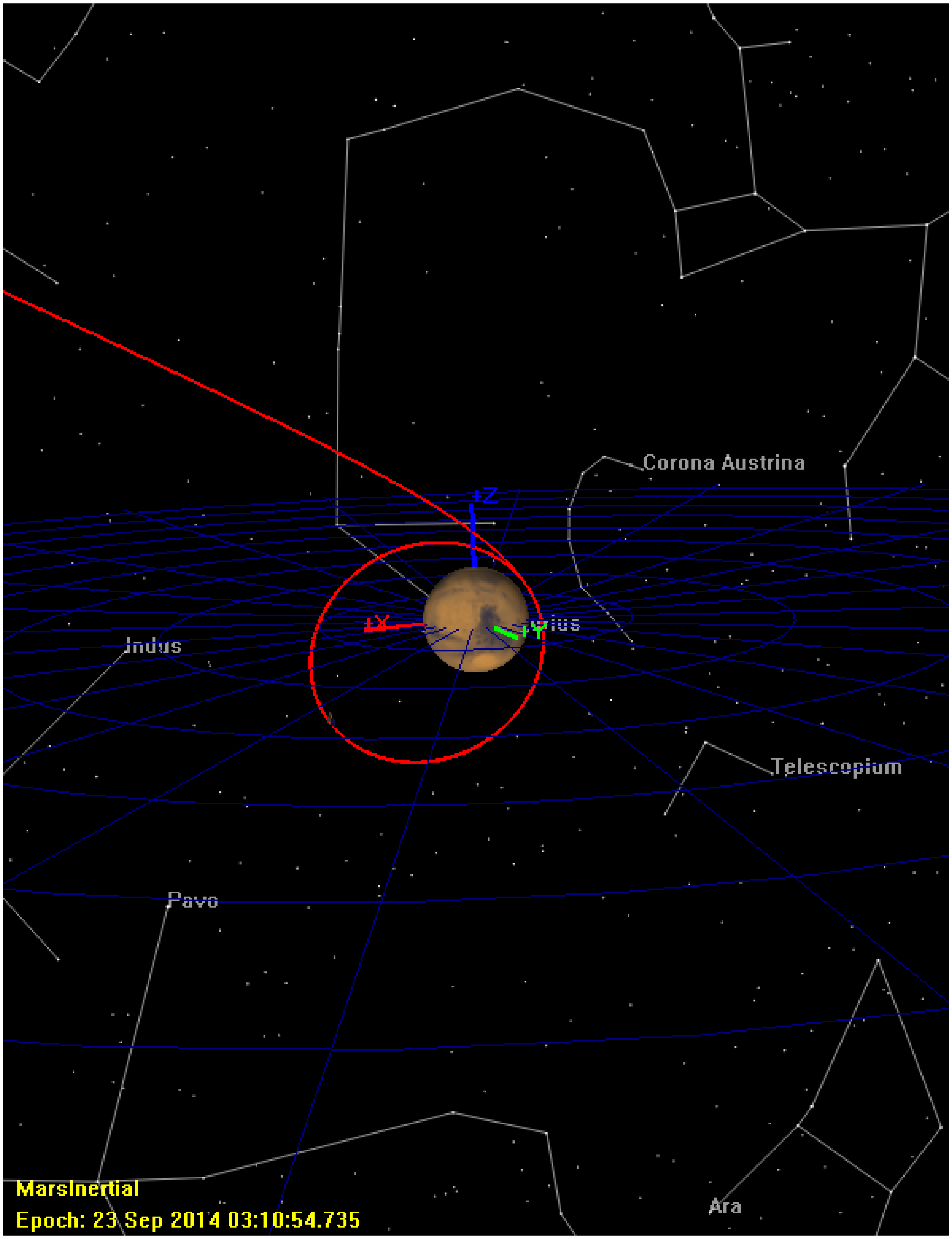


Figure 73. 3D view of Mars Capture orbit after MOI maneuver (MarsView)

If you were to continue developing this mission, you can store the final solution of the second **Target** sequence as the initial condition of **MOI** resource. This is so that when you make small changes, the subsequent runs will take less time. To do this, follow these steps:

1. In the **Mission** tree, double-click **Mars Capture** to edit its properties.

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

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

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

   ```
   Delta V Vector:

   Element 1: -1.6034665169868 km/s

   Element 2: 0.0000000000000 km/s

   Element 3: 0.0000000000000 km/s
   ```
3. Scroll down and under `Mass depletion from MainTank` heading, `Delta V` and `Mass Change` tells you MOI maneuver's magnitude and how much fuel was used for the maneuver:

   ```
   Delta V: 1.6034665169868 km/s

   Mass change: -1076.0639629424 kg
   ```

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

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

   ```
   TA = 180.00000241484 deg

   RMAG = 12000.019889021 km
   ```

Optimal Lunar Flyby using Multiple Shooting

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

Objective and Overview

> **Note**
>
> For highly elliptic earth orbits (HEO), it is often cheaper to use the Moon's gravity to raise periapsis or to perform plane changes, than it is to use the spacecraft's propulsion resources. However, designing lunar flyby's to achieve multiple specific mission constraints is non-trivial and requires modern optimization techniques to minimize fuel usage while simultaneously satisfying trajectory constraints. In this tutorial, you will learn how to design flyby trajectories by writing a GMAT script to perform multiple shooting optimization. As the analyst, your goal is to design a lunar flyby that provides a mission orbit periapsis of TBD km and changes the inclination of the mission orbit to TBD degrees. (Note: There are other mission constraints that will be discussed in more detail below.)
>
> To efficiently solve the problem, we will employ the Multiple Shooting Method to break down the sensitive boundary value problem into smaller, less sensitive problems. We will employ three trajectory segments. The first segment will begin at Transfer Orbit Insertion (TOI) and will propagate forward; the second segment is centered at lunar periapsis and propagates both forward and backwards. The third segment is centered on Mission Orbit Insertion (MOI) and propagates forwards and backwards. See figures 1 and 2 that illustrate the final orbit solution and the "Control Points" and "Patch Points" used to solve the problem.

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

1. The spacecraft is at orbit perigee,
2. The spacecraft is at an altitude of 285 km.
3. The inclination of the transfer orbit is 28.5 degrees.

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

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

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

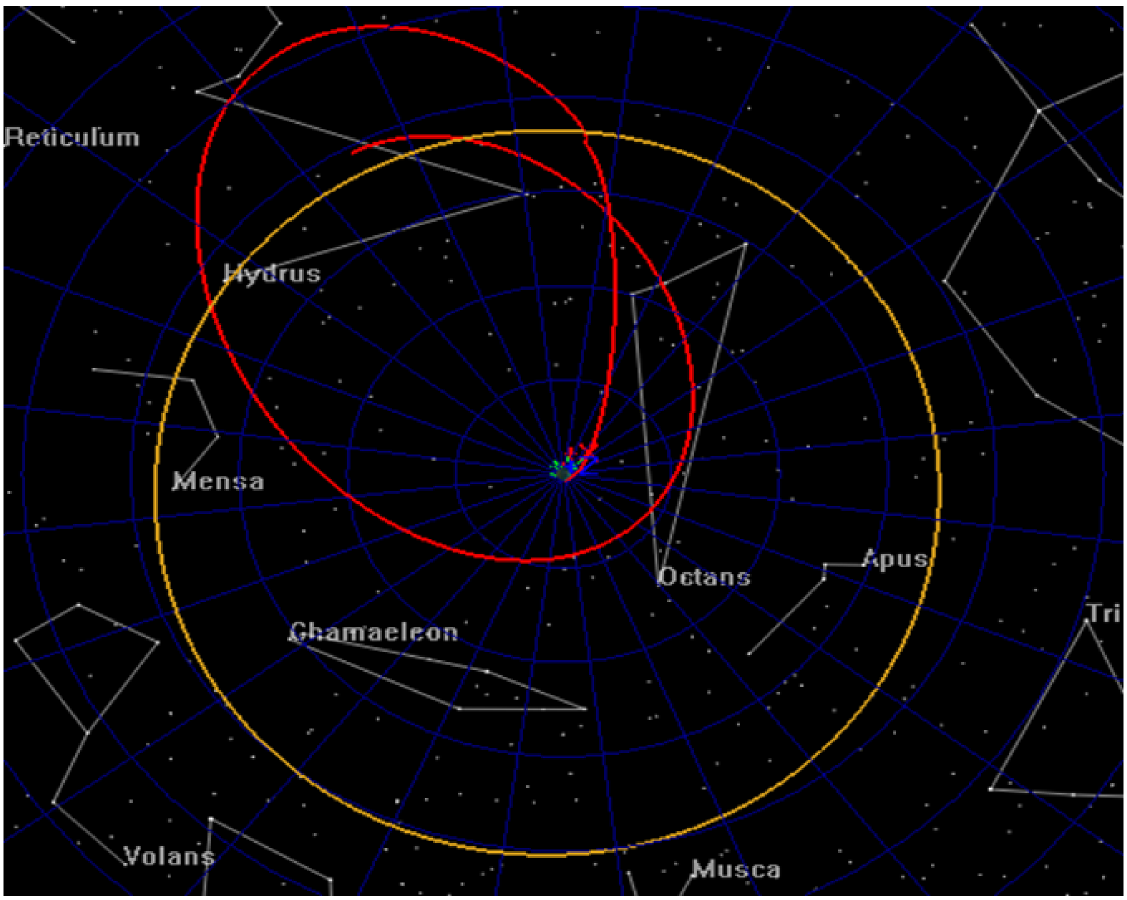


Figure 74. View of Lunar Flyby from Normal to Earth Equator

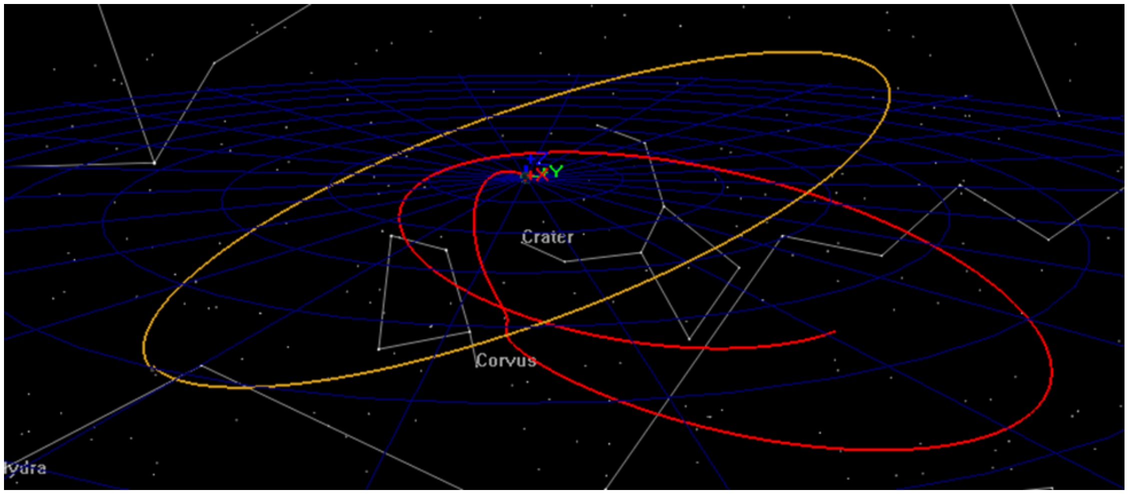


Figure 75. View of Lunar Flyby Geometry

Figure 3 illustrates the mission timeline and how control points and patch points are defined. Control points are drawn using a solid blue circle and are defined as locations where the state of the spacecraft is treated as an optimization variable. Patch points are drawn with an empty blue circle and are defined as locations where position and/or velocity continuity is enforced. For this tutorial, we place control points at TOI, the lunar flyby and MOI. At each patch point, the six Cartesian state elements, and the epoch are varied for a total of 18 optimization variables. At the MOI patch point, there is an additional optimization variable for the delta V to

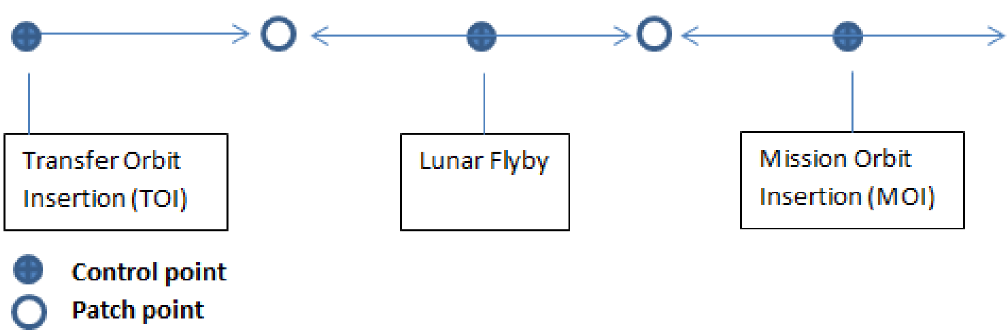


Figure 76. Definition of Control and Patch Points

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

1. Create a Moon-centered coordinate system.
2. Create 5 spacecraft required for modeling segments.
3. Create an Earth-centered and a Moon-centered propagator.
4. Create an impulsive maneuver.
5. Create many user variables for use in the script.
6. Create A VF13ad optimizer.

7. Create plots for tracking the optimization process.

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

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

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

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

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

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

Create a Moon-centered Coordinate System

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

```
%-----------------------------------------------------
% Configure coordinate systems
%-----------------------------------------------------

Create CoordinateSystem MoonMJ2000Eq
MoonMJ2000Eq.Origin = Luna
MoonMJ2000Eq.Axes   = MJ2000Eq
```

Create the Spacecraft

You will need 5 **Spacecraft** for this mission design. The epoch and state information will be set in the mission sequence and here we only need to configure coordinate systems for the **Spacecraft**. The **Spacecraft** named **satTOI** models the transfer orbit through the first patch point. Use the **EarthMJ200Eq CoordinateSystem** for **satTOI**. **satFlyBy_Forward** and

satFlyBy_Backward model the trajectory from the flyby backwards to patch point 1 and forward to patch point 2 respectively. Use the **MoonMJ2000Eq CoordinateSystem** for **satFlyBy_Forward** and **satFlyBy_Backward**. Similarly, **satMOI_Forward** and **satMOI_Backward** model the trajectory on either side of the MOI maneuver. Use the **MoonMJ2000Eq CoordinateSystem** for **satMOI_Forward** and **satMOI_Backward.**

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

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

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

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

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

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

Create the Propagators

Modeling the motion of the spacecraft when near the earth and near the moon requires two propagators; one Earth-centered, and one Moon-centered. The script below configures the **ForceModel** named **NearEarthForceModel** to use JGM-2 8x8 harmonic gravity model, with point mass perturbations from the Sun and Moon, and the SRP perturbation. The **ForceModel** named **NearMoonForceModel** is similar but uses point mass gravity for all bodies. Note that the integrators are configured for performance and not for accuracy to improve run times for the tutorial. There are times when integrator accuracy can cause issues with optimizer performance due to noise in the numerical solutions.

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

Create ForceModel NearEarthForceModel
NearEarthForceModel.CentralBody               = Earth
NearEarthForceModel.PrimaryBodies             = {Earth}
```

```
NearEarthForceModel.PointMasses               = {Luna, Sun}
NearEarthForceModel.SRP                       = On
NearEarthForceModel.GravityField.Earth.Degree = 8
NearEarthForceModel.GravityField.Earth.Order  = 8

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

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

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

Create the Maneuvers

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

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

Create ImpulsiveBurn MOI
MOI.CoordinateSystem   = Local
MOI.Origin             = Earth
MOI.Axes               = VNB
```

Create the User Variables

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

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

```
%  Variables for defining constraint values
Create Variable conTOIPeriapsis conMOIPeriapsis conTOIInclination
Create Variable conLunarPeriapsis conMOIApoapsis conMOIInclination
Create Variable launchRdotV finalPeriapsisValue

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

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

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

Create the Optimizer

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

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

Create VF13ad NLPOpt
NLPOpt.ShowProgress          = true
NLPOpt.ReportStyle           = Normal
NLPOpt.ReportFile            = 'VF13adVF13ad1.data'
NLPOpt.MaximumIterations     = 200
NLPOpt.Tolerance             = 1e-004
NLPOpt.UseCentralDifferences = false
NLPOpt.FeasibilityTolerance  = 0.1
```

Create the 3-D Graphics

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

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

Create OrbitView EarthView
```

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

Create XPPlots/Reports

Below we create several **XYPlots** and a **ReportFile**. We will use **XYPlots** to monitor the progress of the optimizer in satisfying constraints. **PositionError1** plots the position error at the first patch point... **VelocityError2** plots the velocity error at the second patch point, and so on. **OrbitDimErrors** plots the errors in the periapsis and apoapsis radii for the mission orbit. When optimization is proceeding as expected, these plots should show errors driven to zero.

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

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

Create XYPlot OrbitDimErrors
OrbitDimErrors.SolverIterations = All
```

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

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

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

```
Create ReportFile debugData
debugData.SolverIterations = Current
debugData.Precision        = 16
debugData.WriteHeaders     = Off
debugData.LeftJustify      = On
debugData.ZeroFill         = Off
debugData.ColumnWidth      = 20
debugData.WriteReport      = false
```

Configure the Mission Sequence

Overview of the Mission Sequence

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

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

Define Initial Guesses

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

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

```
BeginMissionSequence

%  Define initial guesses for optimization variables
BeginScript 'Initial Guess Values'

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

EndScript
```

Initialize Variables

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

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

   %  Some constants
   earthRadius          = 6378.1363

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

EndScript

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

   %   Loop initializations
   loopIdx = loopIdx + 1

EndOptimize
```

Caution

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

Vary and Set Spacecraft Epochs

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

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

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

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

%  Configure epochs and spacecraft
satTOI.Epoch.TAIModJulian           = toiEpoch
satMOI_Backward.Epoch.TAIModJulian  = moiEpoch
satFlyBy_Forward.Epoch.TAIModJulian = flybyEpoch
patchOneEpoch                       = refEpoch + patchOneElapsedDays
patchTwoEpoch                       = refEpoch + patchTwoElapsedDays
```

Vary Control Point States

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

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

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

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

```
satFlyBy_Backward = satFlyBy_Forward
```

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

```
%  Vary the states and delta V
Vary NLPOpt(satTOI.X           = ...
satTOI.X, {Perturbation = 0.00001, MaxStep = 100})
Vary NLPOpt(satTOI.Y           = ...
satTOI.Y, {Perturbation = 0.000001, MaxStep = 100})
Vary NLPOpt(satTOI.Z           = ...
satTOI.Z, {Perturbation = 0.00001, MaxStep = 100})
Vary NLPOpt(satTOI.VX          = ...
satTOI.VX, {Perturbation = 0.00001, MaxStep = 0.05})
Vary NLPOpt(satTOI.VY          = ...
satTOI.VY, {Perturbation = 0.000001, MaxStep = 0.05})
Vary NLPOpt(satTOI.VZ          = ...
satTOI.VZ, {Perturbation = 0.000001, MaxStep = 0.05})
Vary NLPOpt(satFlyBy_Forward.X  = ...
satFlyBy_Forward.MoonMJ2000Eq.X, {Perturbation = 0.00001, MaxStep = 100})
```

```
Vary NLPOpt(satFlyBy_Forward.Y  = ...
satFlyBy_Forward.MoonMJ2000Eq.Y, {Perturbation = 0.00001, MaxStep = 100})
Vary NLPOpt(satFlyBy_Forward.Z  = ...
satFlyBy_Forward.MoonMJ2000Eq.Z, {Perturbation = 0.00001, MaxStep = 100})
Vary NLPOpt(satFlyBy_Forward.VX = ...
satFlyBy_Forward.MoonMJ2000Eq.VX, {Perturbation = 0.00001, MaxStep = 0.1})
Vary NLPOpt(satFlyBy_Forward.VY = ...
satFlyBy_Forward.MoonMJ2000Eq.VY, {Perturbation = 0.00001, MaxStep = 0.1})
Vary NLPOpt(satFlyBy_Forward.VZ = ...
satFlyBy_Forward.MoonMJ2000Eq.VZ, {Perturbation = 0.00001, MaxStep = 0.1})
Vary NLPOpt(satMOI_Backward.X   = ...
satMOI_Backward.X, {Perturbation = 0.000001, MaxStep = 40000})
Vary NLPOpt(satMOI_Backward.Y   = ...
satMOI_Backward.Y, {Perturbation = 0.000001, MaxStep = 40000})
Vary NLPOpt(satMOI_Backward.Z   = ...
satMOI_Backward.Z, {Perturbation = 0.000001, MaxStep = 40000})
Vary NLPOpt(satMOI_Backward.VX  = ...
satMOI_Backward.VX, {Perturbation = 0.00001, MaxStep = 0.1})
Vary NLPOpt(satMOI_Backward.VY  = ...
satMOI_Backward.VY, {Perturbation = 0.00001, MaxStep = 0.1})
Vary NLPOpt(satMOI_Backward.VZ  = ...
satMOI_Backward.VZ, {Perturbation = 0.00001, MaxStep = 0.1})
Vary NLPOpt(MOI.Element1        = ...
MOI.Element1, {Perturbation = 0.0001, MaxStep = 0.005})

%  Initialize spacecraft and do some reporting
satFlyBy_Backward = satFlyBy_Forward
satMOI_Forward    = satMOI_Backward
deltaTimeFlyBy    = flybyEpoch - toiEpoch
```

Apply Constraints at Control Points

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

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

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

Propagate the Segments

We are now ready to propagate the spacecraft to the patch points. We must propagate **satTOI** forward to **patchOneEpoch**, propagate s**atFlyBy_Backward** backwards to **patchOneEpoch**, propagate **satFlyBy_Forward** to **patchTwoEpoch**, and propagate **satMOI_Backward** to **patchTwoEpoch**. Notice that some **Propagate** commands are applied inside of **If** statements to ensure that propagation is performed in the correct direction.%

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

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

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

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

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

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

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

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

Compute Some Quantities and Apply Patch Constraints

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

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

Apply Patch Point Constraints

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

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

Apply Constraints on Mission Orbit

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

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

Apply Cost Function

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

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

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

Stop
```

Design the Trajectory

Overview

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

1. Run the script configuration and verify your configuration.
2. Run the mission applying only the patch point constraints to provide a smooth trajectory.
3. Run the mission with all constraints applied generating an optimal solution.

4. Run the mission with an alternative initial guess.
5. Add a new constraint and rerun the mission.

Step 1: Verify Your Configuration

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

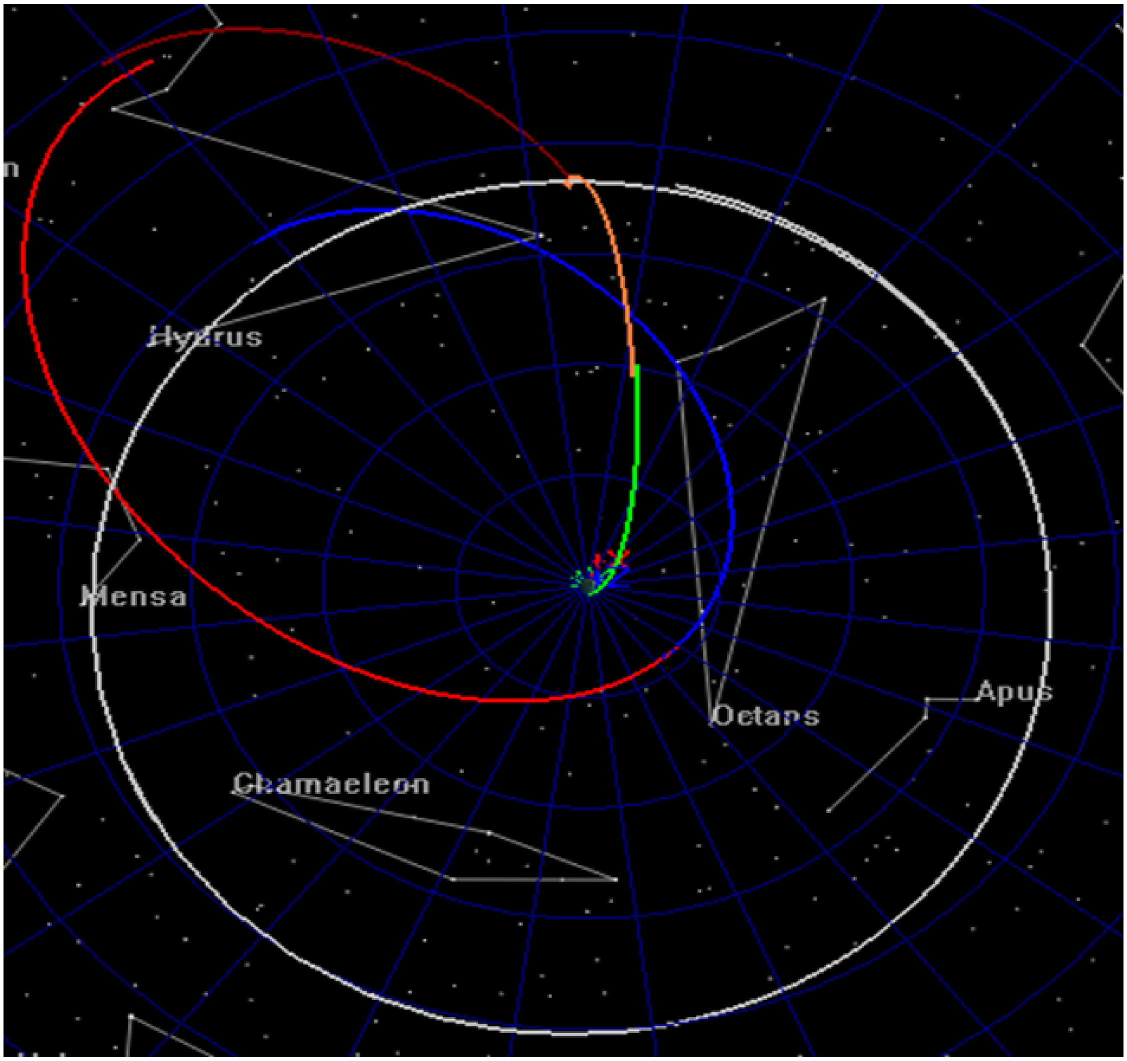


Figure 77. View of Discontinuous Trajectory

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

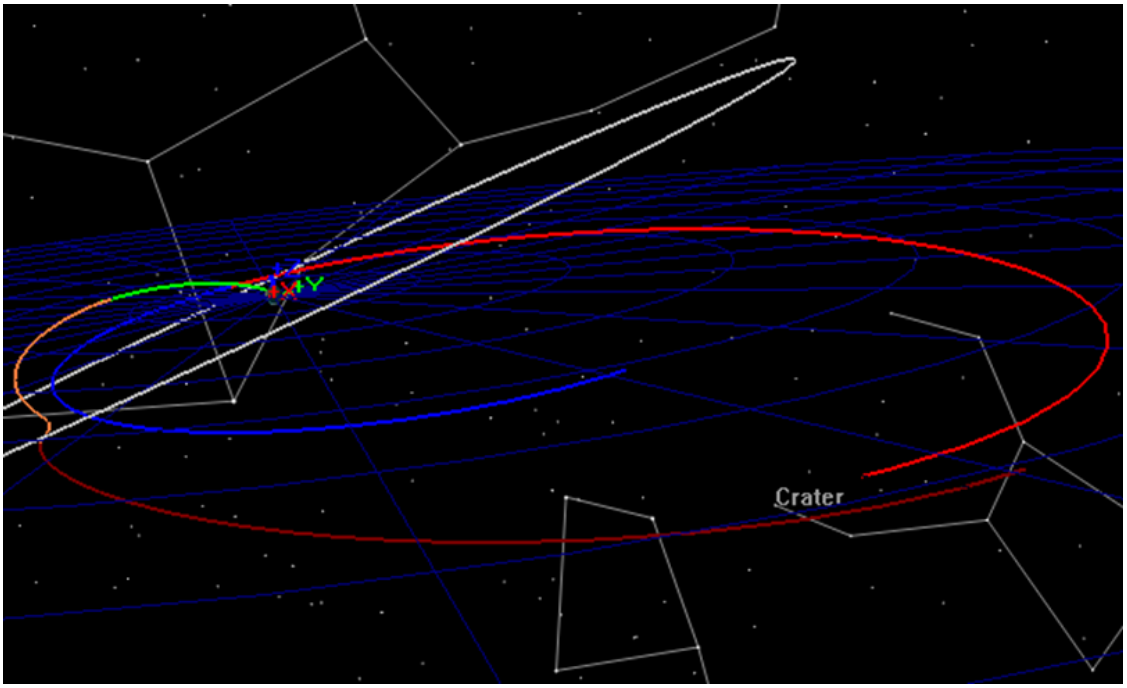


Figure 78. Alternate View (1) of Discontinuous Trajectory

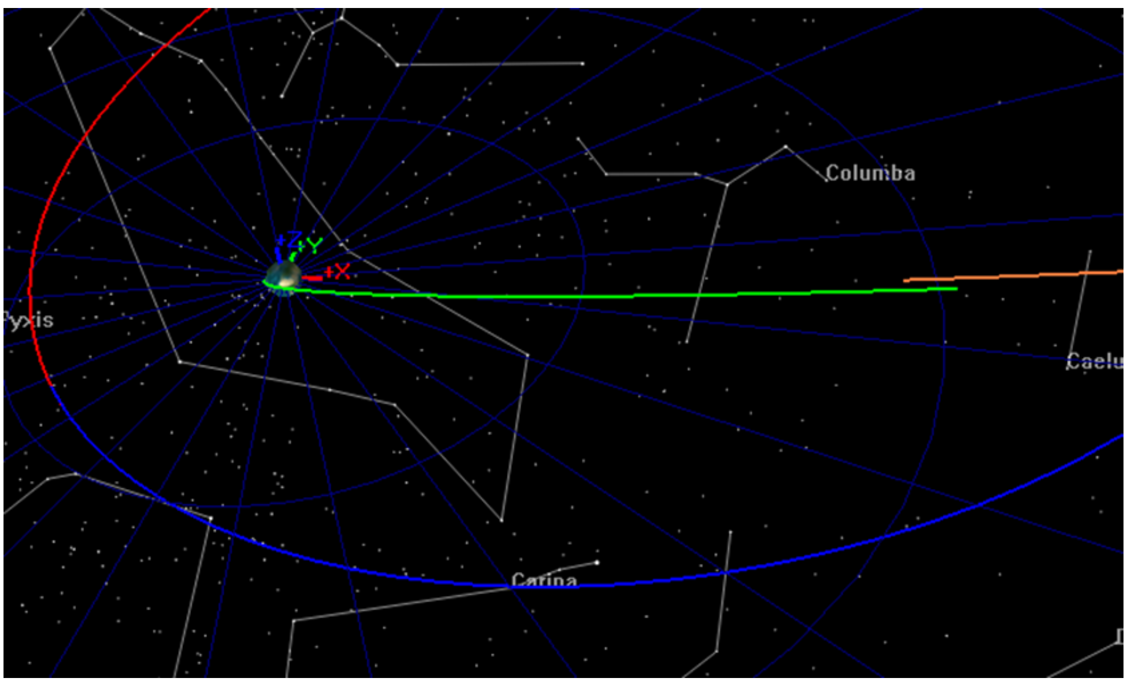


Figure 79. Alternate View (2) of Discontinuous Trajectory

Step 2: Find a Smooth Trajectory

At this point in the tutorial, your script is configured to eliminate the patch point discontinuities but does not apply mission constraints. We need to make a few small modifications before proceeding.

We will turn off the **OrbitView** to improve the run time, and we will remove the **Stop** command so that the optimizer will attempt to find a solution.

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

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

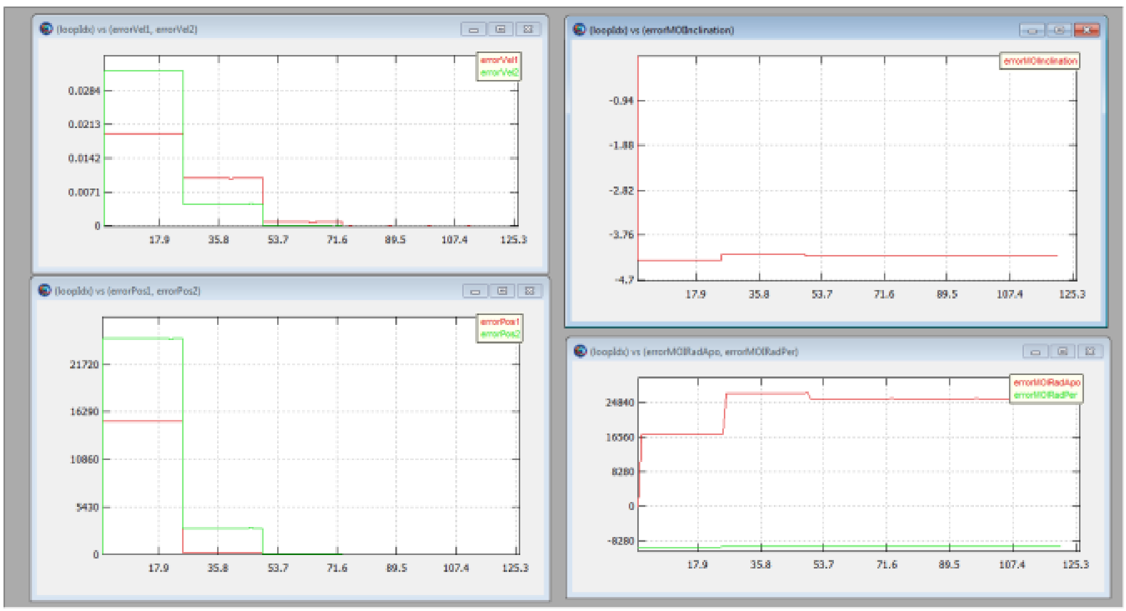


Figure 80. Smooth Trajectory Solution

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

Step 3: Find an Optimal Trajectory

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

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

```
NonlinearConstraint NLPOpt(satTOI.INC=conTOIInclination)
```

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

2. Click **Save Sync Run**.

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

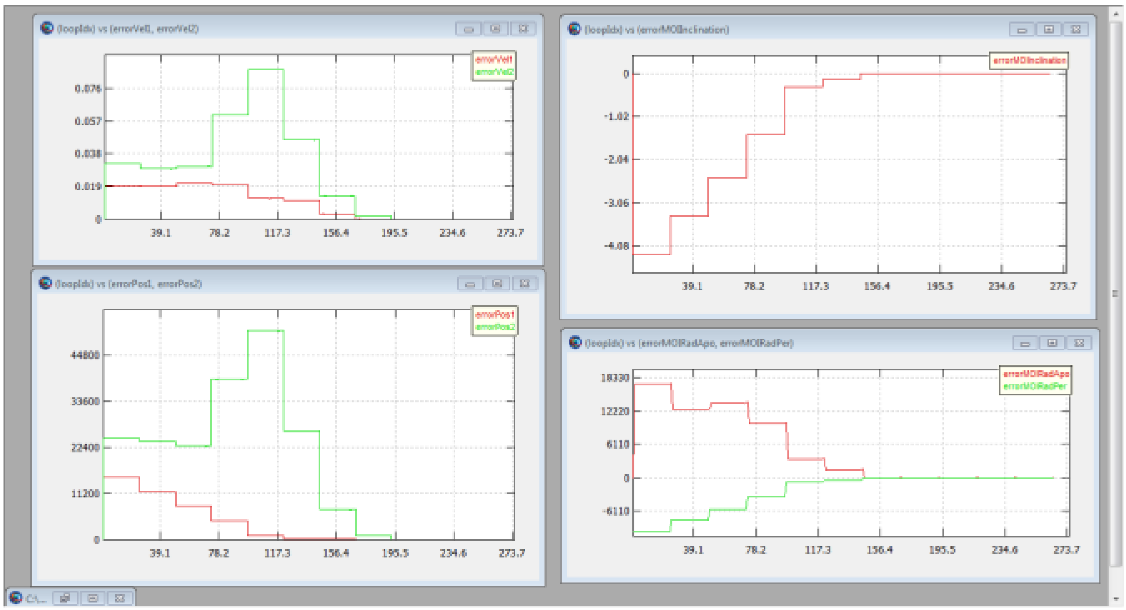


Figure 81. Optimal Trajectory Solution

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

```
Equality Constraint Variances:
      Delta satTOI.INC = 1.44773082411e-011
      Delta satTOI.RadPer = 7.08496372681e-010
      Delta satMOI_Backward.RadPer = -3.79732227884e-007
      Delta launchRdotV = -1.87725390788e-014
      Delta satTOI.EarthMJ2000Eq.X = 0.00037122167123
      Delta satTOI.EarthMJ2000Eq.Y = 2.79954474536e-005
      Delta satTOI.EarthMJ2000Eq.Z = 2.78138068097e-005
      Delta satTOI.EarthMJ2000Eq.VX = -3.87579257577e-009
      Delta satTOI.EarthMJ2000Eq.VY = 1.5329883335e-009
      Delta satTOI.EarthMJ2000Eq.VZ = -6.84140494256e-010
      Delta satMOI_Backward.EarthMJ2000Eq.X = 0.0327844279818
      Delta satMOI_Backward.EarthMJ2000Eq.Y = 0.0501471919124
      Delta satMOI_Backward.EarthMJ2000Eq.Z = 0.0063349630509
```

```
      Delta satMOI_Backward.EarthMJ2000Eq.VX = -7.5196416871e-008
      Delta satMOI_Backward.EarthMJ2000Eq.VY = -7.48570442854e-008
      Delta satMOI_Backward.EarthMJ2000Eq.VZ = -6.01668809219e-009
      Delta satMOI_Forward.EarthMJ2000Eq.INC = -1.25488952563e-010
      Delta satMOI_Forward.RadApo = -0.000445483252406
```

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

Step 4: Use a New Initial Guess

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

```
launchEpoch = 27698.2503232
flybyEpoch = 27703.7774182
moiEpoch = 27723.6487435
satTOI.X = -6651.63393843
satTOI.Y = -229.372171037
satTOI.Z = -168.481408909
satTOI.VX = 0.244028352166
satTOI.VY = -9.56544906767
satTOI.VZ = 5.11103080924
satFlyBy_Forward.X = 869.368923086
satFlyBy_Forward.Y = -6284.53685414
satFlyBy_Forward.Z = -3598.94426638
satFlyBy_Forward.VX = 1.14614444527
satFlyBy_Forward.VY = -0.726070354598
satFlyBy_Forward.VZ = -0.617780594192
satMOI_Backward.X = -53541.9714485
satMOI_Backward.Y = -68231.6304631
satMOI_Backward.Z = -1272.77554803
satMOI_Backward.VX = 2.0799329871
satMOI_Backward.VY = -1.89082570193
satMOI_Backward.VZ = -0.284385092038
```

We see in this case the optimization converged and found essentially the same solution of -0.0907079 km/s

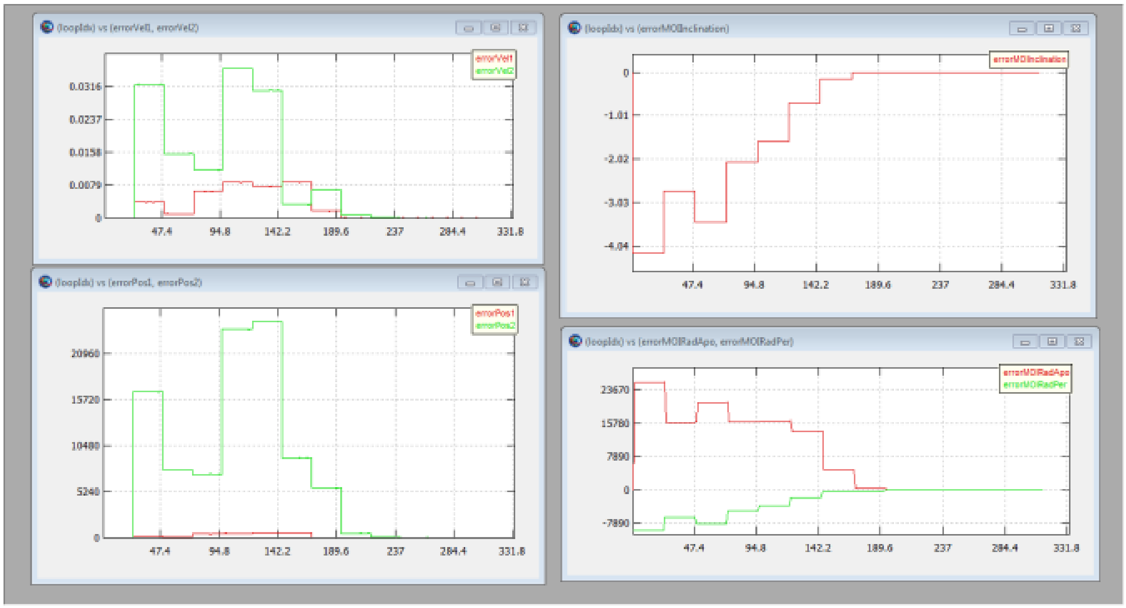


Figure 82. Solution Using New Guess

Step 5: Apply a New Constraint

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

Reference Guide

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

The *Resources* section provides general information on GMAT Resources such as **Spacecraft**, **Propagators**, **Coordinate Systems**, and **EphemerisFiles** to name just a few. Go here for details regarding syntax, options, variable ranges and data types, defaults, and expected behavior. Each section contains detailed, copy-and-paste ready examples.

The *Commands* section provides general information on GMAT Commands such as **Maneuver**, **Assignment**, **Optimize**, and **Propagate** to name just a few. Go here for details regarding syntax, options, variable ranges and data types, defaults, and expected behavior. Each section contains detailed, copy-and-paste ready examples.

The *System* section provides information on system configuration, external interfaces, the script language, and the command line interface.

Resources

Table of Contents

Array

A user-defined one- or two-dimensional array variable

Description

The **Array** resource is used to store a one- or two-dimensional set of numeric values, such as a vector or a matrix. Individual elements of an array can be used in place of a literal numeric value in most commands.

Arrays must be dimensioned at the time of creation, using the following syntax:

```
Create Array anArray[rows, columns]
```

If only one dimension is specified, a row vector is created.

Array values are initialized to zero at creation. Values can be assigned individually using literal numeric values or (in the Mission Sequence) **Variable** resources, **Array** resource elements, resource parameters of numeric type, or **Equation** commands that evaluate to scalar numeric values.

```
anArray(row, column) = value
```

If only one dimension is specified during assignment, *`row`* is assumed to be 1.

An **Array** can also be assigned as a whole in the Mission Sequence using another **Array** resource or an **Equation** that evaluates to an array. Both sides of the assignment must be identically-sized.

```
anArray = array expression
```

See Also: String, Variable

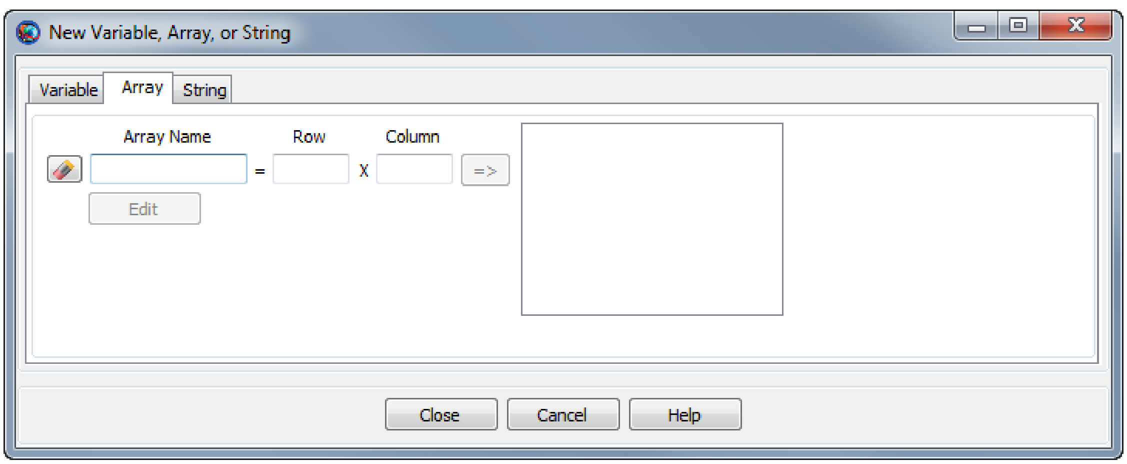
Fields

The **Array** resource has no fields; instead, the resource elements themselves are set to the desired values.

Field	Description
`rows`	The number of rows (during creation), or the row being addressed. The total size of the array is *`rows`* × *`columns`*. This field is required. **Data Type** Integer **Allowed Values** 1 ≤ *`rows`* ≤ 1000 **Access** set **Default Value** 1 **Units** N/A **Interfaces** GUI, script

Field	Description
`columns`	The number of columns (during creation), or the column being addressed. The total size of the array is *`rows`* × *`columns`*. This field is required. **Data Type** Integer **Allowed Values** 1 ≤ *`columns`* ≤ 1000 **Access** set **Default Value** 1 **Units** N/A **Interfaces** GUI, script
`value`	The value of the array element being addressed. **Data Type** Real number **Allowed Values** -∞ < *`value`* < ∞ **Access** set, get **Default Value** 0.0 **Units** N/A **Interfaces** GUI, script

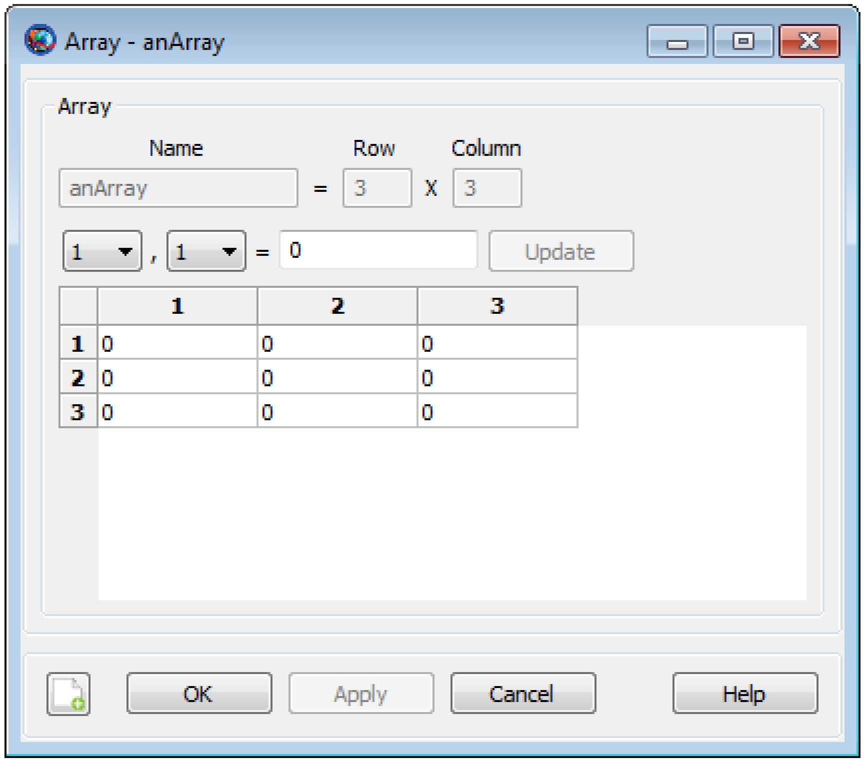
GUI



The GMAT GUI lets you create multiple **Array** resources at once without leaving the window. To create an **Array**:

1. In the **Array Name** box, type the desired name of the array.
2. In the **Row** and **Column** boxes, type the desired number of rows and columns, respectively. To create a one-dimensional array, set **Row** to 1.
3. Click the **=>** button to create the array and add it to the list on the right.
4. Click the **Edit** button to edit the array element values.

You can create multiple **Array** resources this way. To edit an existing array in this window, click it in the list on the right. Click **Edit** to change the element values, or edit the **Row** and **Column** values. You must click the **=>** button again to save changes to the size of the array.



You can edit the elements of an **Array** by either clicking **Edit** while creating an array, or by double-clicking the array in the resources tree in the main GMAT window. The edit window allows you to change array elements individually using the row and column lists and clicking **Update**, or by directly entering data in the table in the lower portion of the window. The data table recognizes a few different mouse and keyboard controls:

- Click a cell once to select it
- Click a selected cell again, double-click an unselected cell, or press F2 to edit the value
- Use the arrow keys to select adjacent cells
- Click the corner header cell to select the entire table
- Drag the column and row separators to adjust the row height or column width
- Double-click the row or column separators in the heading to auto-size the row height or column width

Remarks

GMAT **Array** resources store an arbitrary number of numeric values organized into one or two dimensions, up to a maximum of 1000 elements per dimension. Internally, the elements are stored as double-precision real numbers, regardless of whether or not fractional portions are present. **Array** resources can be created and assigned using one or two dimension specifiers. This example shows the behavior in each case:

```
% a is a row vector with 3 elements
Create Array a[3]
a(1) = 1    % same as a(1, 1) = 1
a(2) = 2    % same as a(1, 2) = 2
a(3) = 3    % same as a(1, 3) = 3
```

```
% b is a matrix with 5 rows and 3 columns
Create Array b[5, 3]
b(1) = 1    % same as b(1, 1) = 1
b(2) = 2    % same as b(1, 2) = 2
b(3) = 3    % same as b(1, 3) = 3
b(4) = 4    % error: b(1, 4) does not exist
b(4, 3) = 4 % row 4, column 3
```

Examples

Creating and reporting an array:

```
Create ReportFile aReport
Create Variable i idx1 idx2
Create Array fib[9]

BeginMissionSequence

fib(1) = 0
fib(2) = 1
For i=3:9
   idx1 = i-1
   idx2 = i-2
   fib(i) = fib(idx1) + fib(idx2)
EndFor
Report aReport fib
```

Barycenter

The center of mass of selected celestial bodies

Description

A **Barycenter** is the center of mass of a set of celestial bodies. GMAT contains two barycenter resources: a built-in **SolarSystemBarycenter** resource and the **Barycenter** resource that allows you to build a custom **Barycenter** such as the Earth-Moon barycenter. This resource cannot be modified in the Mission Sequence.

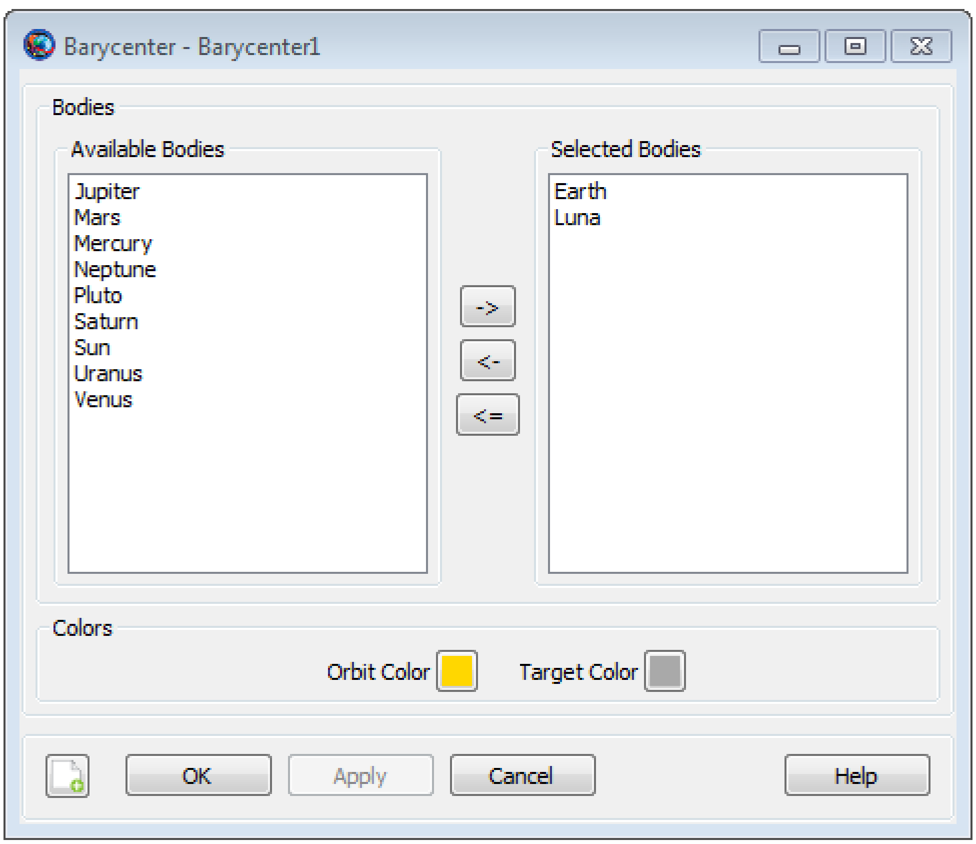
See Also: LibrationPoint, CoordinateSystem, CelestialBody, SolarSystem, Color

Fields

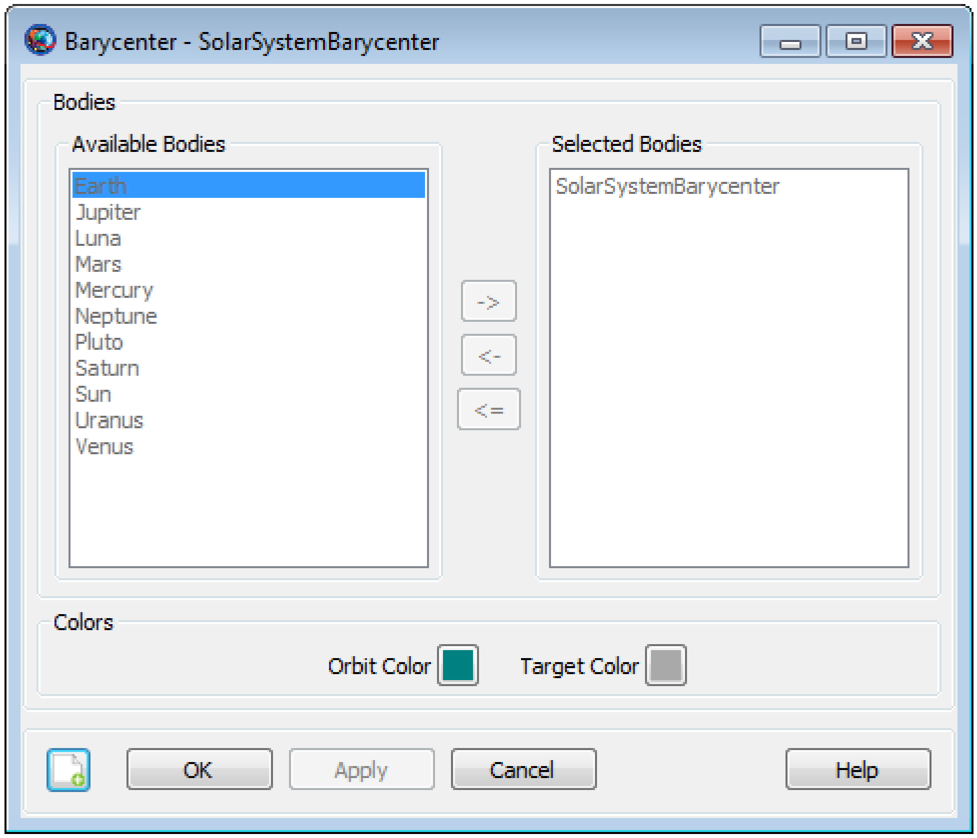
Field	Description
BodyNames	The list of **CelestialBody** resources included in the Barycenter. Providing empty brackets sets the bodies to the default list described below. **Data Type**: String array **Allowed Values**: array of celestial bodies. You cannot add bodies to the built-in **SolarySystemBarycenter** resource. A **CelestialBody** can only appear once in the **BodyNames** list. **Access**: set **Default Value**: **Earth**, **Luna** **Units**: N/A **Interfaces**: GUI, script
OrbitColor	Allows you to set available colors on user-defined **Barycenter** object orbits. The barycenter orbits are drawn using the **OrbitView** graphics resource. Colors on **Barycenter** object can be set through a string or an integer array. For example: Setting a barycenter's orbit color to red can be done in the following two ways: `Barycenter.OrbitColor = Red` or `Barycenter.OrbitColor = [255 0 0]`. This field can be modified in the Mission Sequence as well. **Data Type**: Integer Array or String **Allowed Values**: Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255. **Access**: set **Default Value**: Gold **Units**: N/A **Interfaces**: GUI, script

Field	Description
TargetColor	Allows you to select available colors for **Barycenter** object's perturbing orbital trajectories that are drawn during iterative processes such as Differential Correction or Optimization. The target color can be identified through a string or an integer array. For example: Setting a barycenter's perturbing trajectory color to yellow can be done in following two ways: `Barycenter.TargetColor = Yellow` or `Barycenter.TargetColor = [255 255 0]`. This field can be modified in the Mission Sequence as well. **Data Type** Integer Array or String **Allowed Values** Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255. **Access** set **Default Value** DarkGray **Units** N/A **Interfaces** GUI, script

GUI



The **Barycenter** dialog box allows you to define the celestial bodies included in a custom **Barycenter**. All celestial bodies, including user-defined bodies, are available for use in a **Barycenter** and appear in either the **Available Bodies** list or the **Selected Bodies** list. The example above illustrates the default configuration which contains **Earth** and **Luna**.



The **SolarySystemBarycenter** dialog box shown above is a built-in object and you cannot modify its configuration. See the Remarks section for details regarding the model for the **SolarSystemBarycenter**.

Remarks

Built-in SolarSystemBarycenter Object

The built-in **SolarSystemBarycenter** is modelled using the ephemerides selected in the **SolarySystem.EphemerisSource** field. For example, if you select **DE421** for **SolarSystem.EphemerisSource**, then the barycenter location is computed by calling the DE421 ephemeris routines. For DE and SPICE ephemerides, the model for the solar system barycenter includes the planets and several hundred minor planets and asteroids. Note that you cannot add bodies to the **SolarSystemBarycenter**.

Custom Barycenter Objects

You can create a custom barycenter using the **Barycenter** resource. The position and velocity of a **Barycenter** is a mass-weighted average of the position and velocity of the included celestial bodies. In the equations below m_i, r_i, and v_i are respectively the mass, position, and velocity of the i^{th} body in the barycenter, and r_b and v_b are respectively the position and velocity of the barycenter.

$$\mathbf{r}_b = \frac{\sum_{i=1}^{n} m_i \mathbf{r}_i}{\sum_{i=1}^{n} m_i}$$

$$\mathbf{v}_b = \frac{\sum_{i=1}^{n} m_i \mathbf{v}_i}{\sum_{i=1}^{n} m_i}$$

Setting Colors On Barycenter Orbits

GMAT allows you to assign colors to barycenter orbits that are drawn using the **OrbitView** graphics resource. GMAT also allows you to assign colors to perturbing barycenter orbital trajectories which are drawn during iterative processes such as differential correction or optimization. The **Barycenter** object's **OrbitColor** and **TargetColor** fields are used to assign colors to both orbital and perturbing trajectories. See the Fields section to learn more about these two fields. Also see Color documentation for discussion and examples on how to set colors on a barycenter orbit.

Examples

Define the state of a spacecraft in **SolarSystemBarycenter** coordinates.

```
Create CoordinateSystem SSB
SSB.Origin = SolarSystemBarycenter
SSB.Axes   = MJ2000Eq

Create ReportFile aReport

Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = SSB
aSpacecraft.X  = -27560491.88656896
aSpacecraft.Y  = 132361266.8009069
aSpacecraft.Z  = 57419875.95483227
aSpacecraft.VX = -29.78491261798486
aSpacecraft.VY = 2.320067257851091
aSpacecraft.VZ = -1.180722388963864

BeginMissionSequence

Report aReport aSpacecraft.EarthMJ2000Eq.X aSpacecraft.EarthMJ2000Eq.Y ...
             aSpacecraft.EarthMJ2000Eq.Z
```

Report the state of a spacecraft in **SolarSystemBarycenter** coordinates.

```
Create CoordinateSystem SSB
SSB.Origin = SolarSystemBarycenter
SSB.Axes   = MJ2000Eq

Create Spacecraft aSpacecraft
Create ReportFile aReport

BeginMissionSequence

Report aReport aSpacecraft.SSB.X aSpacecraft.SSB.Y aSpacecraft.SSB.Z ...
      aSpacecraft.SSB.VX aSpacecraft.SSB.VY aSpacecraft.SSB.VZ
```

Create an Earth-Moon **Barycenter** and use it in a Sun-Earth-Moon **LibrationPoint**.

```
Create Barycenter EarthMoonBary
EarthMoonBary.BodyNames = {Earth,Luna}

Create LibrationPoint SunEarthMoonL2
SunEarthMoonL2.Primary   = Sun
SunEarthMoonL2.Secondary = EarthMoonBary
SunEarthMoonL2.Point     = L2

Create CoordinateSystem SEML2Coordinates
SEML2Coordinates.Origin = SunEarthMoonL2
SEML2Coordinates.Axes   = MJ2000Eq

Create Spacecraft aSpacecraft
GMAT aSpacecraft.DateFormat = UTCGregorian
GMAT aSpacecraft.Epoch = '09 Dec 2005 13:00:00.000'
GMAT aSpacecraft.CoordinateSystem = SEML2Coordinates
GMAT aSpacecraft.X  = -32197.88223741966
GMAT aSpacecraft.Y  = 211529.1500044117
GMAT aSpacecraft.Z  = 44708.57017366499
GMAT aSpacecraft.VX = 0.03209516489451751
GMAT aSpacecraft.VY = 0.06086386504053736
GMAT aSpacecraft.VZ = 0.0550442738917212

Create ReportFile aReport

BeginMissionSequence

Report aReport aSpacecraft.EarthMJ2000Eq.X aSpacecraft.EarthMJ2000Eq.Y ...
             aSpacecraft.EarthMJ2000Eq.Z
```

CelestialBody

A celestial body model

Description

The **CelestialBody** resource is a model of a celestial body containing settings for the physical properties, as well as the models for the orbital motion and orientation. GMAT contains built-in models for the Sun, the 8 planets, Earth's moon, and Pluto. You can create a custom **CelestialBody** resource to model a planet, asteroid, comet, or moon. This resource cannot be modified in the Mission Sequence.

See Also: SolarSystem, Barycenter, LibrationPoint, CoordinateSystem, Color

Fields

<table>
<tr><th>Field</th><th colspan="2">Description</th></tr>
<tr><td rowspan="7">CentralBody</td><td colspan="2">The central body of the celestial body. The central body field is used primarily by the GUI.</td></tr>
<tr><td>Data Type</td><td>String</td></tr>
<tr><td>Allowed Values</td><td>Comet, Planet, Asteroid, or Moon</td></tr>
<tr><td>Access</td><td>set</td></tr>
<tr><td>Default Value</td><td>For Comet, Planet, Asteroid, the default is Sun. For Moon, the default is Earth.</td></tr>
<tr><td>Units</td><td>N/A</td></tr>
<tr><td>Interfaces</td><td>GUI, script</td></tr>
<tr><td rowspan="7">EquatorialRadius</td><td colspan="2">The body's equatorial radius.</td></tr>
<tr><td>Data Type</td><td>Real</td></tr>
<tr><td>Allowed Values</td><td>Real > 0</td></tr>
<tr><td>Access</td><td>set</td></tr>
<tr><td>Default Value</td><td>6378.1363</td></tr>
<tr><td>Units</td><td>km</td></tr>
<tr><td>Interfaces</td><td>GUI, script</td></tr>
<tr><td rowspan="7">FileName</td><td colspan="2">Path and/or name of texture map file used in OrbitView graphics.</td></tr>
<tr><td>Data Type</td><td>String</td></tr>
<tr><td>Allowed Values</td><td>A file of the following format:

.jpeg, .bmp, .png, .gif, .tif, .pcx, .pnm, .tga, or .xpm</td></tr>
<tr><td>Access</td><td>set</td></tr>
<tr><td>Default Value</td><td><code>'../data/graphics/texture/GenericCelestialBody.jpg'</code></td></tr>
<tr><td>Units</td><td>N/A</td></tr>
<tr><td>Interfaces</td><td>GUI, script</td></tr>
</table>

<table>
<tr><th>Field</th><th colspan="2">Description</th></tr>
<tr><td>Flattening</td><td colspan="2">The body's polar flattening.</td></tr>
<tr><td></td><td>Data Type</td><td>Real</td></tr>
<tr><td></td><td>Allowed Values</td><td>Real >= 0</td></tr>
<tr><td></td><td>Access</td><td>set</td></tr>
<tr><td></td><td>Default Value</td><td>0.0033527</td></tr>
<tr><td></td><td>Units</td><td>N/A</td></tr>
<tr><td></td><td>Interfaces</td><td>GUI, script</td></tr>
<tr><td>Mu</td><td colspan="2">The body's gravitational parameter.</td></tr>
<tr><td></td><td>Data Type</td><td>Real</td></tr>
<tr><td></td><td>Allowed Values</td><td>Real > 0</td></tr>
<tr><td></td><td>Access</td><td>set</td></tr>
<tr><td></td><td>Default Value</td><td>398600.4415</td></tr>
<tr><td></td><td>Units</td><td>km^3/s^2</td></tr>
<tr><td></td><td>Interfaces</td><td>GUI, script</td></tr>
<tr><td>NAIFId</td><td colspan="2">NAIF Integer ID for body.</td></tr>
<tr><td></td><td>Data Type</td><td>Integer</td></tr>
<tr><td></td><td>Allowed Values</td><td>Integer</td></tr>
<tr><td></td><td>Access</td><td>set</td></tr>
<tr><td></td><td>Default Value</td><td>-123456789</td></tr>
<tr><td></td><td>Units</td><td>N/A</td></tr>
<tr><td></td><td>Interfaces</td><td>GUI, script</td></tr>
<tr><td>NutationUpdateInterval</td><td colspan="2">The time interval between updates for Earth nutation matrix. If NutationUpdateInterval = 3600, then GMAT only updates nutation on an hourly basis.</td></tr>
<tr><td></td><td>Data Type</td><td>Real</td></tr>
<tr><td></td><td>Allowed Values</td><td>Real >= 0</td></tr>
<tr><td></td><td>Access</td><td>set</td></tr>
<tr><td></td><td>Default Value</td><td>60</td></tr>
<tr><td></td><td>Units</td><td>sec.</td></tr>
<tr><td></td><td>Interfaces</td><td>GUI, script</td></tr>
</table>

Field	Description
OrbitColor	Allows you to set available colors on built-in or user-defined **CelestialBody** objects that are drawn on the 3D **OrbitView** graphics displays. Colors on a **CelestialBody** object can be set through a string or an integer array. For example: Setting a celestial body's orbit color to red can be done in the following two ways: `CelestialBody.OrbitColor = Red` or `Celestialbody.OrbitColor = [255 0 0]`. This field can be modified in the Mission Sequence as well. **Data Type**: Integer Array or String **Allowed Values**: Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255. **Access**: set **Default Value**: Orchid for user-defined **Planet**, Pink for user-defined **Comet**, Salmon for user-defined **Asteroid** and Tan for user-defined **Moon** **Units**: N/A **Interfaces**: GUI, script
OrbitSpiceKernelName	List of SPK kernels. Providing emtpy brackets unloads previously loaded kernels. **Data Type**: Reference array **Allowed Values**: valid array of SPK kernels **Access**: set **Default Value**: N/A **Units**: N/A **Interfaces**: GUI, script
OrientationEpoch	The reference epoch for orientation data. **Data Type**: String **Allowed Values**: 6116.0 <= Epoch <= 58127.5 **Access**: set **Default Value**: 21545.0 **Units**: A1 Modified Julian Epoch **Interfaces**: GUI, script

Field	Description
PosVelSource	The model for user-defined body orbit ephemeredes. GMAT currently only supports a single ephemeris model for custom bodies (SPICE) and this is set using **PosVelSource** field. The default for **PosVelSource** is SPICE and it is not necessary to configure this field in the current version of GMAT. This field has no effect for built-in bodies. **Data Type** String **Allowed Values** **SPICE** **Access** set **Default Value** **DE405** for build in bodies. **SPICE** for user defined bodies. **Units** N/A **Interfaces** GUI, script
RotationConstant	The body's spin angle at the orientation epoch. **Data Type** Real **Allowed Values** Real **Access** set **Default Value** 190.147 **Units** deg **Interfaces** GUI, script
RotationDataSource	For **Earth** default is **FK5IAU1980**, for **Luna** default is **DE405**, for selected built in bodies **IAU2000**, and for selected built in bodies and all user defined bodies, default is **IAUSimplified**. **Data Type** String **Allowed Values** **IAUSimplified**, **DE405**, **FK5IAU1980**, **IAU2000**. See discussion below for more details as not all options are allowed for all bodies. **Access** set **Default Value** For **Earth** default is **FK5IAU1980**, for **Luna** default is **DE405**, for selected built in bodies **IAU2000**, and for selected built in bodies and all user defined bodies, default is **IAUSimplified**. **Units** N/A **Interfaces** GUI, script

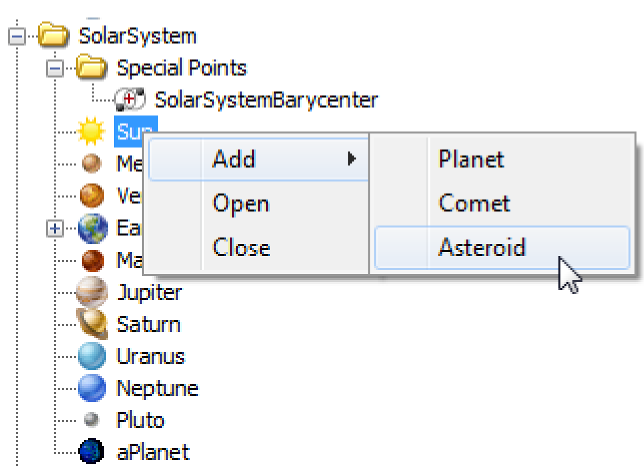
Field	Description	
RotationRate	The body's spin rate.	
	Data Type	Real
	Allowed Values	Real
	Access	set
	Default Value	360.9856235
	Units	deg/day
	Interfaces	GUI, script
SpinAxisDECConstant	The declination of the body's spin axis at the orientation epoch.	
	Data Type	Real
	Allowed Values	Real
	Access	set
	Default Value	90
	Units	deg
	Interfaces	GUI, script
SpinAxisDECRate	The rate of change of the body's spin axis declination.	
	Data Type	Real
	Allowed Values	Real
	Access	set
	Default Value	-0.5570
	Units	deg/century
	Interfaces	GUI, script
SpinAxisRAConstant	The right ascension of the body's spin axis at the orientation epoch.	
	Data Type	Real
	Allowed Values	Real
	Access	set
	Default Value	-0.641
	Units	deg
	Interfaces	GUI, script
SpinAxisRARate	The rate of change of the body's right ascension.	
	Data Type	Real
	Allowed Values	Real
	Access	set
	Default Value	-0.641
	Units	deg/century
	Interfaces	GUI, script

Field	Description
TargetColor	Allows you to set available colors on **CelestialBody** object's perturbing orbital trajectories that are drawn during iterative processes such as Differential Correction or Optimization. The target color can be identified through a string or an integer array. For example: Setting a celestial body's perturbing trajectory color to yellow can be done in following two ways: `Celestialbody.TargetColor = Yellow` or `Celestialbody.TargetColor = [255 255 0]`. This field can be modified in the Mission Sequence as well. **Data Type**: Integer Array or String **Allowed Values**: Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255. **Access**: set **Default Value**: Dark Gray for built-in or user-defined **Planet**, **Comet**, **Asteroid** and **Moon** **Units**: N/A **Interfaces**: GUI, script

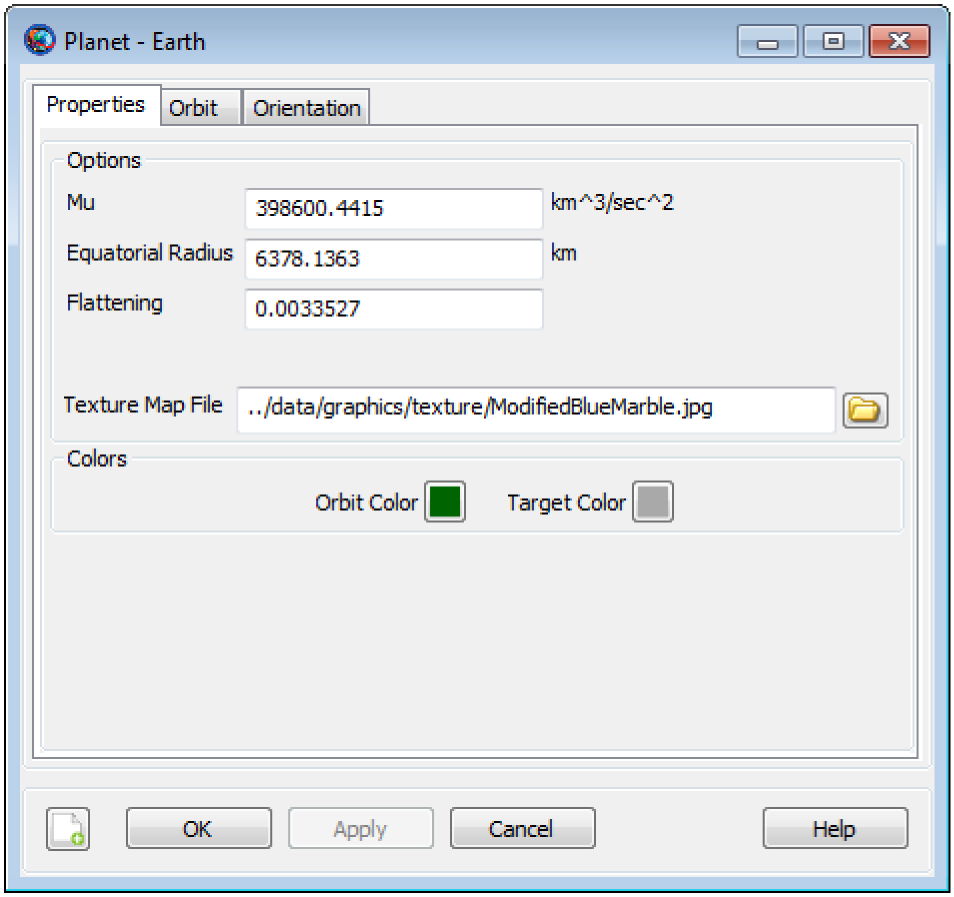
GUI

The **CelestialBody** GUI has three tabs that allow you to set the physical properties, orbital properties, and the orientation model. **CelestialBody** resources can be used in **ForceModels**, **CoordinateSystems**, **LibrationPoints**, and **Barycenters**, among others. For a built-in **CelestialBody**, the **Orbit** and **Orientation** tabs are largely inactive and the behavior is discussed below. To create a custom **Asteroid** - as an example of how to create a custom **CelestialBody** - perform the following steps.

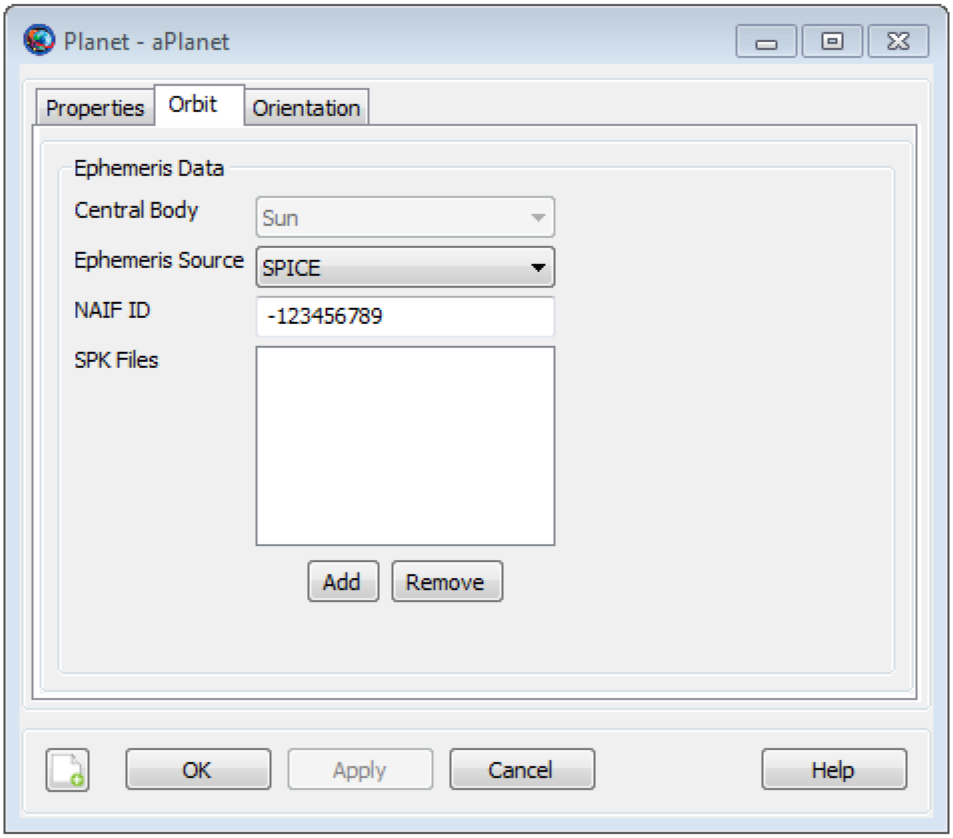
1. In the **Resource Tree**, expand the **SolarSystem** folder.
2. Right-click **Sun** and select **Add** -> **Asteroid**.
3. In the **New Asteroid** dialog box, type the desired name.



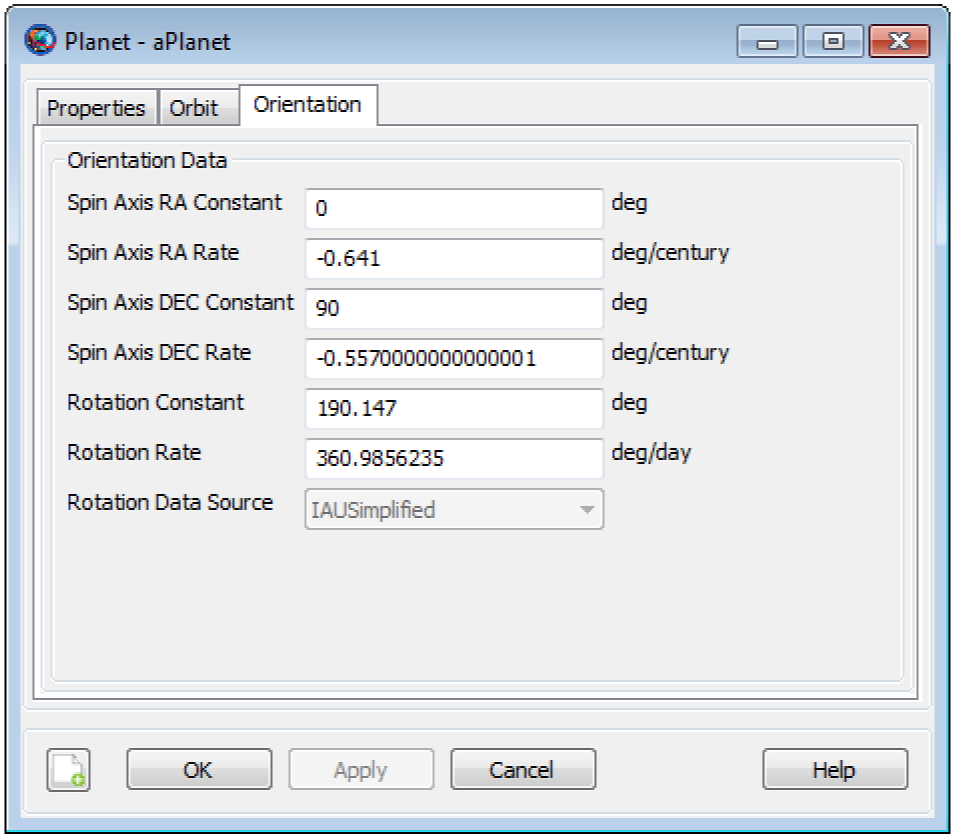
The **CelestialBody** Properties tab is shown below. GMAT models all bodies as spherical ellipsoids and you can set the **Equatorial Radius**, **Flattening**, and **Mu** (gravitational parameter) on this dialog box, as well as the texture map used in **OrbitView** graphics displays.



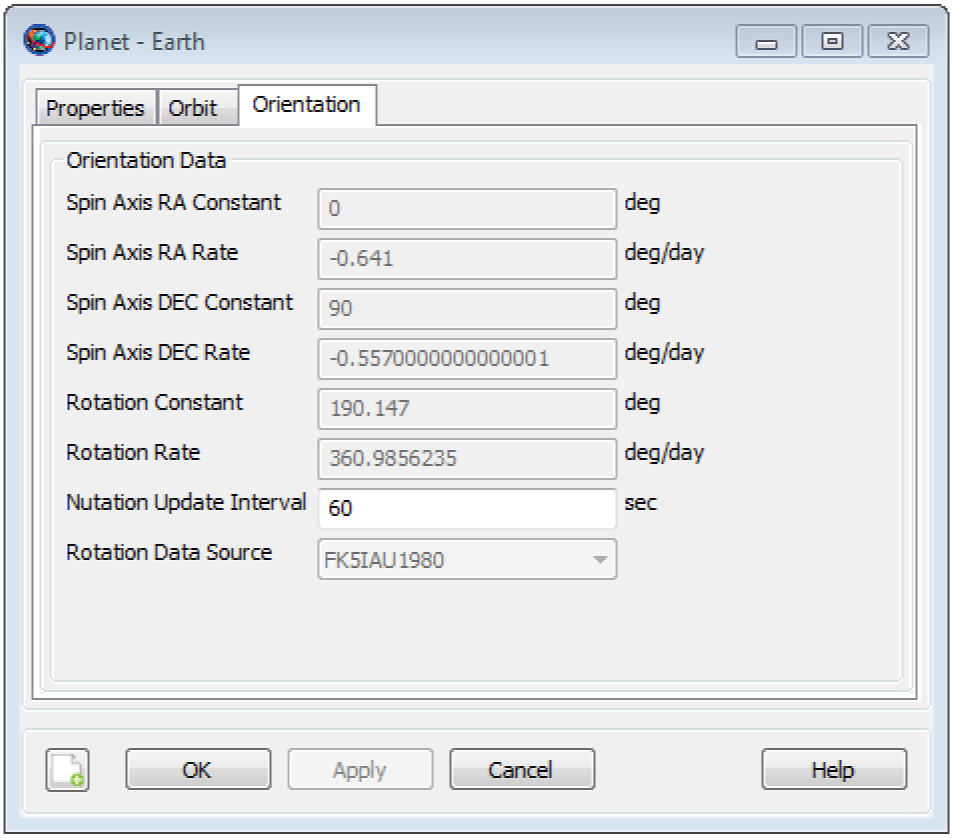
The **CelestialBody Orbit** tab is shown below for creating a custom **CelestialBody**. Settings on this panel are inactive for built-in celestial bodies and the ephemeris for built-in bodies is configured on the **SolarSystem** dialog. The **CentralBody** field is populated automatically when the object is created and is always inactive. To configure **SPICE** ephemerides for a custom body, provide a list of SPK files and the **NAIF ID**. See the discussion below for more information on configuring **SPICE** files.



The **CelestialBody Orientation** tab is shown below. Most settings on this panel are inactive for built-in celestial bodies and exceptions for the Earth and Earth's moon are described further below. To define the orientation for a celestial body you provide a reference epoch, the initial orientation at the reference epoch, and angular rates. See the discussion below for a more detailed description of the orientation model.



The Earth and Earth's moon have unique fields to configure their orientation models. The Earth has an extra field called **NutationUpdateInterval** that can be used when lower fidelity, higher performance simulations are required.

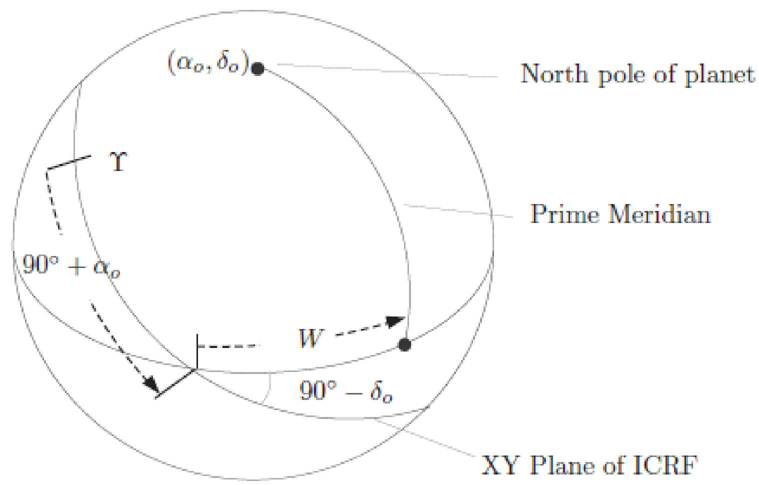


Remarks

Celestial Body Orientation Model

The orientation of built-in celestial bodies is modeled using high fidelity theories on a per-body basis. The orientation of Earth is modeled using IAU-1976/FK5. The orientation of the Moon is modeled using lunar librations from the DE405 file. The remaining built-in celestial body orientations are modeled using data published by the IAU/IAG in "Report of the IAU/IAG Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites: 2000".

The orientation of a custom **CelestialBody** is modeled by providing three angles and their rates based on IAU/IAG conventions. The figure below illustrates the angles. The angles αo, δo, and W, are respectively the **SpinAxisRAConstant**, **SpinAxisDECConstant**, and **RotationConstant**. The angular rates are respectively **SpinAxisRARate**, **SpinAxisDECRate**, and **RotationRate**. All angles are referenced to the X-Y plane of the **ICRF** axis system. The constant values **SpinAxisRAConstant**, **SpinAxisDECConstant**, and **RotationConstant** are defined to be the values at the epoch defined in **OrientationEpoch**.



Below is an example illustrating how to configure a **CelestialBody** according to the IAU 2006 recommended values for Vesta. Note the orientation epoch typically used by the IAU is 01 Jan 2000 12:00:00.00.000 TDB and this must be converted to A1ModJulian which can easily be performed using the **Spacecraft Orbit** dialog box.

```
Create Asteroid Vesta
Vesta.CentralBody         = Sun
%  Note that currently the only available
%  format for OrientationEpoch is A1ModJulian
Vesta.OrientationEpoch    = 21544.99962789878
Vesta.SpinAxisRAConstant  = 301.9
Vesta.SpinAxisRARate      = 0.9
Vesta.SpinAxisDECConstant = 90.9
Vesta.SpinAxisDECRate     = 0.0
Vesta.RotationConstant    = 292.9
Vesta.RotationRate        = 1617.332776
```

Note: The orientation models available for Earth and Luna have additional fields for configuration. Earth has an additional field called **NutationUpdateInterval** that controls the update frequency for the Nutation matrix. For high fidelity applications, **NutationUpdateInterval** should be set to zero. The **RotationDataSource** field for Earth and Luna defines the theory used for the rotation of those bodies. Currently, only FK5IAU1980 and DE405 are available for Earth and Luna respectively and the field is displayed for information purposes only. Future versions of GMAT will support DE421 for Luna and IAU-2000A theory for Earth.

Setting Colors On Orbits Of Celestial Bodies

GMAT allows you to assign colors to orbits of celestial bodies that are drawn in the **OrbitView** graphics display windows. GMAT also allows you to assign colors to perturbing celestial body orbital trajectories drawn during iterative processes such as differential correction or optimization. The **CelestialBody** object's **OrbitColor** and **TargetColor** fields are used to assign colors to both orbital and perturbing trajectories. See the Fields section for description of these two fields. Also see Color documentation for discussion and examples on how to set colors on a celestial body.

Configuring Orbit Ephemerides

The ephemerides for built-in celestial bodies is specified by the **SolarSystem.EphemerisSource** field and the same source is used for all built-in bodies. Ephemerides for a custom **CelestialBody** are provided by SPICE files. Archives of available SPICE files can be found at the JPL NAIF site and the Solar System Dynamics site . JPL provides utilities to create custom SPICE files in the event existing kernels don't satisfy requirements for your application. To create custom SPICE kernels, see the documentation provided by JPL. The list of NAIF Ids for celestial bodies is located here.

Note that the DE files model the barycenter of planetary systems. So for Jupiter, when using **DE405** for example, you are modeling Jupiter's location as the barycenter of the Jovian system. **SPICE** kernels differentiate the barycenter of a planetary system from the location of the individual bodies. So when using **SPICE** to model Jupiter, you are modeling the location of Jupiter using Jupiter's center of mass.

To specify the SPICE kernels for a custom **CelestialBody**, use the **NAIFId**, **CentralBody**, and **SourceFileName** fields. GMAT is distributed with an SPK file for CERES which has **NAIF ID** 2000001. Here is how to configure a **CelestialBody** to use the CERES SPICE ephemeris data.

```
Create CelestialBody Ceres
Ceres.CentralBody = Sun
Ceres.SourceFilename = '../data/planetary_ephem/spk/ceres_1900_2100.bsp'
```

Note: GMAT currently only supports a single ephemeris model for custom bodies (SPICE) and this is set using PosVelSource field. The default for PosVelSource is SPICE and it is not necessary to configure this field in the current version of GMAT.

Warning

NIAF distributes SPICE kernels for many celestial bodies and each kernel is consistent with a particular primary ephemeris release such as DE421. For high precision analysis, it is important to ensure that the ephemerides used for a custom celestial body are consistent with the ephemeris source selection in the **SolarSystem.EphemerisSource** field. SPICE kernels are typically distributed with a ".cmt" file and in that file the line that contains the ephemeris model looks like this:

Planetary Ephemeris Number: DE-0421/LE-0421

Configuring Physical Properties

GMAT models all celestial bodies as spherical ellipsoids. To define the physical properties use the **Flattening**, **EquatorialRadius**, and **Mu** fields.

Examples

Configure a **CelestialBody** to model Saturn's moon Titan. Note you must obtain the SPICE kernel named "sat351.bsp" from here and place it in the directory identified in the script snippet below

```
Create Moon Titan
Titan.NAIFId               = 606
```

```
Titan.OrbitSpiceKernelName = {...
                    '../data/planetary_ephem/spk/DE421AllPlanets.bsp',...
                    '../data/planetary_ephem/spk/sat288.bsp'}
Titan.EquatorialRadius     = 2575
Titan.Flattening           = 0
Titan.Mu                   = 8978.5215
Titan.PosVelSource         = 'SPICE'
Titan.CentralBody          = 'Saturn'
Titan.RotationDataSource   = 'IAUSimplified'
Titan.OrientationEpoch     = 21545
Titan.SpinAxisRAConstant   = 36.41
Titan.SpinAxisRARate       = -0.036
Titan.SpinAxisDECConstant  = 83.94
Titan.SpinAxisDECRate      = -0.004
Titan.RotationConstant     = 189.64
Titan.RotationRate         = 22.5769768
```

CoordinateSystem

An axis and origin pair

Description

A **CoordinateSystem** in GMAT is defined as an origin and an axis system. You can select the origin of a **CoordinateSystem** from various points such as a **CelestialBody**, **Spacecraft**, **GroundStation**, or **LibrationPoint** to name a few. GMAT supports numerous axis systems such as J2000 equator, J2000 ecliptic, **ICRF**, **ITRF**, **Topocentric**, and **ObjectReferenced** among others. **CoordinateSystems** are tightly integrated into GMAT to enable you to define, report, and visualize data in coordinate systems relevant to your application. This resource cannot be modified in the Mission Sequence.

See Also: Spacecraft, Calculation Parameters, OrbitView

Fields

Field	Description
AlignmentVectorX	The x component of the **AlignmentVector** expressed in the local frame (for example, expressed in the **LocalAlignedConstrained** frame). Used for the following axis systems: **LocalAlignedConstrained**. **Data Type**: Real **Allowed Values**: -∞ < Real < ∞ (norm of **AlignmentVector** >= 1e-9) **Access**: set **Default Value**: **1** **Units**: N/A **Interfaces**: gui,script
AlignmentVectorY	The y component of the **AlignmentVector** expressed in the local frame (for example, expressed in the **LocalAlignedConstrained** frame). Used for the following axis systems: **LocalAlignedConstrained**. **Data Type**: Real **Allowed Values**: -∞ < Real < ∞ (norm of **AlignmentVector**>= 1e-9) **Access**: set **Default Value**: **0** **Units**: N/A **Interfaces**: gui, script
AlignmentVectorZ	The z component of the **AlignmentVector** expressed in the local frame (for example, expressed in the **LocalAlignedConstrained** frame). Used for the following axis systems: **LocalAlignedConstrained**. **Data Type**: Real **Allowed Values**: -∞ < Real < ∞ (norm of **AlignmentVector**>= 1e-9) **Access**: set **Default Value**: **0** **Units**: N/A **Interfaces**: gui,script

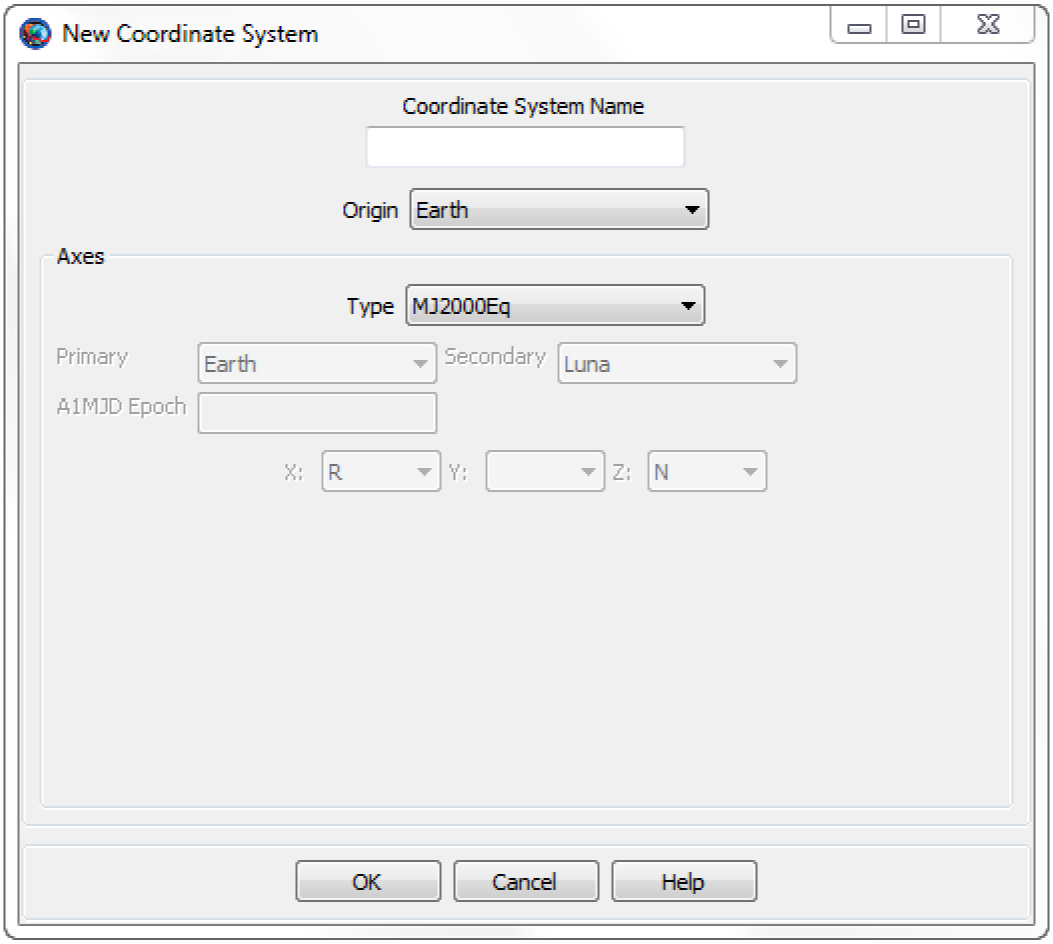
Field	Description
Axes	The axes of the **CoordinateSystem**. **Data Type** String **Allowed Values** **MJ2000Eq**, **MJ2000Ec**, **ICRF**, **ITRF**, **MODEq**, **MODEc**, **TODEq**, **TODEc**, **MOEEq**, **MOEEc**, **TOEEq**, **TOEEc**, **ObjectReferenced**, **Equator**, **BodyFixed**, **BodyInertial**, **GSE**, **GSM**, **Topocentric**, **BodySpinSun** **Access** set **Default Value** **MJ2000Eq** **Units** N/A **Interfaces** GUI, script
ConstraintVectorX	The x component of the **ConstraintVector** expressed in the local frame (for example, expressed in the **LocalAlignedConstrained** frame). Used for the following axis systems: **LocalAlignedConstrained**. **Data Type** Real **Allowed Values** $-\infty$ < Real < ∞ (norm of **ConstraintVector**>= 1e-9) **Access** set **Default Value** **0** **Units** N/A **Interfaces** gui,script
ConstraintVectorY	The y component of the **ConstraintVector** expressed in the local frame (for example, expressed in the **LocalAlignedConstrained** frame). Used for the following axis systems: **LocalAlignedConstrained**. **Data Type** Real **Allowed Values** $-\infty$ < Real < ∞ (norm of **ConstraintVector**>= 1e-9) **Access** set **Default Value** **0** **Units** N/A **Interfaces** gui,script
ConstraintVectorZ	The z component of the **ConstraintVector** expressed in the local frame (for example, expressed in the **LocalAlignedConstrained** frame). Used for the following axis systems: **LocalAlignedConstrained**. **Data Type** Real **Allowed Values** $-\infty$ < Real < ∞ (norm of **ConstraintVector**>= 1e-9) **Access** set **Default Value** **1** **Units** N/A **Interfaces** gui,script

Field	Description	
ConstraintReferenceVectorX	The x component of the **ConstraintReferenceVector** expressed in the **ConstraintCoordinateSystem**. Used for the following axis systems: **LocalAlignedConstrained**.	
	Data Type	Real
	Allowed Values	$-\infty$ < Real < ∞ (norm of **ConstraintReferenceVector**>= 1e-9)
	Access	set
	Default Value	**0**
	Units	N/A
	Interfaces	gui,script
ConstraintReferenceVectorY	The y component of the **ConstraintReferenceVector** expressed in the **ConstraintCoordinateSystem**. Used for the following axis systems: **LocalAlignedConstrained**.	
	Data Type	Real
	Allowed Values	$-\infty$ < Real < ∞ (norm of **ConstraintReferenceVector**>= 1e-9)
	Access	set
	Default Value	**0**
	Units	N/A
	Interfaces	gui,script
ConstraintReferenceVectorZ	The z component of the **ConstraintReferenceVector** expressed in the **ConstraintCoordinateSystem**. Used for the following axis systems: **LocalAlignedConstrained**.	
	Data Type	Real
	Allowed Values	$-\infty$ < Real < ∞ (norm of **ConstraintReferenceVector**>= 1e-9)
	Access	set
	Default Value	**1**
	Units	N/A
	Interfaces	gui,script
Constraint Coordinate System	The coordinate system for the **ConstraintReferenceVector**. Used for the following axis sytems: **LocalAlignedConstrained**.	
	Data Type	Resource
	Allowed Values	**CoordinateSystem**
	Access	set
	Default Value	**EarthMJ2000Eq**
	Units	N/A
	Interfaces	gui,script

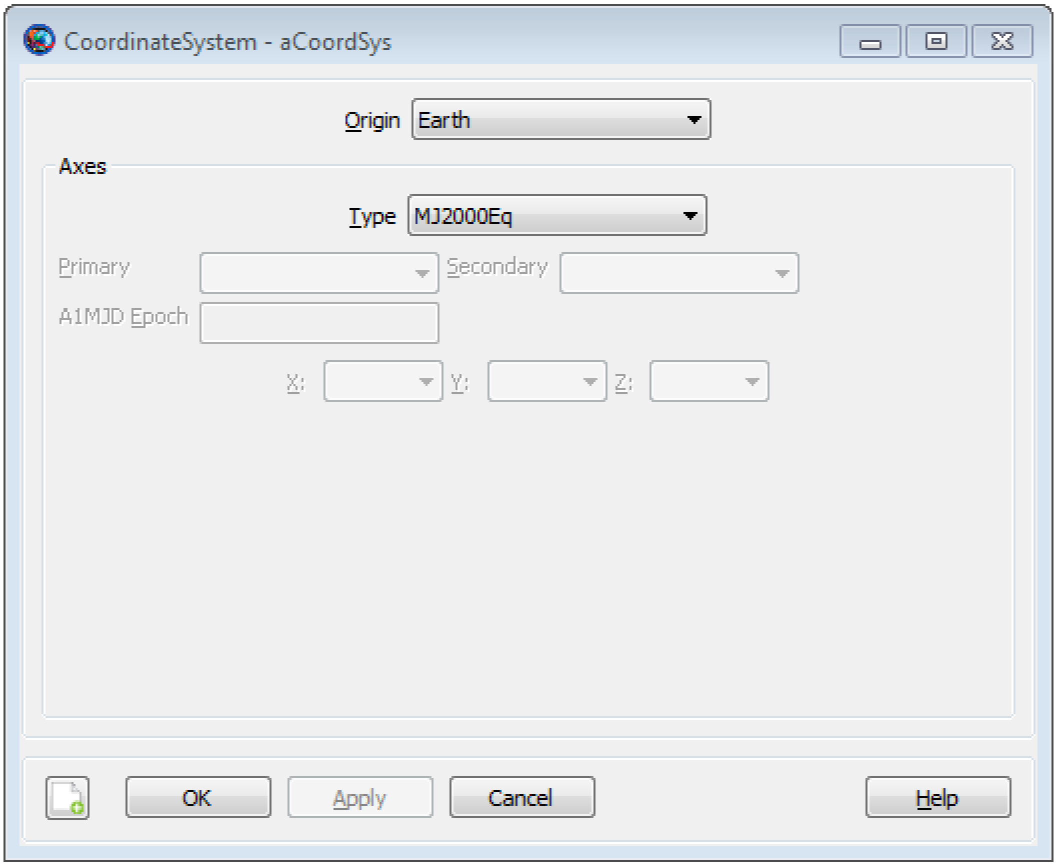
Field	Description	
Epoch	The reference epoch for the **CoordinateSystem**. This field is only used for **TOE** amd **MOE** axis types.	
	Data Type	String
	Allowed Values	A1 Modified Julian epoch.
	Access	set
	Default Value	21545
	Units	Modified Julian Date
	Interfaces	GUI, script
Origin	The origin of the **CoordinateSystem**.	
	Data Type	String
	Allowed Values	**CelestialBody**, **Spacecraft**, **LibrationPoint**, **Barycenter**, **SolarSystemBarycenter**, **GroundStation**
	Access	set
	Default Value	**Earth**
	Units	N/A
	Interfaces	GUI, script
Primary	The primary body for an **ObjectReferenced** axis system. This field is only used if **Axes** = **ObjectReferenced**. See the discussion below for more information on how **Primary** and **Secondary** are used to compute **ObjectReferenced** axes.	
	Data Type	String
	Allowed Values	**CelestialBody**, **Spacecraft**, **LibrationPoint**, **Barycenter**, **SolarSystemBarycenter**, **GroundStation**
	Access	set
	Default Value	**Earth**
	Units	N/A
	Interfaces	GUI, script
ReferenceObject	The reference object for a **LocalAlignedConstrained** axis system. The axes are computed such that the **AlignmentVector** in the body frame is aligned with the vector pointing from the **Origin** to the **ReferenceObject**.	
	Data Type	Resource
	Allowed Values	A Resource that has coordinates. For example: **CelestialBody**, **Spacecraft**, **LibrationPoint**, **Barycenter**, **SolarSystemBarycenter**, **GroundStation.**
	Access	set
	Default Value	**Luna**
	Units	N/A
	Interfaces	gui,script

Field	Description
Secondary	The secondary body for an **ObjectReferenced** axis system. This field is only used if **Axes** = **ObjectReferenced**. See the discussion below for more information on how **Primary** and **Secondary** are used to compute **ObjectReferenced** axes. **Data Type** String **Allowed Values** **CelestialBody**, **Spacecraft**, **LibrationPoint**, **Barycenter**, **SolarSystemBarycenter**, **GroundStation** **Access** set **Default Value** **Luna** **Units** N/A **Interfaces** GUI, script
XAxis	The x-axis definition for an **ObjectReferenced** axis system. This field is only used if **Axes** = **ObjectReferenced**. See the discussion below for more information on how the axes are computed for **ObjectReferenced** axis systems. **Data Type** String **Allowed Values** **R**,**V**, **N**, **-R**, **-V**, **-N**, or empty **Access** set **Default Value** **R** **Units** N/A **Interfaces** GUI, script
YAxis	The y-axis definition for an **ObjectReferenced** axis system. This field is only used if **Axes** = **ObjectReferenced**. See the discussion below for more information on how the axes are computed for **ObjectReferenced** axis systems. **Data Type** String **Allowed Values** **R**,**V**, **N**, **-R**, **-V**,**-N**, or empty **Access** set **Default Value** No Default **Units** N/A **Interfaces** GUI, script
Zaxis	The z-axis for an **ObjectReferenced** axis system. This field is only used if **Axes** = **ObjectReferenced**. See the discussion below for more information on how the axes are computed for **ObjectReferenced** axis systems. **Data Type** String **Allowed Values** **R**,**V**, **N**, **-R**, **-V**,**-N**, or empty **Access** set **Default Value** **N** **Units** N/A **Interfaces** GUI, script

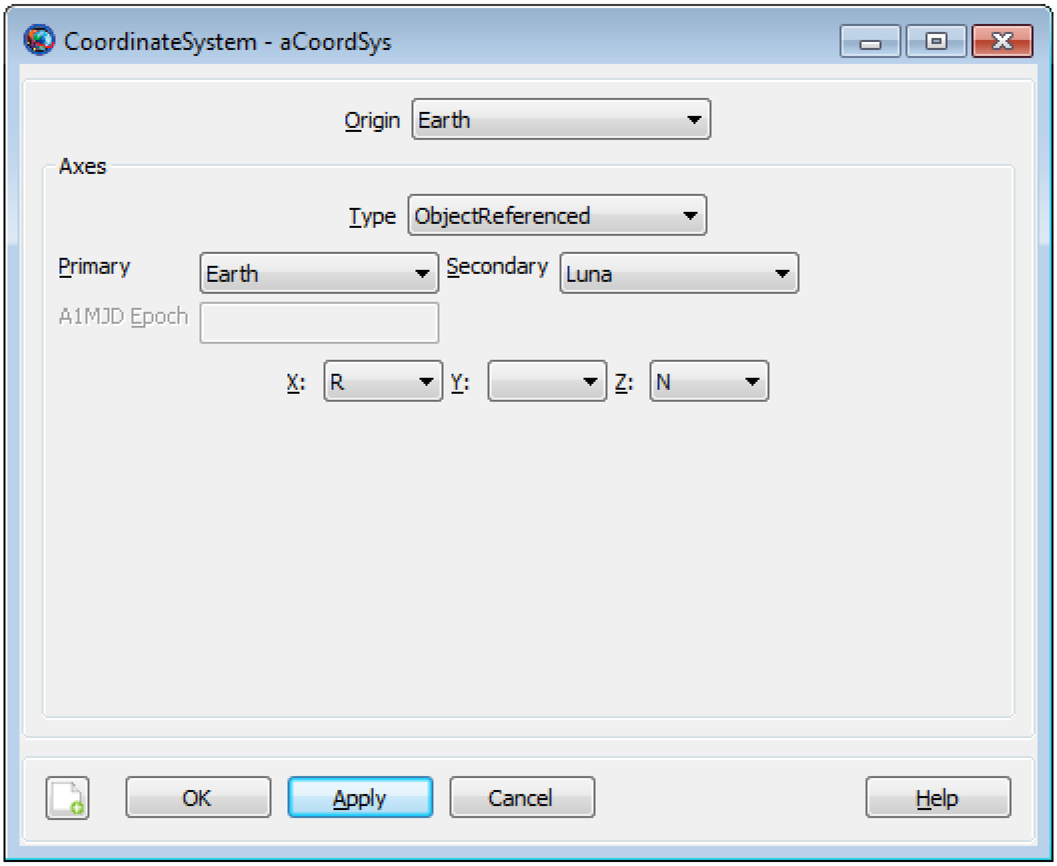
GUI



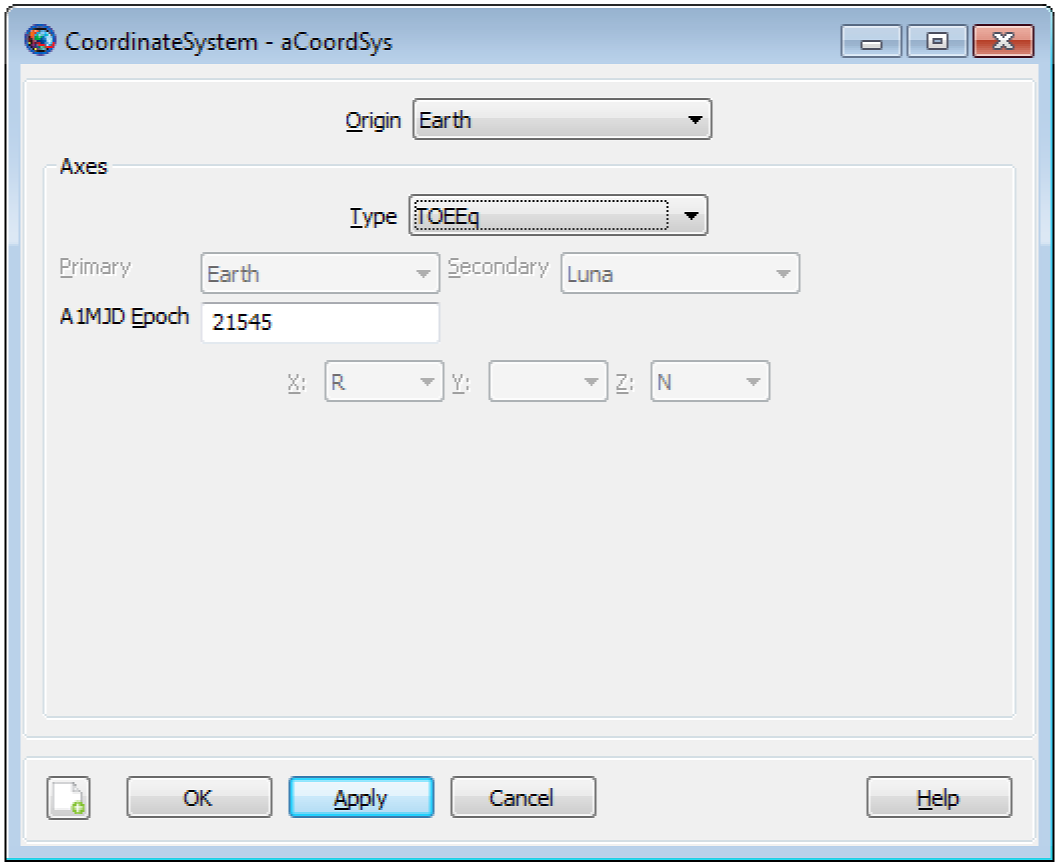
The **New Coordinate System** dialog box shown above appears when you add a new coordinate system in the **Resource Tree**. You provide a name for the new **CoordinateSystem** in the **Coordinate System Name** box and configure the **CoordinateSystem** by selecting the **Origin** and **Axes** types along with other settings. Some settings, such as **Primary** and **Secondary**, are only active for particular **Axes** types and those dependencies are described below.



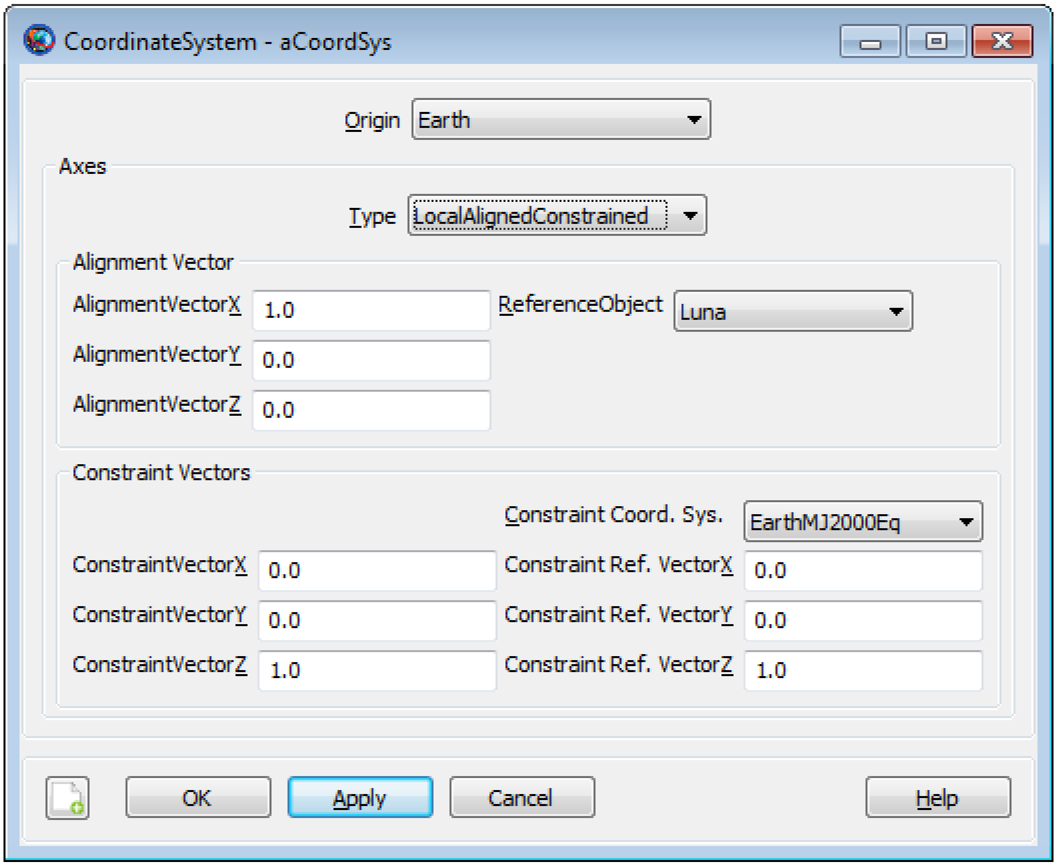
When editing an existing **CoordinateSystem**, you use the **CoordinateSystem** dialog box. The default configuration is shown above.



If you select **ObjectReferenced** for the **Axes** type, then the **Primary**, **Secondary**, **X**, **Y**, and **Z** fields are activated. You can use the **ObjectReferenced** axis system to define coordinates based on the motion of two space objects such as **Spacecraft**, **CelestialBodies**, or **Barycenters** to name a few. See the discussion below for a detailed definition of the **ObjectReferenced** axis system.



If you select **TOEEq**, **TOEEc**, **MOEEq**, or **MOEEc** as the axis type, then the **A1MJd Epoch** field is activated. Use the **A1MJd Epoch** field to define the reference epoch of the coordinate system.



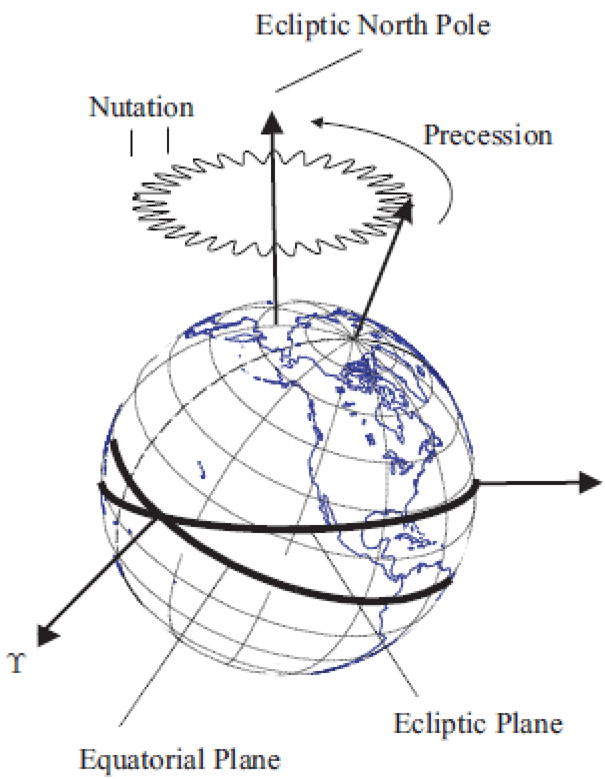
If you select **LocalAlignedConstrained** as the axes **Type**, then **CoordinateSystem** dialog displays the fields illustrated above for configuring the axes.

Remarks

Computation of J2000-Based Axes using IAU76/FK5 Reduction

FK5 reduction is the transformation that rotates a vector expressed in the **MJ2000Eq** system to the **EarthFixed CoordinateSystem**. There are many coordinate systems that are intermediate rotations in FK5 reduction and this section describes how the following axes types are computed: **MJ2000Eq**, **MJ2000Ec**, **EarthFixed**, **MODEq**, **MODEc**,**TODEq**,**TODEc**, **MODEq**, **MODEc**, **TODEq**, and **TODEc** axes systems.

The time varying orientation of the Earth is complex due to interactions between the Earth and its external environment (the Sun and Moon and Planets) and internal dynamics. The orientation cannot currently be modelled to the accuracy required by many space applications and FK5 reduction is a combination of dynamical modelling along with daily corrections from empirical observations. The figure below illustrates components of motion of the Earth with respect to inertial space. The primary components of the motion of the Earth with respect to inertial space are Precession, Nutation, Sidereal time and, Polar Motion.



The principal moment of inertia is defined as the Celestial Ephemeris Pole. Due to the fact that Earth's mass distribution changes with time, the Celestial Ephemeris Pole is not constant with respect to the Earth's surface. Precession is defined as the coning motion that the Celestial Ephemeris Pole makes around the ecliptic north pole. The other principal component of the motion of the Celestial Ephemeris Pole is called nutation and is the oscillation in the angle between the Celestial Ephemeris Pole and the north ecliptic pole. The theory of Precession and Nutation come from dynamical models of the Earth's motion. The Sidereal time is the rotation of the Earth about the Celestial Ephemeris Pole. The sidereal time model is a combination of theory and observation. The Earth's spin axis direction is not constant with respect to the Earth's crust and its motion is called Polar Motion. A portion of polar motion is due to complicated dynamics, and a portion is due to unmodelled errors in nutation. Polar motion is determined from observation.

The True of Date (TOD) systems and Mean of Date (MOD) systems are intermediate coordinate systems in FK5 reduction and are commonly used in analysis. The details of the computations are contained in the GMAT mathematical specification and the figure below is included here for summary purposes. The following abbreviations are used in the figure. PM: Polar Motion, ST: Sideral Time, NUT: Nutation, PREC: Precession, ITRF: International Terrestrial Reference Frame (Earth Fixed), PEF: Pseudo Earth Fixed, TODEq: True of Date Equator, TODEc: True of Date Ecliptic, MODEc: Mean of Date Ecliptic, MODEq: Mean of Date Equator, FK5: J2000 Equatorial Inertial (IAU-1976/1980).

ITRF
PEF
TODEq
TODEc
MODEc
MODEq
FK5

$$\mathbf{R}_{IF} = \mathbf{PREC}^T\mathbf{NUT}^T\mathbf{ST}^T\mathbf{PM}^T = \underbrace{\mathbf{R}_3^T(-\zeta)\mathbf{R}_2^T(\Theta)\mathbf{R}_3^T(-z)}_{\mathbf{PREC}^T}\underbrace{\mathbf{R}_1^T(\bar{\epsilon})\mathbf{R}_3^T(-\Delta\Psi)\mathbf{R}_1^T(-\epsilon)}_{\mathbf{NUT}^T}\underbrace{\mathbf{R}_3^T(\theta_{AST})}_{\mathbf{ST}^T}\underbrace{\mathbf{R}_1^T(-y_p)\mathbf{R}_2^T(-x_p)}_{\mathbf{PM}^T}$$

$$\mathbf{R}_{FI} = \mathbf{PM}\ \mathbf{ST}\ \mathbf{NUT}\ \mathbf{PREC} = \overbrace{\mathbf{R}_2(-x_p)\mathbf{R}_1(-y_p)}^{\mathbf{PM}}\overbrace{\mathbf{R}_3(\theta_{AST})}^{\mathbf{ST}}\overbrace{\mathbf{R}_1(-\epsilon)\mathbf{R}_3(-\Delta\Psi)\mathbf{R}_1(\bar{\epsilon})}^{\mathbf{NUT}}\overbrace{\mathbf{R}_3(-z)\mathbf{R}_2(\Theta)\mathbf{R}_3(-\zeta)}^{\mathbf{PREC}}$$

ITRF
PEF
TODEq
TODEc
MODEc
MODEq
FK5

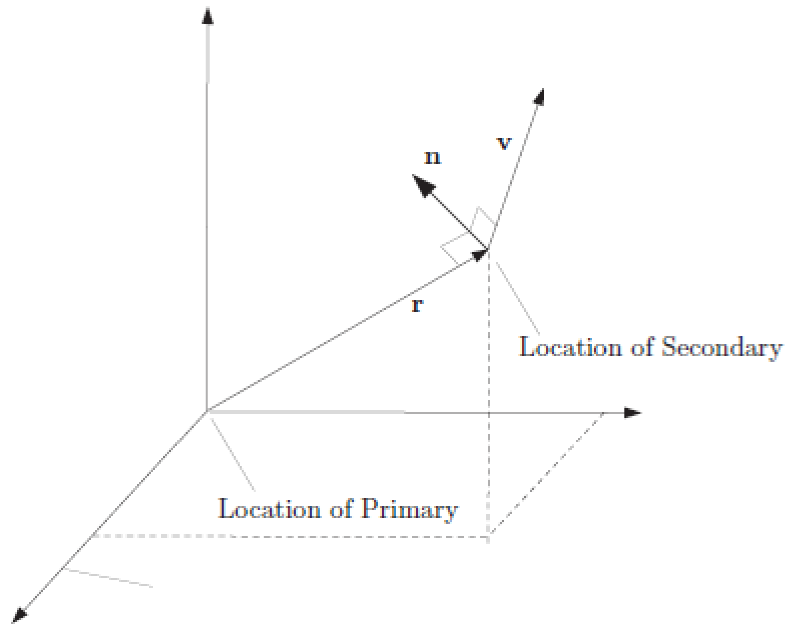
Computation of ICRF and ITRF Axes using IAU2000 Conventions

The computation for the International Celestial Reference Frame (**ICRF**) and the International Terestrial Reference Fame (ITRF) are computed using the IAU 2000A theory with the 2006 update to precession. GMAT uses the Celestial Intermediate Origin (CIO) method of transformation which avoids issues associated with precession and nutation. In the CIO model, the Celestial Intermediate Pole unit vector is modeled using the variables X and S and the CIO locator, s. For performance reasons, GMAT interpolates X, Y, and s, from precomputed values stored in the file named ICRF_Table.txt distributed with GMAT.

GMAT models the rotation from **ICRF** to **MJ200Eq** by rotating through the **EarthFixed** frame which is identical for both the old (1976) and new (2000) theories. For performance reasons, the conversion from **ICRF** to **MJ2000Eq** is interplolated from pre-computed values of the Euler axis and angle between those frames. Note that GMAT does not currenty support the IAU2000 body fixed frame for Earth and that model will be included in a future release.

Computation of ObjectReference Axis System

An **ObjectReferenced** axis system is defined by the motion of one object with respect to another object. The figure below defines the six principal directions of an **Object Referenced** axis system. One is the relative position of the secondary object with respect to the primary object, denoted by r, expressed in the inertial frame. The second is the relative velocity, denoted here by v, of the secondary object with respect to the primary, expressed in the inertial frame. The third direction is the vector normal to the direction of motion which is denoted by n and is calculated using n = r × v. The remaining three directions are the negative of the first three yielding the complete set: {**R**,-**R**, **V**,-**V**, **N**,-**N**}.



You define an **Object Referenced** axis system by defining two axes from the three available [X, Y, and Z] using the six available options {**R**,-**R**, **V**,-**V**, **N**,-**N**}. Given two directions, GMAT constructs an orthogonal, right-handed **CoordinateSystem**. For example, if you choose the x-axis to be in the direction of **R** and the z-axis to be in the direction of **N**, GMAT completes the right-handed set by setting the y-axis in the direction of **N**x**R**. If you choose permutations that result in a non-orthogonal or left-handed **CoordinateSystem**, GMAT will throw an error message.

> **Warning**
>
> GMAT currently assumes that terms involving the cross and dot product of acceleration are zero when computing **ObjectReferenced** rotation matrices.

Overview of Built-in Coordinate Systems

Name	Origin	Axes	Description
EarthMJ2000Eq	**Earth**	**MJ2000Eq**	An Earth equator inertial system based on IAU-1976/ FK5 theory with 1980 update to nutation.
EarthMJ2000Ec	**Earth**	**MJ2000Ec**	An Earth ecliptic inertial system based on IAU-1976/ FK5 theory with 1980 update to nutation.
EarthFixed	**Earth**	**BodyFixed**	An Earth fixed system based on IAU-1976/FK5 theory with 1980 update to nutation.
EarthICRF	**Earth**	**ICRF**	An Earth equator inertial system based on IAU-2000 theory with 2006 update to precession.

Description of Axes Types

Axes Name	Origin Limitations	Base Type	Description
MJ2000Eq	None	IAU-1976 FK5	An inertial coordinate system. The nominal x-axis points along the line formed by the intersection of the Earth's mean equatorial plane and the mean ecliptic plane (at the J2000 epoch), in the direction of Aries. The z-axis is normal to the Earth's mean equator at the J2000 epoch and the y-axis completes the right-handed system. The mean planes of the ecliptic and equator, at the J2000 epoch, are computed using IAU-1976/FK5 theory with 1980 update for nutation.
MJ2000Ec	None	IAU-1976 FK5	An inertial coordinate system. The x-axis points along the line formed by the intersection of the Earth's mean equator and the mean ecliptic plane at the J2000 epoch. The z-axis is normal to the mean ecliptic plane at the J2000 Epoch and the y-axis completes the right-handed set. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
ICRF	None	IAU-2000	An inertial coordinate system. The axes are close to the mean Earth equator and pole at the J2000 epoch, and at the Earth's surface, the RSS difference between vectors expressed in **MJ2000Eq** and **ICRF** is less than 1 m. Note that since **MJ2000Eq** and **ICRF** are imperfect realizations of inertial systems, the transformation between them is time varying. This axis system is computed using IAU-2000A theory with 2006 update for precession.
LocalAligned-Constrained	None	IAU-1976 FK5	The **LocalAlignedConstrained** axis system is an aligned constrained system based on the position of the **ReferenceObject** with respect to the **Origin** and is computed using the well known Triad algorithm. The axes are computed such that the **AlignmentVector**, defined as the components of the alignment vector expressed in the **LocalAlignedConstrained** system, is aligned with the position of the **ReferenceBody** w/r/t the origin. The rotation about the **AlignmentVector** is resolved by minimizing the angle between the **ContraintVector**, defined as the constraint vector expressed in the **LocalAlignedConstrained** system, and the **ConstraintReferenceVector**, defined as the constraint reference vector expressed in the **ConstraintCoordinateSystem**. The alignment vectors and the constraint vectors cannot have zero length. Similarly, the cross products of the constraint vector and alignment vector cannot have zero length.

Axes Name	Origin Limitations	Base Type	Description
MODEq	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to Earth's mean equator at the current epoch. The current epoch is defined by the context of use and usually comes from the spacecraft or graphics epoch. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
MODEc	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to the mean ecliptic at the current epoch. The current epoch is defined by the context of use and usually comes from the spacecraft or graphics epoch. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
TODEq	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to Earth's true equator at the current epoch. The current epoch is defined by the context of use and usually comes from the spacecraft or graphics epoch. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
TODEc	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to Earth's true ecliptic at the current epoch. The current epoch is defined by the context of use and usually comes from the spacecraft or graphics epoch. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
MOEEq	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to Earth's mean equator at the reference epoch. The reference epoch is defined on the **CoordinateSystem** object. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
MOEEc	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to the mean ecliptic at the reference epoch. The reference epoch is defined on the **CoordinateSystem** object. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
TOEEq	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to Earth's true equator at the reference epoch. The reference epoch is defined on the **CoordinateSystem** object. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.

Axes Name	Origin Limitations	Base Type	Description
TOEEc	None	IAU-1976 FK5	A quasi-inertial coordinate system referenced to the true ecliptic at the reference epoch. The reference epoch is defined on the **CoordinateSystem** object. This system is computed using IAU-1976/FK5 theory with 1980 update for nutation.
ObjectReferenced	None	IAU-1976 FK5	An **ObjectReferenced** system is a **CoordinateSystem** whose axes are defined by the motion of one object with respect to another object. See the discussion above for a detailed description of the **ObjectReferenced** axis system.
Equator	Celestial Body	IAU-1976 FK5	A true of date equator axis system for the celestial body selected as the origin. The **Equator** system is defined by the body's equatorial plane and its intersection with the ecliptic plane, at the current epoch. The current epoch is defined by the context of use and usually comes from the spacecraft or graphics epoch. The **Equator** system for Earth is computed using IAU-1976/FK5 theory. For the Moon, the **Equator** system is computed using the theory selected in the field **Luna.RotationDataSource**. For other built-in celestial bodies, the body fixed axes are computed using models provided by the IAU in "Report of the IAU/IAG Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites: 2000".
BodyFixed	Celestial Body or Spacecraft	IAU-1976 FK5	The **BodyFixed** axis system is referenced to the body equator and the prime meridian of the body. The **BodyFixed** system for Earth is computed using IAU-1976/FK5 theory. For the Moon, the **BodyFixed** system is computed using the theory selected in the field Luna.RotationDataSource. For other built-in celestial bodies, the body fixed axes are computed using models provided by the IAU in "Report of the IAU/IAG Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites: 2000". When **Origin** is a **Spacecraft**, the axes are computed using the **Spacecraft**'s attitude model. Note: not all attitude models compute body rates. In the case that body rates are not available on a spacecraft, a request for velocity transformations using a **BodyFixed** axis system will result in an error.

Axes Name	Origin Limitations	Base Type	Description
BodyInertial	Celestial Body	IAU-1976 FK5	An inertial system referenced to the equator (at the J2000 epoch) of the celestial body selected as the origin of the **CoordinateSystem**. Because the **BodyInertial** axis system uses different theories for different bodies, the following definitions describe only the nominal axis configurations. The x-axis points along the line formed by the intersection of the bodies equator and earth's mean equator at J2000. The z-axis points along the body's spin axis direction at the J2000 epoch. The y-axis completes the right-handed set. For Earth, the **BodyInertial** axis system is identical to the **MJ2000Eq** system. For the Moon, the orientation at the J2000 epoch is computed using the theory selected in the field **Luna.RotationDataSource**. For all other built-in celestial bodies, the **BodyInertial** axis system is based upon the IAU report entitled "Report of the IAU/IAG Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites: 2000"
GSE	None	IAU-1976 FK5	The Geocentric Solar Ecliptic system. The x-axis points from Earth to the Sun. The z-axis is defined as the cross product RxV where R and V are earth's position and velocity with respect to the sun respectively. The y-axis completes the right-handed set. The **GSE** axes are computed using the relative motion of the Earth and Sun even if the origin is not Earth.
GSM	None	IAU-1976 FK5	The Geocentric Solar Magnetic system. The x-axis points from Earth to the Sun. The z-axis is defined to be orthogonal to the x-axis and lies in the plane of the x-axis and Earth's magnetic dipole vector. The y-axis completes the right-handed set. The **GSM** axes are computed using the relative motion of the Earth and Sun even if the origin is not Earth.
Topocentric	Earth	IAU-1976 FK5	A **GroundStation**-based coordinate system. The y-axis points due East and the z-axis is normal to the local horizon. The x-axis completes the right handed set.
BodySpinSun	Celestial Body	IAU-1976 FK5	A celestial body spin-axis-referenced system. The x-axis points from the celestial body to the Sun. The y-axis is computed as the cross product of the x-axis and the body's spin axis. The z-axis completes the right-handed set.

Examples

Define a **Spacecraft**'s state in **EarthFixed** coordinates.

```
Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = EarthFixed
aSpacecraft.X = 7100
aSpacecraft.Y = 0
aSpacecraft.Z = 1300
aSpacecraft.VX = 0
aSpacecraft.VY = 7.35
aSpacecraft.VZ = 1
```

Report a **Spacecraft**'s state in **GroundStation Topocentric** coordinates.

```
Create Spacecraft aSat
Create Propagator aProp
Create GroundStation aStation

Create CoordinateSystem stationTopo
stationTopo.Origin = aStation
stationTopo.Axes   = Topocentric

Create ReportFile aReport
aReport.Filename = 'ReportFile1.txt'
aReport.Add = {aSat.stationTopo.X aSat.stationTopo.Y aSat.stationTopo.Z ...
               aSat.stationTopo.VX aSat.stationTopo.VY aSat.stationTopo.VZ}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedSecs = 8640.0}
```

View a trajectory in an **ObjectReferenced**, rotating-**LibrationPoint** system.

```
%  Create the Earth-Moon Barycenter and Libration Point
Create Barycenter EarthMoonBary
EarthMoonBary.BodyNames = {Earth,Luna};

Create LibrationPoint SunEarthMoonL1
SunEarthMoonL1.Primary   = Sun;
SunEarthMoonL1.Secondary = EarthMoonBary
SunEarthMoonL1.Point     = L1;

%  Create the coordinate system
Create CoordinateSystem RotatingSEML1Coord
RotatingSEML1Coord.Origin    = SunEarthMoonL1
RotatingSEML1Coord.Axes      = ObjectReferenced
RotatingSEML1Coord.XAxis     = R
RotatingSEML1Coord.ZAxis     = N
RotatingSEML1Coord.Primary   = Sun
RotatingSEML1Coord.Secondary = EarthMoonBary

%  Create the spacecraft and propagator
Create Spacecraft aSpacecraft
aSpacecraft.DateFormat       = UTCGregorian
aSpacecraft.Epoch            = '09 Dec 2005 13:00:00.000'
aSpacecraft.CoordinateSystem = RotatingSEML1Coord
aSpacecraft.X  = -32197.88223741966
```

```
aSpacecraft.Y  = 211529.1500044117
aSpacecraft.Z  = 44708.57017366499
aSpacecraft.VX = 0.03209516489451751
aSpacecraft.VY = 0.06100386504053736
aSpacecraft.VZ = 0.0550442738917212

Create Propagator aPropagator
aPropagator.FM           = aForceModel
aPropagator.MaxStep = 86400
Create ForceModel aForceModel
aForceModel.PointMasses = {Earth,Sun,Luna}

% Create a 3-D graphic
Create OrbitView anOrbitView
anOrbitView.Add                 = {aSpacecraft,  Earth, Sun, Luna}
anOrbitView.CoordinateSystem     = RotatingSEML1Coord
anOrbitView.ViewPointReference   = SunEarthMoonL1
anOrbitView.ViewPointVector      = [-1500000 0 0 ]
anOrbitView.ViewDirection        = SunEarthMoonL1
anOrbitView.ViewUpCoordinateSystem = RotatingSEML1Coord
anOrbitView.Axes                 = Off
anOrbitView.XYPlane              = Off

BeginMissionSequence

Propagate aPropagator(aSpacecraft, {aSpacecraft.ElapsedDays = 180})
```

DifferentialCorrector

A numerical solver

Description

A **DifferentialCorrector** (DC) is a numerical solver for solving boundary value problems. It is used to refine a set of variable parameters in order to meet a set of goals defined for the modeled mission. The DC in GMAT supports several numerical techniques. In the mission sequence, you use the **DifferentialCorrector** resource in a **Target** control sequence to solve the boundary value problem. In GMAT, differential correctors are often used to determine the maneuver components required to achieve desired orbital conditions, say, B-plane conditions at a planetary flyby.

You must create and configure a **DifferentialCorrector** resource for your application by setting numerical properties of the solver such as the algorithm type, the maximum number of allowed iterations and choice of derivative method used to calculate the finite differences. You can also select among different output options that show increasing levels of information for each differential corrector iteration.

This resource cannot be modified in the Mission Sequence.

See Also: Target, Vary, Achieve

Fields

Field	Description
Algorithm	The numerical method used to solve the boundary value problem. **Data Type**: String **Allowed Values**: **NewtonRaphson**, **Broyden**, **ModifiedBroyden** **Access**: set **Default Value**: **NewtonRaphson** **Units**: N/A **Interfaces**: GUI, script
DerivativeMethod	Chooses between one-sided and central differencing for numerically determining the derivative. Only used when **Algorithm** is set to **NewtonRaphson**. **Data Type**: String **Allowed Values**: **ForwardDifference**, **BackwardDifference**, **CentralDifference** **Access**: set **Default Value**: **ForwardDifference** **Units**: N/A **Interfaces**: GUI, script

<table>
<tr><th>Field</th><th>Description</th></tr>
<tr><td>MaximumIterations</td><td>Sets the maximum number of nominal passes the DifferentialCorrector is allowed to take during the attempt to find a solution. If the maximum iterations is reached, GMAT exits the target loop and continues to the next command in the mission sequence. In this case, the objects retain their states as of the last nominal pass through the targeting loop.

Data Type: Integer
Allowed Values: Integer >= 1
Access: set
Default Value: 25
Units: N/A
Interfaces: GUI, script</td></tr>
<tr><td>ReportFile</td><td>Specifies the path and file name for the DifferentialCorrector report. The report is only generated if ShowProgress is set to true.

Data Type: String
Allowed Values: Filename consistent with OS
Access: set
Default Value: <code>DifferentialCorrectorDCName.data</code>, where <code>DCname</code> is the name of the DifferentialCorrector
Units: N/A
Interfaces: GUI, script</td></tr>
<tr><td>ReportStyle</td><td>Controls the amount and type of information written to the file defined in the ReportFile field. Currently, the Normal and Concise options contain the same information: the Jacobian, the inverse of the Jacobian, the current values of the control variables, and achieved and desired values of the constraints. Verbose contains values of the perturbation variables in addition to the data for Normal and Concise. Debug contains detailed script snippets at each iteration for objects that have control variables.

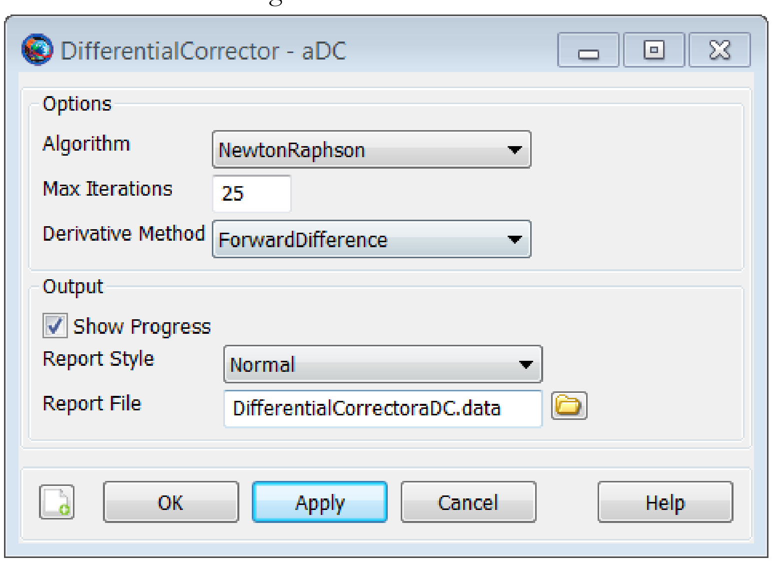
Data Type: String
Allowed Values: Normal, Concise, Verbose, Debug
Access: set
Default Value: Normal
Units: N/A
Interfaces: GUI, script</td></tr>
</table>

Field	Description
ShowProgress	When the **ShowProgress** field is set to true, then data illustrating the progress of the differential correction process are written to the message window and the **ReportFile**. The message window is updated with information on the current control variable values and the contraint variances. When the **ShowProgress** field is set to false, no information on the progress of the differential correction process is displayed to the message window or written to the **ReportFile**. **Data Type**: String **Allowed Values**: `true`, `false` **Access**: set **Default Value**: `true` **Units**: N/A **Interfaces**: GUI, script

GUI

The **DifferentialCorrector** dialog box allows you to specify properties of a **DifferentialCorrector** such as the numerical algorithm, maximum iterations, choice of derivative method used to calculate the finite differences, and choice of reporting options.

To create a **DifferentialCorrector** resource, navigate to the **Resources** tree, expand the **Solvers** folder, right-click on the **Boundary Value Solvers** folder, point to **Add**, and click **DifferentialCorrector**. A resource named **DC1** will be created. Double-click on the **DC1** resource to bring up the following **Differential Corrector** dialog box.



Remarks

Supported Algorithm Details

GMAT supports several algorithms for solving boundary value problems including **Newton Raphson**, **Broyden**, and **Modified Broyden**. These algorithms use finite differencing or other numerical approximations to compute the Jacobian of the constraints and independent variables. The default algorithm is currently **NewtonRaphson**. **Brodyen**'s method and **ModifiedBroyden** usually take more iterations but fewer function evaluations than **NewtonRaphson** and so are often faster. A description of each algorithm is provided below. We recommend trying different algorithm options for your application to determine which algorithm provides the best balance of performance and robustness.

Newton-Raphson

The **NewtonRaphson** algorithm is a quasi-Newton method that computes the Jacobian using finite differencing. GMAT supports forward, central, and backward differencing to compute the Jacobian.

Broyden

Broyden's method uses the slope between state iterations as an approximation of the first derivative instead of numerically calculating the first derivative using finite differencing. This results in substantially fewer function evaluations. The Broyden iterate is updated using the following equation.

$$\mathrm{J}_k = \mathrm{J}_{k-1} + \frac{f(\mathrm{x}_k) - f(\mathrm{x}_{k-1}) - \mathrm{J}_{k-1}(\mathrm{x}_k - \mathrm{x}_{k-1})}{\|\mathrm{x}_k - \mathrm{x}_{k-1}\|^2}(\mathrm{x}_k - \mathrm{x}_{k-1})^T$$

ModifiedBroyden

The modified **Broyden**'s method updates the inverse of the Jacobian matrix to avoid numerical issues in matrix inversion when solving near singular problems. Like **Broyden**'s method, it requires fewer function evaluations than the **NewtonRaphson** algorithm. The inverse of the Jacobian, H, is updated using the following equation,

$$\mathrm{H}_{\mathrm{k}+1} = \mathrm{H}_{\mathrm{k}} + (\mathrm{s}_{\mathrm{k}} - \mathrm{H}_{\mathrm{k}}\mathrm{y}_{\mathrm{k}})\mathrm{v}_{\mathrm{k}}^{\mathrm{T}}$$

where

$$s_k = x_{k+1} - x_k$$

$$y_k = f(x_{k+1}) - f(x_k)$$

$$\mathrm{v}_{\mathrm{k}} = \frac{\mathrm{H}_{\mathrm{k}}^{\mathrm{T}}\mathrm{s}_{\mathrm{k}}}{\mathrm{s}_{\mathrm{k}}^{\mathrm{T}}\mathrm{H}_{\mathrm{k}}\mathrm{y}_{\mathrm{k}}}$$

Resource and Command Interactions

The **DifferentialCorrector** object can only be used in the context of targeting-type commands. Please see the documentation for **Target**, **Vary**, and **Achieve** for more information and worked examples.

Examples

Create a **DifferentialCorrector** configured to use **Broyden**'s method and use it to solve for an apogee raising maneuver.

```
Create Spacecraft aSat
Create Propagator aProp
Create ImpulsiveBurn aDeltaV
Create OrbitView a3DPlot
a3DPlot.Add = {aSat,Earth};

Create DifferentialCorrector aDC
aDC.Algorithm = 'Broyden'

BeginMissionSequence

Propagate aProp(aSat){aSat.Periapsis}

Target aDC

    Vary aDC(aDeltaV.Element1 = 0.01)
    Maneuver aDeltaV(aSat)
    Propagate aProp(aSat){aSat.Apoapsis}
    Achieve aDC(aSat.RMAG = 12000)

EndTarget
```

To see further examples for how the **DifferentialCorrector** object is used in conjunction with **Target**, **Vary**, and **Achieve** commands to solve orbit problems, see the **Target** command examples.

EphemerisFile

Generate spacecraft's ephemeris data

Description

EphemerisFile is a user-defined resource that generates spacecraft's ephemeris data in a report format. You can generate spacecraft's ephemeris data in any of the user-defined coordinate frames. GMAT allows you to output ephemeris data in either CCSDS or SPK file formats. See the Remarks section for more details. **EphemerisFile** resource can be configured to generate ephemeris data at default integration steps or by entering user-selected step sizes.

GMAT allows you to generate any number of ephemeris data files by creating multiple **EphermisFile** resources. Spacecraft's ephemeris data is always provided in UTC epoch format. An **EphemerisFile** resource can be created using either the GUI or script interface. GMAT also provides the option of when to write and stop writing ephemeris data to a text file through the **Toggle On/Off** commands. See the Remarks section below for detailed discussion of the interaction between **EphemerisFile** resource and **Toggle** command.

See Also: CoordinateSystem, Toggle

Fields

Field	Description
CoordinateSystem	Allows you to set the interpolation order for the available interpolator methods (**Lagrange** or **Hermite**) for either **CCSDS-OEM**, **SPK** or **Code 500** file formats. This field cannot be modified in the Mission Sequence. **Data Type**: String **Allowed Values**: For CCSDS-OEM and Code-500 file formats: 1 <= Integer Number <= 10. For SPK file format: 1 <= Odd Integer Number <= 9 **Access**: set, get **Default Value**: **EarthMJ2000Eq** **Units**: N/A **Interfaces**: GUI, script

Field	Description
EpochFormat	The ephemeris file is generated at the step size that is specified for **StepSize** field. The user can generate ephemeris file at default Integration step size (using raw integrator steps) or by defining a fixed step size provided by user. For Code-500 ephemeris, only fixed step size is supported This field cannot be modified in the Mission Sequence. **Data Type** Enumeration **Allowed Values** **UTCGregorian**, **UTCModJulian**, **TAIGregorian**, **TAIModJulian**, **TTGregorian**, **TTModJulian**, **A1Gregorian**, **A1ModJulian** **Access** Set **Default Value** **UTCGregorian** **Units** N/A **Interfaces** GUI, script
FileFormat	Allows the user to generate ephemeris file in three available file formats: CCSDS-OEM, SPK or Code-500. This field cannot be modified in the Mission Sequence. **Data Type** Enumeration **Allowed Values** **CCSDS-OEM**, **SPK**, **Code-500** **Access** Set **Default Value** **CCSDS-OEM** **Units** N/A **Interfaces** GUI, script
FileName	Allows the user to generate ephemeris file in three available file formats: CCSDS-OEM, SPK and Code-500. This field cannot be modified in the Mission Sequence. **Data Type** String **Allowed Values** Valid File Path and Name **Access** set **Default Value** `EphemerisFile1.eph` **Units** N/A **Interfaces** GUI, script
FinalEpoch	Allows the user to specify the time span of an ephemeris file. Ephemeris file is generated up to final epoch that is specified in **FinalEpoch** field. This field cannot be modified in the Mission Sequence. **Data Type** String **Allowed Values** user-defined final epoch or Default Value **Access** set **Default Value** `FinalSpacecraftEpoch` **Units** N/A **Interfaces** GUI, script

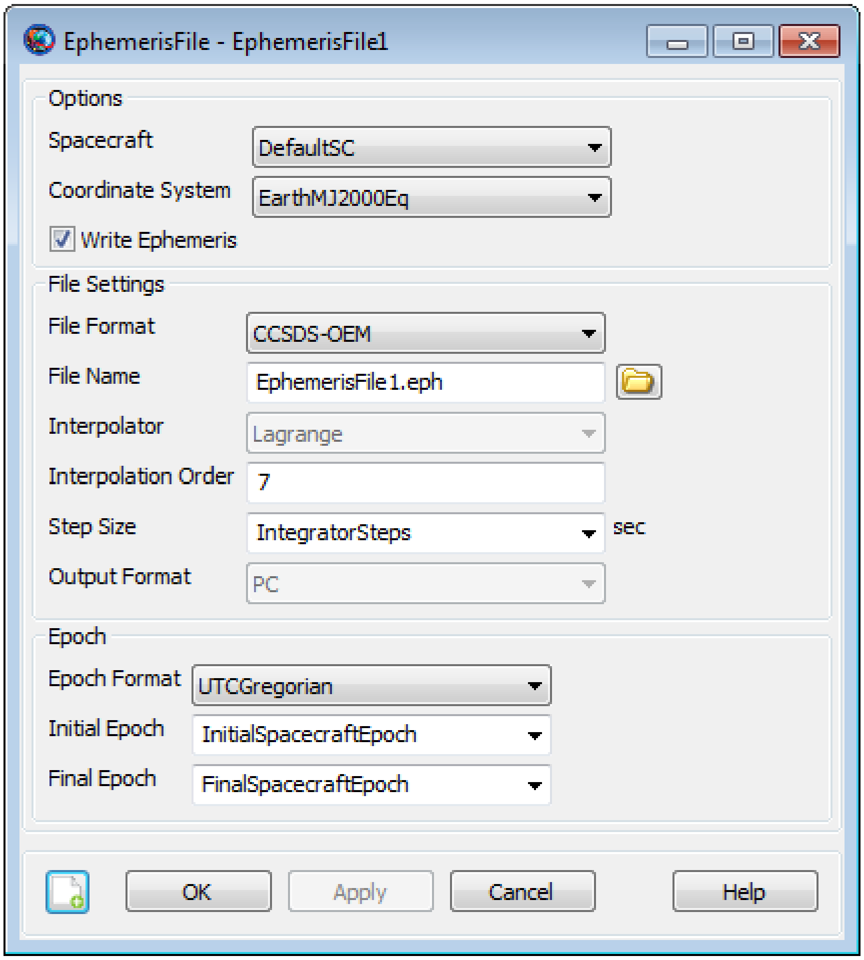
Field	Description
InitialEpoch	Allows the user to specify the starting epoch of the ephemeris file. Ephemeris file is generated starting from the epoch that is defined in **InitialEpoch** field. This field cannot be modified in the Mission Sequence. **Data Type** String **Allowed Values** user-defined initial epoch or Default Value **Access** set **Default Value** `InitialSpacecraftEpoch` **Units** N/A **Interfaces** GUI, script
InterpolationOrder	Allows you to set the interpolation order for the available interpolator methods (**Lagrange** or **Hermite**) for either **CCSDS-OEM** or **SPK** file formats. This field cannot be modified in the Mission Sequence. **Data Type** Integer **Allowed Values** 1 <= Integer Number <= 10 **Access** Set **Default Value** 7 **Units** N/A **Interfaces** GUI, script
Interpolator	This field defines the available interpolator method that was used to generate ephemeris file. Available **Interpolators** are **Lagrange** or **Hermite**. This field cannot be modified in the Mission Sequence. **Data Type** String **Allowed Values** **Lagrange** for CCSDS-OEM and Code-500 files, **Hermite** for SPK file **Access** set **Default Value** **Lagrange** **Units** N/A **Interfaces** GUI, script
Maximized	Allows the user to maximize the generated ephemeris file window. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** true,false **Access** set **Default Value** false **Units** N/A **Interfaces** script

Field	Description	
OutputFormat	Allows the user to specify what type of format they want GSFC Code-500 ephmeris to be generated in. GSFC Code-500 ephemeris can be generated in the PC or UNIX version. This field cannot be modified in the Mission Sequence.	
	Data Type	String
	Allowed Values	**PC**, **UNIX**
	Access	Set
	Default Value	**PC**
	Units	N/A
	Interfaces	GUI, script
RelativeZOrder	Allows the user to select which generated ephemeris file display window is to displayed first on the screen. The **EphemerisFile** resource with lowest **RelativeZOrder** value will be displayed last while **EphemerisFile** resource with highest **RelativeZOrder** value will be displayed first. This field cannot be modified in the Mission Sequence.	
	Data Type	Integer
	Allowed Values	Integer ≥ 0
	Access	set
	Default Value	0
	Units	N/A
	Interfaces	script
Size	Allows the user to control the display size of generated ephemeris file panel. First value in [0 0] matrix controls horizonal size and second value controls vertical size of ephemeris file display window. This field cannot be modified in the Mission Sequence.	
	Data Type	Real array
	Allowed Values	Any Real number
	Access	set
	Default Value	[0 0]
	Units	N/A
	Interfaces	script
Spacecraft	Allows the user to generate ephemeris data of spacecraft(s) that are defined in **Spacecraft** field. This field cannot be modified in the Mission Sequence.	
	Data Type	String
	Allowed Values	Default spacecraft or any number of user-defined spacecrafts or formations
	Access	set, get
	Default Value	**DefaultSC**
	Units	N/A
	Interfaces	GUI, script

Field	Description
StepSize	The ephemeris file is generated at the step size that is specified for **StepSize** field. The user can generate ephemeris file at default Integration step size (using raw integrator steps) or by defining a fixed step size. For `CCSDS-OEM` file format, you can generate ephemeris at either Integrator steps or fixed step size. For `SPK` file format, GMAT lets you generate ephemeris at only raw integrator step sizes. For `Code-500` ephemeris file type, you can generate ephemeris at only fixed step sizes. This field cannot be modified in the Mission Sequence. **Data Type** Real **Allowed Values** Real Number > 0.0 or equals Default Value **Access** Set **Default Value** `IntegratorSteps` for `CCSDS-OEM` and `SPK` file formats and `60` seconds for `Code-500` file format **Units** N/A **Interfaces** GUI, script
UpperLeft	Allows the user to pan the generated ephemeris file display window in any direction. First value in [0 0] matrix helps to pan the window horizontally and second value helps to pan the window vertically. This field cannot be modified in the Mission Sequence. **Data Type** Real array **Allowed Values** Any Real number **Access** set **Default Value** [0 0] **Units** N/A **Interfaces** script
WriteEphemeris	Allows the user to optionally calculate/write or not calculate/write an ephemeris that has been created and configured. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** true,false **Access** set **Default Value** true **Units** Unit **Interfaces** GUI, script

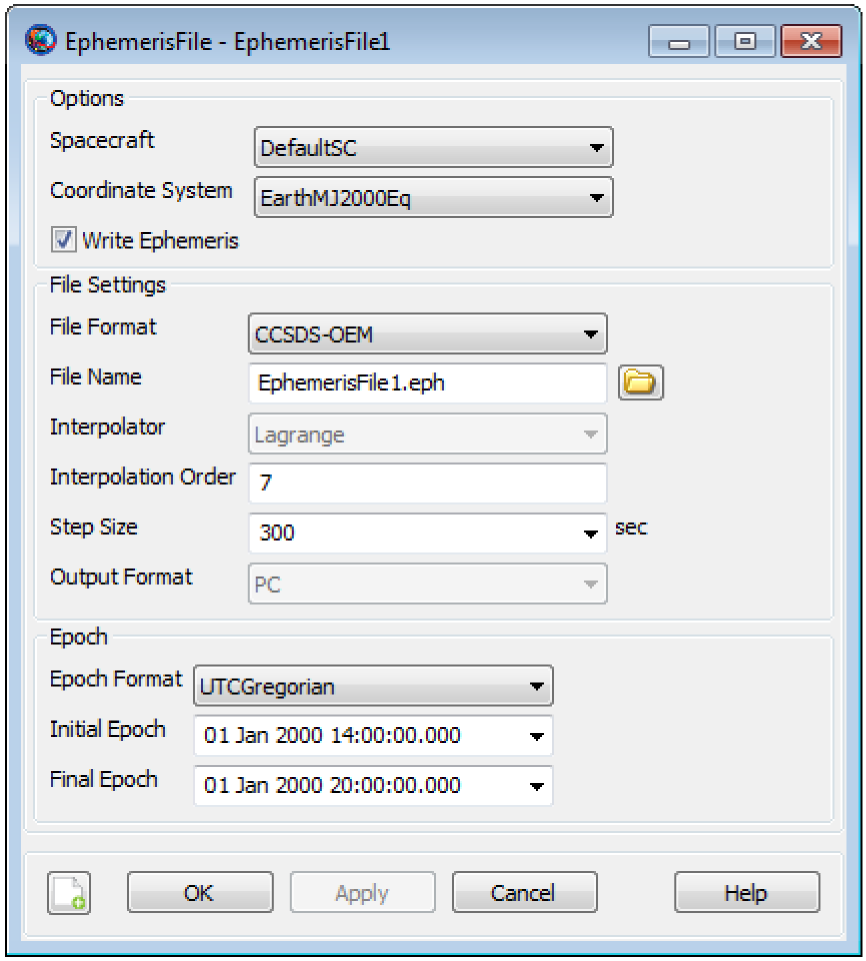
GUI

The figure below shows the default settings for the **EphemerisFile** resource:



GMAT allows you to modify **InitialEpoch**, **FinalEpoch** and **StepSize** fields of **EphemerisFile** resource. Instead of always generating the ephemeris file at default time span settings of **InitialSpacecraftEpoch** and **FinalSpacecraftEpoch**, you can define your own initial and final epochs. Similarly, instead of using the default **IntegratorSteps** setting for **StepSize** field, you can generate the ephemeris file at the step size of your choice.

The GUI figure below shows ephemeris file which will be generated from initial epoch of 01 Jan 2000 14:00:00.000 to final epoch of 01 Jan 2000 20:00:00.000 while using non-default step size of 300 seconds:



Remarks

Behavior of Coordinate System Field for CCSDS, Code 500 and SPK File Formats

If the selected **CoordinateSystem** uses MJ2000Eq axes, the CCSDS ephemeris file contains "EME2000" for the REF_FRAME according to CCSDS convention. By CCSDS requirements, non-standard axes names are allowed when documented in an ICD. The **CoordinateSystems** specifications document in the user's guide is the ICD for all axes supported by GMAT. Also if you create a new coordinate system whose origin is Luna, then the CCSDS ephemeris file contains "Moon" for the CENTER_NAME.

For code 500 file format, J2000 epoch can be with reference to any central body that you select. For code 500 and SPK file formats, GMAT can only write ephemeris for a coordinate system under **CoordinateSystem** field that references MJ2000Eq axis type for any central body.

There is one important difference between GMAT and IAU conventions. By IAU convention, there is no name for the IAU2000 axes that is independent of the origin. GCRF is coordinate system centered at earth with IAU2000 axes, and ICRF is a coordinate system centered at the solar system barycenter with IAU2000 axes. We have chosen to name the IAU2000 axes ICRF regardless of the origin. Please refer to **CoordinateSystems** specifications document to read more about built-in coordinate systems and description of Axes types that GMAT supports.

Behavior of Ephemeris File during Discontinuous & Iterative Processes

When generating an ephemeris file for a mission sequence, GMAT separately interpolates ephemeris segments that are bounded by discontinuous or discrete mission events. Discontinuous or discrete mission sequence events can range from impulsive or finite-burn maneuvers, changes in dynamics models or when using assignment commands. Furthermore, when a mission sequence employs iterative processes such as differential correction or optimization, GMAT only writes the ephemeris for the final solution from the iterative processes. See the Examples section below to see how an ephemeris file is generated during a discontinuous event such as an impulsive burn and iterative process like differential correction.

Version 1 of CCSDS Orbit Data Messages (ODMs) document used to require that the ephemeris be generated in increasing time order and only going forward. However version 2 of CCSDS ODM document now allows for ephemeris file to be generated backwards as well. Currently in GMAT, when you propagate a spacecraft backwards in time, then the ephemeris is also generated backwards.

Warning

The Code500 ephemeris file requires fixed time steps and has a pre-defined format for handling chunks of ephemeris data. The format does not allow chunking to stop and start at state discontinuities that occur at impulsive maneuvers. GMAT's current behavior is to interpolate across those discontinuities as the code 500 format does not elegantly support ephemerides with discontinuities. This is acceptable for small maneuvers but becomes less accurate as the maneuvers grow in magnitude. We recommend using more modern ephemeris file formats for this reasson.

Behavior of Ephemeris File When It Does Not Meet CCSDS File Format Requirements

When an ephemeris file is generated, it needs to follow the Recommended Standard for ODMs that has been prepared by the CCSDS. The set of orbit data messages described in the Recommended Standard is the baseline concept of trajectory representation in data interchange applications that are cross-supported between Agencies of the CCSDS. CCSDS-ODM Recommended Standard documents establishes a common framework and provides a common basis for the interchange of orbit data.

Currently, the ephemeris file that is generated by GMAT meets most of the recommended standards that are prescribed by the CCSDS. However whenever there is a case when GMAT's ephemeris violates CCSDS file format requirements, then the generated ephemeris file will display a warning in ephemeris file's Header section. More specifically, this warning will be given under COMMENT and it will let you know that this ephemeris file does not fully satisfy CCSDS file formatting requirements.

Behavior of Interpolation Order Field for CCSDS, SPK and Code 500 File Formats

For CCSDS file formats, whenever there is not enough raw data available to support the requested interpolation type and order, GMA throws an error message and stops interpolation. GMAT still generates the ephemeris file but no spacecraft ephemeris data is written to the file and only the file's Header section will be there. Within the Header section and under COMMENT, a message will be thrown saying that not enough raw data is available to generate spacecraft ephemeris data at the requested interpolation order.

For SPK file formats, raw data is always collected at every integrator step for each segment and then sent to SPK kernel writer. GMAT does not perform any interpolation for SPK files as SPK contains its own interpolation. As a result, **InitialEpoch** and **FinalEpoch** fields behave differently for SPK ephemerides. The first epoch on the file is the first step after **InitialEpoch**. The last epoch on the file is the last step before **FinalEpoch.**

For code 500 file formats, you can set the interpolation order and currently GMAT supports Lagrange as the available interpolator method. For code 500 file formats, if there is not enough raw data available to support interpolation type and order, GMAT will throw an error message and stop interpolation.

Behavior When Using EphemerisFile Resource & Toggle Command

EphemerisFile resource generates ephemeris file at each propagation step of the entire mission duration. If you want to generate ephemeris data during specific points in your mission, then a **Toggle On/Off** command can be inserted into the **Mission** tree to control when the **EphemerisFile** resource writes data. When **Toggle Off** command is issued for an **EphemerisFile** subscriber, no data is sent to a file until a **Toggle On** command is issued. Similarly, when a **Toggle On** command is used, ephemeris data is sent to a file at each integration step until a **Toggle** Off command is used.

Below is an example script snippet that shows how to use **Toggle Off/On** commands while using the **EphemerisFile** resource. No ephemeris data is sent for first two days of propagation and only the data that is collected during last four days of propagation is sent to text file called '`EphemerisFile1.eph`':

```
Create Spacecraft aSat
Create Propagator aProp

Create EphemerisFile anEphmerisFile

anEphmerisFile.Spacecraft = aSat
anEphmerisFile.Filename = 'EphemerisFile1.eph'

BeginMissionSequence

Toggle anEphmerisFile Off
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
Toggle anEphmerisFile On
Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

Behavior of Code 500 Ephemeris File During Discontinuous & Iterative Processes

Code 500 ephemeris file follows the ephemeris format and definitions that have been defined in *Flight Dynamics Division (FDD) Generic Data Product Formats Interface Control Document.*

Unlike CCSDS ephemeris file, code 500 ephemeris does not support separate chunks in the data blocks whenever discontinuous or discrete mission events such as impulsive/finite maneuvers, change in dynamics or assignment command takes place. Rather, code 500 ephemeris is generated all in one continuous data block regardless of any number of mission events that may occur between initial and final epochs of ephemeris file. Furthermore, when a mission sequence employs iterative processes such as differential correction or optimization, GMAT will only write the ephemeris for the final solution from the iterative processes. Code 500 ephemeris does not allow non-monotonic ephemeris generation and an exception will be thrown if propagation direction changes. Furthermore, any discontinuities created by assignments may result in invalid code 500 files.

Code 500 Ephemeris Header Records

The standard format for Code 500 ephemeris files has a logical record length of 2800 bytes. Code 500 files have two header records, ephemeris header record 1 and ephemeris record 2, followed by as many ephemeris data records as required for the file timespan. Many parameters in ephemeris file's header records are mandatory while some fields are optional. GMAT's Code 500 ephemeris header records only specifies fields that are mandatory and optional fields have not been included. Code 500's ephemeris header record 1 is mandatory while ephemeris record 2 is optional. Complete description of ephemeris format and list of mandatory and optional ephemeris header record parameters is defined in *Flight Dynamics Division (FDD) Generic Data Product Formats Interface Control Document*. In GMAT, only required fields have been written in header record 1 while header record 2 is left blank. Table below lists header record 1's required fields and any additional comments pertaining to that field.

Required Fields	Comments
productId	'EPHEM '
satId	123.000000
timeSystemIndicator	2.000000
StartDateOfEphem_YYYMMDD	value depends on run time
startDayCountOfYear	value depends on run time
startSecondsOfDay	value depends on run time
endDateOfEphem_YYYMMDD	value depends on run time
endDayCountOfYear	value depends on run time
endSecondsOfDay	value depends on run time
stepSize_SEC	value depends on run time
startYYYYMMDDHHMMSSsss.	value depends on run time
endYYYYMMDDHHMMSSsss.	value depends on run time
tapeId	'STANDARD'
sourceId	'GTDS '
headerTitle	'
centralBodyIndicator	value depends on run time
refTimeForDUT_YYMMDD	570918.000000
coordSystemIndicator1	'2000'
coordSystemIndicator2	4
orbitTheory	'COWELL '

Required Fields	Comments
timeIntervalBetweenPoints_DUT	value depends on run time
timeIntervalBetweenPoints_SEC	value depends on run time
outputIntervalIndicator	1
epochTimeOfElements_DUT	value depends on run time
epochTimeOfElements_DAY.	value depends on run time
epochA1Greg.	value depends on run time
epochUtcGreg.	value depends on run time
yearOfEpoch_YYY	value depends on run time
monthOfEpoch_MM	value depends on run time
dayOfEpoch_DD	value depends on run time
hourOfEpoch_HH	value depends on run time
minuteOfEpoch_MM	value depends on run time
secondsOfEpoch_MILSEC	value depends on run time
keplerianElementsAtEpoch_RAD[0]	value depends on run time
keplerianElementsAtEpoch_RAD[1]	value depends on run time
keplerianElementsAtEpoch_RAD[2]	value depends on run time
keplerianElementsAtEpoch_RAD[3]	value depends on run time
keplerianElementsAtEpoch_RAD[4]	value depends on run time
keplerianElementsAtEpoch_RAD[5]	value depends on run time
cartesianElementsAtEpoch_DULT[0]	value depends on run time
cartesianElementsAtEpoch_DULT[1]	value depends on run time
cartesianElementsAtEpoch_DULT[2]	value depends on run time
cartesianElementsAtEpoch_DULT[3]	value depends on run time
cartesianElementsAtEpoch_DULT[4]	value depends on run time
cartesianElementsAtEpoch_DULT[5]	value depends on run time
startTimeOfEphemeris_DUT	value depends on run time
endTimeOfEphemeris_DUT	value depends on run time
timeIntervalBetweenPoints_DUT	value depends on run time
dateOfInitiationOfEphemComp_YYYMMDD	value depends on run time
timeOfInitiationOfEphemComp_HHMMSS	value depends on run time
utcTimeAdjustment_SEC	0.000000
Pecession/Nutation indicator	1

For ephemeris header record 1, there are some required fields that have not been tabulated in GMAT's Code 500 ephemeris header record 1. These fields that have not been tabulated in header record 1 are listed in the table below. 0.0 indicates "used" and 1.0 means "not used".

Required Fields	Comments
Zonal and tesseral harmonics indicator	1.0
Lunar gravitation perturbation indicator	1.0
Solar radiation perturbation indicator	1.0
Solar gravitation perturbation indicator	1.0
Atmospheric drag perturbation indicator	1.0
Greenwich hour angle at epoch	1.0

Examples

This example shows how to generate a simple ephemeris file. Ephemeris file is generated for two days of propagation. At default settings, ephemeris file is generated at each integrator step and in CCSDS file format. Ephemeris data is sent to text file called '`EphemerisFile2.eph`':

```
Create Spacecraft aSat
Create Propagator aProp

Create EphemerisFile anEphmerisFile

anEphmerisFile.Spacecraft = aSat
anEphmerisFile.Filename = 'EphemerisFile2.eph'

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 2}
```

This example shows how an ephemeris file is generated during an iterative process like differential correction that includes a discontinuous event like an impulsive burn. Ephemeris data is sent to text file called '`EphemerisFile3.eph`':

```
Create Spacecraft aSat
Create Propagator aProp

Create ImpulsiveBurn TOI
Create DifferentialCorrector aDC

Create EphemerisFile anEphmerisFile

anEphmerisFile.Spacecraft = aSat
anEphmerisFile.Filename = 'EphemerisFile3.eph'

BeginMissionSequence

Propagate aProp(aSat) {aSat.Earth.Periapsis}

Target aDC
 Vary aDC(TOI.Element1 = 0.24, {Perturbation = 0.001, Lower = 0.0, ...
 Upper = 3.14159, MaxStep = 0.5})
 Maneuver TOI(aSat)
 Propagate aProp(aSat) {aSat.Earth.Apoapsis}
```

```
 Achieve aDC(aSat.Earth.RMAG = 42165)
EndTarget

Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

FileInterface

An interface to a data file

Description

The **FileInterface** resource is an interface to a data file that can be used to load mission data, like **Spacecraft** state information and physical properties. Once an interface is established to a file, the **Set** command can be used to load the data and apply it to a destination.

The following file formats are currently supported:

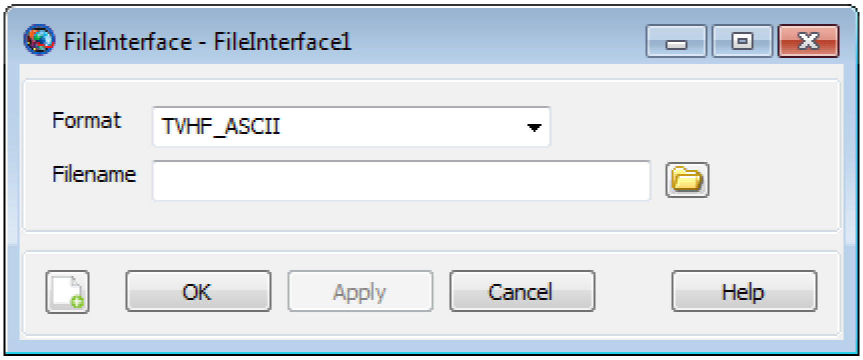
- `TVHF_ASCII`: ASCII format of the TCOPS Vector Hold File (TVHF), defined by the NASA Goddard Space Flight Center Flight Dynamics Facility. This file contains spacecraft state and physical information that can be transferred to a **Spacecraft** resource.

See Also: Set

Fields

Field	Description
Filename	Full path of the file to read. Relative paths are interpreted as relative to the directory containing the GMAT executable. If the path is omitted, it is assumed to be "`./`". **Data Type**: String **Allowed Values**: Valid file path **Access**: set **Default Value**: (None) **Units**: N/A **Interfaces**: GUI, script
Format	Format of the file to read. Currently, the only allowed format is "`TVHF_ASCII`". **Data Type**: Enumerated value **Allowed Values**: **TVHF_ASCII** **Access**: set **Default Value**: **TVHF_ASCII** **Units**: N/A **Interfaces**: GUI, script

GUI



The **FileInterface** GUI has two fields: a list of accepted options for **Format** (currently only **TVHF_ASCII**), and an input box for **Filename**. Click **Browse** to the right of the **Filename** box to interactively select a file.

Remarks

Each file format supported by the **FileInterface** resource exposes a set of keywords that can be used to extract certain data elements. These keywords can be used in the **Data** option of the **Set** command, as follows:

```
Set destination source (Data = {keyword[, keyword]})
```

If the `'All'` keyword is used, those fields with a checkmark in the "All" column are selected.

`TVHF_ASCII`

Keyword	Source field	Description	`'All'`
`CartesianState`	`"CARTESIAN COORDINATES"`	Cartesian state elements (**X**, **Y**, **Z**, **VX**, **VY**, **VZ**)	✓
`Cr`	`"CSUBR"`	Coefficient of reflectivity	✓
`Epoch`	`"EPOCH TIME FOR ELEMEN-TS"`	Epoch of state vector	✓

Limitations

The following limitations apply to the `TVHF_ASCII` format:

- Only the J2000 coordinate system is supported.
- Only the first record in a multiple-record file is loaded.

Examples

Read a TVHF file and use it to configure a spacecraft.

```
Create Spacecraft aSat
```

```
Create FileInterface tvhf
tvhf.Filename = 'statevec.txt'
tvhf.Format = 'TVHF_ASCII'

BeginMissionSequence

Set aSat tvhf
```

FiniteBurn

A finite burn

Description

The **FiniteBurn** resource is used when continuous propulsion is desired. Impulsive burns happen instantaneously through the use of the **Maneuver** command, while finite burns occur continuously starting at the **BeginFiniteBurn** command and lasting until the **EndFiniteBurn** command is reached in the mission sequence. In order to apply a non-zero **Finite Burn**, there must be a **Propagate** command between the **BeginFiniteBurn** and **EndFiniteBurn** commands.

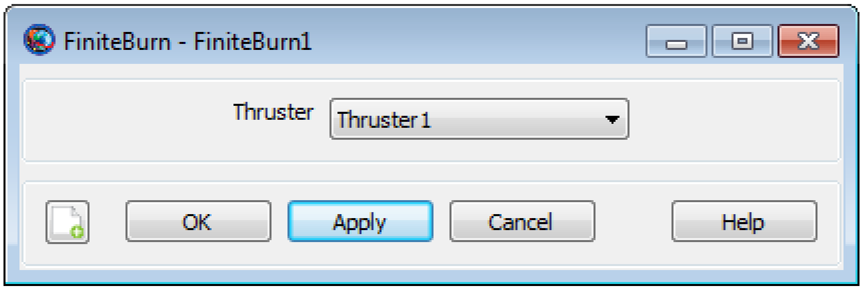
See Also: FuelTank, Thruster, Spacecraft, BeginFiniteBurn, EndFiniteBurn

Fields

Field	Description
Thruster	The **Thruster** field allows the selection of which **Thruster**, from a list of previously created thrusters, to use when applying a finite burn. Currently, using the GUI, you can only select one **Thruster** to attach to a **FiniteBurn** resource. Using the scripting interface, you may attach multiple thrusters to a **FiniteBurn** resource. Using the scripting interface, you may attach multiple thrusters to a **FiniteBurn** resource. In a script command, an empty list, e.g., `FiniteBurn1.Thruster={}`, is allowed but is of limited utility since the GUI will automatically associate a **Thruster**, if one has been created, with the **FiniteBurn**. This field cannot be modified in the Mission Sequence. **Data Type** Reference Array **Allowed Values** Any **Thruster** created by user **Access** set **Default Value** No Default **Units** N/A **Interfaces** GUI, script, or only one
VectorFormat	Deprecated. Allows you to define the format of the finite burn thrust direction. This field has no affect. The finite burn thrust direction, as specified in the **Thruster** resource, is always given in `Cartesian` format. **Data Type** Enumeration **Allowed Values** `Cartesian`, `Spherical` **Access** set **Default Value** `Cartesian` **Units** N/A **Interfaces** script

GUI

The **FiniteBurn** dialog box allows you to specify which thruster to use for the finite burn. The layout of the **FiniteBurn** dialog box is shown below.



Remarks

Configuring a FiniteBurn

To perform a finite burn, the **FiniteBurn** resource itself and a number of related resources and commands must be properly configured. You must associate a specific **Thruster** hardware resource with a created **FiniteBurn**. You must associate a specific **FuelTank** hardware resource with the chosen **Thruster**. Finally, you must attach both the chosen **Thruster** and **FuelTank** to the desired **Spacecraft**. See the example below for additional details.

FiniteBurn Using Multiple Thrusters

Using the GUI, a **FiniteBurn** resource must be associated with exactly one **Thruster**. Future GMAT GUI versions will allow multiple thrusters to be attached to a single **FiniteBurn** resource.

Using the scripting interface, one can assign multiple thrusters to a single **FiniteBurn** resource.

Interactions

Field	Description
Spacecraft resource	Must be created in order to apply any burn.
Thruster resource	As discussed in the **Remarks**, every **FiniteBurn** resource must be associated with at least one **Thruster**. Any **Thruster** created in the resource tree can be incorporated into a **FiniteBurn.**
FuelTank resource	To perform a finite burn, a **FuelTank** must be attached to the **Spacecraft**. (A **FuelTank** is needed to provide pressure and temperature data used when modeling the thrust and specific impulse. A **FuelTank** is also needed if you want to model mass depletion.)
BeginFiniteBurn and EndFiniteBurn command	After a **FiniteBurn** is created, to apply it in the mission sequence, a **BeginFiniteBurn** and **EndFiniteBurn** command must be appended to the mission tree.
Propagate command	In order to apply a non-zero finite burn, there must be a **Propagate** command between the **BeginFiniteBurn** and **EndFiniteBurn** commands.

Examples

Create a default **Spacecraft** and **FuelTank** Resource; Create a default **Thruster** that allows for fuel depletion from the default **FuelTank**; Attach **FuelTank** and **Thruster** to the **Spacecraft**; Create default **ForceModel** and **Propagator**; Create a **Finite Burn** that uses the default thruster and apply a 30 minute finite burn to the spacecraft.

```
% Create a default Spacecraft and FuelTank Resource
Create Spacecraft DefaultSC
Create FuelTank FuelTank1

% Create a default Thruster.  Allow for fuel depletion from
% the default FuelTank.
Create Thruster Thruster1
Thruster1.DecrementMass = true
Thruster1.Tank = {FuelTank1}

%  Attach FuelTank and Thruster to the spacecraft
DefaultSC.Thrusters = {Thruster1}
DefaultSC.Tanks = {FuelTank1}

%  Create default ForceModel and Propagator
Create ForceModel DefaultProp_ForceModel
Create Propagator DefaultProp
DefaultProp.FM = DefaultProp_ForceModel

%  Create a Finite Burn that uses the default thruster
Create FiniteBurn FiniteBurn1
FiniteBurn1.Thrusters = {Thruster1}

BeginMissionSequence

%  Implement 30 minute finite burn
BeginFiniteBurn FiniteBurn1(DefaultSC)
Propagate DefaultProp(DefaultSC) {DefaultSC.ElapsedSecs = 1800}
EndFiniteBurn FiniteBurn1(DefaultSC)
```

FminconOptimizer

The Sequential Quadratic Processor (SQP) optimizer, fmincon

Description

fmincon is a Nonlinear Programming solver provided in MATLAB's Optimization Toolbox. **fmincon** performs nonlinear constrained optimization and supports linear and nonlinear constraints. To use this solver, you must configure the solver options including convergence criteria, maximum iterations, and how the gradients will be calculated. In the mission sequence, you implement an optimizer such as fmincon by using an **Optimize/EndOptimize** sequence. Within this sequence, you define optimization variables by using the **Vary** command, and define cost and constraints by using the **Minimize** and **NonlinearConstraint** commands respectively.

This resource cannot be modified in the Mission Sequence.

See Also: VF13ad,Optimize,Vary, NonlinearConstraint, Minimize

Fields

Field	Description
DiffMaxChange	Upper limit on the perturbation used in MATLAB's finite differencing algorithm. For fmincon, you don't specify a single perturbation value, but rather give MATLAB a range, and it uses an adaptive algorithm that attempts to find the optimal perturbation. **Data Type** String **Allowed Values** Real Number > 0 **Access** Set **Default Value** 0.1 **Units** None **Interfaces** GUI, script
DiffMinChange	Lower limit on the perturbation used in MATLAB's finite differencing algorithm. For fmincon, you don't specify a single perturbation value, but rather give MATLAB a range, and it uses an adaptive algorithm that attempts to find the optimal perturbation. **Data Type** String **Allowed Values** Real Number > 0 **Access** Set **Default Value** 1e-8 **Units** None **Interfaces** GUI, script

Field	Description
MaxFunEvals	Specifies the maximum number of cost function evaluations used in an attempt to find an optimal solution. This is equivalent to setting the maximum number of passes through an optimization loop in a GMAT script. If a solution is not found before the maximum function evaluations, fmincon outputs an ExitFlag of zero, and GMAT continues. **Data Type** String **Allowed Values** Integer > 0 **Access** Set **Default Value** 1000 **Units** None **Interfaces** GUI, script
MaximumIterations	Specifies the maximum allowable number of nominal passes through the optimizer. Note that this is not the same as the number of optimizer iterations that is shown for the **VF13ad** optimzer. **Data Type** String **Allowed Values** Integer > 0 **Access** Set **Default Value** 25 **Units** None **Interfaces** GUI, script
ReportFile	Contains the path and file name of the report file. **Data Type** String **Allowed Values** Any user-defined file name **Access** Set **Default Value** `FminconOptimizerSQP1.data` **Units** None **Interfaces** GUI, script
ReportStyle	Determines the amount and type of data written to the message window and to the report specified by field **ReportFile** for each iteration of the solver (when **ShowProgress** is true). Currently, the **Normal**, **Debug**, and **Concise** options contain the same information: the values for the control variables, the constraints, and the objective function. In addition to this information, the **Verbose** option also contains values of the optimizer-scaled control variables. **Data Type** String **Allowed Values** **Normal**, **Concise**, **Verbose**, **Debug** **Access** Set **Default Value** **Normal** **Units** None **Interfaces** GUI, script

<table>
<tr><th>Field</th><th>Description</th></tr>
<tr><td>ShowProgress</td><td>Determines whether data pertaining to iterations of the solver is both displayed in the message window and written to the report specified by the ReportFile field. When ShowProgress is true, the amount of information contained in the message window and written in the report is controlled by the ReportStyle field.

Data Type Boolean
Allowed Values <code>true</code>, <code>false</code>
Access Set
Default Value <code>true</code>
Units None
Interfaces GUI, script</td></tr>
<tr><td>TolCon</td><td>Specifies the convergence tolerance on the constraint functions.

Data Type String
Allowed Values Real Number > 0
Access Set
Default Value 1e-4
Units None
Interfaces GUI, script</td></tr>
<tr><td>TolFun</td><td>Specifies the convergence tolerance on the cost function value.

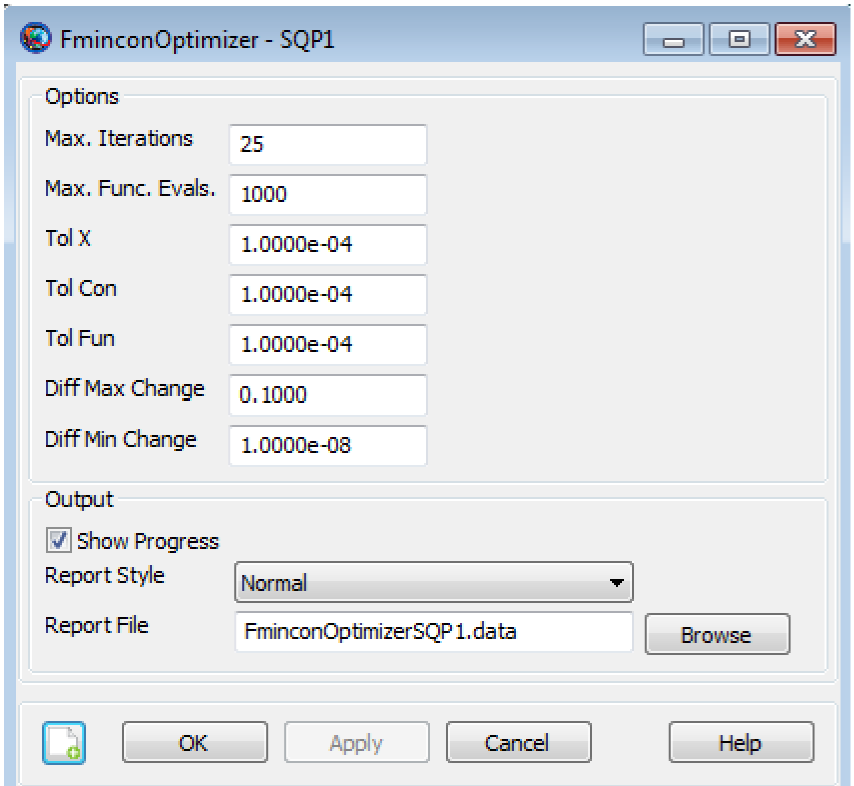
Data Type String
Allowed Values Real Number > 0
Access Set
Default Value 1e-4
Units None
Interfaces GUI, script</td></tr>
<tr><td>TolX</td><td>Specifies the termination tolerance on the vector of independent variables, and is used only if the user sets a value for this field.

Data Type String
Allowed Values Real Number > 0
Access Set
Default Value 1e-4
Units None
Interfaces GUI, script</td></tr>
</table>

GUI

The **FminconOptimizer** dialog box allows you to specify properties of a **FminconOptimizer** resource such as maximum iterations, maximum function evaluations, control variable termination tolerance, constraint tolerance, cost function tolerance, finite difference algorithm parameters, and choice of reporting options.

To create a **FminconOptimizer** resource, navigate to the **Resources** tree, expand the **Solvers** folder, highlight and then right-click on the **Optimizers** sub-folder, point to **Add** and then select **SQP** (**fmincon**). This will create a new **FminconOptimizer** resource, **SQP1**. Double-click on **SQP1** to bring up the **FminconOptimizer** dialog box shown below.



Remarks

fmincon Optimizer Availability

This optimizer is only available if you have access to both MATLAB and MATLAB's Optimization toolbox. GMAT contains an interface to the fmincon optimizer and it will appear to you that fmincon is a built in optimizer in GMAT. Field names for this resource have been copied from those used in MATLAB'S optimset function for consistency with MATLAB in contrast with other solvers in GMAT.

GMAT Stop Button Does Not work, in Some Situations, When Using Fmincon

Sometimes, when developing GMAT scripts, you may inadvertently create a situation where GMAT goes into an inifinite propagation loop. The usual remedy for this situation is to apply the GMAT **Stop** button. Currently, however, if the infinite loop occurs within an **Optimize** sequence using fmincon, there is no way to stop GMAT and you have to shut GMAT down. Fortunately, there are some procedures you can employ to avoid this situation. You should use multiple stopping conditions so that a long propagation cannot occur. For example, if fmincon controls variable, **myVar**, and we know **myVar** should never be more than 2, then do this.

```
Propagate myProp(mySat){mySat.ElapsedDays = myVar, mySat.ElapsedDays = 2}
```

Resource and Command Interactions

The **FminconOptimizer** resource can only be used in the context of optimization-type commands. Please see the documentation for **Optimize**, **Vary**, **NonlinearConstraint**, and **Minimize** for more information and worked examples.

Examples

Create a **FminconOptimizer** resource named SQP1.

```
Create FminconOptimizer SQP1
SQP1.ShowProgress = true
SQP1.ReportStyle = Normal
SQP1.ReportFile = 'FminconOptimizerSQP1.data'
SQP1.MaximumIterations = 25
SQP1.DiffMaxChange = '0.1000'
SQP1.DiffMinChange = '1.0000e-08'
SQP1.MaxFunEvals = '1000'
SQP1.TolX = '1.0000e-04'
SQP1.TolFun = '1.0000e-04'
SQP1.TolCon = '1.0000e-04'
```

For an example of how a **FminconOptimizer** resource can be used within an optimize sequence, see the **Optimize** command examples.

Formation

A collection of spacecraft.

Description

A **Formation** resource allows you to combine spacecraft in a “container” object and then GMAT’s propagation subsystem will model the collection of spacecraft as a coupled dynamic system. You can only propagate **Formation** resources using numerical-integrator type propagators. This resource cannot be modified in the Mission Sequence.

See Also: Propagate, Color

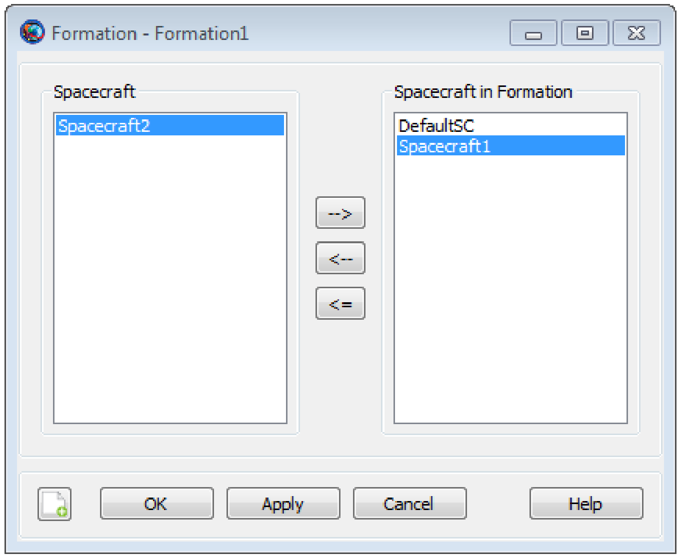
Fields

Field	Description
Add	Adds a list of **Spacecraft** to the **Formation**. The list cannot be empty. **Data Type** Resource array **Allowed Values** array of spacecraft **Access** set **Default Value** empty list **Units** N/A **Interfaces** GUI, script

GUI

To create a simple **Formation** and configure its **Spacecraft**, in the **Resource Tree**:

1. Right-click the **Spacecraft** folder and select **Add Spacecraft**.
2. Right click the **Formations** folder and select **Add Formation**.
3. Double-click **Formation1** to open its dialog box.
4. Click the right-arrow button twice to add **DefaultSC** and **Spacecraft1** to **Formation1**.
5. Click **Ok**.



> **Note**
>
> A **Spacecraft** can only be added to one Formation.

Remarks

A **Formation** is a container object that allows you to model a group of **Spacecraft** as a coupled system. You can add **Spacecraft** to a **Formation** using the **Add** field as shown in the script examples below or in the GUI example above. The primary reasons to use a **Formation Resource** are (1) to simplify the propagation of multiple spacecraft and (2) for performance reasons. You can only add a spacecraft to a one formation, and you cannot add a formation to a formation. GMAT's propagation subsystem models **Formations** as a coupled dynamic system. Once spacecraft have been added to a **Formation**, you can easily propagate all of the spacecraft by simply including the formation in the **Propagate** command statement like this:

```
Propagate aPropagator(aFormation) {aSat1.ElapsedSecs = 12000.0}
```

You can only propagate **Formation** resources using numerical-integrator type propagators. GMAT does not support propagation of the orbit state transition matrix when propagating formations.

When propagating a **Formation**, all spacecraft in the **Formation** must have equivalent epochs. GMAT will allow you to separately propagate a **Spacecraft** that has been added to a **Formation**, like this:

```
aFormation.Add = {aSat1, aSat2}
Propagate aPropagator(aSat1) {aSat1.ElapsedSecs = 12000.0}
```

However, when a **Formation** is propagated, if the epochs of all **Spacecraft** in the **Formation** are not equivalent to a tolerance of a few microseconds, **GMAT** will throw an error and execution will stop.

Setting Colors On Spacecrafts In Formation Resource

If you want to set unique colors on spacecraft trajectories that are nested in the **Formation** resource, then change colors through either the **Spacecraft** resource or the **Propagate** command. See the

Color documentation for discussion and examples on how to set unique colors on **Spacecraft** resource and **Propagate** command.

Examples

Create two **Spacecraft**, add them to a **Formation**, and propagate the **Formation**.

```
Create Spacecraft aSat1 aSat2

Create Formation aFormation
aFormation.Add = {aSat1, aSat2}

Create Propagator aPropagator

BeginMissionSequence

Propagate aPropagator(aFormation) {aSat1.ElapsedSecs = 12000.0}
```

FuelTank

Model of a chemical fuel tank

Description

A **FuelTank** is a thermodynamic model of a tank and is required for finite burn modeling or for impulsive burns that use mass depletion. The thermodynamic properties of the tank are modeled using Boyle's law and assume that there is no temperature change in the tank as fuel is depleted. To use a **FuelTank**, you must first create the tank, and then attach it to the desired **Spacecraft** and associate it with a **Thruster** as shown in the example below.

See Also ImpulsiveBurn,Thruster

Fields

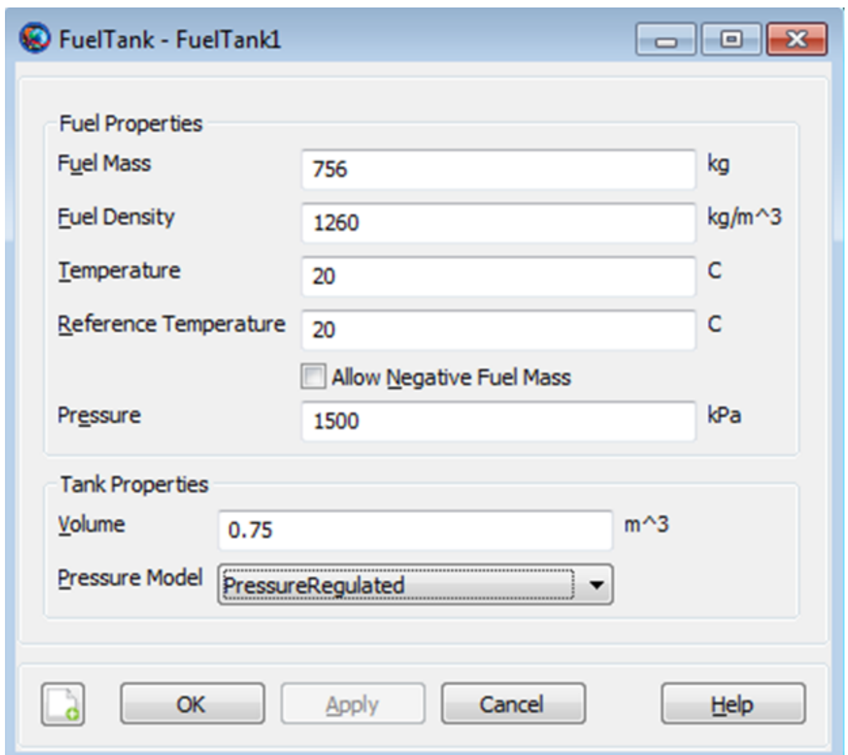
Field	Description
AllowNegativeFuelMass	This field allows the **FuelTank** to have negative fuel mass which can be useful in optimization and targeting sequences before convergence has occurred. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** `true`, `false` **Access** set **Default Value** `false` **Units** N/A **Interfaces** GUI, script
FuelDensity	The density of the fuel. **Data Type** Real **Allowed Values** Real > 0 **Access** set, get **Default Value** 1260 **Units** kg/m^3 **Interfaces** GUI, script
FuelMass	The mass of fuel in the tank. **Data Type** Real **Allowed Values** Real > 0 **Access** set, get **Default Value** 756 **Units** kg **Interfaces** GUI, script

Field	Description
Pressure	The pressure in the tank. **Data Type** Real **Allowed Values** Real > 0 **Access** set, get **Default Value** 1500 **Units** kPa **Interfaces** GUI, script
PressureModel	The pressure model describes how pressure in the **FuelTank** changes as fuel is depleted. This field cannot be modified in the Mission Sequence. **Data Type** Enumeration **Allowed Values** **PressureRegulated**, **BlowDown** **Access** set **Default Value** **PressureRegulated** **Units** N/A **Interfaces** GUI, script
RefTemperature	The temperature of the tank when fuel was loaded. **Data Type** Real **Allowed Values** Real > -273.15 and |Real| > 0.01 **Access** set, get **Default Value** 20 **Units** C **Interfaces** GUI, script
Temperature	The temperature of the fuel and ullage in the tank. GMAT currently assumes ullage and fuel are always at the same temperature. **Data Type** Real **Allowed Values** Real > -273.15 **Access** set, get **Default Value** `20` **Units** C **Interfaces** GUI, script

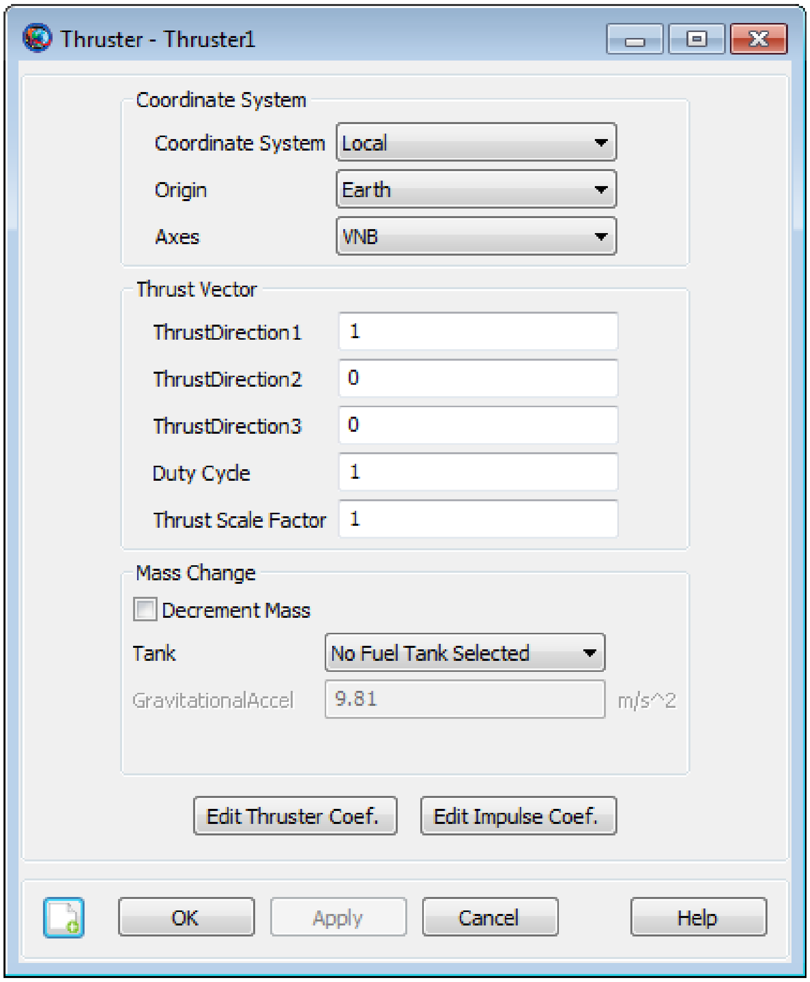
Field	Description	
Volume	The volume of the tank. GMAT checks to ensure that the input volume of the tank is larger than the calculated volume of fuel loaded in the tank and throws an exception in the case that the calculated fuel volume is larger than the input tank volume.	
	Data Type	Real
	Allowed Values	Real > 0 such that calculated fuel volume is < input tank Volume.
	Access	set, get
	Default Value	0.75
	Units	m^3
	Interfaces	GUI, script

GUI

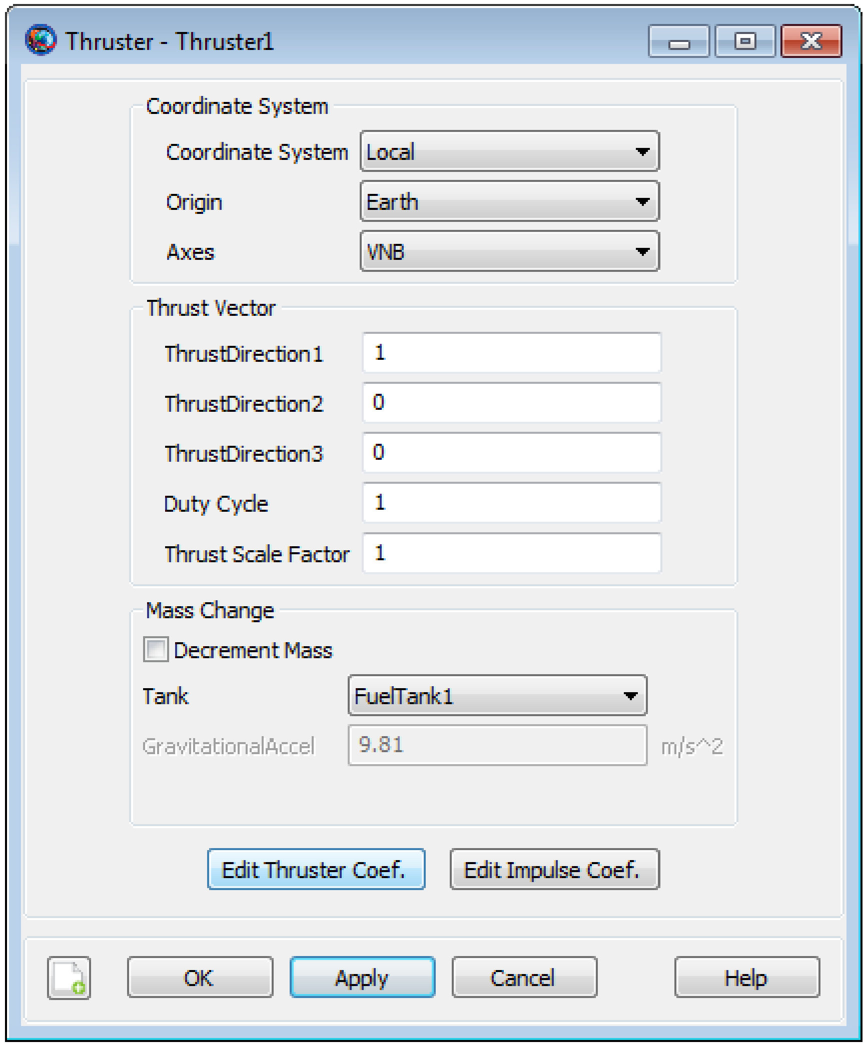
The **FuelTank** dialog box allows you to specify properties of a fuel tank including fuel mass, density, and temperature as well as tank pressure and volume. The layout of the **FuelTank** dialog box is shown below.



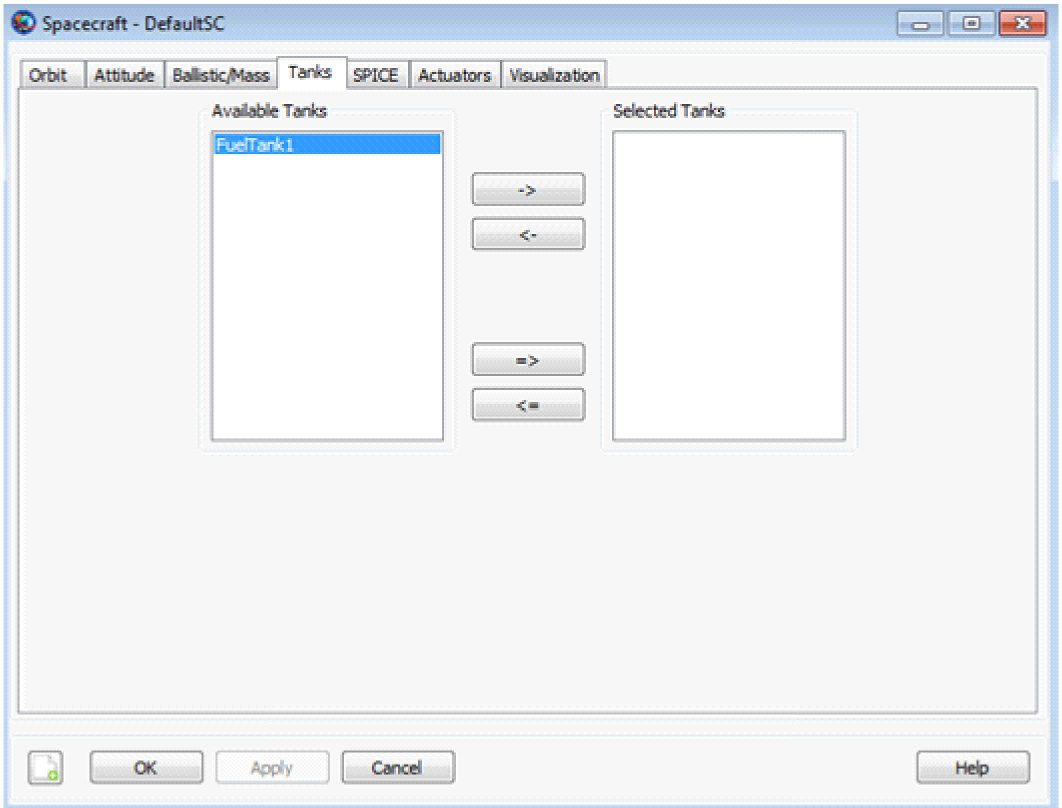
The **Thruster** resource is closely related to the **FuelTank** resource and thus, we also discuss it here. The **Thruster** dialog box allows you to specify properties of a thruster including the coordinate system of the Thrust acceleration direction vector, the thrust magnitude and Isp. The layout of the **Thruster** dialog box is shown below.



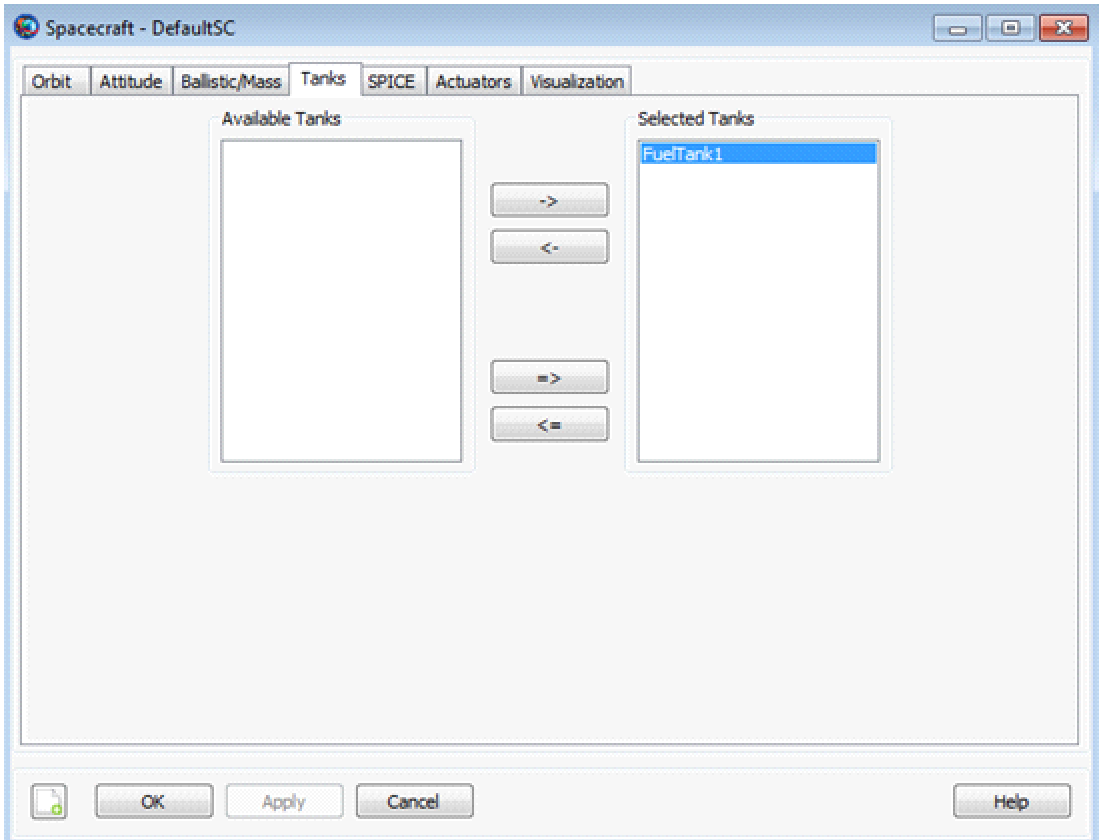
When performing a finite burn, you will typically want to model fuel depletion. To do this, select the **Decrement Mass** button and then select the previously created **FuelTank** as shown below.



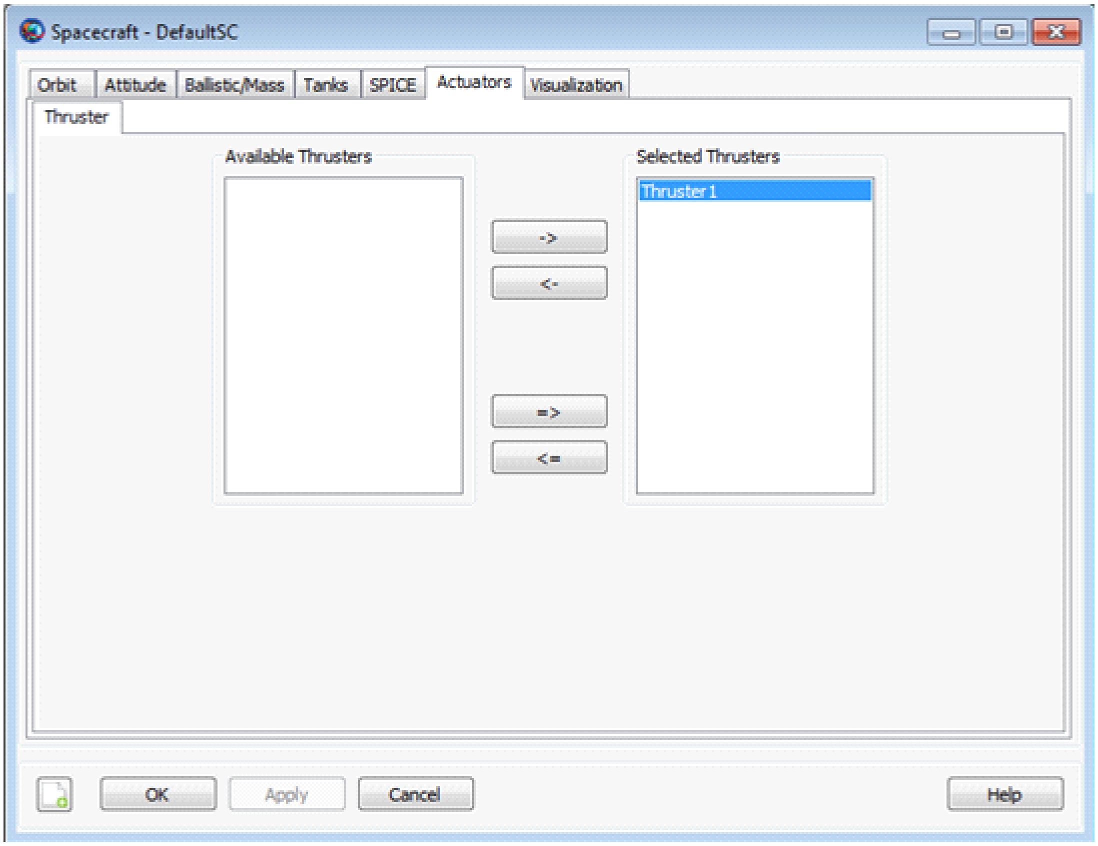
Thus far, we have created both a **FuelTank** and a **Thruster**, and we have associated a **FuelTank** with our **Thruster**. We are not done yet. We must tell GMAT that we want to attach both the **FuelTank** and the **Thruster** to a particular spacecraft. To do this, double click on the desired spacecraft under the **Spacecraft** resource to bring up the associated GUI panel. Then click on the **Tanks** tab to bring up the following GUI display.



Next, select the desired **FuelTank** and use the right arrow button to attach the **FuelTank** to the spacecraft. Then, click the **Apply** button as shown below.



Similarly, to attach a **Thruster** to a spacecraft, double click on the desired spacecraft under the **Spacecraft** resource and then select the **Actuators** tab. Then select the desired thruster and use the right arrow to attach the thruster to the spacecraft. Finally, click the **Apply** button as shown below.



Remarks

Use of FuelTank Resource in Conjunction with Maneuvers

A **FuelTank** is used in conjunction with both impulsive and finite maneuvers. To implement an impulsive maneuver, one must first create an **ImpulsiveBurn** resource and (optionally) associate a **FuelTank** with it. The actual impulsive maneuver is implemented using the **Maneuver** command. See the **Maneuver** command documentation for worked examples on how the **FuelTank** resource is used in conjunction with impulsive maneuvers.

To implement a finite maneuver, you must first create both a **Thruster** and a **FiniteBurn** resource. You must also associate a **FuelTank** with the **Thruster** resource and you must associate a **Thruster** with the **FiniteBurn** resource. The actual finite maneuver is implemented using the **BeginFiniteBurn/EndFiniteBurn** commands. See the **BeginFiniteBurn/EndFiniteBurn** command documentation for worked examples on how the **FuelTank** resource is used in conjunction with finite maneuvers.

Behavior When Configuring Tank and Attached Tank Properties

Create a default **FuelTank** and attach it to a **Spacecraft** and **Thruster**.

```
%  Create the FuelTank Resource
Create FuelTank aTank
aTank.AllowNegativeFuelMass = false
aTank.FuelMass = 756
```

```
aTank.Pressure = 1500
aTank.Temperature = 20
aTank.RefTemperature = 20
aTank.Volume = 0.75
aTank.FuelDensity = 1260
aTank.PressureModel = PressureRegulated
%  Create a Thruster and assign it a FuelTank
Create Thruster aThruster
aThruster.Tank = {aTank}

%  Add the FuelTank and Thruster to a Spacecraft
Create Spacecraft aSpacecraft
aSpacecraft.Tanks = {aTank}
aSpacecraft.Thrusters = {aThruster}
```

As exhibited below, there are some subtleties associated with setting and getting parent vs. cloned resources. In the example above, `aTank` is the parent **FuelTank** resource and the field `aSpacecraft.Tanks` is populated with a cloned copy of `aTank`.

Create a second spacecraft and attach a fuel tank using the same procedure used in the previous example. Set the **FuelMass** in the parent resource, `aTank`, to 900 kg.

```
%  Add the FuelTank and Thruster to a second Spacecraft
Create Spacecraft bSpacecraft
bSpacecraft.Tanks = {aTank}
bSpacecraft.Thrusters = {aThruster}
aTank.FuelMass = 900    %Can be performed in both resource and
                        %command modes
```

Note that, in the example above, setting the value of the parent resource, `aTank`, changes the fuel mass value in both cloned fuel tank resources. More specifically, the value of both `aSpacecraft.aTank.FuelMass` and `bSpacecraft.aTank.FuelMass` are both now equal to the new value of 900 kg. We note that the assignment command for the parent resource, `aTank.FuelMass`, can be performed in both resource and command modes.

To change the value of the fuel mass in only the first created spacecraft, **aSpacecraft**, we do the following.

```
%  Create the Fuel Tank Resource
aTank.FuelMass = 756   %Fuel tank mass in both s/c set back to default
aSpacecraft.aTank.FuelMass = 1000 %Can only be performed in command mode.
```

As a result of the commands in the previous example, the value of `aSpacecraft.aTank.FuelMass` is `1000` kg and the value of `bSpacecraft.aTank.FuelMass` is 756 kg. We note that the assignment command for the cloned resource, `aSpacecraft.aTank.FuelMass`, can only be performed in command mode.

Caution: Value of AllowNegativeFuelMass Flag Can Affect Iterative Processes

By default, GMAT will not allow the fuel mass to be negative. However, occasionally in iterative processes such as targeting, a solver will try values of a maneuver parameter that result in total fuel depletion. Using the default tank settings, this will throw an exception stopping the run unless you set the AllowNegativeFuelMass flag to true. GMAT will not allow the the total spacecraft mass to be negative. If DryMass + FuelMass is negative GMAT will throw an exception and stop.

Examples

Create a default **FuelTank** and attach it to a **Spacecraft** and **Thruster**.

```
%  Create the Fuel Tank Resource
Create FuelTank aTank
aTank.AllowNegativeFuelMass = false
aTank.FuelMass = 756
aTank.Pressure = 1500
aTank.Temperature = 20
aTank.RefTemperature = 20
aTank.Volume = 0.75
aTank.FuelDensity = 1260
aTank.PressureModel = PressureRegulated

%  Create a Thruster and assign it a FuelTank
Create Thruster aThruster
aThruster.Tank = {aTank}

%  Add the FuelTank and Thruster to a Spacecraft
Create Spacecraft aSpacecraft
aSpacecraft.Tanks = {aTank}
aSpacecraft.Thrusters = {aThruster}

BeginMissionSequence
```

GroundStation

A ground station model.

Description

A **GroundStation** models a facility fixed to the surface of a **CelestialBody**. There are several state representations available for defining the location of a ground station including Cartesian and spherical. This resource cannot be modified in the Mission Sequence.

See Also: CoordinateSystem, Color

Fields

Field	Description
Altitude	The altitude of the station with respect to the **HorizonReference**. **Data Type** Real **Allowed Values** $-\infty <$ Real $< \infty$ **Access** set **Default Value** 0 **Units** km **Interfaces** GUI, script
CentralBody	The central body of the **GroundStation**. **Data Type** String **Allowed Values** **Earth**. (Ground stations are currenly only supported with respect to Earth) **Access** set **Default Value** **Earth** **Units** N/A **Interfaces** GUI, script
HorizonReference	The system used for the horizon. **Sphere** is equivalent to Geocentric, **Ellipsoid** is equivalent to Geodetic. **Data Type** String **Allowed Values** **Sphere, Ellipsoid** **Access** set **Default Value** **Sphere** **Units** N/A **Interfaces** GUI, script

Field	Description	
Id	The Id of the **GroundStation** used in estimation and measurement modelling..	
	Data Type	String
	Allowed Values	Must begin with a letter; may contain letters, integers, dashes, underscores
	Access	set,
	Default Value	StationId
	Units	N/A
	Interfaces	GUI, script
Latitude	The latitude of the station with respect to **HorizonReference**.	
	Data Type	Real
	Allowed Values	-90 < Real < 90
	Access	set
	Default Value	0
	Units	deg.
	Interfaces	GUI, script
Location1	The first component of the **GroundStation** location. When **StateType** is **Cartesian**, **Location1** is the x-component of station location in the body-fixed system. When **StateType** is **Spherical** or **Elliposoid**, **Location1** is the **Longitude** (deg.) of the **GroundStation**.	
	Data Type	Real
	Allowed Values	-∞ < Real < ∞ for **Cartesian**, See **Longitude**, **Latitude**, **Altitude** for others.
	Access	set
	Default Value	6378.1363
	Units	see description
	Interfaces	GUI, script
Location2	The second component of the **GroundStation** location. When **StateType** is **Cartesian**, **Location2** is the y-component of station location in the body-fixed system. When **StateType** is **Spherical** or **Ellipsoid**, **Location2** is the **Latitude** (deg.) of the **GroundStation**.	
	Data Type	Real
	Allowed Values	-∞ < Real < ∞ for **Cartesian**, See **Longitude**, **Latitude**, **Altitude** for others.
	Access	set
	Default Value	0
	Units	see description
	Interfaces	GUI, script

<table>
<tr><th>Field</th><th>Description</th></tr>
<tr><td>Location3</td><td>The third component of the GroundStation location. When StateType is Cartesian, Location3 is the z-component of station location in the body-fixed system. When StateType is Spherical or Elliposoid, Location3 is the height (km) of the GroundStation above the reference shape.

Data Type Reals
Allowed Values -∞ < Real < ∞ for Cartesian, See Longitude, Latitude, Altitude for others.
Access set,
Default Value 0
Units see description
Interfaces GUI, script</td></tr>
<tr><td>Longitude</td><td>The longitude of the station.

Data Type Real
Allowed Values value >=0
Access set
Default Value 0
Units deg.
Interfaces GUI, script</td></tr>
<tr><td>OrbitColor</td><td>Allows you to select available colors for a user-defined GroundStation. The GroundStation object is drawn on a spacecraft's ground track plot created by GroundTrackPlot 2D graphics display resource. The colors can be identified through a string or an integer array. For example: Setting groundstation's color to red can be done in following two ways: <code>GroundStation.OrbitColor = Red</code> or <code>GroundStation.OrbitColor = [255 0 0]</code>. This field can be modified in the Mission Sequence as well.

Data Type Integer Array or String
Allowed Values Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255.
Access set
Default Value Thistle
Units N/A
Interfaces GUI, script</td></tr>
<tr><td>StateType</td><td>The type of state used to define the location of the ground station. For example, Cartesian or Ellipsoid.

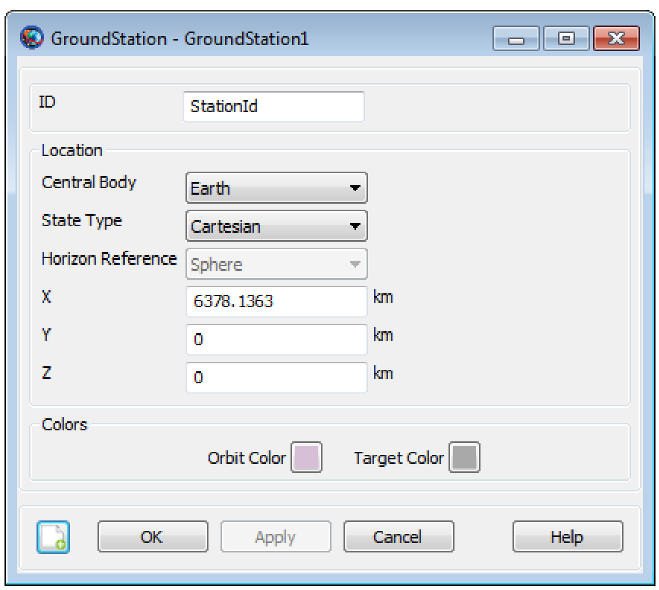
Data Type String
Allowed Values Cartesian, Spherical, Ellipsoid
Access set
Default Value Cartesian
Units N/A
Interfaces GUI, script</td></tr>
</table>

Field	Description
TargetColor	Allows you to select available colors for a user-defined **GroundStation** object during iterative processes such as Differential Correction or Optimization. The target color can be identified through a string or an integer array. For example: Setting groundstation's target color to yellow color can be done in following two ways: `GroundStation.TargetColor = Yellow` or `GroundStation.TargetColor = [255 255 0]`. This field can be modified in the Mission Sequence as well. **Data Type** Integer Array or String **Allowed Values** Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255. **Access** set **Default Value** DarkGray **Units** N/A **Interfaces** GUI, script

GUI

To create a **GroundSation**, starting from the **Resource Tree**:

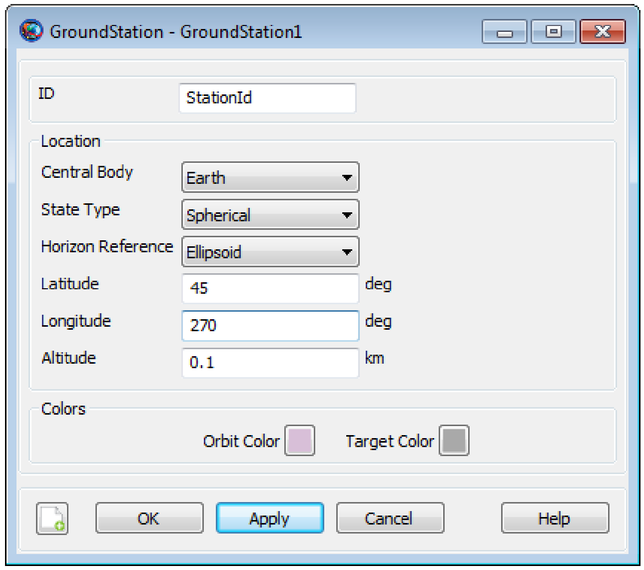
1. Right-click the **GroundStation** folder and select **Add Ground Station**.
2. Double-click **GroundStation1**.



You can set the ground station location in several state representations. The **Cartesian** representation is illustrated above. To set the **Longitude**, **Latitude**, and **Altitude** to 45 deg., 270 deg., and 0.1 km respectively, with respect to the reference ellipsoid:

1. In the **StateType** menu, select **Spherical**.
2. In the **HorizonReference** menu, select **Ellipsoid.**

3. In the **Latitude** text box, type **`45`**.
4. In the **Longitude** text box, type **`270`**.
5. In the **Altitude** text box, type **`0.1`**.



Remarks

The **GroundStation** model allows you to configure a facility by defining the location in body-fixed coordinates using one of several state representations. GMAT supports **Cartesian**, **Sphere**, and **Ellipsoid** representations and examples below show how to configure a **GroundStation** in each representation. When using the **Ellipsoid** model or **Sphere** representations, GMAT uses the physical properties - flattening and radius for example - defined on the **CelestialBody** resource.

Setting Colors On a Ground Station Facility

GMAT allows you to set colors on a ground station facility that you create. The **GroundStations** are drawn on the **GroundTrackPlot** 2D graphics display. The **GroundStation** object's **OrbitColor** and **TargetColor** fields are used to set colors on a ground station facility. See the Fields section to read more about these two fields. Also See Color documentation for discussion and examples on how to set colors on a ground station facility.

Examples

Configure a **GroundStation** in Geodetic coordinates.

```
Create GroundStation aGroundStation
aGroundStation.CentralBody       = Earth
aGroundStation.StateType         = Spherical
aGroundStation.HorizonReference = Ellipsoid
aGroundStation.Location1         = 60
aGroundStation.Location2         = 45
aGroundStation.Location3         = 0.01
```

```
% or alternatively

aGroundStation.Latitude  = 60
aGroundStation.Longitude = 45
aGroundStation.Altitude  = 0.01
```

Configure a **GroundStation** in Geocentric coordinates.

```
Create GroundStation aGroundStation
aGroundStation.CentralBody      = Earth
aGroundStation.StateType        = Spherical
aGroundStation.HorizonReference = Sphere
aGroundStation.Location1        = 59.83308194090783
aGroundStation.Location2        = 45
aGroundStation.Location3        = -15.99424674414058

% or alternatively

aGroundStation.Latitude        = 59.83308194090783
aGroundStation.Longitude       = 45
aGroundStation.Altitude        = -15.99424674414058
```

Configure a **GroundStation** in Geocentric coordinates.

```
Create GroundStation aGroundStation
aGroundStation.CentralBody = Earth
aGroundStation.StateType   = Cartesian
aGroundStation.Location1   = 2260.697433050543
aGroundStation.Location2   = 2260.697433050542
aGroundStation.Location3   = 5500.485954732006
```

GroundTrackPlot

A user-defined resource that draws longitude and latitude time-history of a spacecraft

Description

The **GroundTrackPlot** resource allows you to draw spacecraft's longitude and latitude time-history onto the texture map of a user-selected central body. GMAT allows you to draw ground track plots of any number of spacecrafts onto a single texture map. You can also create multiple **GroundTrackPlot** resources by using either the GUI or script interface of GMAT. GMAT also provides the option of when to plot and stop plotting ground track of a spacecraft to a **GroundTrackPlot** through the **Toggle On/Off** command. See the Remarks section below for detailed discussion of the interaction between **GroundTrackPlot** resource and the **Toggle** command. **GroundTrackPlot** resource also allows you to display any number of user-defined ground stations onto the texture map of the central body.

See Also: Toggle, GroundStation, Color

Fields

Field	Description
Add	Allows the user to pick selected resources such as **Spacecrafts** or **GroundStations**. The **GroundTrackPlot** object is used to draw spacecraft's longtitude and latitude time-history on a two-dimensional texture map of a central body that you select. After creating **GroundStation** object, you can also add ground stations onto the the texture map of the central body. To select multiple **Spacecrafts** or **GroundStations**, seperate the list by comma and enclose the list in curly brackets. For Example: `DefaultGroundTrackPlot.Add = {aSat, bSat, aGroundStaton, bGroundStation}.` This field cannot be modified in the Mission Sequence. **Data Type**: Reference Array **Allowed Values**: **Spacecraft**, **GroundStation** **Access**: Set **Default Value**: **DefaultSC** **Units**: N/A **Interfaces**: GUI, script
CentralBody	The central body of the Ground track plot. This field cannot be modified in the Mission Sequence. **Data Type**: Resource reference **Allowed Values**: **CelestialBody** **Access**: set **Default Value**: **Earth** **Units**: N/A **Interfaces**: GUI, script

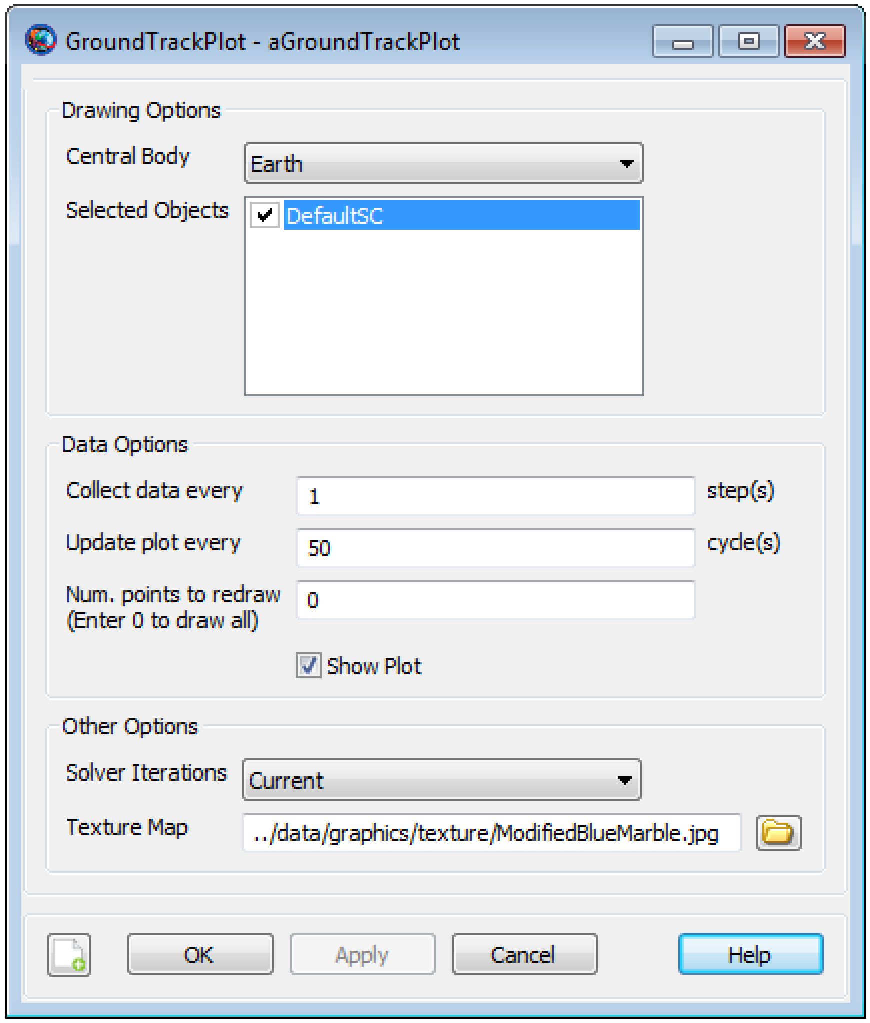
Field	Description
DataCollectFrequency	The number of integration steps to skip between plot points. This field cannot be modified in the Mission Sequence. **Data Type** Integer **Allowed Values** integer >= 1 **Access** set **Default Value** 1 **Units** N/A **Interfaces** GUI, script
Maximized	Allows the user to maximize the **GroundTrackPlot** window. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** true,false **Access** set **Default Value** false **Units** N/A **Interfaces** script
NumPointsToRedraw	The number of plot points to retain and redraw during propagation and animation. 0 indicates to redraw all. This field cannot be modified in the Mission Sequence. **Data Type** Integer **Allowed Values** integer >= 0 **Access** set **Default Value** 0 **Units** N/A **Interfaces** GUI, script
RelativeZOrder	Allows the user to select which **GroundTrackPlot** window to display first on the screen. The **GroundTrackPlot** with lowest **RelativeZOrder** value will be displayed last while **GroundTrackPlot** with highest **RelativeZOrder** value will be displayed first. This field cannot be modified in the Mission Sequence. **Data Type** Integer **Allowed Values** Integer ≥ 0 **Access** set **Default Value** 0 **Units** N/A **Interfaces** script

Field	Description
ShowPlot	This field specifies whether to show ground track plot during a mission run. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** True, False **Access** set **Default Value** True **Units** N/A **Interfaces** GUI, script
Size	Allows the user to control the display size of **GroundTrackPlot** window. First value in [0 0] matrix controls horizonal size and second value controls vertical size of **GroundTrackPlot** display window. This field cannot be modified in the Mission Sequence. **Data Type** Real array **Allowed Values** Any Real number **Access** set **Default Value** [0 0] **Units** N/A **Interfaces** script
SolverIterations	This field determines whether or not ground track data associated with perturbed trajectories during a solver (**Targeter**, **Optimize**) sequence is displayed in the **GroundTrackPlot**. When **SolverIterations** is set to **All**, all perturbations/iterations are plotted in the **GroundTrackPlot**. When **SolverIterations** is set to **Current**, only the current solution or perturbation is plotted in **GroundTrackPlot**. When **SolverIterations** is set to **None**, only the final nominal run is plotted on the **GroundTrackPlot**. **Data Type** Enumeration **Allowed Values** **All**, **Current**, **None** **Access** set **Default Value** **Current** **Units** N/A **Interfaces, Interfaces** GUI, script

Field	Description
TextureMap	Allows you to enter or select any user-defined texture map image for the central body. This field cannot be modified in the Mission Sequence. **Data Type** String **Allowed Values** Valid File Path and Name **Access** set **Default Value** `../data/graphics/texture/ModifiedBlueMarble.jpg` **Units** N/A **Interfaces** GUI, script
UpdatePlotFrequency	The number of plot points to collect before updating a ground track plot. This field cannot be modified in the Mission Sequence. **Data Type** Integer **Allowed Values** integer > 1 **Access** set **Default Value** 50 **Units** N/A **Interfaces** GUI, script
Upperleft	Allows the user to pan the **GroundTrackPlot** display window in any direction. First value in [0 0] matrix helps to pan the **GroundTrackPlot** window horizontally and second value helps to pan the window vertically. This field cannot be modified in the Mission Sequence. **Data Type** Real array **Allowed Values** Any Real number **Access** set **Default Value** [0 0] **Units** None **Interfaces** script

GUI

Default Name and Settings for the **GroundTrackPlot** Resource:



Remarks

Behavior when using GroundTrackPlot Resource & Toggle Command

The **GroundTrackPlot** resource draws the longitude and latitude time-history of a spacecraft at each propagation step of the entire mission duration. If you want to report data to a **GroundTrackPlot** at specific points in your mission, then a **Toggle On**/**Off** command can be inserted into the mission sequence to control when the **GroundTrackPlot** is to draw data. When **Toggle Off** command is issued for a **GroundTrackPlot**, no ground track data is drawn until a **Toggle On** command is issued. Similarly when a **Toggle On** command is used, ground track data is drawn at each integration step until a **Toggle Off** command is used.

Below is an example script snippet that shows how to use **Toggle Off** and **Toggle On** command while using the **GroundTrackPlot** resource. **GroundTrackPlot** is turned off for the first 2 days of the propagation:

```
Create Spacecraft aSat
Create Propagator aProp
```

```
Create GroundTrackPlot aGroundTrackPlot
aGroundTrackPlot.Add = {aSat}

BeginMissionSequence

Toggle aGroundTrackPlot Off
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
Toggle aGroundTrackPlot On
Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

Behavior when Plotting Data in Iterative Processes

GMAT allows you to specify how data is plotted onto a plot during iterative processes such as differential correction or optimization. The **SolverIterations** field of **GroundTrackPlot** resource supports 3 options which are described in the table below:

SolverIterations options	Description
Current	Shows only current iteration/perturbation in an iterative process and draws current iteration to a plot
All	Shows all iterations/perturbations in an iterative process and draws all iterations/perturbations to a plot
None	Shows only the final solution after the end of an iterative process and draws only final solution to a plot

Behavior when Plotting Longitude and Latitude time-history of a Spacecraft

GMAT's **GroundTrackPlot** resource allows you to draw longitude and latitude time-history of a spacecraft. You can choose to draw ground track plot of multiple spacecrafts onto a single texture map of a central body.

> **Warning**
>
> The longitude and latitude of a spacecraft is drawn as an approximation that includes straight line segments and longitude/latitude data does not takes into account central body shape or its oblateness.

Behavior When Specifying Empty Brackets in GroundTrackPlot's Add Field

When using **GroundTrackPlot.Add** field, if brackets are not populated with user-defined spacecrafts, then GMAT turns off **GroundTrackPlot** resource and no plot is generated. If you run the script with **Add** field having empty brackets, then GMAT throws in a warning message in the Message Window indicating that **GroundTrackPlot** resource will be turned off since no SpacePoints were added to the plot. Below is a sample script snippet that generates such a warning message:

```
Create Spacecraft aSat aSat2
Create Propagator aProp
```

```
Create GroundTrackPlot aGroundTrackPlot

aGroundTrackPlot.Add = {}

BeginMissionSequence;
Propagate aProp(aSat, aSat2) {aSat.ElapsedDays = 1}
```

Examples

This example shows how to use **GroundTrackPlot** resource. A single spacecraft and a ground station is added to the **GroundTrackPlot**. Spacecraft's ground track is plotted for one day of propagation:

```
Create Spacecraft aSat
Create Propagator aProp

Create GroundStation aGroundStation

Create GroundTrackPlot aGroundTrackPlot
aGroundTrackPlot.Add = {aSat, aGroundStation}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

Propagate a spacecraft for two days around a non-default central body. Spacecraft's ground track is plotted on planet Mars:

```
Create Spacecraft aSat
aSat.CoordinateSystem = MarsJ2000Eq
aSat.SMA = 8000
aSat.ECC = 0.0003

Create ForceModel aFM
aFM.CentralBody = Mars
aFM.PointMasses = {Mars}

Create Propagator aProp
aProp.FM = aFM

Create CoordinateSystem MarsJ2000Eq
MarsJ2000Eq.Origin = Mars
MarsJ2000Eq.Axes = MJ2000Eq

Create GroundTrackPlot aGroundTrackPlot
aGroundTrackPlot.Add = {aSat}
aGroundTrackPlot.CentralBody = Mars

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 2}
```

ImpulsiveBurn

An impulsive maneuver

Description

The **ImpulsiveBurn** resource allows the spacecraft to undergo an instantaneous Delta-V (ΔV), as opposed to a finite burn which is not instantaneous, by specifying the three vector components of the Delta-V. You can configure the burn by defining its coordinate system and vector component values. For **Local** coordinate systems, the user can choose the **Origin** and type of **Axes**. Depending on the mission, it may be simpler to use one coordinate system over another.

See Also Maneuver,FuelTank,BeginFiniteBurn

Fields

Field	Description
Axes	Allows you to define a spacecraft centered set of axes for the impulsive burn. This field cannot be modified in the Mission Sequence. **Data Type** String **Allowed Values** **VNB**, **LVLH**, **MJ2000Eq**, **SpacecraftBody** **Access** set **Default Value** **VNB** **Units** N/A **Interfaces** GUI, script
B	Deprecated. Z-component of the applied impulsive burn (Delta-V) **Data Type** Real **Allowed Values** Real **Access** set, get **Default Value** 0 **Units** km/s **Interfaces** GUI, script
CoordinateSystem	Determines what coordinate system the orientation parameters, **Element1**, **Element2**, and **Element3** refer to. This field cannot be modified in the Mission Sequence. **Data Type** Reference Array **Allowed Values** **Local**, **EarthMJ2000Eq**, **EarthMJ2000Ec**, **EarthFixed**, or any user defined system **Access** set **Default Value** **Local** **Units** N/A **Interfaces** GUI, script

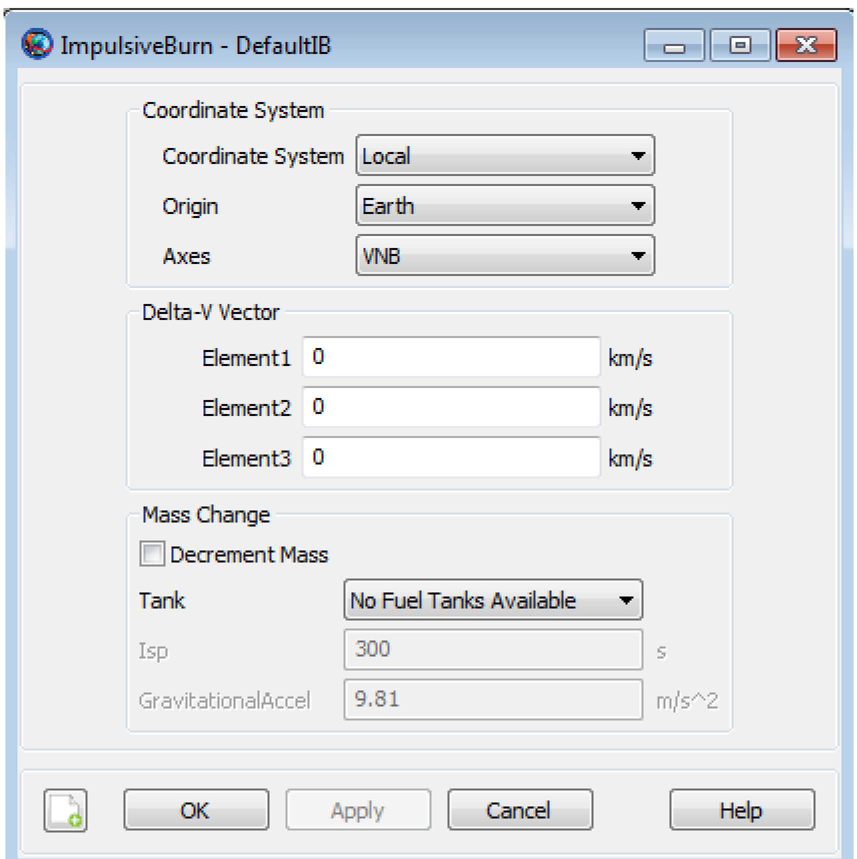
Field	Description	
DecrementMass	Flag which determines if the **FuelMass** is to be decremented as it used. This field cannot be modified in the Mission Sequence.	
	Data Type	String
	Allowed Values	true, false
	Access	set
	Default Value	`false`
	Units	N/A
	Interfaces	GUI, script
Element1	X-component of the applied impulsive burn (Delta-V)	
	Data Type	Real
	Allowed Values	Real
	Access	set, get
	Default Value	0
	Units	km/s
	Interfaces	GUI, script
Element2	Y-component of the applied impulsive burn (Delta-V)	
	Data Type	Real
	Allowed Values	Real
	Access	set, get
	Default Value	0
	Units	km/s
	Interfaces	GUI, script
Element3	Z-component of the applied impulsive burn (Delta-V)	
	Data Type	Real
	Allowed Values	Real
	Access	set, get
	Default Value	0
	Units	km/s
	Interfaces	GUI, script
GravitationalAccel	Value of the gravitational acceleration used to calculate fuel depletion.	
	Data Type	Real
	Allowed Values	Real > `0`
	Access	set, get
	Default Value	9.81
	Units	m/s^2
	Interfaces	GUI, script

Field	Description
Isp	Value of the specific impulse of the fuel **Data Type** Real **Allowed Values** Real **Access** set, get **Default Value** 300 **Units** s **Interfaces** GUI, script
N	Deprecated. Y-component of the applied impulsive burn (Delta-V) **Data Type** Real **Allowed Values** Real **Access** set, get **Default Value** 0 **Units** km/s **Interfaces** GUI, script
Origin	The **Origin** field, used in conjunction with the **Axes** field, allows the user to define a spacecraft centered set of axes for the impulsive burn. This field cannot be modified in the Mission Sequence. **Data Type** Reference Array **Allowed Values** **Sun**, **Mercury**, **Venus**, **Earth**, **Luna**, **Mars**,**Jupiter**, **Saturn**, **Uranus**, **Neptune**, **Pluto** **Access** set **Default Value** **Earth** **Units** N/A **Interfaces** GUI, script
Tank	**FuelTank** from which the **Thruster** draws propellant from. This field cannot be modified in the Mission Sequence. **Data Type** Reference Array **Allowed Values** User defined list of **FuelTanks** **Access** set **Default Value** N/A **Units** N/A **Interfaces** GUI, script
V	Deprecated. X-component of the applied impulsive burn (Delta-V) **Data Type** Real **Allowed Values** Real **Access** set, get **Default Value** 0 **Units** km/s **Interfaces** GUI, script

Field	Description
VectorFormat	Deprecated. Allows you to define the format of the **ImpulsiveBurn Delta-V Vector**. This field has no affect. The **ImpulsiveBurn Delta-V Vector** is always given in `Cartesian` format. **Data Type** Enumeration **Allowed Values** `Cartesian`, `Spherical` **Access** set **Default Value** `Cartesian` **Units** N/A **Interfaces** script

GUI

The **ImpulsiveBurn** dialog box allows you to specify properties of an **ImpulsiveBurn** including Delta-V component values and choice of **Coordinate System**. If you choose to model fuel loss associated with an impulsive burn, you must specify choice of fuel tank as well as ISP value and gravitational acceleration used to calculate fuel use. The layout of the **ImpulsiveBurn** dialog box is shown below.



The **Origin** and **Axes** fields are only relevant if **Coordinate System** is set to Local. See the Remarks for more detail on local coordinate systems.

If **Decrement Mass** is checked, then you can select the desired **FuelTank** used as the fuel supply for mass depletion.

Remarks

Local Coordinate Systems

Here, a Local **Coordinate System** is defined as one that we configure "locally" using the **ImpulsiveBurn** resource interface as opposed to defining a coordinate system using the **Coordinate Systems** folder in the **Resources** Tree.

To configure a Local **Coordinate System**, you must specify the coordinate system of the input Delta-V vector, **Element1-3**. If you choose a local **Coordinate System**, the four choices available, as given by the **Axes** sub-field, are **VNB**, **LVLH**, **MJ2000Eq**, and **SpacecraftBody**. **VNB** or Velocity-Normal-Binormal is a non-inertial coordinate system based upon the motion of the spacecraft with respect to the **Origin** sub-field. For example, if the **Origin** is chosen as Earth, then the X-axis of this coordinate system is the along the velocity of the spacecraft with respect to the Earth, the Y-axis is along the instantaneous orbit normal (with respect to the Earth) of the spacecraft, and the Z-axis points away from the Earth as much as possible while remaining orthogonal to the other two axes, completing the right-handed set.

Similarly, Local Vertical Local Horizontal or **LVLH** is a non-inertial coordinate system based upon the motion of the spacecraft with respect to the body specified in the Origin sub-field. If you choose Earth as the origin, then the X-axis of this coordinate system points from the center of the Earth to the spacecraft, the Z-axis is along the instantaneous orbit normal (with respect to the Earth) of the spacecraft, and the Y-axis completes the right-handed set. For typical bound orbits, the Y-axis is approximately aligned with the velocity vector. In the event of a perfectly circular orbit, the Y axis is exactly along the velocity vector.

MJ2000Eq is the J2000-based Earth-centered Earth mean equator inertial **Coordinate System**. Note that the **Origin** sub-field is not needed to define this coordinate system.

SpacecraftBody is the coordinate system used by the spacecraft. Since the thrust is applied in this system, GMAT uses the attitude of the spacecraft, a spacecraft attribute, to determine the inertial thrust direction. Note that the **Origin** sub-field is not needed to define this coordinate system.

Deprecated Field Names for an ImpulsiveBurn

Note that the standard method, as shown below, for specifying the components of an ImpulsiveBurn is to use the **Element1**, **Element2**, and **Element3** field names.

```
Create ImpulsiveBurn DefaultIB
DefaultIB.Element1 = -3
DefaultIB.Element2 = 7
DefaultIB.Element3 = -2
```

For this current version of GMAT, you may also use the field names **V**, **N**, and **B** in place of **Element1**, **Element2**, and **Element3**, respectively. The commands below are equivalent to the commands above.

```
Create ImpulsiveBurn DefaultIB
```

```
DefaultIB.V = -3
DefaultIB.N = 7
DefaultIB.B = -2
```

It is important to note that the **V**, **N**, **B** field names do not necessarily correspond to some Velocity, Normal, Binormal coordinate system. The coordinate system of any **ImpulsiveBurn** is always specified by the **CoordinateSystem**, **Origin**, and **Axes** fields. Because of the confusion that the **V**, **N**, **B** field names can cause, their use will not be allowed in future versions of GMAT. If you use the **V**, **N**, **B** field names in this version of GMAT, you will receive a warning to this affect.

Interactions

Resource	Description
Spacecraft resource	Must be created in order to apply any **ImpulsiveBurn**
FuelTank resource	If you want to model mass depletion for an **ImpulsiveBurn**, attach a **FuelTank** to the maneuvered **Spacecraft** as a source of fuel mass.
Maneuver command	Must use the **Maneuver** command to apply an **ImpulsiveBurn** to a **Spacecraft**.
Vary command	If you want to allow the **ImpulsiveBurn** components to vary in order to achieve some goal, then the **Vary** command, as part of a **Targe**t or **Optimize** command sequence, must be used.

Examples

Create a default **FuelTank** and an **ImpulsiveBurn** that allows for fuel depletion, assign the **ImpulsiveBurn** the default **FuelTank**, attach the **FuelTank** to a **Spacecraft**, and apply the **ImpulsiveBurn** to the **Spacecraft**.

```
%  Create the FuelTank Resource
Create FuelTank FuelTank1
FuelTank1.AllowNegativeFuelMass = false
FuelTank1.FuelMass = 756
FuelTank1.Pressure = 1500
FuelTank1.Temperature = 20
FuelTank1.RefTemperature = 20
FuelTank1.Volume = 0.75
FuelTank1.FuelDensity = 1260
FuelTank1.PressureModel = PressureRegulated

Create ImpulsiveBurn DefaultIB
DefaultIB.CoordinateSystem = Local
DefaultIB.Origin = Earth
DefaultIB.Axes = VNB
DefaultIB.Element1 = 0.001
DefaultIB.Element2 = 0
DefaultIB.Element3 = 0
DefaultIB.DecrementMass = true
DefaultIB.Tank = {FuelTank1}
DefaultIB.Isp = 300
```

```
DefaultIB.GravitationalAccel = 9.810000000000001

%  Add the the FuelTank to a Spacecraft
Create Spacecraft DefaultSC
DefaultSC.Tanks = {FuelTank1}

BeginMissionSequence
Maneuver DefaultIB(DefaultSC)
```

LibrationPoint

An equilibrium point in the circular, restricted 3-body problem

Description

A **LibrationPoint**, also called a Lagrange point, is an equilibrium point in the circular restricted three-body problem (CRTBP). There are five libration points, three of which are unstable in the CRTBP sense, and two that are stable. See the discussion below for a detailed explanation of the different libration points and for examples configuring GMAT for common libration point regimes. This resource cannot be modified in the Mission Sequence.

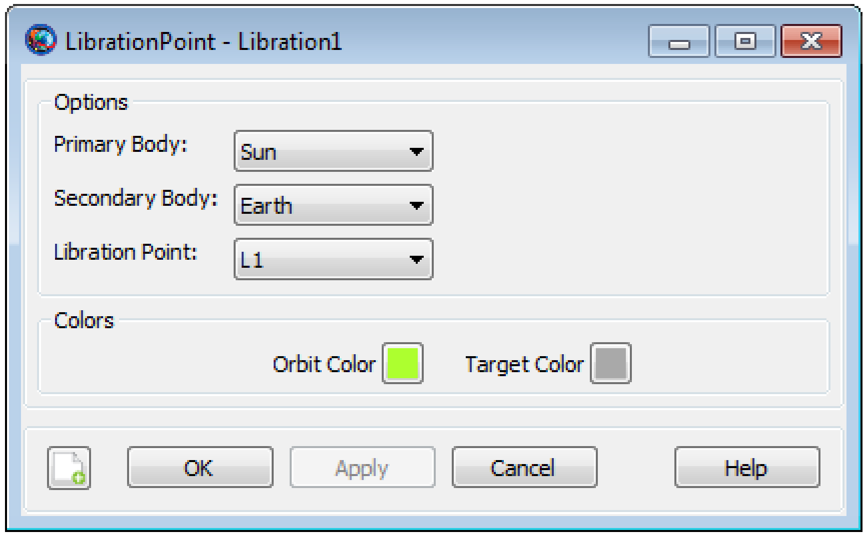
See Also: Barycenter, Color

Fields

Field	Description
OrbitColor	Allows you to set available colors on user-defined **LibrationPoint** orbits. The libration point orbits are drawn using the 3D **OrbitView** graphics displays. Colors on a **LibrationPoint** object can be set through a string or an integer array. For example: Setting a libration point's orbit color to red can be done in the following two ways: `LibrationPoint.OrbitColor = Red` or `LibrationPoint.OrbitColor = [255 0 0]`. This field can be modified in the Mission Sequence as well.. **Data Type**: Integer Array or String **Allowed Values**: Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255. **Access**: set **Default Value**: GreenYellow **Units**: N/A **Interfaces**: GUI, script
Point	The libration point index. **Data Type**: String **Allowed Values**: **L1, L2, L3, L4**, or **L5** **Access**: set **Default Value**: **L1** **Units**: N/A **Interfaces**: GUI, script

Field	Description	
Primary	The primary body or barycenter.	
	Data Type	String
	Allowed Values	**CelestialBody** or **Barycenter**. **Primary** cannot be **SolarSystemBarycenter** and **Primary** cannot be the same as **Secondary**.
	Access	set
	Default Value	**Sun**
	Units	N/A
	Interfaces	GUI, script
Secondary	The secondary body or barycenter.	
	Secondary	String
	Allowed Values	**CelestialBody** or **Barycenter**. **Secondary** cannot be **SolarSystemBarycenter** and **Primary** cannot be the same as **Secondary**.
	Access	set
	Default Value	**Earth**
	Units	N/A
	Interfaces	GUI, script
TargetColor	Allows you to set available colors on **LibrationPoint** object's perturbing orbital trajectories that are drawn during iterative processes such as Differential Correction or Optimization. The target color can be identified through a string or an integer array. For example: Setting a libration point's perturbing trajectory color to yellow can be done in following two ways: `LibrationPoint.TargetColor = Yellow` or `LibrationPoint.TargetColor = [255 255 0]`. This field can be modified in the Mission Sequence as well.	
	Data Type	Integer Array or String
	Allowed Values	Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255.
	Access	set
	Default Value	DarkGray
	Units	N/A
	Interfaces	GUI, script

GUI

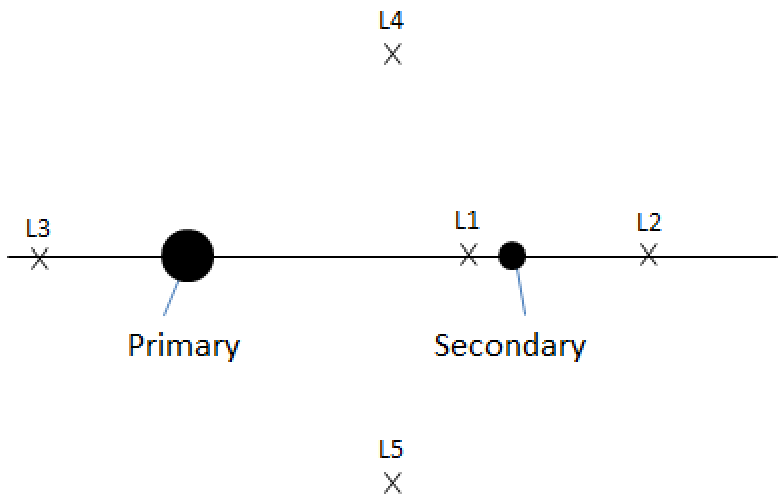


The **LibrationPoint** dialog box allows you to select the **Primary Body**, **Secondary Body**, and the libration point index. You can select from celestial bodies and barycenters. You cannot choose the **SolarSystemBarycenter** as either the **Primary** or **Secondary** and the **Primary** and **Secondary** cannot be the same object.

Remarks

Overview of Libration Point Geometry

A **LibrationPoint**, also called a Lagrange point, is an equilibrium point in the Circular Restricted Three Body Problem (CRTBP). The definitions for the libration points used in GMAT are illustrated in the figure below where the **Primary** and **Secondary** bodies are shown in a rotating frame defined with the x-axis pointing from the **Primary** to the **Secondary**. GMAT is configured for the full ephemeris problem and computes the location of the libration points by assuming that at a given instant in time, the CRTBP theory developed by Lagrange and Szebehely can be used to compute the location of the libration points using the locations of the primary and secondary from the JPL ephemerides. The three collinear points (L1, L2, and L3) are unstable (even in the CRTBP) and the triangular points (L4, and L5) are stable in CRTBP.



Configuring a Libration Point

GMAT allows you to define the **Primary** and/or **Secondary** as a **CelestialBody** or **Barycenter** (except **SolarSystemBarycenter**). This allows you to set the **Primary** as the Sun, and the **Secondary** as the Earth-Moon barycenter for modelling Sun-Earth-Moon libration points. See the examples below for details.

Setting Colors On Libration Point Orbits

GMAT allows you to assign colors to libration point orbits that are drawn using the **OrbitView** graphics display windows. GMAT also allows you to assign colors to perturbing libration point orbital trajectories which are drawn during iterative processes such as differential correction or optimization. The **LibrationPoint** object's **OrbitColor** and **TargetColor** fields are used to assign colors to both orbital and perturbing trajectories. See the Fields section to learn more about these two fields. Also see Color documentation for discussion and examples on how to set colors on a libration point orbit.

Examples

Create and use an Earth-Moon **LibrationPoint.**

```
%  Create the libration point and rotating libration point coordinate system
Create LibrationPoint EarthMoonL2
EarthMoonL2.Primary   = Earth
EarthMoonL2.Secondary = Luna
EarthMoonL2.Point     = L2

Create CoordinateSystem EarthMoonRotLibCoord
EarthMoonRotLibCoord.Origin    = EarthMoonL2
EarthMoonRotLibCoord.Axes      = ObjectReferenced
EarthMoonRotLibCoord.XAxis     = R
EarthMoonRotLibCoord.ZAxis     = N
EarthMoonRotLibCoord.Primary   = Earth
EarthMoonRotLibCoord.Secondary = Luna
```

```
%  Configure the spacecraft and propagator
Create Spacecraft aSat
aSat.DateFormat       = TAIModJulian
aSat.Epoch            = '25220.0006220895'
aSat.CoordinateSystem = EarthMoonRotLibCoord
aSat.DisplayStateType = Cartesian
aSat.X  = 9999.752137149568
aSat.Y  = 1.774296833900735e-007
aSat.Z  = 21000.02640446094
aSat.VX = -1.497748388797418e-005
aSat.VY = -0.2087816321971509
aSat.VZ = -5.424716732371777e-006

Create ForceModel EarthMoonL2Prop_ForceModel
EarthMoonL2Prop_ForceModel.PointMasses = {Earth, Luna, Sun}
Create Propagator EarthMoonL2Prop
EarthMoonL2Prop.FM = EarthMoonL2Prop_ForceModel

%  Create the orbit view
Create OrbitView ViewEarthMoonRot
ViewEarthMoonRot.Add                = {Earth, Luna, Sun,...
                                               aSat, EarthMoonL2}
ViewEarthMoonRot.CoordinateSystem   = EarthMoonRotLibCoord
ViewEarthMoonRot.ViewPointReference = EarthMoonL2
ViewEarthMoonRot.ViewDirection      = EarthMoonL2
ViewEarthMoonRot.ViewScaleFactor    = 5

Create Variable I

BeginMissionSequence

% Prop for 3 xz-plane crossings
For I = 1:3
  Propagate 'Prop to Y Crossing' EarthMoonL2Prop(aSat) ...
                      {aSat.EarthMoonRotLibCoord.Y = 0}
EndFor
```

Create and use a Sun, Earth-Moon **LibrationPoint**.

```
%  Create the Earth-Moon Barycenter and Libration Point
Create Barycenter EarthMoonBary
EarthMoonBary.BodyNames = {Earth,Luna}

Create LibrationPoint SunEarthMoonL1
SunEarthMoonL1.Primary   = Sun
SunEarthMoonL1.Secondary = EarthMoonBary
SunEarthMoonL1.Point     = L1

%  Create the coordinate system
Create CoordinateSystem RotatingSEML1Coord
RotatingSEML1Coord.Origin    = SunEarthMoonL1
RotatingSEML1Coord.Axes      = ObjectReferenced
RotatingSEML1Coord.XAxis     = R
RotatingSEML1Coord.ZAxis     = N
```

```
RotatingSEML1Coord.Primary   = Sun
RotatingSEML1Coord.Secondary = EarthMoonBary

%  Create the spacecraft and propagator
Create Spacecraft aSpacecraft
aSpacecraft.DateFormat       = UTCGregorian
aSpacecraft.Epoch            = '09 Dec 2005 13:00:00.000'
aSpacecraft.CoordinateSystem = RotatingSEML1Coord
aSpacecraft.X  = -32197.88223741966
aSpacecraft.Y  = 211529.1500044117
aSpacecraft.Z  = 44708.57017366499
aSpacecraft.VX = 0.03209516489451751
aSpacecraft.VY = 0.06100386504053736
aSpacecraft.VZ = 0.0550442738917212

Create Propagator aPropagator
aPropagator.FM           = aForceModel
aPropagator.MaxStep = 86400
Create ForceModel aForceModel
aForceModel.PointMasses = {Earth,Sun,Luna}

% Create a 3-D graphic
Create OrbitView anOrbitView
anOrbitView.Add                    = {aSpacecraft,  Earth, Sun, Luna}
anOrbitView.CoordinateSystem       = RotatingSEML1Coord
anOrbitView.ViewPointReference     = SunEarthMoonL1
anOrbitView.ViewPointVector        = [-1500000 0 0 ]
anOrbitView.ViewDirection          = SunEarthMoonL1
anOrbitView.ViewUpCoordinateSystem = RotatingSEML1Coord
anOrbitView.Axes                   = Off
anOrbitView.XYPlane                = Off

BeginMissionSequence

Propagate aPropagator(aSpacecraft, {aSpacecraft.ElapsedDays = 180})
```

MatlabFunction

Declaration of an external MATLAB function

Description

The **MatlabFunction** resource declares to GMAT that the name given refers to an existing external function in the MATLAB language. This function can be called in the Mission Sequence like a built-in function, with some limitations. See the **CallMatlabFunction** reference for details. Both user-created functions and built-in functions (like cos or path) are supported.

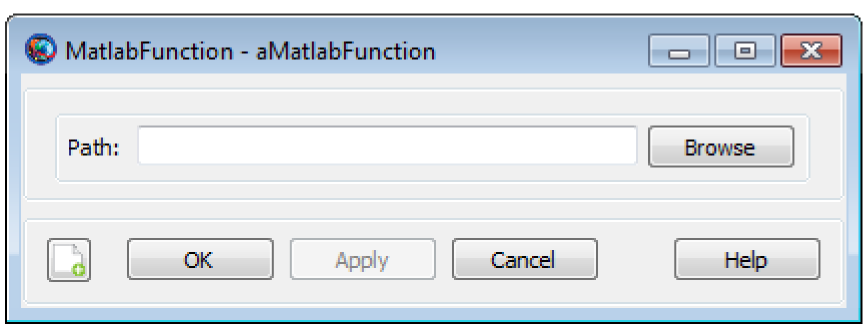
GMAT supports passing data to and from MATLAB through the function. It requires that a supported and properly configured version of MATLAB exist on the system. See the MATLAB Interface documentation for general details on the interface.

See Also: CallMatlabFunction, MATLAB Interface

Fields

Field	Description
FunctionPath	Paths to add to the MATLAB search path when the associated function is called. Separate multiple paths with semicolons (on Windows) or colons (on other platforms). **Data Type** String **Allowed Values** Valid file path(s) **Access** set, get **Default Value** `MATLAB_FUNCTION_PATH` properties in the startup file **Units** N/A **Interfaces** GUI, script

GUI



The **MatlabFunction** GUI window is very simple; it has a single file input box for the function path, and a Browse button that lets you graphically select the path.

Remarks

Search Path

When a function declared as a **MatlabFunction** is called, GMAT starts MATLAB in the background with a custom, configurable search path. MATLAB then searches for the named function in this search path. The search is case-sensitive, so the name of the function name and the **MatlabFunction** resource must be identical.

The search path consists of the following components, in order:

1. **FunctionPath** field of the associated **MatlabFunction** resource (default: empty)
2. `MATLAB_FUNCTION_PATH` entries in the GMAT startup file (default: `GMAT\userfunctions\matlab`)
3. MATLAB search path (returned by the MATLAB `path()` function)

If multiple MATLAB functions are called within a run, the **FunctionPath** fields for each are prepended to the search path at the time of the function call.

Multiple paths can be combined in the **FunctionPath** field by separating the paths with a semicolon (on Windows) or a colon (on Mac OS X and Linux).

Working Directory

When MATLAB starts in the background, its working directory is set to the GMAT `bin` directory.

Examples

Call a simple built-in MATLAB function:

```
Create MatlabFunction sinh
Create Variable x y

BeginMissionSequence

x = 1
[y] = sinh(x)
```

Call an external custom MATLAB function:

```
Create Spacecraft aSat
Create ImpulsiveBurn aBurn
Create Propagator aProp

Create MatlabFunction CalcHohmann
CalcHohmann.FunctionPath = 'C:\path\to\functions'

Create Variable a_target mu dv1 dv2
mu = 398600.4415

BeginMissionSequence
```

```
% calculate burns for circular Hohmann transfer (example)
[dv1, dv2] = CalcHohmann(aSat.SMA, a_target, mu)

% perform first maneuver
aBurn.Element1 = dv1
Maneuver aBurn(aSat)

% propagate to apoapsis
Propagate aProp(aSat) {aSat.Apoapsis}

% perform second burn
aBurn.Element1 = dv2
Maneuver aBurn(aSat)
```

Return the MATLAB search path and working directory:

```
Create MatlabFunction path pwd
Create String pathStr pwdStr
Create ReportFile aReport

BeginMissionSequence

[pathStr] = path
[pwdStr] = pwd

Report aReport pathStr
Report aReport pwdStr
```

OrbitView

A user-defined resource that plots 3-Dimensional trajectories

Description

The **OrbitView** resource allows you to plot trajectories of a spacecraft or a celestial body. GMAT also allows you to plot trajectories associated with multiple spacecrafts or celestial bodies. You can create multiple **OrbitView** resources by using either the GUI or script interface of GMAT. **OrbitView** plots also come with multiple options that allow you to customize the view of spacecraft's trajectories. See the Fields section below for detailed discussion on available plotting and drawing options.

GMAT also provides the option of when to start and stop plotting spacecraft's trajectories to an **OrbitView** resource through the **Toggle On/Off** command. See the Remarks section below for detailed discussion of the interaction between an **OrbitView** resource and the **Toggle** command. GMAT's **Spacecraft**, **SolarSystem** and **OrbitView** resources also interact with each other throughout the entire mission duration. Discussion of the interaction between these resources is also mentioned in the Remarks section.

See Also: Toggle, Spacecraft, SolarSystem, CoordinateSystem, Color

Fields

Field	Description
Add	This field allows you to add a **Spacecraft**, **Celestial body**, **Libration Point**, or **Barycenter** resource to a plot. When creating a plot, the **Earth** is added as a default body and may be removed at any time. You can add a **Spacecraft**, **Celestial body**, **Libration Point**, or **Barycenter** to a plot by using the name used to create the resource. The GUI's **Selected** field is the equivalent of the script's **Add** field. In the event of no **Add** command or no resources in the **Selected** field, GMAT should run without the **OrbitView** plot and a warning message will be displayed in the message window. The following warning message is sufficient: The OrbitView named "DefaultOrbitView" will be turned off. No SpacePoints were added to plot. This field cannot be modified in the Mission Sequence. **Data Type**: Reference Array **Allowed Values**: **Spacecraft**, **CelestialBody**, **LibrationPoint**, **Barycenter** **Access**: set **Default Value**: **DefaultSC**, **Earth** **Units**: N/A **Interfaces**: GUI, script

Field	Description
Axes	Allows you to draw the Cartesian axis system associated with the coordinate system selected under the **CoordinateSystem** field of an **OrbitView** plot. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** On, Off **Access** set **Default Value** On **Units** N/A **Interfaces** GUI, script
EclipticPlane	Allows you to draw a grid representing the **Ecliptic Plane** in an **OrbitView** plot. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** On, Off **Access** set **Default Value** Off **Units** N/A **Interfaces** GUI, script
CoordinateSystem	Allows you to select which **coordinate system** to use to draw the plot data. A **coordinate system** is defined as an **origin** and an **axis system**. The **CoordinateSystem** field allows you to determine the **origin** and **axis system** of an **OrbitView** plot. See the **CoordinateSystem** resource fields for information of defining different types of **coordinate systems**. This field cannot be modified in the Mission Sequence. **Data Type** String **Allowed Values** **CoordinateSystem** resource **Access** set **Default Value** **EarthMJ2000Eq** **Units** N/A **Interfaces** GUI, script

Field	Description
DataCollectFrequency	Allows you to define how data is collected for plotting. It is often inefficient to draw every ephemeris point associated with a trajectory. Often, drawing a smaller subset of the data still results in smooth trajectory plots, while executing more quickly. The **DataCollectFrequency** is an integer that represents how often to collect data and store for plotting. If **DataCollectFrequency** is set to 10, then data is collected every 10 integration steps. This field cannot be modified in the Mission Sequence. **Data Type** Integer **Allowed Values** Integer ≥ 1 **Access** set **Default Value** 1 **Units** N/A **Interfaces** GUI, script
DrawObject	The **DrawObject** field allows you the option of displaying **Spacecraft** or **Celestial** resources on the **OrbitView** plot. This field cannot be modified in the Mission Sequence. **Data Type** Boolean array **Allowed Values** true, false **Access** set **Default Value** [true true] **Units** N/A **Interfaces** GUI, script
EnableConstellations	Allows you the option of displaying star constellations on the **OrbitView** Plot. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** On, Off **Access** set **Default Value** On **Units** N/A **Interfaces** GUI, script
EnableStars	This field gives you the option of displaying stars on the **OrbitView** Plot. When the **EnableStars** field is turned off, then **EnableConstellations** field is automatically diabled. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** On, Off **Access** set **Default Value** On **Units** N/A **Interfaces** GUI, script

Field	Description
Grid	Allows you to draw a grid representing the longitude and latitude lines on the celestial bodies added to an **OrbitView** plot. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** On, Off **Access** set **Default Value** Off **Units** N/A **Interfaces** GUI, script
Maximized	Allows you to maximize the **OrbitView** plot window. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** True, False **Access** set **Default Value** false **Units** N/A **Interfaces** script
NumPointsToRedraw	When **NumPointsToRedraw** field is set to zero, all ephemeris points are drawn. When **NumPointsToRedraw** is set to a positive integer, say 10 for example, only the last 10 collected data points are drawn. See **DataCollectFrequency** for explanation of how data is collected for an **OrbitView** plot. This field cannot be modified in the Mission Sequence. **Data Type** Integer **Allowed Values** Integer ≥ 1 **Access** set **Default Value** 0 **Units** N/A **Interfaces** GUI, script
RelativeZOrder	Allows you to select which **OrbitView** window to display first on the screen. The **OrbitViewPlot** with lowest **RelativeZOrder** value will be displayed last while **OrbitViewPlot** with highest **RelativeZOrder** value will be displayed first. This field cannot be modified in the Mission Sequence. **Data Type** Integer **Allowed Values** Integer ≥ 0 **Access** set **Default Value** 0 **Units** N/A **Interfaces** script

Field	Description
ShowPlot	Allows you to turn off a plot for a particular run, without deleting the plot, or removing it from the script. If you select true, then the plot will be shown. If you select false, then the plot will not be shown. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** True, False **Access** set **Default Value** True **Units** N/A **Interfaces** GUI, script
ShowLabels	Allows you to turn on or off spacecraft and celestial body Object labels. If you select true, then spacecraft and celestial body object labels will show up in orbit view plot. If you select false, then spacecraft and celestial body labels will not be shown in the orbit plot. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** True, False **Access** set **Default Value** True **Units** N/A **Interfaces** GUI, script
Size	Allows you to control the display size of **OrbitViewPlot** window. First value in [0 0] matrix controls horizonal size and second value controls vertical size of **OrbitViewPlot** display window. This field cannot be modified in the Mission Sequence. **Data Type** Real array **Allowed Values** Any Real number **Access** set **Default Value** [0 0] **Units** N/A **Interfaces** script

Field	Description
SolverIterations	This field determines whether or not data associated with perturbed trajectories during a solver (**Targeter**, **Optimize**) sequence is plotted to **OrbitView**. When **SolverIterations** is set to **All**, all perturbations/iterations are plotted to an **OrbitView** plot. When **SolverIterations** is set to **Current**, only current solution is plotted to an **OrbitView**. When **SolverIterations** is set to **None**, this shows only final solution after the end of an iterative process and draws only final trajectory to an **OrbitView** plot. **Data Type** Enumeration **Allowed Values** **All**, **Current**, **None** **Access** set **Default Value** **Current** **Units** N/A **Interfaces** GUI, script
StarCount	Allows you to enter the number of stars that need to be displayed in an **OrbitView** plot. This field cannot be modified in the Mission Sequence. **Data Type** Integer **Allowed Values** Integer ≥ 1 **Access** set **Default Value** 7000 **Units** N/A **Interfaces** GUI, script
SunLine	Allows you to draw a line that starts at the center of central body and points towards the **Sun**. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** On, Off **Access** set **Default Value** Off **Units** N/A **Interfaces** GUI, script

Field	Description
UpdatePlotFrequency	This field lets you specify how often to update an **OrbitView** plot is updated with new data collected during the process of propagating spacecraft and running a mission. Data is collected for a plot according to the value defined by **DataCollectFrequency**. An **OrbitView** plot is updated with the new data, according to the value set in **UpdatePlotFrequency**. If **UpdatePlotFrequency** is set to 10 and **DataCollectFrequency** is set to 2, then the plot is updated with new data every 20 (10*2) integration steps. This field cannot be modified in the Mission Sequence. **Data Type** Integer **Allowed Values** Integer ≥ 1 **Access** set **Default Value** 50 **Units** N/A **Interfaces** GUI, script
UpperLeft	Allows you to pan the **OrbitView** plot window in any direction. First value in [0 0] matrix helps to pan the **OrbitView** window horizontally and second value helps to pan the window vertically. This field cannot be modified in the Mission Sequence. **Data Type** Real array **Allowed Values** Any Real number **Access** set **Default Value** [0 0] **Units** N/A **Interfaces** script
UseInitialView	This field lets you control the view of an **OrbitView** plot between multiple runs of a mission sequence. The first time a specific **OrbitView** plot is created, GMAT will automatically use the view as defined by the fields associated with **View Definition**, **View Up Direction**, and **View Option**. However, if you change the view using the mouse, GMAT will retain this view upon rerunning the mission as long as **UseInitialView** is set to false. If **UseInitialView** is set to true, the view for an **OrbitView** plot will be returned to the view defined by the initial settings. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** On, Off **Access** set **Default Value** On **Units** N/A **Interfaces** GUI, script

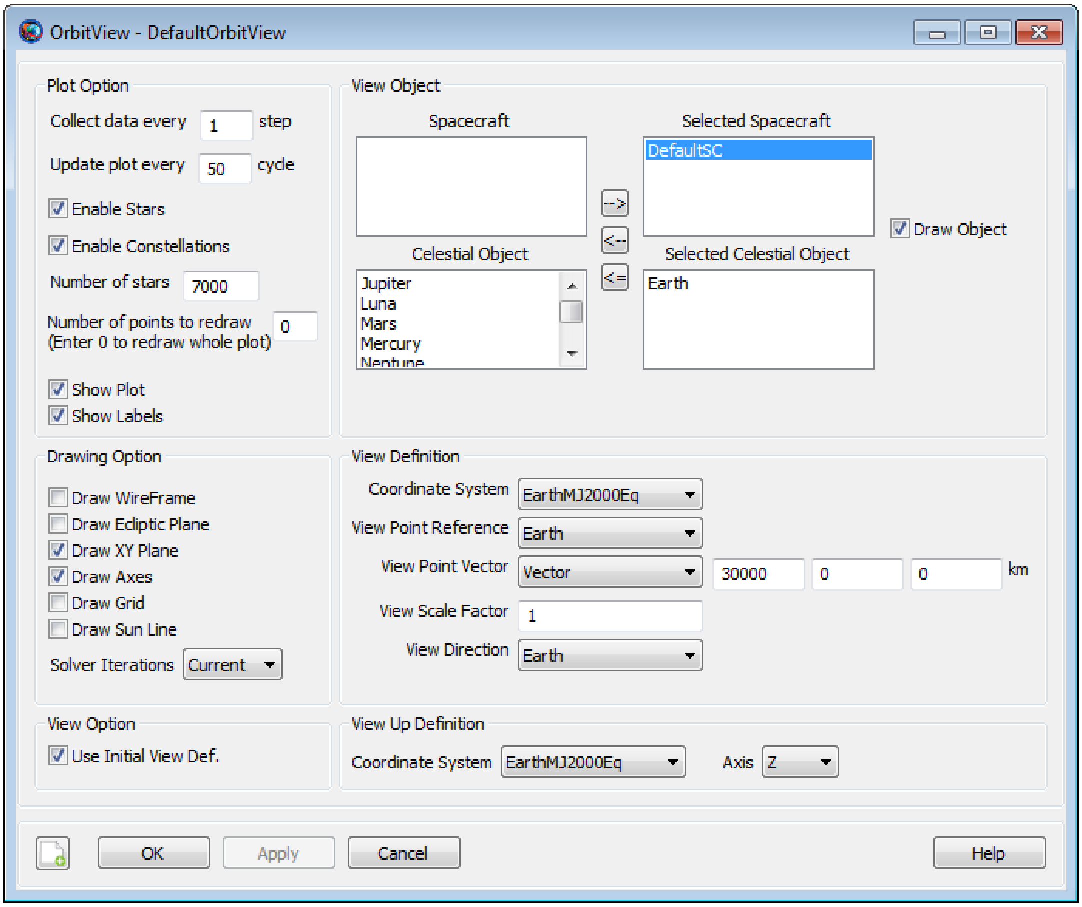
Field	Description
ViewDirection	Allows you to select the direction of view in an **OrbitView** plot. You can specify the view direction by choosing a resource to point at such as a **Spacecraft**, **Celestial body**, **Libration Point**, or **Barycenter**. Alternatively, you can also specify a vector of the form [x y z]. If the user specification of **ViewDirection**, **ViewPointReference**, and **ViewPointVector** results in a zero vector, GMAT uses [0 0 10000] for **ViewDirection**. This field cannot be modified in the Mission Sequence. **Data Type** Reference array **Allowed Values** **Spacecraft**, **CelestialBody**, **LibrationPoint**, **Barycenter**, or a 3-vector of numerical values **Access** set **Default Value** Earth **Units** km or N/A **Interfaces** GUI, script
ViewPointReference	This optional field allows you to change the reference point from which **ViewPointVector** is measured. **ViewPointReference** defaults to the origin of the coordinate system for the plot. A **ViewPointReference** can be any **Spacecraft**, **Celestial body**, **Libration Point**, or **Barycenter**. This field cannot be modified in the Mission Sequence. **Data Type** Reference array **Allowed Values** **Spacecraft**, **CelestialBody**, **LibrationPoint**, **Barycenter**, or a 3-vector of numerical values **Access** set **Default Value** Earth **Units** km or N/A **Interfaces** GUI, script

Field	Description
ViewPointVector	The product of **ViewScaleFactor** and **ViewPointVector** field determines the view point location with respect to **ViewPointReference**. **ViewPointVector** can be a vector, or any of the following resources: **Spacecraft**, **Celestial body**, **Libration Point**, or **Barycenter**. The location of the view point in three-dimensional space is defined as the vector addition of **ViewPointReference** and the vector defined by product of **ViewScaleFactor** and **ViewPointVector** in the coordinate system chosen by you. This field cannot be modified in the Mission Sequence. **Data Type** — Reference array **Allowed Values** — **Spacecraft**, **CelestialBody**, **LibrationPoint**, **Barycenter**, or a 3-vector of numerical values **Access** — set **Default Value** — [30000 0 0] **Units** — km or N/A **Interfaces** — GUI, script
ViewScaleFactor	This field scales **ViewPointVector** before adding it to **ViewPointReference**. The **ViewScaleFactor** allows you to back away from an object to fit in the field of view. This field cannot be modified in the Mission Sequence. **Data Type** — Real **Allowed Values** — Real Number ≥ 0 **Access** — set **Default Value** — 1 **Units** — N/A **Interfaces** — GUI, script
ViewUpAxis	This field lets you define which axis of the **ViewUpCoordinateSystem** field will appear as the up direction in an **OrbitView** plot. See the comments under **ViewUpCoordinateSystem** for more details of fields used to determine the up direction in an **OrbitView** plot. This field cannot be modified in the Mission Sequence. **Data Type** — Enumeration **Allowed Values** — **X** , **-X** , **Y** , **-Y** , **Z** , **-Z** **Access** — set **Default Value** — **Z** **Units** — N/A **Interfaces** — GUI, script

Field	Description
ViewUpCoordinateSystem	The **ViewUpCoordinateSystem** and **ViewUpAxis** fields are used to determine which direction appears as up in an **OrbitView** plot and together with the fields associated the the **View Direction**, uniquely define the view. The fields associated with the **View Definition** allows you to define the point of view in three-dimensional space, and the direction of the line of sight. However, this information alone is not enough to uniquely define the view. We also must provide how the view is oriented about the line of sight. This is accomplished by defining what direction should appear as the up direction in the plot and is configured using the **ViewUpCoordinateSystem** field and the **ViewUpAxis** field. The **ViewUpCoordinateSystem** allows you to select a coordinate system to define the up direction. Most of the time this system will be the same as the coordinate system chosen under the **CoordinateSystem** field. This field cannot be modified in the Mission Sequence. **Data Type** String **Allowed Values** **CoordinateSystem** resource **Access** set **Default Value** **EarthMJ2000Eq** **Units** N/A **Interfaces** GUI, script
WireFrame	When the **WireFrame** field is set to **On**, celestial bodies are drawn using a wireframe model. When the **WireFrame** field is set to **Off**, then celestial bodies are drawn using a full map. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** Off, On **Access** set **Default Value** Off **Units** N/A **Interfaces** GUI, script
XYPlane	Allows you to draw a grid representing the **XY-plane** of the coordinate system selected under the **CoordinateSystem** field of the **OrbitView** plot. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** On, Off **Access** set **Default Value** On **Units** N/A **Interfaces** GUI, script

GUI

The figure below shows the default settings for the **OrbitView** resource:



OrbitView Window Mouse Controls

The list of controls in the table below helps you navigate through the **OrbitView** graphics window. "**Left**" and "**Right**" designate the mouse button which have to be pressed.

Control	Description
Left Drag	Helps to change camera orientation. Camera orientation can be changed in **Up**/**Down**/**Left**/**Right** directions.
Right Drag	Helps to zoom in and out of the graphics window. Moving the cursor in **Up** direction leads to zoom out of the graphics window. Moving the cursor in **Down** direction helps to zoom into the graphics window.
Shift+Right Drag	Helps to adjust the **Field of View**.

Remarks

Behavior when using OrbitView Resource & Toggle Command

The **OrbitView** resource plots spacecraft's trajectory at each propagation step of the entire mission duration. If you want to report data to an **OrbitView** plot at specific points in your mission, then a

Toggle On/Off command can be inserted into the mission sequence to control when **OrbitView** is to plot a given trajectory. When **Toggle Off** command is issued for an **OrbitView**, no trajectory is drawn until a **Toggle On** command is issued. Similarly, when a **Toggle On** command is used, trajectory is plotted at each integration step until a **Toggle Off** command is used.

```
Create Spacecraft aSat
Create Propagator aProp

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth}

BeginMissionSequence

Toggle anOrbitView Off
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
Toggle anOrbitView On
Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

Behavior when using OrbitView, Spacecraft and SolarSystem Resources

Spacecraft resource contains information about spacecraft's orbit. **Spacecraft** resource interacts with **OrbitView** throughout the entire mission duration. The trajectory data retrieved from the spacecraft is what gets plotted at each propagation step of the entire mission duration. Similarly, the sun and all other planets available under the **SolarSystem** resource may be plotted or referenced in the **OrbitView** resource as well.

Behavior when reporting data in Iterative Processes

GMAT allows you to specify how trajectories are plotted during iterative processes such as differential correction or optimization. The **SolverIterations** field of **OrbitView** resource supports 3 options which are described in the table below:

SolverIterations options	Description
Current	Shows only current iteration/perturbation in an iterative process and plots current trajectory.
All	Shows all iterations/perturbations in an iterative process and plots all perturbed trajectories.
None	Shows only the final solution after the end of an iterative process and plots only that final trajectory.

Behavior when plotting multiple spacecrafts

GMAT allows you to plot trajectories of any number of spacecrafts when using the **OrbitView** resource. The initial epoch of all the spacecrafts must be same in order to plot the trajectories. If initial epoch of one of the spacecrafts does not match with initial epoch of other spacecrafts, then GMAT throws in an error alerting you that there is a coupled propagation error mismatch between the spacecrafts. GMAT also allows you to propagate trajectories of spacecrafts using any combination of the propagators that you may create.

Below is an example script snippet that shows how to plot trajectories of multiple spacecrafts that use different propagators:

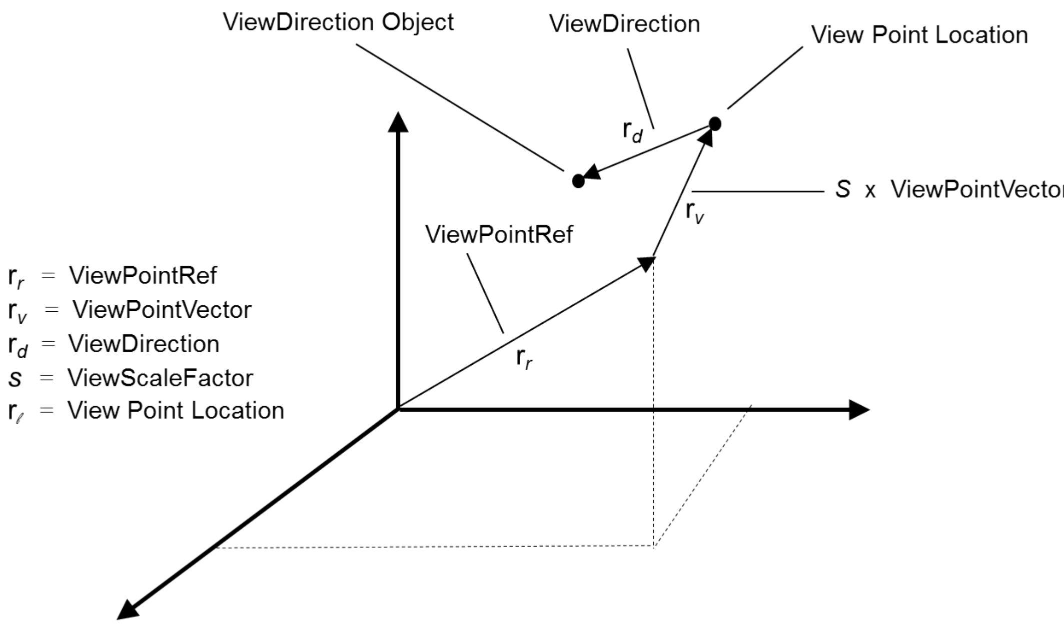
```
Create Spacecraft aSat aSat2 aSat3
aSat2.INC = 45.0
aSat3.INC = 90.0
aSat3.SMA = 9000

Create Propagator aProp
Create Propagator bProp

Create OrbitView anOrbitView anOrbitView2

anOrbitView.Add = {aSat, aSat2, Earth}
anOrbitView2.Add = {aSat3, Earth}

BeginMissionSequence

Propagate aProp(aSat, aSat2) bProp(aSat3) {aSat.ElapsedSecs = 12000.0}
```

OrbitView View Definition Controls

GMAT is capable of drawing orbit plots that allow you to visualize the motion of spacecraft and celestial bodies throughout the mission sequence. Here we discuss the options you can use in setting up and viewing Orbit plots. You can choose many properties including the coordinate system of the orbit view plot and the view location and direction from where visualizations can be seen. The script snippet below shows how to create **OrbitView** resource that includes key view definition controls fields as well. Detailed definitions of all fields for **OrbitView** resource can be found in Fields section.

```
Create OrbitView PlotName
PlotName.CoordinateSystenm      = CoordinateSystemName
PlotName.Add                    = [SpacecraftName, BodyName, ...
                                  LibrationPoint, Barycenter]
PlotName.ViewPointReference     = [ObjectName, VectorName]
PlotName.ViewPointVector        = [ObjectName, VectorName]
PlotName.ViewDirection          = [ObjectName, VectorName]
PlotName.ViewScaleFactor        = [Real Number]
PlotName.ViewUpCoordinateSystem = CoordinateSystemName
PlotName.ViewUpAxis             = [X,-X,Y,-Y,Z,-Z];
```

You can specify the view location and direction of **OrbitView** plot object by using the **ViewPointReference**, **ViewPointVector**, **ViewDirection**, **ViewUpCoordinateSystem** and **ViewUpAxis** fields. Figure below shows a graphical definition of **ViewPointReference**, **ViewPointVector**, and **ViewDirection** fields and how they determine the actual view location and view direction. You can supply **ViewPointReference**, **ViewPointVector** and **ViewDirection** fields by either giving a vector in the format [x y z] or by specifying an object name. If a vector is given for one of the quantities, then we simply use it in its appropriate place in the computations below. If an object is given, we must determine the vector associated with it. The rest of this section is devoted in determining **ViewPointReference**, **ViewPointVector** and **ViewDirection** fields if you specify an object.



ViewPointReference field defines the point from which **ViewPointVector** is measured. If an object is given for **ViewPointReference** field, i.e. when you have the following in the sample script:

```
MyOrbitViewPlot.CoordinateSystenm     = MyCoordSys
MyOrbitViewPlot.ViewPointReference    = ViewRefObject
```

then we need to determine $\mathbf{r}_r$ as illustrated in above figure. If ViewRefObject is the same as the origin of MyCoordSys, then $\mathbf{r}_r$ = [0 0 0]. Otherwise $\mathbf{r}_r$ is the cartesian position of **ViewPointReference** in MyCoordSys.

$$r_r = \begin{pmatrix} \text{ViewRefObject.MyCoordSys.X} \\ \text{ViewRefObject.MyCoordSys.Y} \\ \text{ViewRefObject.MyCoordSys.Z} \end{pmatrix}$$

ViewPointVector field points from **ViewPointReference** ($\mathbf{r}_r$) in the direction of the view point location. If an object is given for **ViewPointVector** field, i.e. you have the following in the sample script:

```
MyOrbitViewPlot.CoordinateSystenm     = MyCoordSys
MyOrbitViewPlot.ViewPointVector       = ViewPointObject
```

then we need to determine $\mathbf{r}_v$ as illustrated in above figure by using the coordinate system conversion routine to calculate the following:

$$r_v = \begin{pmatrix} \text{ViewPointObject.MyCoordSys.X} \\ \text{ViewPointObject.MyCoordSys.Y} \\ \text{ViewPointObject.MyCoordSys.Z} \end{pmatrix}$$

We now know everything to calculate the location of the view point in the desired coordinate system. From inspection of the above figure, we see that the relation is:

$$r_\ell = r_r + s\, r_v$$

Now that we know the view point location, we need to determine the ViewDirection: $\mathbf{r}_d$ as illustrated in above figure. If a vector was specified for **ViewDirection** field, then no computations are required. However, if an object was given as shown in the following sample script:

```
MyOrbitViewPlot.CoordinateSystenm    = MyCoordSys
MyOrbitViewPlot.ViewDiection         = ViewDirectionObject
```

then we calculate $\mathbf{r}_d$ from the following:

$$r_d = \begin{pmatrix} \text{ViewDirectionObject.MyCoordSys.X} \\ \text{ViewDirectionObject.MyCoordSys.Y} \\ \text{ViewDirectionObject.MyCoordSys.Z} \end{pmatrix} - r_\ell$$

Note that ViewDirection vector $\mathbf{r}_d$ must not be zero vector [0 0 0].

ViewUpCoordinateSystem and **ViewUpAxis** fields are used to determine which direction appears as up in an **OrbitView** plot. Most of the time, coordinate system chosen under **ViewUpCoordinateSystem** field will be the same as the coordinate system selected under the **CoordinateSystem** field. **ViewUpAxis** field allows you to define which axis of the **ViewUpCoordinateSystem** field will appear as the up direction in an orbit plot.

Below are some examples that show how to generate **OrbitView** plots using different View Definition Controls configurations:

Earth Inertial view with spacecraft: This example shows orbit view plot with Earth and a spacecraft. Since **ViewPointReference** field is set to an object (i.e. Earth), hence ViewPointRef vector in above figure is [0 0 0] in EarthMJ2000Eq coordinate system. The **ViewPointVector** field is set to a vector (i.e. set to [0 0 40000]). This means that the view is from 40000 km above the Earth's equatorial plane on the z-axis of the EarthMJ2000Eq coordinate system. The view direction (specified in **ViewDirection** field) is towards the earth.

```
Create Spacecraft aSat

Create Propagator aProp

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth}

anOrbitView.CoordinateSystem = EarthMJ2000Eq
anOrbitView.ViewPointReference = Earth
anOrbitView.ViewPointVector = [ 0 0 40000 ]
anOrbitView.ViewDirection = Earth
anOrbitView.ViewScaleFactor = 1
anOrbitView.ViewUpCoordinateSystem = EarthMJ2000Eq
anOrbitView.ViewUpAxis = Z
```

```
BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

Earth Inertial view with spacecraft and Luna: This example shows orbit view plot with Earth, spacecraft and Moon. Note **ViewPointReference** field is set to an object (i.e. Earth), hence ViewPointRef vector in above figure = [0 0 0] in EarthMJ2000Eq coordinate system. **ViewPointVector** field is still set to a vector (i.e. set to [0 0 500000]). This means that the view is from 500000 km above the Earth's equatorial plane on the z-axis of the EarthMJ2000Eq coordinate system. **ViewDirection** field defines the view direction which is set towards the earth.

```
Create Spacecraft aSat

Create Propagator aProp

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth, Luna}

anOrbitView.CoordinateSystem = EarthMJ2000Eq
anOrbitView.ViewPointReference = Earth
anOrbitView.ViewPointVector = [ 0 0 500000 ]
anOrbitView.ViewDirection = Earth
anOrbitView.ViewScaleFactor = 1
anOrbitView.ViewUpCoordinateSystem = EarthMJ2000Eq
anOrbitView.ViewUpAxis = Z

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 5}
```

View of spacecraft from Luna in Earth inertial frame: This example of an orbit view plot shows spacecraft as viewed from Luna orbiting around Earth in an inertial reference frame. **ViewPointReference** field is set to an object (i.e. Earth), hence ViewPointRef vector is [0 0 0] in EarthMJ2000Eq coordinate system. This time **ViewPointVector** field is set to an object (i.e. Luna). This means that the spacecraft will be seen from the vantage point of Luna. Note that **ViewDirection** field is set to spacecraft (aSat). This means that view direction as seen from Luna is towards the spacecraft. After you run this example, re-run this example but this time with **ViewScaleFactor** field set to 2 and see what happens. You'll notice that **ViewScaleFactor** simply scales **ViewPointVector** field.

```
Create Spacecraft aSat

Create Propagator aProp

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth, Luna}

anOrbitView.CoordinateSystem = EarthMJ2000Eq
anOrbitView.ViewPointReference = Earth
anOrbitView.ViewPointVector = Luna
anOrbitView.ViewDirection = aSat
anOrbitView.ViewScaleFactor = 1
anOrbitView.ViewUpCoordinateSystem = EarthMJ2000Eq
```

```
anOrbitView.ViewUpAxis = Z

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 5}
```

View towards Luna from Earth as spacecraft orbits around Luna in inertial frame: This example of an orbit view plot shows view of Luna from vantage point of Earth as a spacecraft orbits around Luna. **ViewPointReference** field is set to an object (i.e. Luna), hence ViewPointRef vector in above figure is [0 0 0] in LunaMJ2000Eq coordinate system. **ViewPointVector** field is set to an object (i.e. Earth). This means that the camera or vantage point is located at Earth. **ViewDirection** field is also set to an object (i.e. Luna). This means that view direction as seen from Earth is towards Luna.

```
Create Spacecraft aSat

Create CoordinateSystem LunaMJ2000Eq
LunaMJ2000Eq.Origin = Luna
LunaMJ2000Eq.Axes = MJ2000Eq

aSat.CoordinateSystem = LunaMJ2000Eq
aSat.SMA = 7300
aSat.ECC = 0.4
aSat.INC = 90
aSat.RAAN = 270
aSat.AOP = 315
aSat.TA = 180

Create ForceModel aFM
aFM.CentralBody = Luna
aFM.PointMasses = {Luna}

Create Propagator aProp
aProp.FM = aFM

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Luna, Earth}
anOrbitView.CoordinateSystem = LunaMJ2000Eq
anOrbitView.ViewPointReference = Luna
anOrbitView.ViewPointVector = Earth
anOrbitView.ViewDirection = Luna
anOrbitView.ViewScaleFactor = 1;
anOrbitView.ViewUpCoordinateSystem = LunaMJ2000Eq;
anOrbitView.ViewUpAxis = Z;

BeginMissionSequence
Propagate aProp(aSat) {aSat.ElapsedDays = 5}
```

View towards spacecraft1 from spacecraft2 in inertial frame: This example of an orbit view plot shows spacecraft1 (aSat1) being viewed from spacecraft2 (aSat2) as they move in inertial reference frame. **ViewPointReference** field is set to an object (i.e. Earth), hence ViewPointRef vector in above figure is [0 0 0] in EarthMJ2000Eq coordinate system. **ViewPointVector** field is set to an object (i.e. aSat2) and **ViewDirection** field is also set to an object (i.e. aSat1). This means that aSat1 will be viewed from the vantage point of aSat2.

```
Create Spacecraft aSat aSat2

aSat2.X = 19500
aSat2.Z = 10000

Create Propagator aProp

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, aSat2, Earth,}

anOrbitView.CoordinateSystem = EarthMJ2000Eq
anOrbitView.ViewPointReference = Earth
anOrbitView.ViewPointVector = aSat2
anOrbitView.ViewDirection = aSat
anOrbitView.ViewScaleFactor = 1.0
anOrbitView.ViewUpCoordinateSystem = EarthMJ2000Eq
anOrbitView.ViewUpAxis = Z

BeginMissionSequence

Propagate aProp(aSat, aSat2){aSat.ElapsedSecs = 12000.0}
```

Orbit view plot of Sun-Earth-Moon L1 Rotating System: This example of an orbit view plot shows the Earth and spacecraft in the Sun-Earth-Moon rotating coordinate system. **ViewPointReference** field is set to an object (i.e. ESL1), hence ViewPointRef vector in above figure is [0 0 0] in SunEarthMoonL1 rotating coordinate system. **ViewPointVector** field is set to a vector (i.e. [0 0 30000]). This means that the view is taken from 30000 km above the SunEarthMoonL1 coordinate system's XY plane on the z-axis of the SunEarthMoonL1 coordinate system. **ViewDirection** field is also set to an object (i.e. ESL1). This means that view direction as seen from 30000 km above the SunEarthMoonL1 coordinate system's XY plane is towards ESL1. Note that in this example, **ViewScaleFactor** is set to 25. This simply scales or amplifies **ViewPointVector** field 25 times its original value.

```
Create Spacecraft aSat

GMAT aSat.DateFormat = UTCGregorian;
GMAT aSat.Epoch = '01 Apr 2013 00:00:00.000'
GMAT aSat.CoordinateSystem = EarthMJ2000Eq
GMAT aSat.DisplayStateType = Cartesian
GMAT aSat.X = 1429457.8833484
GMAT aSat.Y = 147717.32846679
GMAT aSat.Z = -86529.655549364
GMAT aSat.VX = -0.037489820883615
GMAT aSat.VY = 0.32032521614858
GMAT aSat.VZ = 0.15762889268226

Create Barycenter EarthMoonBarycenter
GMAT EarthMoonBarycenter.BodyNames = {Earth, Luna}

Create LibrationPoint ESL1
GMAT ESL1.Primary = Sun
GMAT ESL1.Secondary = EarthMoonBarycenter
GMAT ESL1.Point = L1
```

```
Create ForceModel aFM
aFM.CentralBody = Earth
aFM.PointMasses = {Luna, Sun}

Create Propagator aProp
aProp.FM = aFM

Create CoordinateSystem SunEarthMoonL1
GMAT SunEarthMoonL1.Origin = ESL1
GMAT SunEarthMoonL1.Axes = ObjectReferenced
GMAT SunEarthMoonL1.XAxis = R
GMAT SunEarthMoonL1.ZAxis = N
GMAT SunEarthMoonL1.Primary = Sun
GMAT SunEarthMoonL1.Secondary = EarthMoonBarycenter

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth, Sun}
anOrbitView.CoordinateSystem = SunEarthMoonL1
anOrbitView.ViewPointReference = ESL1
anOrbitView.ViewPointVector = [ 0 0 30000 ]
anOrbitView.ViewDirection = ESL1
anOrbitView.ViewScaleFactor = 25
anOrbitView.ViewUpCoordinateSystem = SunEarthMoonL1
anOrbitView.ViewUpAxis = Z

BeginMissionSequence
Propagate aProp(aSat) {aSat.ElapsedDays = 15}
```

Behavior when using View Definition panel of OrbitView Resource

Currently in **OrbitView** resource's View Definition panel, fields like **ViewPointReference**, **ViewPointVector** and **ViewDirection** are initialized but not dynamically updated during a mission run. **OrbitView** resource's View Definition panel sets up geometry at initial epoch and then mouse controls geometry of the simulation from that point on.

Spacecraft Model Considerations in GMAT's OrbitView

GMAT displays spacecraft models by reading model data from 3D Studio files describing the spacecraft shape and colors. These files have the file extension .3ds, and are generally called 3ds files. 3ds files contain data that defines the 3-dimensional coordinates of vertices outlining the spacecraft, a mapping of those vertices into triangles used to create the displayed surface of the spacecraft, and information about the colors and texture maps used to fill in the displayed triangles.

GMAT's implementation of the spacecraft model can display models consisting of up to 200,000 vertices that map up to 100,000 triangles. The GMAT model can use up 500 separate color or texture maps to fill in these triangles.

Behavior When Specifying Empty Brackets in OrbitView's Add Field

When using **OrbitView.Add** field, if brackets are not populated with user-defined spacecrafts, then GMAT turns off **OrbitView** resource and no plot is generated. If you run the script with **Add** field having empty brackets, then GMAT throws in a warning message in the Message Window indicating that **OrbitView** resource will be turned off since no SpacePoints were added to the plot. Below is a sample script snippet that generates such a warning message:

```
Create Spacecraft aSat aSat2
Create Propagator aProp

Create OrbitView anOrbitView
anOrbitView.Add = {}

BeginMissionSequence
Propagate aProp(aSat, aSat2){aSat.ElapsedSecs = 12000.0}
```

Examples

Propagate spacecraft for 1 day and plot the orbit at every integrator step:

```
Create Spacecraft aSat
Create Propagator aProp

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

Plotting orbit during an iterative process. Notice **SolverIterations** field is selected as **All**. This means all iterations/perturbations will be plotted.

```
Create Spacecraft aSat
Create Propagator aProp

Create ImpulsiveBurn TOI
Create DifferentialCorrector aDC

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth}
anOrbitView.SolverIterations = All

BeginMissionSequence

Propagate aProp(aSat) {aSat.Earth.Periapsis}

Target aDC
  Vary aDC(TOI.Element1 = 0.24, {Perturbation = 0.001, Lower = 0.0, ...
  Upper = 3.14159, MaxStep = 0.5})
  Maneuver TOI(aSat)
  Propagate aProp(aSat) {aSat.Earth.Apoapsis}
  Achieve aDC(aSat.Earth.RMAG = 42165)
EndTarget
```

Plotting spacecraft's trajectory around non-default central body. This example shows how to plot a spacecraft's trajectory around Luna:

```
Create Spacecraft aSat

Create CoordinateSystem LunaMJ2000Eq
LunaMJ2000Eq.Origin = Luna
LunaMJ2000Eq.Axes = MJ2000Eq

aSat.CoordinateSystem = LunaMJ2000Eq
aSat.SMA = 7300
aSat.ECC = 0.4
aSat.INC = 90
aSat.RAAN = 270
aSat.AOP = 315
aSat.TA = 180

Create ForceModel aFM
aFM.CentralBody = Luna
aFM.PointMasses = {Luna}

Create Propagator aProp
aProp.FM = aFM

Create OrbitView anOrbitView

anOrbitView.Add = {aSat, Luna}
anOrbitView.CoordinateSystem = LunaMJ2000Eq
anOrbitView.ViewPointReference = Luna
anOrbitView.ViewDirection = Luna

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

Plotting spacecraft's trajectory around non-default central body. This example shows how to plot a spacecraft's trajectory around Mars:

```
Create Spacecraft aSat

Create CoordinateSystem MarsMJ2000Eq
MarsMJ2000Eq.Origin = Mars
MarsMJ2000Eq.Axes = MJ2000Eq

aSat.CoordinateSystem = MarsMJ2000Eq
aSat.SMA = 7300
aSat.ECC = 0.4
aSat.INC = 90
aSat.RAAN = 270
aSat.AOP = 315
aSat.TA = 180

Create ForceModel aFM
aFM.CentralBody = Mars
aFM.PointMasses = {Mars}

Create Propagator aProp
```

```
aProp.FM = aFM

Create OrbitView anOrbitView

anOrbitView.Add = {aSat, Mars}
anOrbitView.CoordinateSystem = MarsMJ2000Eq
anOrbitView.ViewPointReference = Mars
anOrbitView.ViewDirection = Mars

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

Plotting spacecraft's trajectory around non-default central body. This example shows how to plot a spacecraft's trajectory around Sun. This is an interplanetary trajectory. Spacecraft is shown on an outgoing hyperbolic trajectory in an EarthView and then an interplanetary trajectory is drawn around Sun in a SunView. Mars Orbit around Sun is also shown:

```
Create Spacecraft aSat

aSat.CoordinateSystem = EarthMJ2000Eq
aSat.DateFormat = UTCGregorian
aSat.Epoch = '18 Nov 2013 20:26:24.315'

aSat.X = 3728.345810006184
aSat.Y = 4697.943961035268
aSat.Z = -2784.040094879185
aSat.VX = -9.502477543864449
aSat.VY = 5.935188001372066
aSat.VZ = -2.696272103530009

Create ForceModel aFM
aFM.CentralBody = Earth
aFM.PointMasses = {Earth}

Create ForceModel bFM
aFM.CentralBody = Sun
aFM.PointMasses = {Sun}

Create Propagator aProp
aProp.FM = aFM

Create Propagator bProp
aProp.FM = bFM

Create CoordinateSystem SunEcliptic
SunEcliptic.Origin = Sun
SunEcliptic.Axes = MJ2000Ec

Create OrbitView EarthView SunView

EarthView.Add = {aSat, Earth}
EarthView.CoordinateSystem = EarthMJ2000Eq
EarthView.ViewPointReference = Earth
```

```
EarthView.ViewDirection = Earth

SunView.Add = {aSat, Mars, Sun}
SunView.CoordinateSystem = SunEcliptic
SunView.ViewPointReference = Sun
SunView.ViewDirection = Sun
SunView.ViewPointVector = [ 0 0 500000000 ]

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 3}
Propagate bProp(aSat) {aSat.ElapsedDays = 225}
```

Propagator

A propagator models spacecraft motion

Overview of Propagator Components

A **Propagator** is the GMAT component used to model spacecraft motion. GMAT contains two types of propagators: a numerical integrator type, and an ephemeris type. When using a numerical integrator type **Propagator**, you can choose among a suite of numerical integrators implementing Runge-Kutta and predictor corrector methods. Numeric **Propagators** also require a **ForceModel**. Additionally, you can configure a **Propagator** to use SPICE kernels for propopagation. This resource cannot be modified in the Mission Sequence. However, you set one **Propagator** equal to another **Propagator** in the mission,(i.e. `myPropagator = yourPropagator`).

GMAT's documentation for **Propagator** components is broken down into three sections:

- For numerical **Propagator** documentation see Numerical Propagator
- For **ForceModel** documentation see Force Model
- For SPICE **Propagator** documentation see SPK-Configured Propagator

See Also: Spacecraft, Propagate

Numerical Propagator

Overview

A **Propagator** object that uses a numerical integrator (as opposed to an ephemeris propagator) is one of a few objects in GMAT that is configured differently in the scripting and in the GUI. In the GUI, you configure the integrator and force model setting on the same dialog box. See the Remarks section below for detailed discussion of GMAT's numerical integrators as well as performance and accuracy comparisons, and usage recommendations. This resource cannot be modified in the Mission Sequence. However, you can do whole object assignment in the mission,(i.e. `myPropagator = yourPropagator`).

When working in the script, you must create a **ForceModel** object separately from the **Propagator** and specify the force model using the “**FM**” field on the propagator object. See the Examples section later in this section for details.

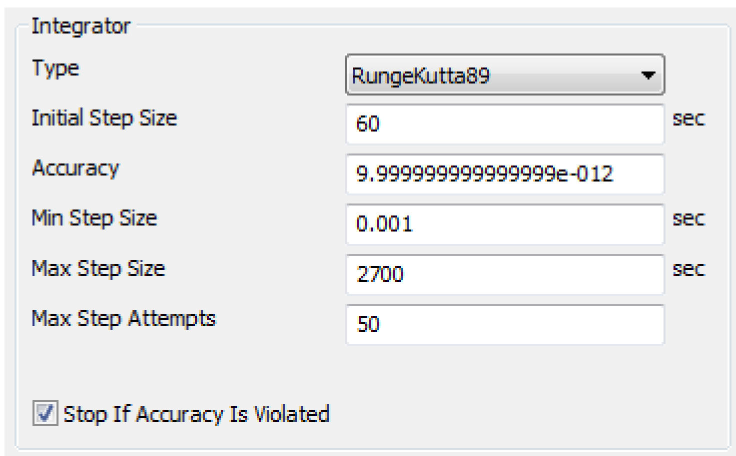
Options

Option	Description
`Accuracy`	The desired accuracy for an integration step. GMAT uses the method selected in the **ErrorControl** field on the Force Model to determine a metric of the integration accuracy. For each step, the integrator ensures that the error in accuracy is smaller than the value defined by the **ErrorControl** metric. **Data Type** Real **Allowed Values** Real > 0 AND Real < 1 **Default Value** 1e-11 except for ABM integrator which is 1e-10 **Interfaces** GUI, script **Access** set **Units** N/A
FM	Identifies the force model used by an integrator. If no force model is provided, GMAT uses an Earth centered propagator with a 4x4 gravity model. **Data Type** Resource reference **Allowed Values** **ForceModel** **Default Value** N/A **Interfaces** GUI, script **Access** set **Units** N/A
InitialStepSize	The size of the first step attempted by the integrator. **Data Type** Real **Allowed Values** Real > 0.0001 **Default Value** 60 **Interfaces** GUI, script **Access** set **Units** sec.
LowerError	The lower bound on integration error, used to determine when to make the step size larger. Applies only to **AdamsBashforthMoulton** integrator. **Data Type** Real **Allowed Values** Real > 0 AND 0 < **LowerError** <**TargetError** < **Accuracy** **Default Value** 1e-13 **Interfaces** GUI, script **Access** set **Units** N/A

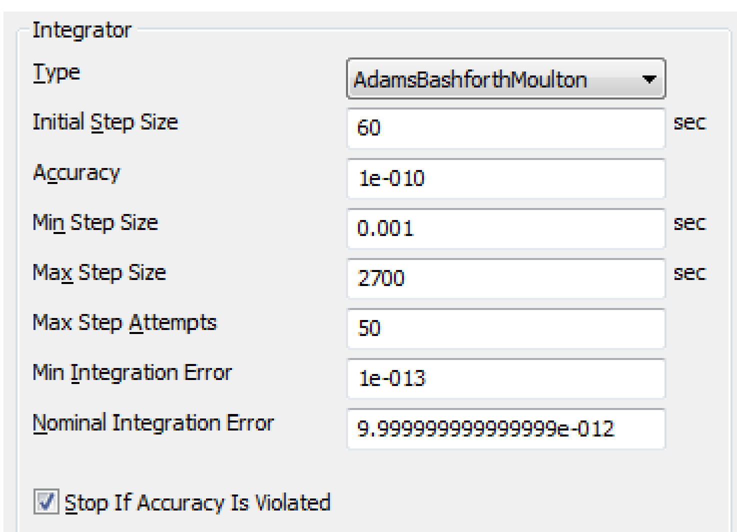
Option	Description	
MaxStep	The maximum allowable step size.	
	Data Type	Real
	Allowed Values	Real > 0 AND **MinStep** <= **MaxStep**
	Default Value	2700
	Interfaces	GUI, script
	Access	set
	Units	N/A
MaxStepAttempts	The number of attempts the integrator takes to meet the tolerance defined by the **Accuracy** field.	
	Data Type	Integer
	Allowed Values	Integer >= 1
	Default Value	50
	Interfaces	GUI, script
	Access	set
	Units	N/A
MinStep	The minimum allowable step size.	
	Data Type	Real
	Allowed Values	Real > 0 AND **MinStep** <= **MaxStep**
	Default Value	0.001
	Interfaces	GUI, script
	Access	set
	Units	sec.
StopIfAccuracy-IsViolated	Flag to stop propagation if integration error value defined by **Accuracy** is not satisfied.	
	Data Type	Boolean
	Allowed Values	true, false
	Default Value	true
	Interfaces	GUI, script
	Access	set
	Units	N/A
TargetError	The nominal bound on integration error, used to set the target integration accuracy when adjusting step size. Applies only to **AdamsBashforthMoulton** integrator.	
	Data Type	Real
	Allowed Values	Real > 0 AND 0 < **LowerError** < **TargetError** < **Accuracy**
	Default Value	1e-11
	Interfaces	GUI, script
	Access	set
	Units	N/A

Option	Description
Type	Specifies the integrator or analytic propagator used to model the time evolution of spacecraft motion. **Data Type** Enumeration **Allowed Values** **PrinceDormand78**, **PrinceDormand853**, **PrinceDormand45**, **RungeKutta89**,**RungeKutta68**, **RungeKutta56**, **AdamsBashforthMoulton**, **SPK** **Default Value** **RungeKutta89** **Interfaces** GUI, script **Access** set **Units** N/A

GUI



Settings for the embedded Runge-Kutta integrators. Select the desired integrator from the **Type** menu.



The Adams-Bashforth-Moulton integrator has additional settings as shown.

Remarks

Best Practices for Using Numerical Integrators

The comparison data presented in a later section suggest that the **PrinceDormand78** integrator is the best all purpose integrator in GMAT. When in doubt, use the **PrinceDormance78** integrator, and set **MinStep** to zero so that the integrator's adaptive step algorithm controls the minimum integration step size. Below are some important comments on GMAT's step size control algorithms and the dangers of using a non-zero value for the minimum integration step size. The **AdamsBashforthMoulton** integrator is a low order integrator and we only recommend its use for low precision analysis when a predictor-corrector algorithm is required. We recommend that you study the performance and accuracy analysis documented later in this section to select a numerical integrator for your application. You may need to perform further analysis and comparisons for your application.

Caution

Caution: GMAT's default error computation mode is **RSStep** and this is a more stringent error control method than **RSSState** that is often used as the default in other software such as STK. If you set Accuracy to a very small number, 1e-13 for example, and leave **ErrorControl** set to **RSSStep**, integrator performance will be poor, for little if any improvement in the accuracy of the orbit integration. To find the best balance between integration accuracy and performance, we recommend you experiment with the accuracy setting for your selected integrator for your application. You can start with a relatively high setting of **Accuracy**, say 1e-9, and lower the accuracy by an order of magnitude at a time and compare the final orbital states to determine where smaller values of **Accuracy** result in longer propagation times without providing more accurate orbital solutions.

Caution

Caution: GMAT allows you to set a minimum step on numerical integrators. It is possible that the requested **Accuracy** cannot be achieved given the **MinimumStep** setting. The **Propagator** flag **StopIfAccuracyIsViolated** determines the behavior if **Accuracy** cannot be satisfied. If **StopIfAccuracyIsViolated** is true, GMAT will throw an error and stop execution if integration accuracy is not satisfied. If **StopIfAccuracyIsViolated** is false, GMAT will only throw a warning that the integration accuracy was not satisfied but will continue to propagate the orbit.

Numerical Integrators Overview

The table below describes each numerical integrator in detail.

Option	Description
RungeKutta89	An adaptive step, ninth order Runge-Kutta integrator with eighth order error control. The coefficients were derived by J. Verner. Verner developed several sets of coefficients for an 89 integrator and we have chosen the coefficients that are the most robust but not necessarily the most efficient.

Option	Description
PrinceDormand78	An adaptive step, eighth order Runge-Kutta integrator with seventh order error control. The coefficients were derived by Prince and Dormand.
PrinceDormand853	An adaptive step, eighth order Runge-Kutta integrator with 5th order error control that incorporates a 3rd order correction, as described in section II.10 of "Solving Ordinary Differential Equations I: Nonstiff Problems" by Hairer, Norsett and Warner. The coefficients were derived by Prince and Dormand. This integrator performs surprisingly well at loose Accuracy settings.
PrinceDormand45	An adaptive step, fifth order Runge-Kutta integrator with fourth order error control. The coefficients were derived by Prince and Dormand.
RungeKutta68	A second order Runge-Kutta-Nystrom type integrator with coefficients developed by by Dormand, El-Mikkawy and Prince. The integrator is a 9-stage Nystrom integrator, with error control on both the dependent variables and their derivatives. This second order implementation will correctly integrate forces that are non-conservative but it is not recommended for this use. See the integrator comparisons below for numerical comparisons. You cannot use this integrator to integrate mass during a finite maneuver because the mass flow rate is a first order differential equation not supported by this integrator.
RungeKutta56	An adaptive step, sixth order Runge-Kutta integrator with fifth order error control. The coefficients were derived by E. Fehlberg.
AdamsBashforthMoulton	A fourth-order Adams-Bashford predictor / Adams-Moulton corrector as described in Fundamentals of Astrodynamics by Bate, Mueller, and White. The predictor step extrapolates the next state of the variables using the the derivative information at the current state and three previous states of the variables. The corrector uses derivative information evaluated for this state, along with the derivative information at the original state and two preceding states, to tune this state, giving the final, corrected state. The ABM integrator uses the RungeKutta89 integrator to start the integration process. The ABM is a low order integrator and should not be used for precise applications or for highly nonlinear applications such as celestial body flybys.

Performance & Accuracy Comparison of Numerical Integrators

The tables below contain performance comparison data for GMAT's numerical integrators. The first table shows the orbit types, dynamics models, and propagation duration for each test case included in the comparison. Five orbit types were compared: low earth orbit, Molniya, Mars transfer (Type 2), Lunar transfer, and finite burn (case 1 is blow down, and case 2 is pressure regulated). For each test case, the orbit was propagated forward for a duration and then back-propagated to the intial epoch. The error values in the table are the RSS difference of the final position after forward and backward propagation to the initial position. The run time data for each orbit type is normalized on the integrator with the fasted run time for that orbit type. For all test cases the **ErrorControl** setting was set to **RSSStep**. **Accuracy** was set to 1e-12 for all integrators except for **AdamsBashfourthMoulton** which was set to 1e-11 because of poor performance when **Accuracy** was set to 1e-11.

Orbit	Dynamics Model	Duration
LEO	Earth 20x20, Sun, Moon, drag using MSISE90 density, SRP	1 day
Molniya	Earth 20x20, Sun, Moon, drag using Jacchia Roberts density, SRP	3 days
Mars Transfer	Near Earth: Earth 8x8, Sun, Moon, SRP Deep Space: All planets as point mass perturbations Near Mars: Mars 8x8 SRP	333 days
Lunar Transfer	Earth central body with all planets as point mass perturbations	5.8 days
Finite Burn (case 1 and 2)	Point mass gravity	7200 sec.

Comparing the run time data for each integrator shown in the table below we see that the **PrinceDormand78** integrator was the fastest for 4 of the 6 cases and tied with the **RungeKutta89** integrator for LEO test case. For the Lunar flyby case, the **RungeKutta89** was the fastest integrator, however, in this case the **PrinceDormand78** integrator was at least 2 orders of magnitude more accurate given equaivalent **Accuracy** settings. Notice that the **AdamsBashforthMoulton** integrator has km level errors for some orbits because it is a low-order integrator.

		RKV89	RKN68	RK56	PD45	PD78	ABM	PD853
ISS	Run Time	1.53	**1.00**	2.14	2.78	1.46	3.41	1.80
	Error (m)	0.003	64.060	0.022	0.002	0.006	0.012	0.013
Molniya	Run Time	1.32	1.47	1.99	3.08	**1.00**	3.35	1.92
	Error (m)	0.007	0.601	0.059	0.032	0.043	380.125	0.031
Lunar Flyby	Run Time	**1.00**	1.01	2.26	2.98	2.21	3.30	1.39
	Error (m)	0.063	0.017	0.002	0.023	0.000	0.236	0.080
Mars Transfer	Run Time	1.02	1.04	1.14	1.40	**1.00**	3.07	1.11
	Error (m)	0.030	0.001	0.043	0.194	0.009	25.231	0.030
Finite burn 1	Run Time	1.27	**N/A**	1.24	1.26	**1.00**	1.45	1.07
	Error (m)	0.002	N/A	0.006	0.002	0.002	0.000	0.002
Finite burn 2	Run Time	1.03	**N/A**	1.18	1.31	**1.00**	1.54	1.12
	Error (m)	0.002	N/A	0.000	0.000	0.001	0.003	0.002

Fields Unique to the AdamsBashforthMoulton Integrator

The **AdamsBashforthMoulton** integrator has two additional fields named **TargetError** and **LowerError** that are only active when **Type** is set to **AdamsBashforthMoulton**. If you are using another integrator type, those fields must be removed from your script file to avoid parsing errors. When working in the GUI, this is performed automatically. See examples below for more details.

Examples

Propagate an orbit using a general purpose Runge-Kutta integrator:

```
Create Spacecraft aSat
```

```
Create ForceModel aForceModel

Create Propagator aProp
aProp.FM              = aForceModel
aProp.Type            = PrinceDormand78
aProp.InitialStepSize = 60
aProp.Accuracy        = 1e-011
aProp.MinStep         = 0
aProp.MaxStep         = 86400
aProp.MaxStepAttempts = 50
aProp.StopIfAccuracyIsViolated = true

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = .2}
```

Propagate using a fixed step configuration. Do this by setting **InitialStepSize** to the desired fixed step size and setting **ErrorControl** to **None**. This example propagates in constant steps of 30 seconds:

```
Create Spacecraft aSat
Create ForceModel aForceModel
aForceModel.ErrorControl = None

Create Propagator aProp
aProp.FM              = aForceModel
aProp.Type            = PrinceDormand78
aProp.InitialStepSize = 30

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = .2}
```

Propagate an orbit using an Adams-Bashforth-Moulton predictor-corrector integrator:

```
Create Spacecraft aSat
Create ForceModel aForceModel
aForceModel.ErrorControl = RSSStep

Create Propagator aProp
aProp.FM              = aForceModel
aProp.Type            = AdamsBashforthMoulton
aProp.InitialStepSize = 60
aProp.MinStep         = 0
aProp.MaxStep         = 86400
aProp.MaxStepAttempts = 50
%  Note the following fields must be set with decreasing values!
aProp.Accuracy        = 1e-010
aProp.TargetError     = 1e-011
aProp.LowerError      = 1e-013
aProp.StopIfAccuracyIsViolated = true

BeginMissionSequence
```

```
Propagate aProp(aSat) {aSat.ElapsedDays = .2}
```

Force Model

Overview

A **ForceModel** is a model of the environmental forces and dynamics that affect the motion of a spacecraft. GMAT supports numerous force models such as point mass and spherical harmonic gravity models, atmospheric drag, solar radiation pressure, tide models, and relativistic corrections. A **ForceModel** is configured and attached to the **Propagator** object (see the **Propagator** object for differences between script and GUI configuration when configuring a **Propagator**). The **Propagator**, along with the **Propagate** command, uses a **ForceModel** to numerically solve the orbital equations of motion (forwards or backwards in time) using the forces configured in the **ForceModel** object, and may include thrust terms in the case of powered flight. See the discussion below for detailed information on how to configure force models for your application. This resource cannot be modified in the Mission Sequence.

See Also: Propagator

Fields

Option	Description
CentralBody	The central body of propagation. **CentralBody** must be a celestial body and cannot be a **LibrationPoint**, **Barycenter**, **Spacecraft**, or other special point. **Data Type**: Resource reference **Allowed Values**: **CelestialBody** **Access**: set **Default Value**: **Earth** **Units**: N/A **Interfaces**: GUI, script
Drag	Deprecated. This field has been replaced with **Drag.AtmosphereModel**.
Drag.AtmosphereModel	Specifies the atmosphere model used in the drag force. This field is only active if there is a **PrimaryBody**. **Data Type**: Enumeration **Allowed Values**: If **PrimaryBody** is **Earth**: **None**, **JacchiaRoberts**, **MSISE86**, **MSISE90** (with plugin), **NRLMSISE00** (with plugin) If **PrimaryBody** is **Mars**: **None**, **MarsGRAM2005** (with plugin) **Access**: set **Default Value**: **None** **Units**: N/A **Interfaces**: GUI, script

Option	Description
Drag.DensityModel	Enabled when **Drag.AtmosphereModel** is **Mars-GRAM2005**. Specifies the Mars-GRAM density model to use. **Mean** is mean density with any optional wave model perturbations enabled by the input file. **High** is **Mean** density plus 1 standard deviation. **Low** is **Mean** density minus 1 standard deviation. **Data Type**: Enumeration **Allowed Values**: **High**, **Low**, **Mean** **Access**: set **Default Value**: **Mean** **Units**: N/A **Interfaces**: script
Drag.F107	The instantaneous value of solar flux at wavelength of 10.7 cm. This field is only active if there is a **PrimaryBody**. Realistic values for this seeting are 50 <= **Drag.F107** <= 400. **Data Type**: Real **Allowed Values**: **Drag.F107**>= 0 **Access**: set **Default Value**: 150 **Units**: W/m^2/Hz **Interfaces**: GUI, script
Drag.F107A	The average (monthly) value of solar flux at wavelength of 10.7 cm. This field is only active in the script if there is a **PrimaryBody**. Realistic values for this seeting are 50 <= **Drag.F107A** <= 400. **Data Type**: Real **Allowed Values**: **Drag.F107A**>=0 **Access**: set **Default Value**: 150 **Units**: W/m^2/Hz **Interfaces**: script

Option	Description
Drag.InputFile	Enabled when **Drag.AtmosphereModel** is **Mars-GRAM2005**. Path to the Mars-GRAM input namelist file that configures the model. See the MarsGRAM2005 section [298] for details on the individual settings in this file and how they are used by GMAT. Relative paths are relative to the GMAT `bin` directory. **Data Type**: String **Allowed Values**: Valid path to a Mars-GRAM input namelist file **Access**: set **Default Value**: `'../data/atmosphere/Mars-GRAM2005/inputstd0.txt'` **Units**: N/A **Interfaces**: script
Drag.MagneticIndex	The geomagnetic index (Kp) used in density calculations. Kp is a planetary 3-hour-average, geomagnetic index that measures magnetic effects of solar radiation. This field is only active if there is a **PrimaryBody**. **Data Type**: Real **Allowed Values**: 0 <= Real Number <= 9 **Access**: set **Default Value**: 3 **Units**: N/A **Interfaces**: script

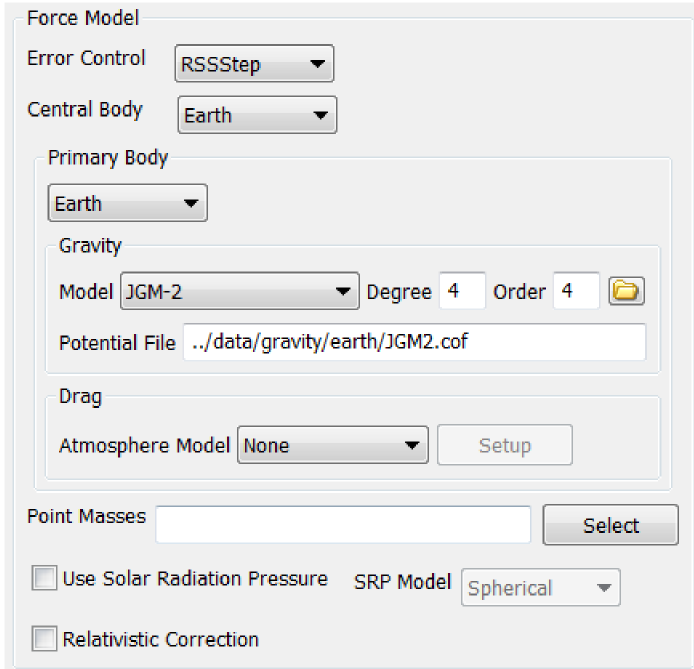
Option	Description
ErrorControl	Controls how error in the current integration step is estimated. The error in the current step is computed by the selection of **ErrorControl** and compared to the value set in the **Accuracy** field to determine if the step has an acceptable error or needs to be improved. All error measurements are relative error, however, the reference for the relative error changes depending upon the selection of **ErrorControl**. **RSSStep** is the Root Sum Square (RSS) relative error measured with respect to the current step. **RSSState** is the (RSS) relative error measured with respect to the current state. **LargestStep** is the state vector component with the largest relative error measured with respect to the current step. **LargestState** is the state vector component with the largest relative error measured with respect to the current state. Setting **ErrorControl** to **None** turns off error control and the integrator takes constant steps at the value defined by **InitialStepSize** on the numerical integrator. **Data Type** Enumeration **Allowed Values** **None**, **RSSStep**, **RSSState**, **LargestState**, **LargestStep** **Access** set **Default Value** **RSSStep** **Units** N/A **Interfaces** GUI, script
GravityField.Earth.EarthTideModel	Flag for type of Earth tide model. This field is always active but only used in the dynamics when there is a harmonic gravity model for Earth. **Data Type** Enumeration **Allowed Values** **None**, **SolidAndPole** **Access** set **Default Value** **None** **Units** N/A **Interfaces** script
GravityField.*PrimaryBodyName*.Degree	The degree of the harmonic gravity field. This field is only active if there is a **PrimaryBody**. **Data Type** Integer **Allowed Values** 0<**Degree**<Max Degree On File **Access** set **Default Value** 4 (When loading a custom file in the GUI, GMAT sets **Degree** to the max value on the file) **Units** N/A **Interfaces** GUI, script

Option	Description
GravityField. ***`PrimaryBodyName`*****.Order**	The order of the harmonic gravity field. This field is only active if there is a **PrimaryBody**. **Data Type** Integer **Allowed Values** 0<**Order**<Max Degree On File AND **Degree** <= **Order** **Access** set **Default Value** 4 (When loading a custom file in the GUI, GMAT sets **Order** to the max value on the file) **Units** N/A **Interfaces** GUI, script
GravityField. ***`PrimaryBodyName`*****.PotentialFile**	The gravity potential file. This field is only active if there is a **PrimaryBody**. See discussion below for detailed explanation of supported file types and how to configure gravity files. **Data Type** String **Allowed Values** path and name of .cof OR .grv file **Access** set **Default Value** JGM2.cof **Units** N/A **Interfaces** GUI, script
Model	A GUI list of "configured' gravity files defined in the file gmat_startup_file.txt. **Model** allows you to quickly choose between gravity files distributed with GMAT. For example, if **PrimaryBody** is Earth, you can select among Earth gravity models provided with GMAT such as **JGM-2** and **EGM-96**. If you select **Other**, you can provide the path and filename for a custom gravity file. **Data Type** String **Allowed Values** **JGM-2**, **JGM-3**, **EGM-96**, **Mars-50C**, **MGNP-180U** **Access** set,get **Default Value** **JGM-2** **Units** N/A **Interfaces** GUI

Option	Description
PointMasses	A list of celestial bodies to be treated as point masses in the force model. A body cannot be both the **PrimaryBody** and in the **PointMasses** list. An empty list "{}" removes all points masses from the list. **Data Type**: Resource array **Allowed Values**: array of **CelestialBodies** not selected as **PrimaryBody** **Access**: set **Default Value**: Empty List **Units**: N/A **Interfaces**: GUI, script
PrimaryBodies	A body modeled with a "complex" force model. A primary body can have an atmosphere and harmonic gravity model. Currently GMAT only supports one primary body per force model. The primary body must be the same as the **CentralBody**, and cannot be included in the **PointMasses** field. **Data Type**: Resource reference **Allowed Values**: **CelestialBody** not included in **PointMasses**. **Access**: set **Default Value**: Earth **Units**: N/A **Interfaces**: GUI, script
RelativisticCorrection	Sets relativistic correction on or off. **Data Type**: Enumeration **Allowed Values**: **On**, **Off** **Access**: set **Default Value**: **Off** **Units**: N/A **Interfaces**: GUI, script
SRP	Sets SRP force on or off. See the Remarks section for a detailed explanation of SRP configuration. The SRP model used is set in the SRP.Model field. **Data Type**: Enumeration **Allowed Values**: **On**, **Off** **Access**: set **Default Value**: Off **Units**: N/A **Interfaces**: GUI, script

Option	Description
SRP.Flux	The value of SRP flux at 1 AU. This field is only active in the script if **SRP** is on. **Data Type** Real **Allowed Values** 1200 <**SRP.Flux** < 1450 **Access** set **Default Value** 1367 **Units** W/m^2 **Interfaces** script
SRP.Flux_Pressure	The solar flux at 1 AU divided by the speed of light. This field is only active in the script if SRP is on. See the Remarks section for a detailed explanation of SRP configuration. **Data Type** Real **Allowed Values** 4.33e-6 < **SRP.Flux_Pressure** < 4.84e-6 **Access** set **Default Value** 4.55982118135874e-006 **Units** W *s/m^3 **Interfaces** script
SRP.Model	The model for SRP acceleration. **Data Type** Enumeration **Allowed Values** **Spherical,SPADFile** **Access** set **Default Value** Spherical **Units** N/A **Interfaces** GUI, script
SRP.Nominal_Sun	The value of one Astronomical Unit in km used in scaling SRP.Flux, which is flux at 1 AU, to the flux at spacecraft distance from sun. This field is only active in the script if SRP is on. See the Remarks section for a detailed explanation of SRP configuration. **Data Type** Real **Allowed Values** 135e6<**Nominal_Sun**<165e6 **Access** set **Default Value** 149597870.691 **Units** km **Interfaces** script

GUI



Settings for the **ForceModel** object.

Remarks

Overview of Primary Body/Central Body and Field Interactions

In GMAT, a primary body is a celestial body that is modeled with a complex force model which may include a spherical harmonic gravity model, tides, or drag. A body cannot appear in both the **PrimaryBodies** and **PointMasses** fields. GMAT currently requires that there are no more than one primary body per **ForceModel**, but this behavior will change in future versions and the user interface is designed to naturally support this future development area.

GMAT currently requires that the primary body is either the same as the **CentralBody** or set to **None**. If you change the **CentralBody** in the GUI, GMAT changes the primary body to **None**, and you can then select between **None** and the central body. When you select a primary body in the GUI, the **Gravity** and **Drag** fields activate and allow you to select models for those forces consistent with the body selected in the **PrimaryBodies** field. For example, if you select Earth as the primary body, you can only select Earth drag models in the **Drag.AtmosphereModel** field. See the field list above for available models.

Configuring Gravitational Models

GMAT supports point mass gravity, spherical harmonic, and Earth tide models. On a **Propagator**, all celestial bodies are classified into two mutually exclusive categories: **PrimaryBodies**, and **Point Masses**. To model a body as a point mass, add it to the **PointMasses** list. GMAT currently requires that there be only a single body in the **PrimaryBodies** list. When a primary body is selected, the **CentralBody** and primary body must be the same.

Bodies modeled as **PointMasses** use the gravitational parameter defined on the body (i.e. Earth.Mu) in the equations of motion. Bodies defined as **PrimaryBodies** use the constants defined on the potential file in the equations of motion. GMAT supports two gravity file formats: the .cof format and the STK .grv format. You can provide a custom potential file for your application as long as it is one of the supported formats. Potential files defined in the startup file are available in the **Model** list in the GUI. For example, the following lines in the startup file configure GMAT so that EGM96 is an available option for **Model** in the GUI when the primary body is Earth:

```
EARTH_POT_PATH          = DATA_PATH/gravity/earth/
EGM96_FILE              = EARTH_POT_PATH/EGM96.cof
```

Below is an example script snippet for configuring a custom gravity model including Earth tides.

```
Create ForceModel aForceModel
aForceModel.CentralBody = Earth
aForceModel.PrimaryBodies = {Earth}
aForceModel.GravityField.Earth.Degree = 21
aForceModel.GravityField.Earth.Order  = 21
aForceModel.GravityField.Earth.PotentialFile = 'c:\MyData\File.cof'
aForceModel.GravityField.Earth.EarthTideModel = 'SolidAndPole'
```

Configuring Drag Models

GMAT supports many density models for Earth including **Jacchia-Roberts** and various MSISE models. Density models for non-Earth bodies -- the Mars-GRAM model for example -- are included using custom plug-in components and are currently only supported in the script interface.

To configure Earth density models, select Earth as the primary body, In the GUI, this activates the **AtmosphereModel** list. You can configure the solar flux values using the **Setup** button next to the **AtmosphereModel** list after you have selected an atmosphere model. Below is an example script snippet for configuring the **NRLMSISE00** density model.

```
Create ForceModel aForceModel
GMAT aForceModel.PrimaryBodies = {Earth}
GMAT aForceModel.Drag.AtmosphereModel = NRLMSISE00
GMAT aForceModel.Drag.F107 = 145
GMAT aForceModel.Drag.F107A = 160
GMAT aForceModel.Drag.MagneticIndex = 4
```

Caution

Caution: GMAT uses the original single precision FORTAN code developed by the scientists who created the MSISE models. At low altitudes, the single precision density can cause numeric issues in the double precision integrator step size control and integration can be unacceptably slow. You can avoid the performance issue by using either fixed step integration or by using a relatively high **Accuracy** value such as 1e-8. You may need to experiment with the **Accuracy** setting to a value acceptable for your application.

Note that when you select **None** for **Drag.AtmosphereModel** , the fields **Drag.F107**, **Drag.F107A**, and **Drag.MagneticIndex** are inactive and must be removed from your script file to avoid parsing errors. When working in the GUI, this is performed automatically.

The table below describes the limits on altitude for drag models supported by GMAT.

Model	Theoretical Altitude (h) Limits	Comments
MSISE86	90 < h < 1000	GMAT will not allow propagation below 90 km altitude.
MSISE90	0 < h <1000	GMAT will allow propagation below 0 km altitude but results are non-physical.
NRLMSISE00	0 < h <1000	GMAT will allow propagation below 0 km altitude but results are non-physical.
JacchiaRoberts	h > 100	GMAT will not allow propagation below 100 km altitude.

MarsGRAM2005

When **PrimaryBody** is **Mars**, you can choose Mars-GRAM 2005 as your atmosphere model. This model is only available when the `libMarsGRAM` plugin is available and enabled in the GMAT startup file.

When using the **MarsGRAM2005** atmosphere model, three new fields are available in the script language (but not the GUI):

- **Drag.InputFile**
- **Drag.DensityModel**

See the Fields section for details on these fields.

In addition, the space weather fields are treated as follows:

- **Drag.F107**: value of 10.7 cm solar flux at 1 AU, as documented in the Fields section
- **Drag.F107A**: not used
- **Drag.MagneticIndex**: not used

The Mars-GRAM 2005 input file is a text file in FORTRAN NAMELIST format. Most variables in this file are passed directly to the Mars-GRAM model and are used as intended. However, some are replaced internally by GMAT-supplied values. The following table lists those input variables that are handled specially.

Input Variable	GMAT usage
(Unlisted)	Passed through to Mars-GRAM 2005 model
`DATADIR`	Always `'../data/atmosphere/MarsGRAM2005/binFiles'`
`GCMDIR`	Always `'../data/atmosphere/MarsGRAM2005/binFiles'`
`IERT`	Always 1 (Earth-receive time)
`IUTC`	Always 0 (TT time)

Input Variable	GMAT usage
MONTH	Replaced by current propagation epoch
MDAY	Replaced by current propagation epoch
MYEAR	Replaced by current propagation epoch
NPOS	Always 1
IHR	Replaced by current propagation epoch
IMIN	Replaced by current propagation epoch
ISEC	Replaced by current propagation epoch
LonEW	Always 1 (positive East)
F107	Replaced by value of **Drag.F107**
FLAT	Replaced by current propagation state
FLON	Replaced by current propagation state
FHGT	Replaced by current propagation state
MOLAhgts	Always 0 (reference ellipsoid)
iup	Always 0 (no output)
ipclat	Always 0 (planetographic input)
requa	Replaced by value of **Mars.EquatorialRadius**
rpole	Replaced by GMAT's value of Mars polar radius (calculated from **Mars.EquatorialRadius** and **Mars.Flattening**)

The input file is read by the Mars-GRAM 2005 model code, which has limited error checking. If the input file or data files are incorrect or missing, GMAT may exhibit unintended behavior. Note that local winds returned by the Mars-GRAM 2005 model are not included in GMAT's drag model.

Configuring an SRP Model

GMAT supports a spherical SRP model, and an SRP file for high fidelity SRP modelling. Both models use a dual cone model for central body shadowing of the spacecraft. See the Spacecraft Ballistic/Mass Properties documentation for configuring a SPAD file for a spacecraft . The script snippet below shows how to configure two **ForceModels**, one that use **Spherical** and on that uses a **SPADFile**.

```
% A spherical SRP model
Create ForceModel aForceModel_1
aForceModel_1.PrimaryBodies = {Earth}
aForceModel_1.SRP = On
aForceModel_1.SRP.Model = Spherical

% A SPAD SRP model
Create ForceModel aForceModel_2
aForceModel_2.PrimaryBodies = {Earth}
aForceModel_2.SRP = On
aForceModel_2.SRP.Model = SPADFile
```

You can define the solar flux using two approaches which are currently only supported in the script interface. One approach is to define the flux value using the **SRP.Flux** field and the value of an astronomical unit (in km) using the **Nominal_Sun** field as shown in the following example.

```
Create ForceModel aForceModel
aForceModel.PrimaryBodies = {Earth}
aForceModel.SRP = On
aForceModel.SRP.Flux = 1367
aForceModel.SRP.Nominal_Sun = 149597870.691
```

An alternative approach is to define the flux pressure at 1 astronomical unit using the **Flux_Pressure** field as shown below..

```
Create ForceModel aForceModel
aForceModel.PrimaryBodies = {Earth}
aForceModel.SRP = On
aForceModel.SRP.Flux_Pressure = 4.53443218374393e-006
aForceModel.SRP.Nominal_Sun = 149597870.691
```

If you mix flux settings, as shown in the example below, GMAT will use the last approach in the script. Here, GMAT will use the **Flux_Pressure** setting.

```
Create ForceModel aForceModel
aForceModel.PrimaryBodies = {Earth}
aForceModel.SRP = On
aForceModel.SRP.Flux = 1370
aForceModel.SRP.Nominal_Sun = 149597870
aForceModel.SRP.Flux_Pressure = 4.53443218374393e-006
```

Caution

Caution: GMAT's default option for configuring solar flux for an SRP model is to use **SRP.Flux** and **Nominal_Sun** fields. If you initially configured the **Flux_Pressure** field, when you save your mission via the save button in the toolbar, GMAT will write out **SRP.Flux** and **Nominal_Sun** values consistent with your setting of **Flux_Pressure**.

Variational Equations and the STM

GMAT can optionally propagate the orbit State Transition Matrix (STM). For more information on how to configure GMAT to compute the STM, see the Propagate command documentation.

> **Caution**
>
> Caution: GMAT allows you to propagate the State Transition Matrix (STM) along with the orbital state. However, not all variational terms are implemented for STM propagation. The following are implemented: point mass perturbation, spherical harmonics (with tide models), and solar radiation pressure. The following are NOT implemented: drag and relativistic terms, and finite burns. Additionally, the SRP variational term does not include the partial derivative of the percent shadow with respect to orbital state. This approximation is acceptable for orbits with short penumbra durations but is inaccurate for orbits that spend relatively long periods of time in penumbra.

Examples

A **ForceModel** for point mass propagation.

```
Create Spacecraft aSat

Create ForceModel aForceModel
aForceModel.CentralBody = Earth
aForceModel.PointMasses = {Earth}

Create Propagator aProp
aProp.FM = aForceModel

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = .2}
```

A **ForceModel** for high fidelity low Earth orbit propagation.

```
Create Spacecraft aSat

Create ForceModel aForceModel
aForceModel.CentralBody = Earth
aForceModel.PrimaryBodies = {Earth}
aForceModel.PointMasses = {Sun, Luna}
aForceModel.SRP = On
aForceModel.RelativisticCorrection = On
aForceModel.ErrorControl = RSSStep
aForceModel.GravityField.Earth.Degree = 20
aForceModel.GravityField.Earth.Order = 20
aForceModel.GravityField.Earth.PotentialFile = 'EGM96.cof'
aForceModel.GravityField.Earth.EarthTideModel = 'None'
aForceModel.Drag.AtmosphereModel = MSISE90
aForceModel.Drag.F107 = 150
aForceModel.Drag.F107A = 150
aForceModel.Drag.MagneticIndex = 3
aForceModel.SRP.Flux = 1359.388569998901
aForceModel.SRP.SRPModel = Spherical;
aForceModel.SRP.Nominal_Sun = 149597870.691

Create Propagator aProp
```

```
aProp.FM = aForceModel

BeginMissionSequence

Propagate aProp(aSat){aSat.ElapsedDays = .2}
```

A **ForceModel** that uses a SPAD SRP File.

```
Create Spacecraft aSpacecraft;
aSpacecraft.DryMass   = 2000
aSpacecraft.SPADSRPFile = '..\data\vehicle\spad\SphericalModel.spo'
aSpacecraft.SPADSRPScaleFactor = 1;

Create ForceModel aFM;
aFM.SRP = On;
aFM.SRP.SRPModel = SPADFile

Create Propagator aProp;
aProp.FM = aFM;

BeginMissionSequence

Propagate aProp(aSpacecraft) {aSpacecraft.ElapsedDays = 0.2}
```

A **ForceModel** for high fidelity lunar orbit propagation.

```
Create Spacecraft moonSat
GMAT moonSat.DateFormat = UTCGregorian
GMAT moonSat.Epoch.UTCGregorian = 01 Jun 2004 12:00:00.000
GMAT moonSat.CoordinateSystem = MoonMJ2000Eq
GMAT moonSat.DisplayStateType = Cartesian
GMAT moonSat.X = -1486.792117191545200
GMAT moonSat.Y = 0.0
GMAT moonSat.Z = 1486.792117191543000
GMAT moonSat.VX = -0.142927729144255
GMAT moonSat.VY = -1.631407624437537
GMAT moonSat.VZ = 0.142927729144255

Create CoordinateSystem MoonMJ2000Eq
MoonMJ2000Eq.Origin = Luna
MoonMJ2000Eq.Axes   = MJ2000Eq

Create ForceModel MoonLP165P
GMAT MoonLP165P.CentralBody = Luna
GMAT MoonLP165P.PrimaryBodies = {Luna}
GMAT MoonLP165P.SRP = On
GMAT MoonLP165P.SRP.Flux = 1367
GMAT MoonLP165P.SRP.Nominal_Sun = 149597870.691
GMAT MoonLP165P.Gravity.Luna.PotentialFile = ../data/gravity/luna/LP165P.cof
GMAT MoonLP165P.Gravity.Luna.Degree = 20
GMAT MoonLP165P.Gravity.Luna.Order = 20

Create Propagator RKV89
GMAT RKV89.FM = MoonLP165P
```

```
BeginMissionSequence

Propagate RKV89(moonSat) {moonSat.ElapsedSecs = 300}
```

SPK-Configured Propagator

Description

An SPK-configured **Propagator** propagates a spacecraft by interpolating user-provided SPICE kernels. You configure a **Propagator** to use an SPK kernel by setting the **Type** field to **SPK**. SPK kernels and the **NAIFId** are defined on the **Spacecraft** Resource. You control propagation, including stopping conditions, using the **Propagate** command. This resource cannot be modified in the Mission Sequence. However, you can do whole object assignment in the mission,(i.e. `myPropagator = yourPropagator`).

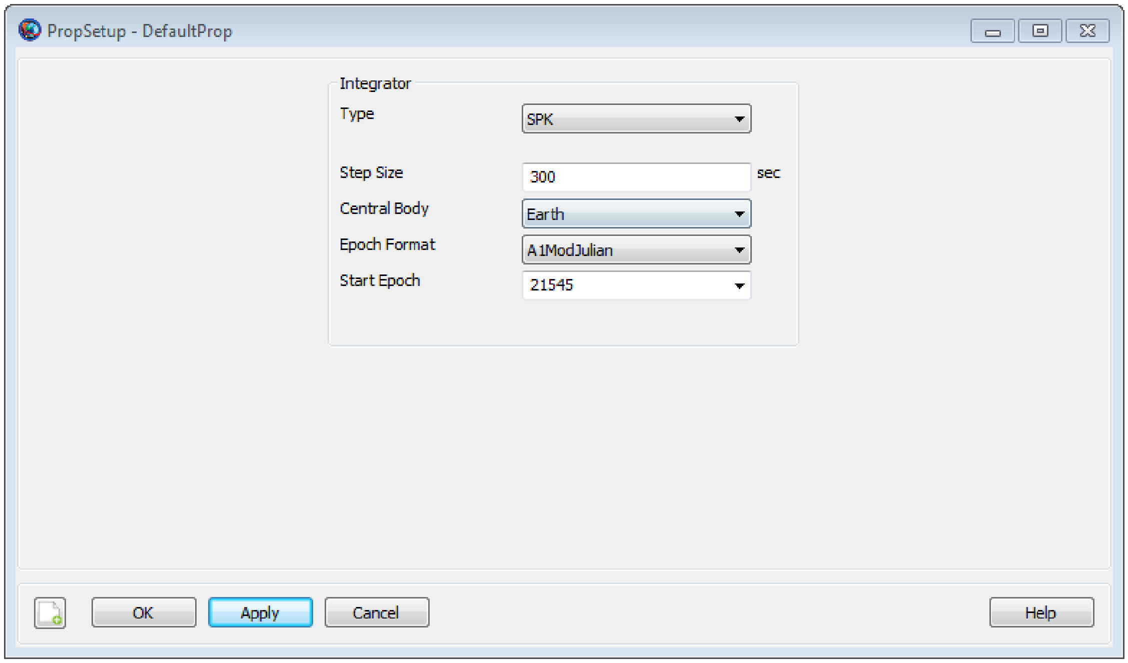
See Also: Spacecraft, Propagate

Fields

Field	Description
CentralBody	The central body of propagation. This field has no affect for SPK propagators. **Data Type** Resource reference **Allowed Values** Celestial body **Access** set **Default Value** **Earth** **Units** N/A **Interfaces** GUI, script
EpochFormat	Only used for an SPK propagator. The format of the epoch contained in the StartEpoch field. **Data Type** Enumeration **Allowed Values** **A1ModJulian**, **TAIModJulian**, **UTCModJulian**, **TTModJulian**, **TDBModJulian**, **A1Gregorian**, **TAIGregorian**, **TTGregorian**, **UTCGregorian**, **TDBGregorian** **Access** set **Default Value** **A1ModJulian** **Units** N/A unless Mod Julian and in that case Modified Julian Date **Interfaces** GUI, script

Field	Description
Start Epoch	Only used for an SPK propagator. The initial epoch of propagation. When an epoch is provided that epoch is used as the initial epoch. When the keyword "FromSpacecraft" is provided, the start epoch is inherited from the spacecraft. **Data Type** String **Allowed Values** "Gregorian: 04 Oct 1957 12:00:00.000 <= Epoch <= 28 Feb 2100 00:00:00.000 Modified Julian: 6116.0 <= Epoch <= 58127.5 or "FromSpacecraft" **Access** set **Default Value** 21545 **Units** N/A **Interfaces** GUI, script
StepSize	The step size for an SPK Propagator. **Data Type** Real **Allowed Values** Real > 0 **Access** set **Default Value** 300 **Units** N/A **Interfaces** GUI, script
Type	Specifies the integrator or analytic propagator used to model time evolution of spacecraft motion. **Data Type** Enumeration **Allowed Values** **PrinceDormand78**, **PrinceDormand45**, **RungeKutta89**,**RungeKutta68**, **RungeKutta56**, **BulirschStoer**, **AdamsBashforthMoulton**, **SPK** **Access** set **Default Value** **RungeKutta89** **Units** N/A **Interfaces** GUI, script

GUI



To configure a **Propagator** to use SPK files, on the **Propagator** dialog box, select **SPK** in the **Type** menu. There are four fields you can configure for an SPK propagator including **StepSize**, **CentralBody**, **EpochFormat**, and **StartEpoch**. Note that changing the **EpochFormat** setting converts the input epoch to the selected format. You can also type **`FromSpacecraft`** into the **StartEpoch** field and the **Propagator** will use the epoch of the **Spacecraft** as the initial propagation epoch.

Remarks

To use an SPK-configured **Propagator**, you must specify the SPK kernels and **NAIFId** on the **Spacecraft**, configure a **Propagator** to use SPK files as opposed to numerical methods, and configure the **Propagate** command to use the configured SPK propagator. The subsections and examples below discuss each of these items in detail.

Configuring Spacecraft SPK Kernels

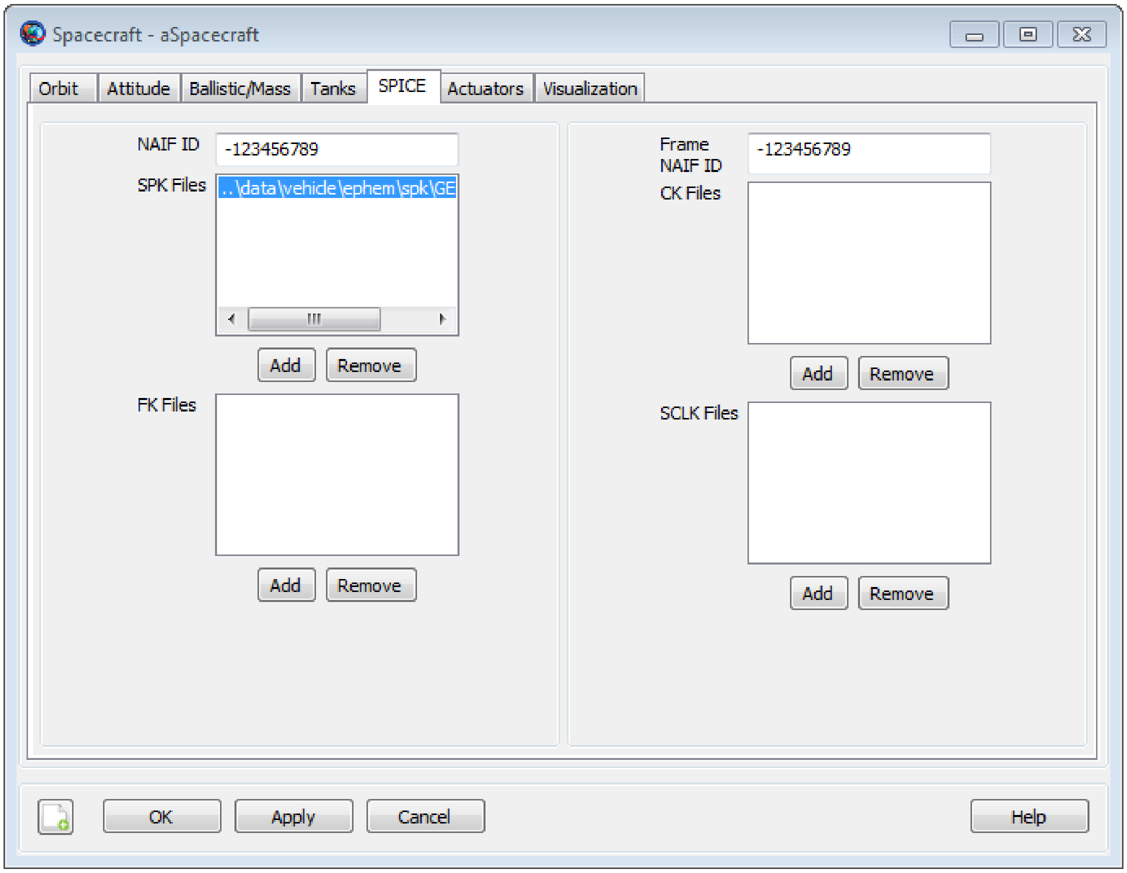
To use an SPK-configured **Propagator**, you must add the SPK kernels to the **Spacecraft** and define the pacecraft's **NAIFId**. SPK Kernels for selected spacecraft are available here. Two sample vehicle spk kernels, (GEOSat.bsp and MoonTransfer.bsp) are distributed with GMAT for example purposes. An example of how to add spacecraft kernels via the script interface is shown below.

```
Create Spacecraft aSpacecraft
GMAT aSpacecraft.NAIFId = -123456789
GMAT aSpacecraft.OrbitSpiceKernelName = {...
                                    '..\data\vehicle\ephem\spk\GEOSat.bsp'}
```

To add **Spacecraft** SPK kernals via the GUI:

1. On the **Spacecraft** dialog box, click the **SPICE** tab.
2. Under the **SPK Files** list, click **Add**.

3. Browse to locate and select the desired SPK file
4. Repeat to add all necessary SPK kernels
5. In the **NAIF ID** field, enter the spacecraft integer NAIF id number. Note: For a given mission, each spacecraft should have a unique NAIF ID if the spacecraft are propagated with an SPK propagator.



You can add more than one kernel to a spacecraft as shown via scripting below, where the files GEOSat1.bsp and GEOSat2.bsp are dummy file names used for example purposes only and are not distributed with GMAT. In the script, you can use relative path or absolute path to define the location of an SKP file. Relative paths are defined with respect to the GMAT bin directory of your local installation.

```
Create Spacecraft aSpacecraft
aSpacecraft.OrbitSpiceKernelName ={'C:\MyDataFiles\GEOSat1.bsp',...
                                   'C:\MyDataFiles\GEOSat2.bsp'}
```

Configuring an SPK Propagator

You can define the **StartEpoch** of propagation of an SPK-configured **Propagator** on either the **Propagator** Resource or inherit the **StartEpoch** from the **Spacecraft**. Below is a script snippet that shows how to inherit the **StartEpoch** from the **Spacecraft**. To inherit the **StartEpoch** from the **Spacecraft** using the GUI

1. Open the SPK propagator dialog box,

2. In the **StartEpoch** field., type **`FromSpacecraft`** or select **FromSpacecraft** from the drop-down menu

To explicitly define the **StartEpoch** on the **Propagator** Resource use the following syntax.

```
Create Propagator spkProp
spkProp.EpochFormat = 'UTCGregorian'
spkProp.StartEpoch = '22 Jul 2014 11:29:10.811'

Create Propagator spkProp2
spkProp2.EpochFormat = 'TAIModJulian'
spkProp2.StartEpoch = '23466.5'
```

To configure the step size, use the StepSize field.

```
Create Propagator spkProp
spkProp.Type = SPK
spkProp.StepSize = 300
```

Interaction with the Propagate Command

An SPK-configured **Propagator** works with the **Propagate** command in the same way numerical propagators work with the **Propagate** command with the following exceptions:

- If a **Propagate** command uses an SPK propagator, then you can only propagate one spacecraft using that propagator. You can however, mix SPK propagators and numeric propagators in a single propagate command.
- SPK-configured **Propagators** will not propagate the STM or compute the orbit Jacobian (A matrix).

In the example below, we assume a **Spacecraft** named **aSpacecraf**t and a **Propagator** named **spkProp** have been configured a-priori. An example command to propagate **aSpacecraft** to Earth Periapsis using **spkProp** is shown below.

```
Propagate spkProp(aSpacecraft) {aSpacecraft.Earth.Periapsis}
```

Below is a script snippet that demonstrates how to propagate backwards using an SPK propagator.

```
Propagate BackProp spkProp(aSpacecraft) {aSpacecraft.ElapsedDays = -1.5}
```

Behavior Near Ephemeris Boundaries

In general, ephemeris interpolation is less accurate near the boundaries of ephemeris files and we recommend providing ephemeris for significant periods beyond the initial and final epochs of your application for this and other reasons. When propagating near the beginning or end of ephemeris files, the use of the double precision arithmetic may affect results. For example, if an ephemeris file has has an initial epoch TDBModJulian = 21545.00037249916, and you specify the StartEpoch in UTC Gregorian, round off error in time conversions and/or truncation of time using the Gregorian format (only accurate to millisecond) may cause the requested epoch to fall slightly outside of the range provided on the ephemeris file. The best solution is to provide extra ephemeris data to avoid time issues at the boundaries and the more subtle issue of poor interpolation.

> **Warning**
>
> To locate requested stopping conditions, GMAT needs to bracket the root of the stopping condition function. Then, GMAT uses standard root finding techniques to locate the stopping condition to the requested accuracy. If the requested stopping condition lies at or near the beginning or end of the ephemeris data, then bracketing the stopping condition may not be possible without stepping off the ephemeris file which throw an error and execution will stop. In this case, you must provide more ephemeris data to locate the desired stopping condition.

Examples

Propagate a GEO spacecraft using an SPK-configured **Propagator**. Define the **StartEpoch** from the spacecraft. Note: the SPK kernel GEOSat.bsp is distributed with GMAT.

```
Create Spacecraft aSpacecraft;
aSpacecraft.Epoch.UTCGregorian = '02 Jun 2004 12:00:00.000'
aSpacecraft.NAIFId = -123456789
aSpacecraft.OrbitSpiceKernelName = {'..\data\vehicle\ephem\spk\GEOSat.bsp'}

Create Propagator spkProp
spkProp.Type = SPK
spkProp.StepSize = 300
spkProp.CentralBody = Earth
spkProp.StartEpoch = FromSpacecraft

Create OrbitView EarthView
EarthView.Add = {aSpacecraft, Earth, Luna}
EarthView.ViewPointVector = [ 30000 -20000 10000 ]
EarthView.ViewScaleFactor = 2.5

BeginMissionSequence
Propagate spkProp(aSpacecraft) {aSpacecraft.TA = 90}
Propagate spkProp(aSpacecraft) {aSpacecraft.ElapsedDays = 2.4}
```

Simulate a lunar transfer using an SPK-configured **Propagator**. Define **StartEpoch** on the **Propagator**. Note: the SPK kernel MoonTransfer.bsp is distributed with GMAT.

```
Create Spacecraft aSpacecraft
aSpacecraft.NAIFId = -123456789
aSpacecraft.OrbitSpiceKernelName = {...
                          '..\data\vehicle\ephem\spk\MoonTransfer.bsp'}

Create Propagator spkProp
spkProp.Type = SPK
spkProp.StepSize = 300
spkProp.CentralBody = Earth
spkProp.EpochFormat = 'UTCGregorian'
spkProp.StartEpoch = '22 Jul 2014 11:29:10.811'

Create OrbitView EarthView
EarthView.Add = {aSpacecraft, Earth, Luna}
```

```
EarthView.ViewPointVector = [ 30000 -20000 10000 ]
EarthView.ViewScaleFactor = 30

BeginMissionSequence
Propagate spkProp(aSpacecraft) {aSpacecraft.ElapsedDays = 12}
```

ReportFile

Report data to a text file

Description

The **ReportFile** resource allows you to write data to a text file that can be viewed after a mission run has been completed. GMAT allows you to report user-defined **Variables, Arrays**, **Strings** and **Object Parameters**. GMAT gives you control over setting formatting properties of the output report file that is generated at the end of a mission run. You can create **ReportFile** resource in either the GUI or script interface. GMAT also provides the option of when to write and stop writing data to a text file through the **Toggle On/Off** command. See the Remarks section below for detailed discussion of the interaction between **ReportFile** resource and **Toggle** command.

See Also: Report, Toggle

Fields

<table>
<tr><th>Field</th><th colspan="2">Description</th></tr>
<tr><td rowspan="7">Add</td><td colspan="2">Allows a user to add any number of user-defined Variables, Arrays, Strings or Object Parameters to a report file. To add multiple user-defined variables or parameters, enclose the reported values with curly brackets. Ex. <code>MyReportName.Add ={Sat.X, Sat.Y, Var1, Array(1,1)}</code>; The GUI's Selected Value(s) field is the equivalent of the script's Add field. This field cannot be modified in the Mission Sequence.</td></tr>
<tr><td>Data Type</td><td>Reference array</td></tr>
<tr><td>Allowed Values</td><td>Any user-defined parameter. Ex. Variables, Arrays, Strings, or Object parameters</td></tr>
<tr><td>Access</td><td>set</td></tr>
<tr><td>Default Value</td><td><code>{DefaultSC.A1ModJulian, DefaultSC.EarthMJ2000Eq.X}</code></td></tr>
<tr><td>Units</td><td>N/A</td></tr>
<tr><td>Interfaces</td><td>GUI, script</td></tr>
<tr><td rowspan="7">ColumnWidth</td><td colspan="2">This field defines the width of the data columns in a report file. The value for ColumnWidth is applied to all columns of data. For example, if ColumnWidth is set to 20, then each data column will be 20 white-spaces wide.</td></tr>
<tr><td>Data Type</td><td>Integer</td></tr>
<tr><td>Allowed Values</td><td>Integer > 1</td></tr>
<tr><td>Access</td><td>set</td></tr>
<tr><td>Default Value</td><td>23</td></tr>
<tr><td>Units</td><td>Characters</td></tr>
<tr><td>Interfaces</td><td>GUI, script</td></tr>
</table>

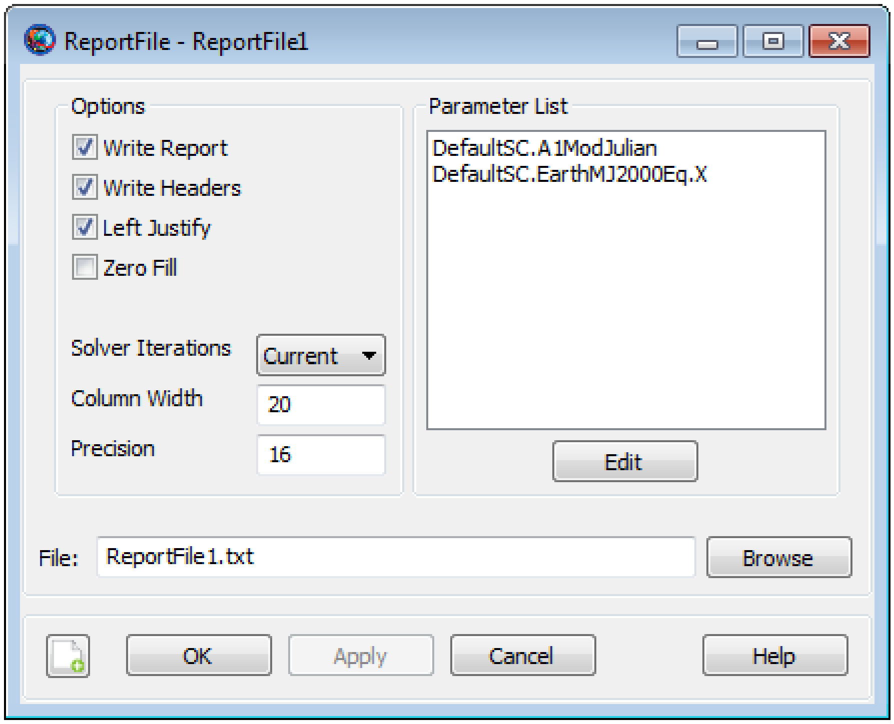
Field	Description
Filename	Allows the user to define the file path and file name for a report file. **Data Type** String **Allowed Values** Valid File Path and Name **Access** set **Default Value** `ReportFile1.txt` **Units** N/A **Interfaces** GUI, script
LeftJustify	When the **LeftJustify** field is set to **On**, then the data is left justified and appears at the left most side of the column. If the **LeftJustify** field is set to **Off**, then the data is centered in the column. **Data Type** Boolean **Allowed Values** On, Off **Access** set **Default Value** On **Units** N/A **Interfaces** GUI, script
Maximized	Allows the user to maximize the **ReportFile** window. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** true,false **Access** set **Default Value** false **Units** N/A **Interfaces** script
Precision	Allows the user to set the number of significant digits of the data written to a report. **Data Type** Integer **Allowed Values** Integer > 1 **Access** set **Default Value** 16 **Units** Same as variable being reported **Interfaces** GUI, script

Field	Description
RelativeZOrder	Allows the user to select which **ReportFile** to display first on the screen. The **ReportFile** with lowest **RelativeZOrder** value will be displayed last while **ReportFile** with highest **RelativeZOrder** value will be displayed first. This field cannot be modified in the Mission Sequence. **Data Type** Integer **Allowed Values** Integer ≥ 0 **Access** set **Default Value** 0 **Units** N/A **Interfaces** script
Size	Allows the user to control the display size of generated report file. First value in [0 0] matrix controls horizonal size and second value controls vertical size of report file window. This field cannot be modified in the Mission Sequence. **Data Type** Real array **Allowed Values** Any Real number **Access** set **Default Value** [0 0] **Units** N/A **Interfaces** script
SolverIterations	This field determines whether or not data associated with perturbed trajectories during a solver (**Targeter**, **Optimize**) sequence is written to a report file. When **SolverIterations** is set to **All**, all perturbations/iterations are written to a report file. When **SolverIterations** is set to **Current**, only current solution is written to a report file. When **SolverIterations** is set to **None**, this shows only final solution after the end of an iterative process and reports only final solution to a report file. **Data Type** Enumeration **Allowed Values** **All**, **Current**, **None** **Access** set **Default Value** **Current** **Units** N/A **Interfaces** GUI, script

Field	Description	
Upperleft	Allows the user to pan the generated report file display window in any direction. First value in [0 0] matrix helps to pan the report file window horizontally and second value helps to pan the window vertically. This field cannot be modified in the Mission Sequence.	
	Data Type	Real array
	Allowed Values	Any Real number
	Access	set
	Default Value	[0 0]
	Units	N/A
	Interfaces	script
WriteHeaders	This field specifies whether to include headers that describe the variables in a report file.	
	Data Type	Boolean
	Allowed Values	True, False
	Access	set
	Default Value	True
	Units	N/A
	Interfaces	GUI, script
WriteReport	This field specifies whether to write data to the report **FileName**.	
	Data Type	Boolean
	Allowed Values	True, False
	Access	set
	Default Value	True
	Units	N/A
	Interfaces	GUI, script
ZeroFill	Allows zeros to be placed in data written to a report to match set precision.	
	Data Type	Boolean
	Allowed Values	On, Off
	Access	set
	Default Value	Off
	Units	N/A
	Interfaces	GUI, script

GUI

Figure below shows default name and settings for the **ReportFile** resource:



Remarks

Behavior When using Filename field

GMAT allows you to specify the name of the report file in two ways. The default naming convention for a report file when using **FileName** field is shown below:

```
Create ReportFile aReport
aReport.Filename = 'ReportFile1.txt'
aReport.WriteReport = true
```

An alternate method for naming a report file is to name the file without using any single quotes around the report file's name.

```
Create ReportFile aReport
aReport.Filename = ReportFile1.txt
aReport.WriteReport = true
```

How data is reported to a report file

GMAT allows you to report data to a report file in two ways: You can use **ReportFile.Add** field or a **Report** command.

You can add data using the **.Add** field of **ReportFile** resource and this method reports data to the report file at each propagation step. Below is an example script snippet that shows how to report epoch and selected orbital elements using the **.Add** field:

```
Create Spacecraft aSat
Create ReportFile aReport
```

```
aReport.Add = {aSat.UTCGregorian aSat.Earth.SMA, aSat.Earth.ECC, ...
aSat.Earth.TA, aSat.EarthMJ2000Eq.RAAN}

Create Propagator aProp

BeginMissionSequence
Propagate aProp(aSat) {aSat.ElapsedSecs = 8640.0}
```

GMAT's **ReportFile.Add** field will not report selected data to the report file at each propagation step if **Propagate** command is not included under the **BeginMissionSequence**.

An alternative method of reporting data to the report file is via the **Report** command. Using the **Report** command allows you to report data to the report file at specific points in your mission. Below is an example script snippet that shows how to report epoch and selected orbital elements using the **Report** command:

```
Create Spacecraft aSat
Create ReportFile aReport

Create Propagator aProp

BeginMissionSequence

Report aReport aSat.UTCGregorian aSat.Earth.SMA aSat.Earth.ECC ...
aSat.Earth.TA aSat.EarthMJ2000Eq.RAAN

Propagate aProp(aSat) {aSat.ElapsedSecs = 8640.0}

Report aReport aSat.UTCGregorian aSat.Earth.SMA aSat.Earth.ECC ...
aSat.Earth.TA aSat.EarthMJ2000Eq.RAAN
```

Behavior and Interactions when using ReportFile Resource & Report Command

Suppose you utilize a **ReportFile** resource and opt not to write a report and select **false** for the field name **WriteReport**, as shown in the example below:

```
Create ReportFile aReport
aReport.Filename = ReportFile1.txt
aReport.Add = {aSat.A1ModJulian, aSat.Earth.SMA}
aReport.WriteReport = false
```

Now assume that at the same time, you decide to utilize **Report** command in the **Mission** tree, as shown in the example script snippet below:

```
BeginMissionSequence;
Report aReport aSat.A1ModJulian aSat.Earth.SMA aSat.Earth.ECC
Propagate aProp(aSat) {aSat.Earth.Periapsis}
Report aReport aSat.A1ModJulian aSat.Earth.SMA aSat.Earth.ECC
```

At this point, you may think that since false option is selected under the field name **WriteReport** in **ReportFile** resource, hence GMAT will not generate the report file called `ReportFile1.txt`. On the Contrary, GMAT will generate a report called `ReportFile1.txt`, but this report will only contain data that was requested using the **Report** command. `ReportFile1.txt` text file will contain epoch, semi-major-axis and eccentricity only at specific points of the mission.

Behavior when reporting data in Iterative Processes

GMAT allows you to specify how data is written to reports during iterative processes such as differential correction or optimization. **SolverIterations** field of **ReportFile** resource supports 3 options which are described in the table below:

SolverIterations options	Description
All	Shows only current iteration/perturbation after the end of an iterative process and reports current solution to a report file.
Current	Shows all iterations/perturbations in an iterative process and reports all iterations/perturbations to a report file.
None	Shows only final solution after the end of an iterative process and reports only final solution to a report file.

Where Reports are written

GMAT allows you to write reports to any desired path or location. You can do this by going to GMAT's startup file called `gmat_startup_file.txt` and define an absolute path under `OUTPUT_PATH`. This allows you to save report files in the directory of your choice as oppose to saving report files in GMAT's default Output folder. In **ReportFile.FileName** field, If no path is provided and only name of the report file is defined, then report files are written to GMAT's default Output folder. The default path where reports are written to is the Output folder located in the main directory where GMAT is installed.

Below is an example script snippet that shows where generated reports are written when only report file's name is provided under the **FileName** field. In this example, `'ReportFile1.txt'` report is written to the Output folder located in the main directory where GMAT is installed:

```
Create ReportFile aReport

aReport.Filename = 'ReportFile1.txt'
aReport.Add = {aSat.A1ModJulian, aSat.Earth.ECC}
```

An alternate method where report files can be written is by defining a relative path. You can define the relative path in GMAT's startup file `gmat_startup_file.txt` under `OUTPUT_PATH`. For example, you can set a relative path by setting `OUTPUT_PATH = C:/Users/rqureshi/Desktop/GMAT/mytestfolder/../output2/`. In this path, the syntax ".." means to "go up one level". After saving the startup file, when the script is executed, the generated report file named under **FileName** field will be written to a path `C:\Users\rqureshi\Desktop\GMAT\output2`.

Another method where report files can be written to is by defining an absolute path in GMAT's startup file `gmat_startup_file.txt` under `OUTPUT_PATH`. For example, you can set an absolute path by setting `OUTPUT_PATH = C:/Users/rqureshi/Desktop/GMAT/mytestfolder/`. When the script is executed, report file named under **FileName** field will be written to an absolute path `C:\Users\rqureshi\Desktop\GMAT\mytestfolder`.

Instead of defining a relative or an absolute path in GMAT's startup file, you can choose to define an absolute path under **FileName** field too. For example, if you set `ReportFile.FileName = C:\Users\rqureshi\Desktop\GMAT\mytestfolder\ReportFile.txt`, then report file will be saved in `mytestfolder`.

Behavior when using ReportFile Resource & Toggle Command

GMAT allows you to use **Toggle** command while using the **Add** field of **ReportFile** resource. When **Toggle Off** command is issued for a **ReportFile**, not data is sent to a report file until a **Toggle On** command is issued. Similarly, when a **Toggle On** command is used, data is sent to a report file at each integration step until a **Toggle Off** command is used.

Below is an example script snippet that shows how to use **Toggle Off** and **Toggle On** command while using the **ReportFile** resource. Spacecraft's cartesian position vector is reported to the report file.

```
Create Spacecraft aSat
Create Propagator aProp

Create ReportFile aReport
aReport.Filename = 'ReportFile1.txt'
aReport.Add = {aSat.UTCGregorian, aSat.EarthMJ2000Eq.X ...
aSat.EarthMJ2000Eq.Y aSat.EarthMJ2000Eq.Z}

BeginMissionSequence

Toggle aReport Off
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
Toggle aReport On
Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

Behavior When Specifying Empty Brackets in ReportFile's Add Field

When using **ReportFile.Add** field, GMAT does not allow brackets to be left empty. The brackets must always be populated with values that you wish to report. If brackets are left empty, then GMAT throws in an exception. Below is a sample script snippet that shows an example of empty brackets. If you were to run this script, then GMAT throws in an execption reminding you that brackets cannot be left empty.

```
Create Spacecraft aSat
Create Propagator aProp
Create ReportFile aReport

aReport.Add = {}

BeginMissionSequence
Propagate aProp(aSat) {aSat.ElapsedSecs = 8640.0}
```

Examples

Propagate an orbit and write cartesian state to a report file at every integrator step

```
Create Spacecraft aSat
```

```
Create Propagator aProp

Create ReportFile aReport
GMAT aReport.Filename = 'ReportFile1.txt'
aReport.Add = {aSat.EarthMJ2000Eq.X aSat.EarthMJ2000Eq.Y ...
aSat.EarthMJ2000Eq.Z aSat.EarthMJ2000Eq.VX ...
aSat.EarthMJ2000Eq.VY aSat.EarthMJ2000Eq.VZ}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedSecs = 8640.0}
```

Propagate an orbit for 1 day and write cartesian state to a report file at specific points in your mission

```
Create Spacecraft aSat
Create Propagator aProp

Create ReportFile aReport
GMAT aReport.Filename = 'ReportFile1.txt'

BeginMissionSequence

Report aReport aSat.EarthMJ2000Eq.X aSat.EarthMJ2000Eq.Y ...
aSat.EarthMJ2000Eq.Z aSat.EarthMJ2000Eq.VX ...
aSat.EarthMJ2000Eq.VY aSat.EarthMJ2000Eq.VZ

Propagate aProp(aSat) {aSat.ElapsedDays = 1}

Report aReport aSat.EarthMJ2000Eq.X aSat.EarthMJ2000Eq.Y ...
aSat.EarthMJ2000Eq.Z aSat.EarthMJ2000Eq.VX ...
aSat.EarthMJ2000Eq.VY aSat.EarthMJ2000Eq.VZ
```

SolarSystem

High level solar system configuration options

Description

The **SolarSystem** resource allows you to define global properties for the model of the solar system including the ephemeris source for built-in celestial bodies and selected settings to improve performance when medium fidelity modelling is acceptable for your application. This resource cannot be modified in the Mission Sequence.

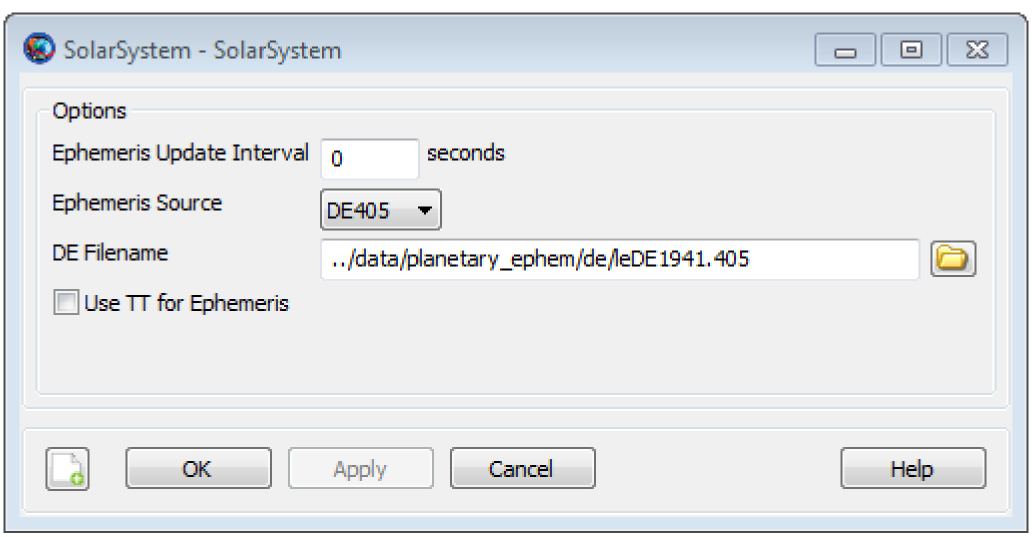
See Also: CelestialBody, LibrationPoint, Barycenter, CoordinateSystem

Fields

Field	Description	
DEFilename	The path and name of the DE file.	
	Data Type	String
	Allowed Values	Valid DE file
	Access	set
	Default Value	`../data/planetary_ephem/de/leDE1941.405`
	Units	N/A
	Interfaces	GUI, script
EphemerisSource	The ephemeris model for built-in celestial bodies.	
	Data Type	String
	Allowed Values	**DE405**, **DE421**, **DE424**, or **SPICE**
	Access	set
	Default Value	**DE405**
	Units	N/A
	Interfaces	GUI, script
EphemerisUpdateInterval	The time between time updates for celetial body ephemeris. For example, if **EphemerisUpdateInterval** = 60, if an ephemeris call is made at time t = 1200, and a subsequent call is made at time t = 1210, the same ephemeris will be returned for the second call. This option is for high speed, low fidelity modelling or for use when modelling orbits far from third body perturbation sources.	
	Data Type	Real
	Allowed Values	Real >= 0
	Access	set
	Default Value	0
	Units	N/A
	Interfaces	GUI, script

Field	Description
LSKFilename	The path and name of the SPK leap second kernel. **Data Type** String **Allowed Values** Valid SPK leapsecond kernel **Access** set **Default Value** `../data/time/naif0010.tls` **Units** N/A **Interfaces** GUI, script
SPKFilename	The path and name of the SPK orbit ephemeris kernel. **Data Type** String **Allowed Values** Valid SPK ephemeris kernel (.bsp) **Access** set **Default Value** `../data/planetary_ephem/spk/DE421AllPlanets.bsp` **Units** N/A **Interfaces** GUI, script
UseTTForEphemeris	Flag to use Terrestrial Time (TT) as input to the orbital ephemeris routines. When set to false, TDB is used. **Data Type** String **Allowed Values** **true,false** **Access** set **Default Value** **false** **Units** N/A **Interfaces** GUI, script

GUI

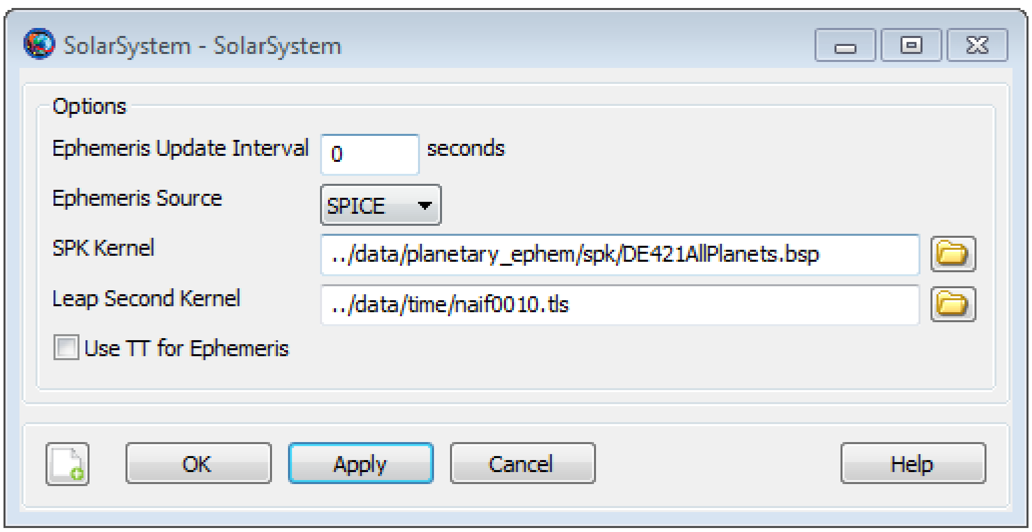


The **SolarSystem** dialog box allows you to configure global properties for solar system modelling and the default configuration is illustrated above. Use **EphemerisSource** to choose the ephemeris model for built-in celestial bodies. If you select either **DE405**, **DE421**, or **DE424** the dialog box above illustrates available options.

Warning

Caution: GMAT allows you to provide user-created DE or SPK kernel files but we recommend using the files distributed with GMAT. The files provided with GMAT have been extensively tested for consistency and accuracy with the original data provided by JPL and other models in GMAT. Using inconsistent ephemeris files or user-generated files can result in instability or numerical issues if the files are not generated correctly.

Changing the ephemeris source for an application is equivalent to making a fundamental change to the model of the solar system. We recommend selecting the **EphemerisSource** early in the analysis process and using that model consistently. In the event that an ephemeris model change is necessary, we recommend that you change the model in the script file and not via the GUI. We allow you to change **EphemerisSource** via the GUI for convenience in early design phases when rigorous consistency in modelling is less important.



If you select **SPICE** for **EphemerisSource**, the **SolarSystem** dialog box reconfigures to allow you to define the SPK Kernel and the leap second kernel.

Remarks

GMAT uses the ephemeris file selected in the **EphemerisSource** field for all built-in celestial bodies. For user-defined bodies, the ephemeris model is specified on the **CelestialBody** object.

- For more information on the DE files provided by JPL see here.
- For general information on SPICE ephemeris files see the JPL NAIF site.
- For information on the SPK kernel named `DE421AllPlanets.bsp` distributed with GMAT see the SPK.Readme located in `\data\planetary_ephem\spk` in the GMAT distribution.

Note: The **SolarSystem** and built-in **CelestialBody** resources require several hundred fields for full configuration. GMAT only saves non-default values for **SolarSystem** and **CelestialBody** to the script so that scripts are not populated with hundreds of default settings.

Examples

Use **DE421** for ephemeris.

```
GMAT SolarSystem.EphemerisSource = 'DE421'

Create Spacecraft aSpacecraft
Create Propagator aPropagator
aPropagator.FM = aForceModel
Create ForceModel aForceModel
aForceModel.PointMasses = {Luna, Sun}

BeginMissionSequence

Propagate aPropagator(aSpacecraft) {aSpacecraft.ElapsedSecs = 12000.0}
```

Use **SPICE** for ephemeris.

```
GMAT SolarSystem.EphemerisSource = 'SPICE'

Create Spacecraft aSpacecraft
Create Propagator aPropagator
aPropagator.FM = aForceModel
Create ForceModel aForceModel
aForceModel.PointMasses = {Luna, Sun}

BeginMissionSequence

Propagate aPropagator(aSpacecraft) {aSpacecraft.ElapsedSecs = 12000.0}
```

Spacecraft

A spacecraft model

Description

A **Spacecraft** resource is GMAT's spacecraft model and includes data and models for the spacecraft's orbit, epoch, attitude, and physical parameters (such as mass and drag coefficient), as well as attached hardware, including tanks and thrusters. The **Spacecraft** model also contains the data that configures how the **Spacecraft** 3-D CAD model is used in an **OrbitView**. **Spacecraft** has certain fields that can be set in the Mission Sequence and some that cannot. See the field tables on the pages below for more information.

GMAT's documentation for **Spacecraft** is extensive and is broken down into the following sections:

- Spacecraft Orbit State
- Spacecraft Epoch
- Spacecraft Ballistic/Mass Properties
- Spacecraft Attitude
- Spacecraft Hardware
- Spacecraft Visualization Properties

Spacecraft Attitude

The spacecraft attitude model

Description

GMAT models the orientation and rate of rotation of a spacecraft using several different mathematical models. Currently, GMAT assumes that a **Spacecraft** is a rigid body. The currently supported attitude models are **Spinner**, **CoordinateSystemFixed**, and **SpiceAttitude**. The **Spinner** model is a simple, inertially fixed spin axis model. The **CoordinateSystemFixed** model allows you to use any **CoordinateSystem** supported by GMAT as the attitude of a **Spacecraft**. The **SpiceAttitude** model allows you to define the **Spacecraft** attitude based on SPICE attitude kernels.

See Also: Spacecraft

Fields

Field	Description
AngularVelocityX	The x-component of **Spacecraft** body angular velocity expressed in the inertial frame. **AngularVelocityX** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** -∞ < Real< ∞ **Access** set,get **Default Value** 0 **Units** deg/sec **Interfaces** GUI, script
AngularVelocityY	The y-component of **Spacecraft** body angular velocity expressed in the inertial frame. **AngularVelocityY** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** -∞ < Real< ∞ **Access** set,get **Default Value** 0 **Units** deg/sec **Interfaces** GUI, script
AngularVelocityZ	The z-component of **Spacecraft** body angular velocity expressed in the inertial frame. **AngularVelocityZ** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** -∞ < Real< ∞ **Access** set,get **Default Value** 0 **Units** deg/sec **Interfaces** GUI, script

Field	Description
Attitude	The attitude mode for the **Spacecraft**. **Data Type** String **Allowed Values** **CoordinateSystemFixed**, **Spinner**, **SpiceAttitude, NadirPointing, CCSDS-AEM, PrecessingSpinner** **Access** set **Default Value** **CoordinateSystemFixed** **Units** N/A **Interfaces** GUI, script
AttitudeConstraintType	The constraint type for resolving attitude ambiguity. The attitude is computed such that the angle between the **BodyConstraintVector** and the constraint defined by **AttitudeConstraintType** is minimized. A **Velocity** constraint uses the inertial velocity vector expressed with respect to the **AttitudeReferenceBody**. An **OrbitNormal** constraint uses the orbit normal vector expressed with respect to the **AttitudeReferenceBody**. **AttitudeConstraintType** is used for the following attitude models: **NadirPointing**. **Data Type** Enumeration **Allowed Values** **Velocity**, **OrbitNormal** **Access** set **Default Value** OrbitNormal **Units** N/A **Interfaces** GUI, script
AttitudeCoordinateSystem	The **CoordinateSystem** used in attitude computations. The **AttitudeCoordinateSystem** field is only used for the following attitude models: **CoordinateSystemFixed**. **Data Type** String **Allowed Values** **CoordinateSystem** resource. **Access** set **Default Value** **EarthMJ2000Eq** **Units** N/A **Interfaces** GUI, script
AttitudeFileName	Path (optional) and name of CCSDS attitude ephemeris message file. If a path is not provided, and GMAT does not find the file in the current directory, then an error occurs and execution is halted. **Data Type** String **Allowed Values** AEM File **Access** set **Default Value** N/A **Units** N/A **Interfaces** GUI, script

Field	Description
AttitudeRate-DisplayState-Type	The attitude rate representation to display in the GUI and script file. **AttitudeRateDisplayType** is used for the following attitude models: **Spinner**. **Data Type** String **Allowed Values** **AngularVelocity**, **EulerAngleRates** **Access** set **Default Value** **AngularVelocity** **Units** N/A **Interfaces** GUI, script
AttitudeReferenceBody	The celestial body used to define nadir. **AttitudeReferenceBody** is used for the following attitude models: **NadirPointing**. **Data Type** Resource **Allowed Values** Celestial Body **Access** set **Default Value** Earth **Units** N/A **Interfaces** GUI, script
AttitudeSpiceKernelName	SPK Kernels for **Spacecraft** attitude. SPK atttitude kernels have extension ".BC". This field cannot be set in the Mission Sequence. An empty list unloads all kernels of this type on the **Spacecraft**. **Data Type** String array **Allowed Values** Array of attitude kernel files **Access** set **Default Value** empty array **Units** N/A **Interfaces** GUI, script
BodyAlignmentVectorX	The x-component of the alignment vector, expressed in the body frame, to align with the opposite of the radial vector. **BodyAlignmentVectorX** is used for the following attitude models: **NadirPointing**. **Data Type** Real **Allowed Values** $-\infty <$ Real $< \infty$ **Access** set **Default Value** 1 **Units** N/A **Interfaces** GUI, script

Field	Description
BodyAlignmentVectorY	The y-component of the alignment vector, expressed in the body frame, to align with the opposite of the radial vector. **BodyAlignmentVectorY** is used for the following attitude models: **NadirPointing**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set **Default Value** 0 **Units** N/A **Interfaces** GUI, script
BodyAlignmentVectorZ	The z-component of the alignment vector, expressed in the body frame, to align with the opposite of the radial vector. **BodyAlignmentVectorZ** is used for the following attitude models: **NadirPointing**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set **Default Value** 0 **Units** N/A **Interfaces** GUI, script
BodyConstraintVectorX	The x-component of the constraint vector, expressed in the body frame. See NadirPointing description for further details. **BodyConstraintVectorX** is used for the following attitude models: **NadirPointing**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set **Default Value** 0 **Units** N/A **Interfaces** GUI, script
BodyConstraintVectorY	The y-component of the constraint vector, expressed in the body frame. See NadirPointing description for further details. **BodyConstraintVectorY** is used for the following attitude models: **NadirPointing**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set **Default Value** 0 **Units** N/A **Interfaces** GUI, script

Field	Description
BodyConstraintVectorZ	The z-component of the constraint vector, expressed in the body frame. See NadirPointing description for further details. **BodyConstraintVectorZ** is used for the following attitude models: **NadirPointing**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set **Default Value** 1 **Units** N/A **Interfaces** GUI, script
BodySpinAxisX	The x-component of the spin axis, expressed in the body frame. **BodySpinAxisX** is used for the following attitude models: **PrecessingSpinner**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set **Default Value** 0 **Units** N/A **Interfaces** GUI, script
BodySpinAxisY	The y-component of the spin axis, expressed in the body frame. **BodySpinAxisY** is used for the following attitude models: **PrecessingSpinner**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set **Default Value** 0 **Units** N/A **Interfaces** GUI, script
BodySpinAxisZ	The z-component of the spin axis, expressed in the body frame. **BodySpinAxisZ** is used for the following attitude models: **PrecessingSpinner**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set **Default Value** 1 **Units** N/A **Interfaces** GUI, script

Field	Description
DCM11	Component (1,1) of the Direction Cosine Matrix. **DCM11** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** -1 <= Real <=1 **Access** set,get **Default Value** 1 **Units** N/A **Interfaces** GUI, script
DCM12	Component (1,2) of the Direction Cosine Matrix. **DCM12** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** -1 <= Real <=1 **Access** set,get **Default Value** 0 **Units** N/A **Interfaces** GUI, script
DCM13	Component (1,3) of the Direction Cosine Matrix. **DCM13** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** -1 <= Real <=1 **Access** set,get **Default Value** 0 **Units** N/A **Interfaces** GUI, script
DCM21	Component (2,1) of the Direction Cosine Matrix. **DCM21** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** -1 <= Real <=1 **Access** set,get **Default Value** 0 **Units** N/A **Interfaces** GUI, script
DCM22	Component (2,2) of the Direction Cosine Matrix. **DCM22** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** -1 <= Real <=1 **Access** set,get **Default Value** 1 **Units** N/A **Interfaces** GUI, script

Field	Description	
DCM23	Component (2,3) of the Direction Cosine Matrix. **DCM23** is used for the following Attitude models: **Spinner**.	
	Data Type	Real
	Allowed Values	-1 <= Real <=1
	Access	set,get
	Default Value	0
	Units	N/A
	Interfaces	GUI, script
DCM31	Component (3,1) of the Direction Cosine Matrix. **DCM31** is used for the following Attitude models: **Spinner**.	
	Data Type	Real
	Allowed Values	-1 <= Real <=1
	Access	set,get
	Default Value	0
	Units	N/A
	Interfaces	GUI, script
DCM32	Component (3,2) of the Direction Cosine Matrix. **DCM32** is used for the following Attitude models: **Spinner**.	
	Data Type	Real
	Allowed Values	-1 <= Real <=1
	Access	set,get
	Default Value	1
	Units	N/A
	Interfaces	GUI, script
DCM33	Component (3,3) of the Direction Cosine Matrix. **DCM33** is used for the following Attitude models: **Spinner**.	
	Data Type	Real
	Allowed Values	-1 <= Real <=1
	Access	set,get
	Default Value	1
	Units	N/A
	Interfaces	GUI, script
EulerAngle1	The value of the first Euler angle. **EulerAngle1** is used for the following Attitude models: **Spinner**.	
	Data Type	Real
	Allowed Values	$-\infty$ < Real < ∞
	Access	set,get
	Default Value	0
	Units	deg.
	Interfaces	GUI, script

Field	Description
EulerAngle2	The value of the second Euler angle. **EulerAngle2** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** $-\infty <$ Real $< \infty$ **Access** set,get **Default Value** 0 **Units** deg. **Interfaces** GUI, script
EulerAngle3	The value of the third Euler angle. **EulerAngle3** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** $-\infty <$ Real $< \infty$ **Access** set,get **Default Value** 0 **Units** deg. **Interfaces** GUI, script
EulerAngleRate1	The value of the first Euler angle rate. **EulerAngleRate1** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** $-\infty <$ Real $< \infty$ **Access** set,get **Default Value** 0 **Units** deg./sec. **Interfaces** GUI, script
EulerAngleRate2	The value of the second Euler angle rate. **EulerAngleRate2** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** $-\infty <$ Real $< \infty$ **Access** set,get **Default Value** 1 **Units** deg./sec. **Interfaces** GUI, script
EulerAngleRate3	The value of the third Euler angle rate. **EulerAngleRate3** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** $-\infty <$ Real $< \infty$ **Access** set,get **Default Value** 1 **Units** deg./sec. **Interfaces** GUI, script

Field	Description
FrameSpiceKernelName	SPK Kernels for **Spacecraft** body frame. SPK Frame kernels have extension ".TF". This field cannot be set in the Mission Sequence. An empty list unloads all kernels of this type on the **Spacecraft**. **Data Type** String array **Allowed Values** Array of .tf files. **Access** set **Default Value** emtpy array **Units** N/A **Interfaces** GUI, script
EulerAngleSequence	The Euler angle sequence used for Euler angle input and output.. **Data Type** String **Allowed Values** **123,231,312,132,321,213,121, 232,313,131,323,212** **Access** set **Default Value** 321 **Units** N/A **Interfaces** GUI, script
InitialPrecessionAngle	The initial precession angle. **InitialPrecessionAngle** is used for the following attitude models: **PrecessingSpinner**. **Data Type** Real **Allowed Values** $-\infty <$ Real $< \infty$ **Access** set **Default Value** 0 **Units** deg. **Interfaces** GUI, script
InitialSpinAngle	The initial attitude spin angle. **InitialSpinAngle** is used for the following attitude models: **PrecessingSpinner**. **Data Type** Real **Allowed Values** $-\infty <$ Real $< \infty$ **Access** set **Default Value** 0 **Units** deg. **Interfaces** GUI, script
NutationAngle	The attitude nutation angle. **NutationAngle** is used for the following attitude models: **PrecessingSpinner**. **Data Type** Real **Allowed Values** $-\infty <$ Real $< \infty$ **Access** set **Default Value** 15 **Units** deg. **Interfaces** GUI, script

Field	Description
NutationReferenceVectorX	The x-component of the nutation reference vector, expressed in the inertial frame. **NutationReferenceVectorX** is used for the following attitude models: **PrecessingSpinner**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set **Default Value** 0 **Units** N/A **Interfaces** GUI, script
NutationReferenceVectorY	The y-component of the nutation reference vector, expressed in the inertial frame. **NutationReferenceVectorY** is used for the following attitude models: **PrecessingSpinner**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set **Default Value** 0 **Units** N/A **Interfaces** GUI, script
NutationReferenceVectorZ	The z-component of the nutation reference vector, expressed in the inertial frame. **NutationReferenceVectorZ** is used for the following attitude models: **PrecessingSpinner**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set **Default Value** 1 **Units** N/A **Interfaces** GUI, script
MRP1	The value of the first modified Rodrigues parameter. **MRP1** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set,get **Default Value** 0 **Units** dimensionless **Interfaces** GUI, script

Field	Description
MRP2	The value of the second modified Rodrigues parameter. **MRP2** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set,get **Default Value** 0 **Units** dimensionless **Interfaces** GUI, script
MRP3	The value of the second modified Rodrigues parameter. **MRP2** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set,get **Default Value** 0 **Units** dimensionless **Interfaces** GUI, script
PrecessionRate	The rate of attitude precession. **InitialPrecessionAngle** is used for the following attitude models: **PrecessingSpinner**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set **Default Value** 0 **Units** deg./s **Interfaces** GUI, script
Q1	First component of quaternion. GMAT's quaternion representation includes the three "vector" components as the first three elements in the quaternion and the "rotation" component as the last element in the quaternion. **Q1** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set,get **Default Value** 0 **Units** dimensionless **Interfaces** GUI, script

Field	Description
Q2	Second component of quaternion. GMAT's quaternion representation includes the three "vector" components as the first three elements in the quaternion and the "rotation" component as the last element in the quaternion. **Q2** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set,get **Default Value** 0 **Units** dimensionless **Interfaces** GUI, script
Q3	Third component of quaternion. GMAT's quaternion representation includes the three "vector" components as the first three elements in the quaternion and the "rotation" component as the last element in the quaternion. **Q3** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set,get **Default Value** 0 **Units** dimensionless **Interfaces** GUI, script
Q4	Fourth component of quaternion. GMAT's quaternion representation includes the three "vector" components as the first three elements in the quaternion and the "rotation" component as the last element in the quaternion. **Q4** is used for the following Attitude models: **Spinner**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set,get **Default Value** 1 **Units** dimensionless **Interfaces** GUI, script

Field	Description
Quaternion	The quaternion vector. GMAT's quaternion representation includes the three "vector" components as the first three elements in the quaternion and the "rotation" component as the last element in the quaternion. **Quaternion** is used for the following Attitude models: **Spinner**. **Data Type** Real array **Allowed Values** Real array (length four) **Access** set,get **Default Value** [0 0 0 1]; **Units** dimensionless **Interfaces** GUI, script
SCClockSpiceKernelName	SPK Kernels for spacecraft clock. SPK clock kernels have extension ".TSC". This field cannot be set in the Mission Sequence. An empty list unloads all kernels of this type on the **Spacecraft**. An empty list unloads all kernels of this type on the **Spacecraft**. **Data Type** String array **Allowed Values** Array of .tsc file names **Access** set,get **Default Value** empty array **Units** N/A **Interfaces** GUI, script
SpinRate	The attitude spin rate. **SpinRate** is used for the following attitude models: **PrecessingSpinner**. **Data Type** Real **Allowed Values** -∞ < Real < ∞ **Access** set **Default Value** 10 **Units** deg./s **Interfaces** GUI, script

Remarks

Overview of Availble Attitude Models

GMAT supports many attitude models including the following: **CoordinateSystemFixed, SpiceAttitude**, **NadirPointing**, **CCSDS-AEM**, **PrecessingSpinner**, and **Spinner** (we recommend using thew new PrecessingSpinner model instead of Spinner). Different attitude models require different information to fully configure the model. For example, when you select the **CoordinateSystemFixed** model, the attitude and body rates are entirely determined by the **CoordinateSystem** model and defining Euler angles or angular velocity components are not required and have no effect. The reference tables above, and the detailed examples for each model type below, describe which fields are used for each model.

> **Note**
>
> GMAT attitude parameterizations such as the DCM rotate from inertial to body.

Overview of State Representations

Quaternion

The quaternion is a four element, non-singular attitude representation. GMAT's quaternion representation includes the three "vector" components as the first three elements in the quaternion and the "rotation" component as the last element in the quaternion. In assignment mode, you can set the quaternions element by element like this

```
aSpacecraft.Q1 = 0.5
aSpacecraft.Q2 = 0.5
aSpacecraft.Q3 = 0.5
aSpacecraft.Q4 = 0.5
```

or simultaneously set the entire quaternion like this

```
aSpacecraft.Quaternion = [0.5 0.5 0.5 0.5]
```

GMAT normalizes the quaternion before use. In command mode, you must enter the entire quaternion as a single vector to avoid scaling components of the quaternion before the entire quaternion is set.

DirectionCosineMatrix (DCM)

The Direction Cosine Matrix is a 3x3 array that contains cosines of the angles between the x, y, and z body axes and the x, y, and z inertial axes. The direction cosine matrix must be ortho-normal and you define the DCM element by element. Here is an example that shows how to define the attitude using the DCM.

```
aSpacecraft.DCM11 = 1
aSpacecraft.DCM12 = 0
aSpacecraft.DCM13 = 0
aSpacecraft.DCM21 = 0
aSpacecraft.DCM22 = 1
aSpacecraft.DCM23 = 0
aSpacecraft.DCM31 = 0
aSpacecraft.DCM32 = 0
aSpacecraft.DCM33 = 1
```

Euler Angles

Euler angles are a sequence of three rotations about coordinate axes to transform from one system to another system. GMAT supports all 12 Euler angle sequences. Here is an example setting attitude using a "321" sequence.

```
aSpacecraft.EulerAngleSequence = '321'
aSpacecraft.EulerAngle1 = 45
aSpacecraft.EulerAngle2 = 45
aSpacecraft.EulerAngle3 = 90
```

Warning

Caution: The Euler angles have singularities that can cause issues during modeling. We recommend using other representations for this reason.

Modified Rogriques parameters

The modified Rodgriques parameters are a modification of the Euer Axis/Angle representation. Specifically, the MRP vector is equal to nhat* tan(Euler Angle/4) where nhat is the unitized Euler Axis.

```
aSpacecraft.MRP1 = 0.2928932188134525
aSpacecraft.MRP2 = 0.2928932188134524
aSpacecraft.MRP3 = 1.149673585146546e-017
```

Euler Angles Rates

The Euler angle rates are the first time derivative of the Euler angles and can be used to define the body rates. Euler angle rates use the same sequence as the EulerAngles. The example below shows how to define the Euler angle rates for a spacecraft.

```
aSpacecraft.EulerAngleSequence = '321'
aSpacecraft.EulerAngleRate1 = -5
aSpacecraft.EulerAngleRate2 = 20
aSpacecraft.EulerAngleRate3 = 30
```

Angular Velocity

The angular velocity is the angular velocity of the spacecraft body with respect to the inertial frame, expressed in the inertial frame. The example below shows how to define the angular velocity for a spacecraft.

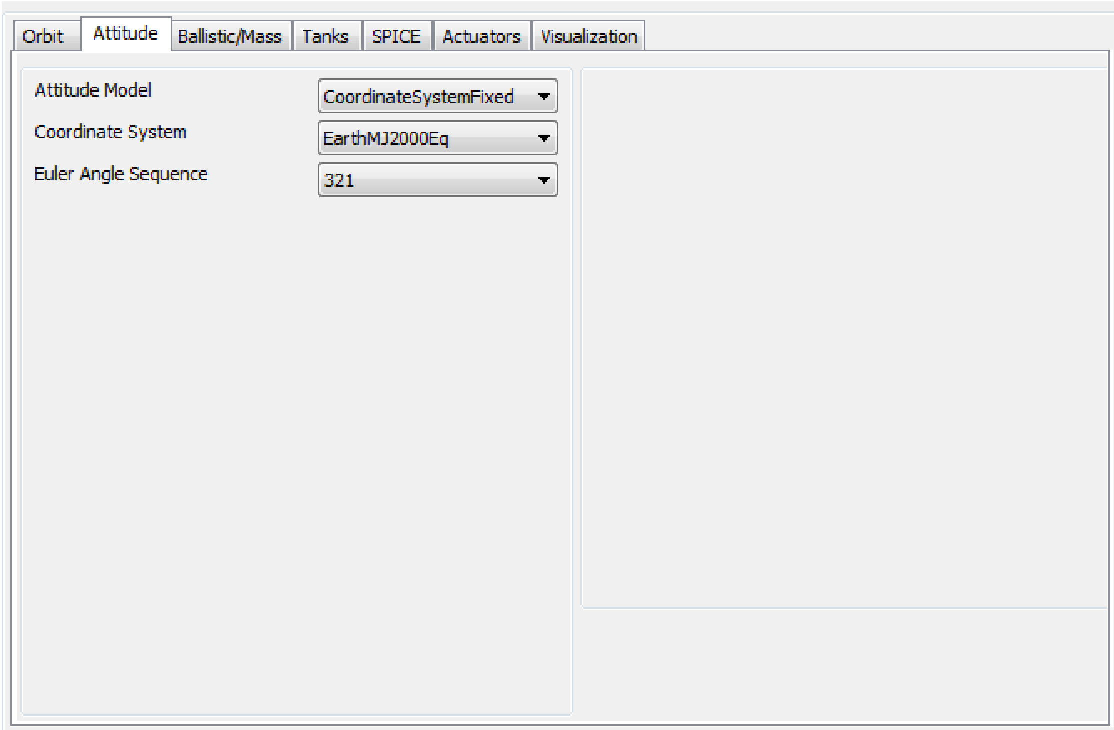
```
aSpacecraft.AngularVelocityX = 5;
aSpacecraft.AngularVelocityY = 10;
aSpacecraft.AngularVelocityZ = 5;
```

Coordinate System Fixed Attitude Model

The **CoordinateSystemFixed** model allows you to use any existing **CoordinateSystem** to define the attitude of a **Spacecraft**. The attitude uses the axes defined on the **CoordinateSystem** to compute the body fixed to inertial matrix and attitude rate parameters such as the angular velocity. To configure this attitude mode, select **CoordinateSystemFixed**, for **Attitude**. You can define the **EulerAngleSequence** used when outputting **EulerAngles** and **EulerAngle rates**.

Warning

For the **CoordinateSystemFixed** attitude model, the attitude is completely described by the selected coordinate system. If you are working in the script, setting attitude parameters (Euler Angles, Quaternion etc.) or setting attitude rate parameters such as (Euler Angle Rates etc.) has no effect.



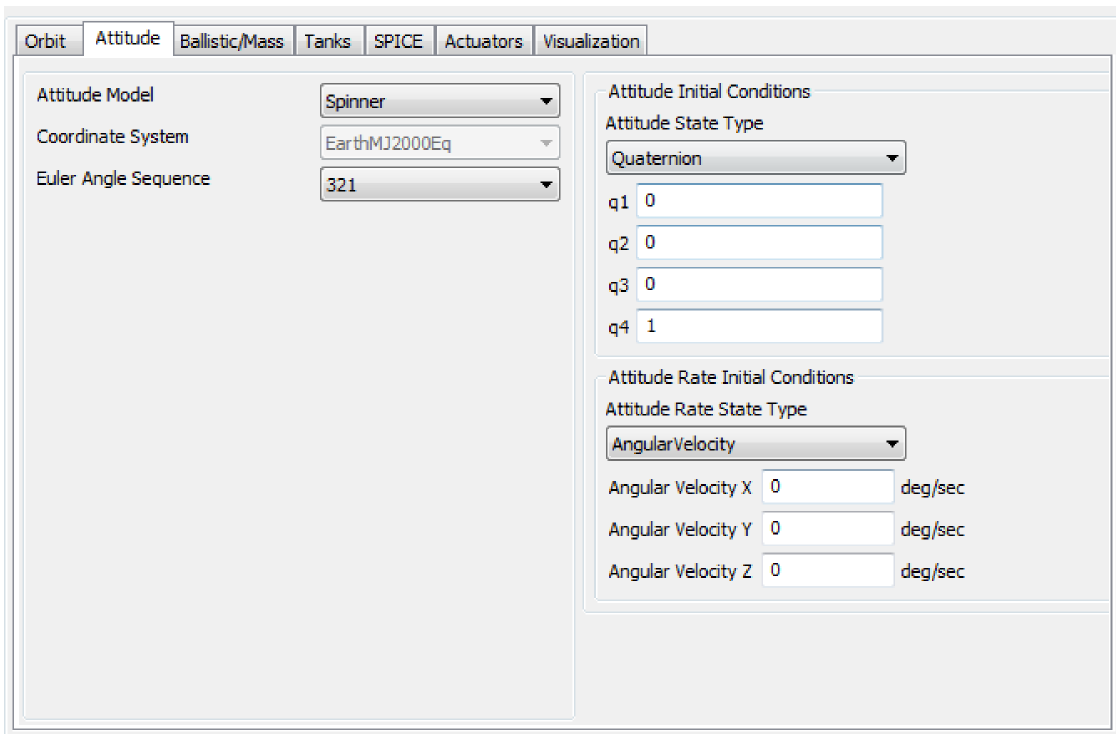
The script example below shows how to configure a **Spacecraft** to use a spacecraft VNB attitude system.

```
Create Spacecraft aSat
aSat.Attitude                  = CoordinateSystemFixed
aSat.ModelRotationZ            = -90
aSat.AttitudeCoordinateSystem = 'attCoordSys'

Create ForceModel Propagator1_ForceModel
Create Propagator Propagator1
Propagator1.FM         = Propagator1_ForceModel
Propagator1.MaxStep    = 10

Create CoordinateSystem attCoordSys
attCoordSys.Origin    = Earth
attCoordSys.Axes      = ObjectReferenced
attCoordSys.XAxis     = V
attCoordSys.YAxis     = N
attCoordSys.Primary   = Earth
attCoordSys.Secondary = aSat

Create OrbitView OrbitView1;
OrbitView1.Add                = {aSat, Earth}
OrbitView1.ViewPointReference = Earth
OrbitView1.ViewPointVector    = [ 30000 0 0 ]

BeginMissionSequence

Propagate Propagator1(aSat) {aSat.ElapsedSecs = 12000.0}
```

Spinner Attitude Model

The **Spinner** attitude model propagates the attitude assuming the spin axis direction is fixed in inertial space. We recommend using the newer PrecessingSpinner model instead of Spinner, and this model is maintained primarily for backwards compatibility. You define the attitude by providing initial body orientation and rates. GMAT propagates the attitude by computing the angular velocity and then rotates the **Spacecraft** about that angular velocity vector at a constant rate defined by the magnitude of the angular velocity. You can define the initial attitude using quaternions, Euler angles, the DCM, or the modified Rodriques parameters. You can define the attitude rates using Euler angles rates or angular velocity. When working with Euler angles, the rotation sequence is determined by the **EulerAngleSequence** field.

> **Warning**
>
> Caution: If you are working in the script, setting the **CoordinateSystem** for the Spinner attitude model has no effect.



The example below configures a **s**pacecraft to spin about the inertial z axis.

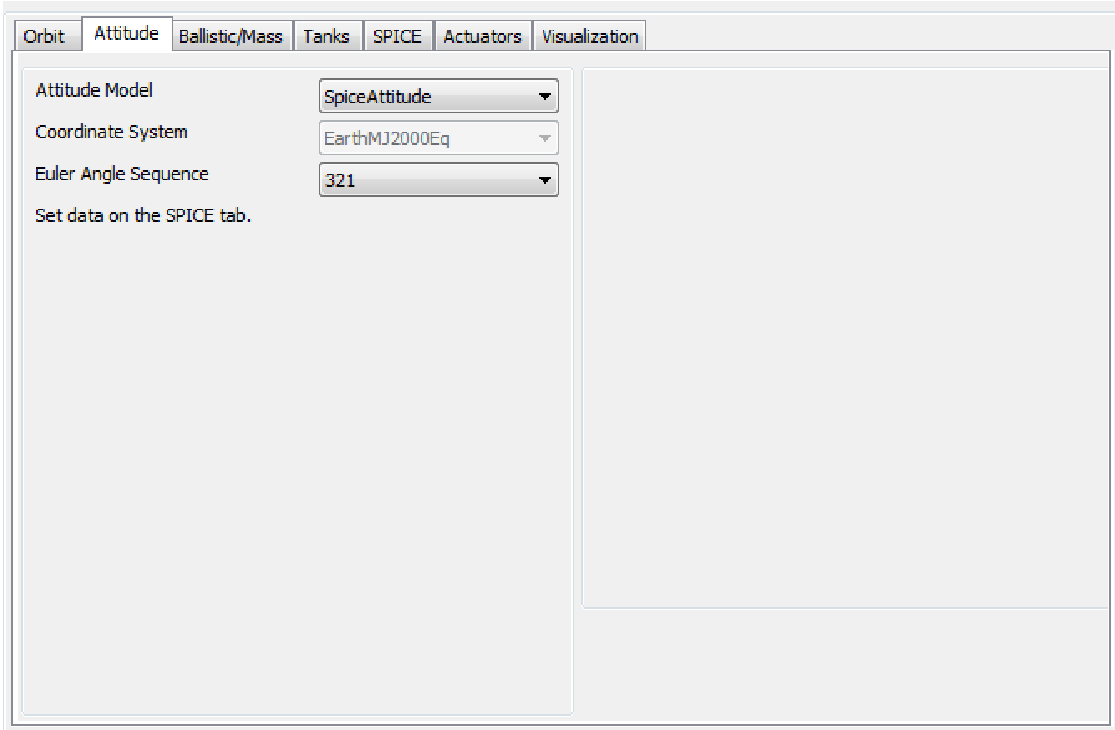
```
Create Spacecraft aSat;
aSat.Attitude          = Spinner
aSat.ModelRotationZ    = -90
aSat.AngularVelocityZ = 5

Create ForceModel Propagator1_ForceModel
Create Propagator Propagator1
GMAT Propagator1.FM         = Propagator1_ForceModel
```

```
GMAT Propagator1.MaxStep   = 10

Create CoordinateSystem attCoordSys
attCoordSys.Origin    = Earth
attCoordSys.Axes      = ObjectReferenced
attCoordSys.XAxis     = V
attCoordSys.YAxis     = N
attCoordSys.Primary   = Earth
attCoordSys.Secondary = aSat

Create OrbitView OrbitView1;
OrbitView1.Add                = {aSat, Earth}
OrbitView1.ViewPointReference = Earth
OrbitView1.ViewPointVector    = [ 30000 0 0 ]

BeginMissionSequence

Propagate Propagator1(aSat) {aSat.ElapsedSecs = 12000.0}
```

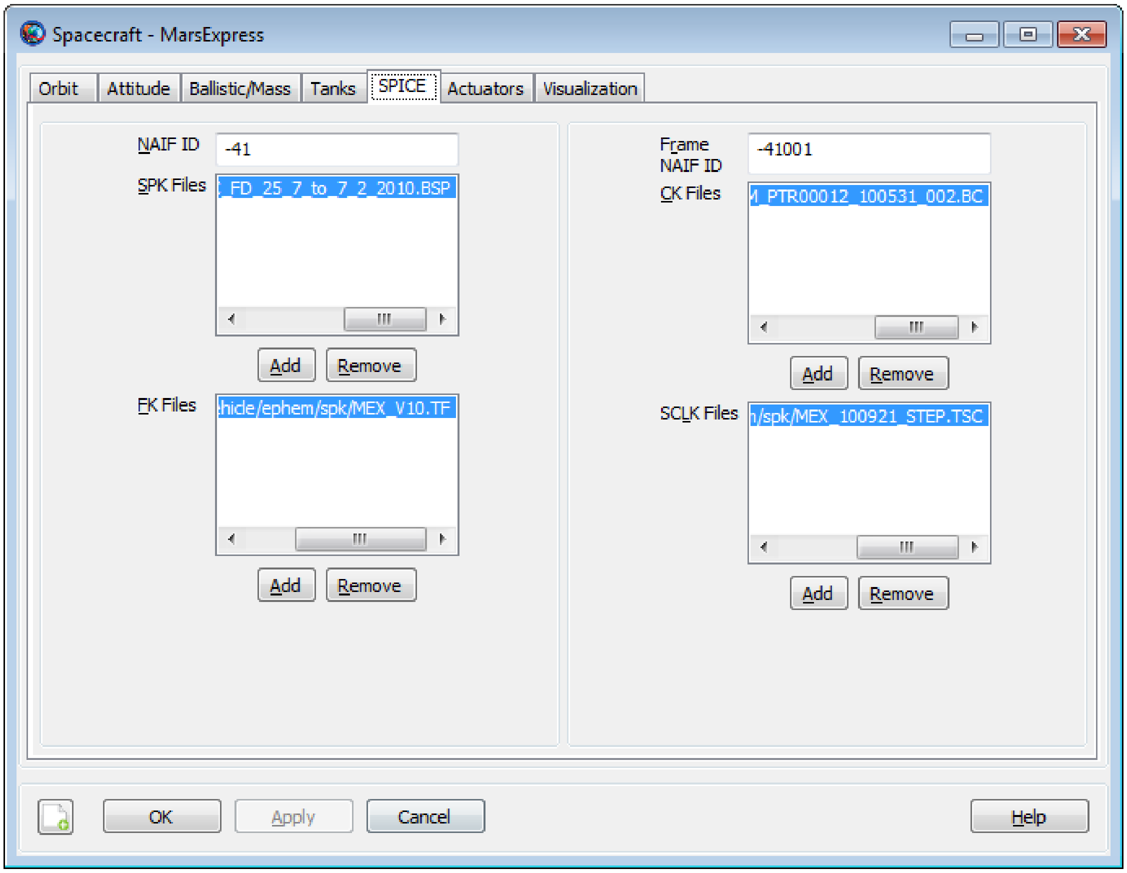
SPK Attitude Model

The **SpiceAttitude** model propagates the attitude using attitude SPICE kernels. To configure a **Spacecraft** to use SPICE kernels select **SpiceAttitude** for the **Attitude** field as shown below.

> **Warning**
>
> Caution: For the **SpiceAttitude** model, the attitude is completely described by the spice kernels. When working in the script, setting the **CoordinateSystem**, attitude parameters (**EulerAngles**, **Quaternion** etc.) or attitude rate parameters such as (**EulerAngleRates** etc.) has no effect.



You must provide three SPICE kernel types for the **SpiceAttitude** model: the attitude kernel (.bc file), the frame kernel (.tf file) and the spacecraft clock kernel (.tsc file). These files are defined on the **Spacecraft** SPICE tab as shown below. In addition to the kernels, you must also provide the **Spacecraft NAIFId** and the **NAIFIdReferenceFrame**. Below is an illustration of the SPICE tab configured for MarsExpress script found later in this section.



The example below configures a **Spacecraft** to use SPK kernels to propagator the attitude for Mars Express. The SPK kernels are distributed with GMAT.

```
Create Spacecraft MarsExpress
MarsExpress.NAIFId = -41
MarsExpress.NAIFIdReferenceFrame = -41001
MarsExpress.Attitude = 'SpiceAttitude'
MarsExpress.OrbitSpiceKernelName = ...
{'../data/vehicle/ephem/spk/MarsExpress_Short.BSP'}
MarsExpress.AttitudeSpiceKernelName = ...
{'../data/vehicle/ephem/spk/MarsExpress_ATNM_PTR00012_100531_002.BC'}
MarsExpress.SCClockSpiceKernelName = ...
{'../data/vehicle/ephem/spk/MarsExpress_MEX_100921_STEP.TSC'}
MarsExpress.FrameSpiceKernelName = ...
{'../data/vehicle/ephem/spk/MarsExpress_MEX_V10.TF'}

Create Propagator spkProp
spkProp.Type = SPK
spkProp.StepSize = 60
spkProp.CentralBody = Mars
spkProp.EpochFormat = 'UTCGregorian'
spkProp.StartEpoch = '01 Jun 2010 16:59:09.815'

Create CoordinateSystem MarsMJ2000Eq
MarsMJ2000Eq.Origin = Mars
```

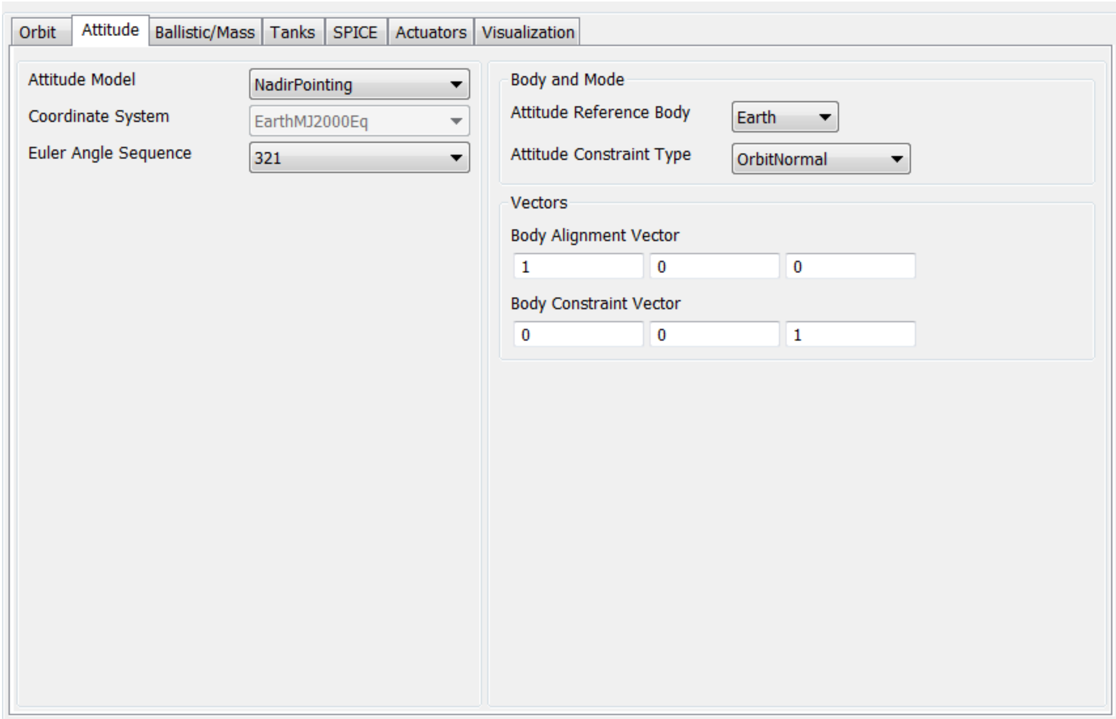
```
MarsMJ2000Eq.Axes = MJ2000Eq

Create OrbitView Enhanced3DView1
Enhanced3DView1.Add = {MarsExpress, Mars}
Enhanced3DView1.CoordinateSystem = MarsMJ2000Eq
Enhanced3DView1.ViewPointReference = Mars
Enhanced3DView1.ViewPointVector = [ 10000 10000 10000 ]
Enhanced3DView1.ViewDirection = Mars

BeginMissionSequence

Propagate spkProp(MarsExpress) {MarsExpress.ElapsedDays = 0.2}
```

Nadir Pointing Model

The **NadirPointing** attitude mode configures the attitude of a spacecraft to point a specified vector in the spacecraft body system in the nadir direction. The ambiguity in angle about the nadir vector is resolved by minimizing the angle between two constraint vectors. Note: the nadir pointing mode points the attitude in the negative radial direction (not opposite the planetodetic normal).

To configure which axis points to nadir, set the **AttitudeReferenceBody** field to the desired celestial body and define the body components of the alignment vector using the **BodyAlignmentVector** fields. To configure the constraint, set the **AttitudeConstraintType** field to the desired constraint type, and define the body components of the constraint using the **BodyConstraintVector** fields. GMAT supports two constraint types, **OrbitNormal** and **Velocity**, and in both cases the vectors are constructed using the inertial spacecraft state with respect to the **AttitudeReferenceBody**.

> **Warning**
>
> Attitude rates are not computed for the **NadirPointing** model. If you perform a computation that requires attitude rate information when using the **NadirPointing** mode, GMAT will throw an error message and execution will stop. Similarly, if the definitions of the **BodyAlignmentVector** and **BodyConstraintVector** fields result in an undefined attitude, an error message is thrown and execution will stop.

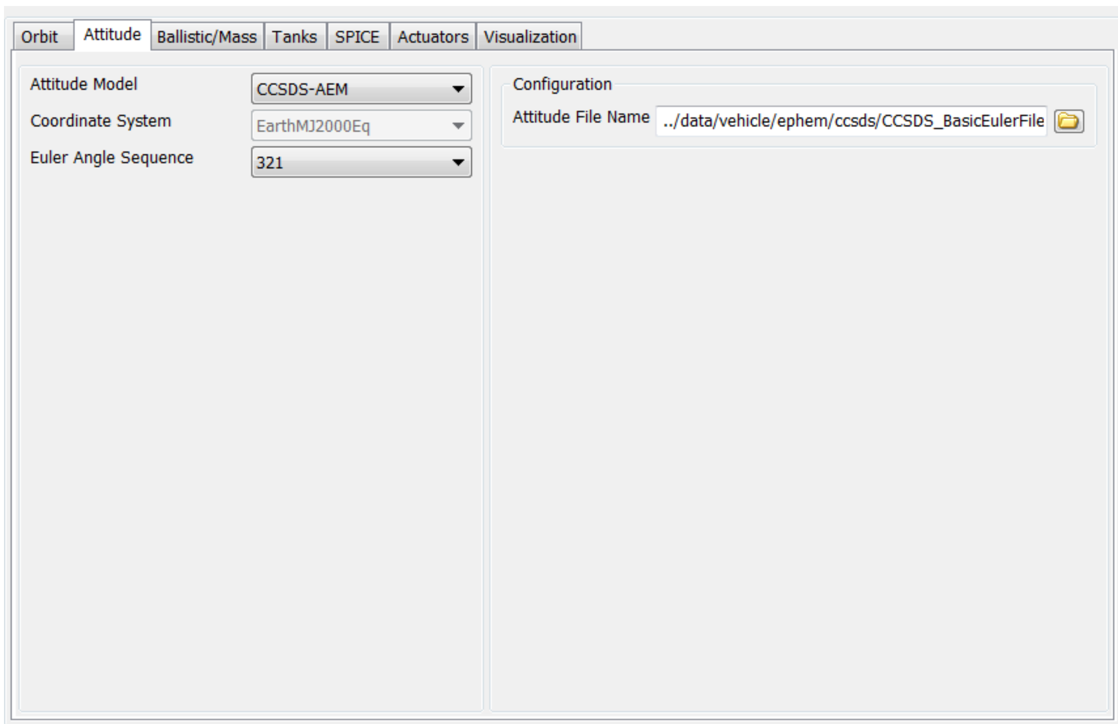


The script example below shows how to configure a **Spacecraft** to use an Earth **NadirPointing** attitude system where the body y-axis points nadir and the angle between the body x-axis and the orbit normal vector is a minimum.

```
Create Spacecraft aSat;
GMAT aSat.Attitude                  = NadirPointing;
GMAT aSat.AttitudeReferenceBody     = Earth
GMAT aSat.AttitudeConstraintType    = OrbitNormal
GMAT aSat.BodyAlignmentVectorX  = 0
GMAT aSat.BodyAlignmentVectorY  = 1
GMAT aSat.BodyAlignmentVectorZ  = 0
GMAT aSat.BodyConstraintVectorX = 1
GMAT aSat.BodyConstraintVectorX = 0
GMAT aSat.BodyConstraintVectorX = 0

Create ForceModel Propagator1_ForceModel
Create Propagator Propagator1
Propagator1.FM        = Propagator1_ForceModel
Propagator1.MaxStep   = 10

Create OrbitView OrbitView1;
OrbitView1.Add                = {aSat, Earth}
OrbitView1.ViewPointReference = Earth
OrbitView1.ViewPointVector    = [ 30000 0 0 ]

BeginMissionSequence

Propagate Propagator1(aSat) {aSat.ElapsedSecs = 12000.0}
```

CCSDS Attitude Ephemeris Message

The CCSDS Attitude Ephemeris Message (AEM) is an ASCII standard for attitude ephemerides documented in "ATTITUDE DATA MESSAGES" RECOMMENDED STANDARD CCSDS 504.0-B-1. GMAT supports some, but not all, of the attitude messages defined in the standard. According to the CCSDS AEM specification, "The set of attitude data messages described in this Recommended Standard is the baseline concept for attitude representation in data interchange applications that are cross-supported between Agencies of the CCSDS." Additionally, the forward of the standard states "Derived Agency standards may implement only a subset of the optional features allowed by the Recommended Standard and may incorporate features not addressed by this Recommended Standard. See the details below for supported keyword types and details for creating AEM files that GMAT can use for attitude modelling.



An AEM file must have the format illustrated below described in Table 4-1 of the standard. The header section contains high level information on the version, originator, and date. The body of the file is composed of paired blocks of Metadata and data. The Metadata sections contain information on the data such as the first and last epoch of the block, the time system employed, the reference frames, the attitude type (quaternion, Euler Angle, etc.) and many other items documented in later sections. The data sections contain lines of epoch and attitude data.

Item			Obligatory?
Header			Yes
Body	Segment 1	Metadata 1	Yes
		Data 1	
	Segment 2	Metadata 2	No
		Data 2	
	. . .	. . .	No
	Segment n	Metadata n	No
		Data n	

An example CCSDS AEM file is shown below

```
CCSDS_AEM_VERS = 1.0
CREATION_DATE = 2002-11-04T17:22:31
ORIGINATOR = NASA/JPL

META_START
COMMENT This file was produced by M.R. Somebody, MSOO NAV/JPL, 2002 OCT 04.
COMMENT It is to be used for attitude reconstruction only.
COMMENT  The relative accuracy of these attitudes is 0.1 degrees per axis.
OBJECT_NAME = MARS GLOBAL SURVEYOR
OBJECT_ID = 1996-062A
CENTER_NAME = mars barycenter
REF_FRAME_A = EME2000
REF_FRAME_B = SC_BODY_1
ATTITUDE_DIR = A2B
TIME_SYSTEM = UTC
START_TIME = 1996-11-28T21:29:07.2555
USEABLE_START_TIME = 1996-11-28T22:08:02.5555
USEABLE_STOP_TIME = 1996-11-30T01:18:02.5555
STOP_TIME = 1996-11-30T01:28:02.5555
ATTITUDE_TYPE = QUATERNION
QUATERNION_TYPE = LAST
INTERPOLATION_METHOD = hermite
INTERPOLATION_DEGREE = 7
META_STOP

DATA_START
1996-11-28T21:29:07.2555 0.56748 0.03146 0.45689 0.68427
1996-11-28T22:08:03.5555 0.42319 -0.45697 0.23784 0.74533
1996-11-28T22:08:04.5555 -0.84532 0.26974 -0.06532 0.45652
< intervening data records omitted here >
1996-11-30T01:28:02.5555 0.74563 -0.45375 0.36875 0.31964
DATA_STOP

META_START
COMMENT This block begins after trajectory correction maneuver TCM-3.
OBJECT_NAME = mars global surveyor
OBJECT_ID = 1996-062A
CENTER_NAME = MARS BARYCENTER
```

```
REF_FRAME_A = EME2000
REF_FRAME_B = SC_BODY_1
ATTITUDE_DIR = A2B
TIME_SYSTEM = UTC
START_TIME = 1996-12-18T12:05:00.5555
USEABLE_START_TIME = 1996-12-18T12:10:00.5555
USEABLE_STOP_TIME = 1996-12-28T21:23:00.5555
STOP_TIME = 1996-12-28T21:28:00.5555
ATTITUDE_TYPE = QUATERNION
QUATERNION_TYPE = LAST
META_STOP

DATA_START
1996-12-18T12:05:00.5555 -0.64585 0.018542 -0.23854 0.72501
1996-12-18T12:10:05.5555 0.87451 -0.43475 0.13458 -0.16767
1996-12-18T12:10:10.5555 0.03125 -0.65874 0.23458 -0.71418
< intervening records omitted here >
1996-12-28T21:28:00.5555 -0.25485 0.58745 -0.36845 0.67394
DATA_STOP
```

CCSDS files require many keywords and fields, some are required for all file types, others are Situationally Required (SR) depending upon the type of file (i.e. If ATTITUDE_TYPE = QUATERNION, then QUATERNION_TYPE must be included). The tables below describe GMAT's implementation starting with header keywords

Keyword	Required	Description and Supported Values
CCSDS_AEM_VERS	Y	Format version in the form of 'x.y', where 'y' is incremented for corrections and minor changes, and 'x' is incremented for major changes. This particular line must be the first non-blank line in the file. In GMAT the version must be set to 1.0. If the version is not set to a supported version, then GMAT throws an exception. Example: CCSDS_AEM_VERS =1.0
COMMENT	N	Comments (allowed after AEM version number and META_START and before a data block of ephemeris lines). Each comment line shall begin with this keyword. GMAT does not use this field.
CREATION_DATE	Y	File creation date/time in one of the following formats: YYYY-MM-DDThh:mm:ss[.d?d] or YYYY-DDDThh:mm:ss[.d?d] where 'YYYY' is the year, 'MM' is the two-digit month, 'DD' is the two-digit day, 'DDD' is the threedigit day of year, 'T' is constant, 'hh:mm:ss[.d?d]' is the UTC time in hours, minutes, seconds, and optional fractional seconds. As many 'd' characters to the right of the period as required may be used to obtain the required precision. All fields require leading zeros. GMAT does not use this field.
ORIGINATOR	Y	Creating agency (value should be specified in an ICD). GMAT does not use this field.

MetaData Keywords are described in the table below.

Keyword	Required	Description and Supported Values
META_START	Y	The AEM message contains both metadata and attitude ephemeris data; this keyword is used to delineate the start of a metadata block within the message (metadata are provided in a block, surrounded by 'META_START' and 'META_STOP' markers to facilitate file parsing). This keyword must appear on a line by itself.
COMMENT	N	Comments allowed only at the beginning of the Metadata section. Each comment line shall begin with this keyword. GMAT does not use this. Example: COMMENT This is a comment

OBJECT_NAME	Y	Spacecraft name of the object corresponding to the attitude data to be given. There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the SPACEWARN Bulletin, which include the Object name and international designator of the participant.
		
		Example:
		
		OBJECT_NAME = EUTELSAT
		
		Note: GMAT does not use this field. In GMAT, you associate a file with a particular spacecraft by configuring a particular spacecraft to use the file as shown below.
		
		`Create Spacecraft aSat`
		`aSat.Attitude = CCSDS-AEM`
		`aSat.AttitudeFileName = myFile.aem`

OBJECT_ID	Y	Spacecraft identifier of the object corresponding to the attitude data to be given. See the AEM specification for recommendations for spacecraft Ids. GMAT does not use this field.
CENTER_NAME	N	Origin of reference frame, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this the value for 'CENTER_NAME' is subject to the same rules as for 'OBJECT_NAME'). There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the NASA/JPL Solar System Dynamics Group . GMAT does not use this field.

Keyword	Required	Description and Supported Values
REF_FRAME_A	Y	The name of the reference frame specifying one frame of the transformation, whose direction is specified using the keyword ATTITUDE_DIR. The full set of values is enumerated in annex A of the AEM standard, with an excerpt provided in the 'Values / Examples' column. In GMAT, REF_FRAME_A can be any of the following and must be different than REF_FRAME_B: EME2000, SC_BODY_1 Example: REF_FRAME_A = EME2000 REF_FRAME_A = SC_Body_1
REF_FRAME_B	Y	The name of the reference frame specifying one frame of the transformation, whose direction is specified using the keyword ATTITUDE_DIR. The full set of values is enumerated in annex A of the AEM standard, with an excerpt provided in the 'Values / Examples' column. In GMAT, REF_FRAME_B can be any of the following and must be different than REF_FRAME_A: EME2000, SC_BODY_1 Example: REF_FRAME_A = EME2000 REF_FRAME_A = SC_Body_1
ATTITUDE_DIR	Y	Rotation direction of the attitude specifying from which frame the transformation is to: A2B specifies a transformation from the REF_FRAME_A to the REF_FRAME_B; B2A specifies a transformation from the REF_FRAME_B to the REF_FRAME_A. Examples: ATTITUDE_DIR = A2B ATTITUDE_DIR = B2A
TIME_SYSTEM	Y	Time system used for both attitude ephemeris data and metadata. GMAT supports the following options: UTC Example: TIME_SYSTEM = UTC

Keyword	Required	Description and Supported Values
START_TIME	Y	Start of TOTAL time span covered by attitude ephemeris data immediately following this metadata block. The START_TIME time tag at a new block of attitude ephemeris data must be equal to or greater than the STOP_TIME time tag of the previous block. See the CREATION_DATE specification for detailed information on time formats. Note: precision in the seconds place is only preserved to a few microseconds. Example: START_TIME = 1996-12-18T14:28:15.117
USEABLE_ START_TIME, USEABLE_ STOP_TIME	N	Optional start and end of USEABLE time span covered by attitude ephemeris data immediately following this metadata block. To allow for proper interpolation near the ends of the attitude ephemeris data block, it may be necessary, depending upon the interpolation method to be used, to utilize these keywords with values within the time span covered by the attitude ephemeris data records as denoted by the START/STOP_TIME time tags. If this is provided, GMAT only uses data in the USEABLE timespan for interpolation. If it is not provided, GMAT uses the data in the START_TIME/STOP_TIME segment for interpolation. See the CREATION_DATE specification for detailed information on time formats. Example: USEABLE_ START_TIME = 1996-12-18T14:28:15.117 USEABLE_ STOP_TIME = 1996-12-18T14:28:15.117
STOP_TIME	Y	End of TOTAL time span covered by the attitude ephemeris data immediately following this metadata block. The STOP_TIME time tag for the block of attitude ephemeris data must be equal to or less than the START_TIME time tag of the next block. See the CREATION_DATE specification for detailed information on time formats. Note: precision in the seconds place is only preserved to a few microseconds. Example: STOP_TIME = 1996-12-18T14:28:15.117
ATTITUDE_TYPE	Y	The format of the data lines in the message. GMAT supports the following types ATTITUDE_TYPE = QUATERNION ATTITUDE_TYPE = EULER_ANGLE

Keyword	Required	Description and Supported Values
QUATERNION_TYPE	SR	The placement of the scalar portion of the quaternion (QC) in the attitude data. This keyword is only used if ATTITUDE_TYPE denotes quaternion and in that case the field is required. Example: QUATERNION_TYPE = FIRST QUATERNION_TYPE = LAST
EULER_ROT_SEQ	SR	The rotation sequence of the Euler angles that rotate from REF_FRAME_A to REF_FRAME_B, or vice versa, as specified using the ATTITUDE_DIR keyword. This keyword is only used if ATTITUDE_TYPE denotes EulerAngles and in that case the field is required. Example: EULER_ROT_SEQ = 321
RATE_FRAME	N	GMAT does not use this field.
INTERPOLATION _METHOD	N	Recommended interpolation method for attitude ephemeris data in the block immediately following this metadata block. Note. GMAT uses spherical linear interpolation when ATTITUDE_TYPE = QUATERNION. GMAT uses lagrange interpolation for ATTITUDE_TYPE = EULER_ANGLE. Examples: INTERPOLATION _METHOD = LINEAR INTERPOLATION _METHOD = LAGRANGE
INTERPOLATION _DEGREE	SR	Recommended interpolation degree for attitude ephemeris data in the block immediately following this metadata block. It must be an integer value. This keyword must be used if the 'INTERPOLATION_METHOD' keyword is used. The field is only used for Lagrange Interpolation and in that case the value must be between 0 and 9. In the case order is zero for Lagrange interpolation, no interpolation is performed, and the attitude returned is the value immediately before the requested epoch. Example: INTERPOLATION _DEGREE = 7

Keyword	Re-quired	Description and Supported Values
META_STOP	Y	The end of a metadata block within the message. The AEM message contains both metadata and attitude ephemeris data; this keyword is used to delineate the end of a metadata block within the message (metadata are provided in a block, surrounded by 'META_START' and 'META_STOP' markers to facilitate file parsing). This keyword must appear on a line by itself.

Data Keywords are described in the table below.

Keyword	Re-quired	Description and Supported Values
DATA_START	Y	The start of an attitude data block within the message. The AEM message contains both metadata and attitude ephemeris data; this keyword is used to delineate the start of a data block within the message (data are provided in a block, surrounded by 'DATA_START' and 'DATA_STOP' markers to facilitate file parsing). This keyword must appear on a line by itself.
DATA_STOP	Y	The end of an attitude data block within the message. The AEM message contains both metadata and attitude ephemeris data; this keyword is used to delineate the end of a data block within the message (data are provided in a block, surrounded by 'DATA_START' and 'DATA_STOP' markers to facilitate file parsing). This keyword must appear on a line by itself.
QUATERNION	SR	Required when ATTITUDE_TYPE = QUATERNION. The general format of a quaternion data line is: Epoch, QC, Q1, Q2, Q3 or Epoch, Q1, Q2, Q3, QC Example: 2000-01-01T11:59:28.000 0.195286 -0.079460 0.3188764 0.92404936
EULER ANGLE	SR	Required when ATTITUDE_TYPE = EULER_ANGLE. The general format of an Euler angle data line is: Epoch, X_Angle, Y_Angle, Z_Angle. Example: 2000-001T11:59:28.000 35.45409 -15.74726 18.803877

Propagate a spacecraft's attitude using a CCSDS AEM file

```
Create Spacecraft aSat ;
GMAT aSat.Attitude = CCSDS-AEM;
GMAT aSat.AttitudeFileName = ...
        '../data/vehicle/ephem/ccsds/CCSDS_BasicEulerFile.aem'
```

```
Create Propagator aProp;

Create OrbitView a3DView
a3DView.Add = {aSat,Earth}

BeginMissionSequence;

Propagate aProp(aSat) {aSat.ElapsedSecs = 3600};
```

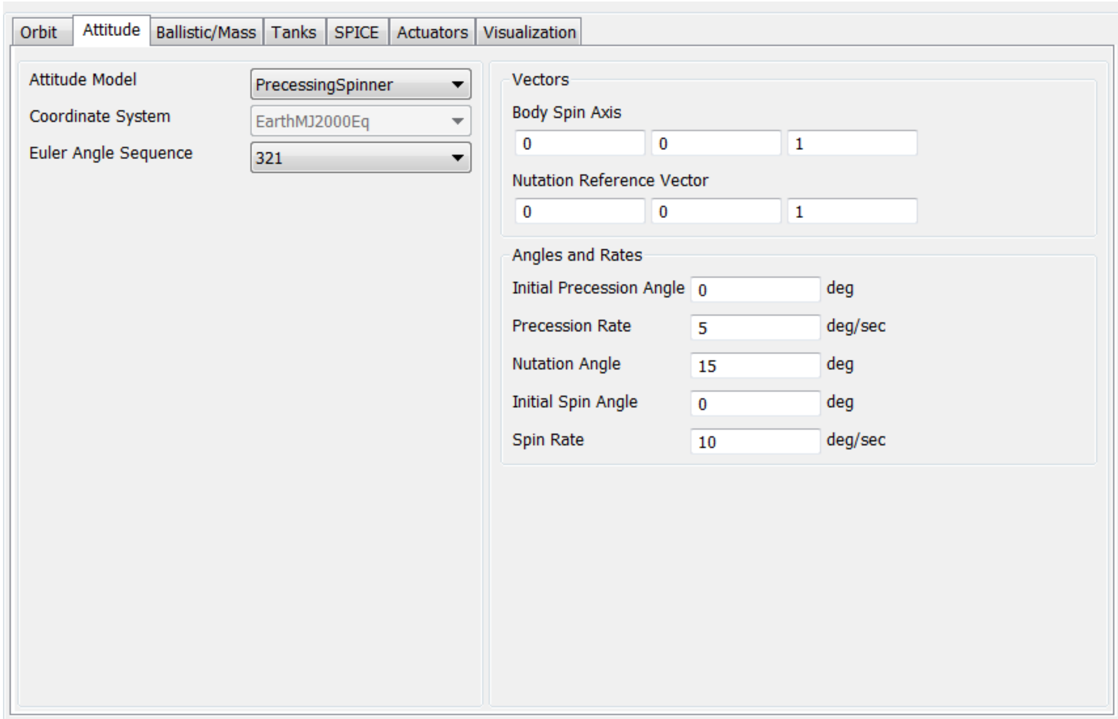
Precessing Spinner Model

The **PrecessingSpinner** attitude mode configures the attitude of a spacecraft to have steady-state precession motion with respect to a specified vector defined in the inertial frame. The spin axis must be provided in the spacecraft body frame.

To configure the spin axis of the spacecraft body, set the **BodySpinAxis**, which is expressed in the body frame, and define the reference vector of the steady-state precession motion using the **NutationReferenceVector**, which is expressed in the inertial frame. To configure the initial attitude of the spacecraft, set **InitialPrecessionAngle** to define the initial angle of the precession, set **InitialSpinAngle** to define the initial angle of the spin, and set **NutationAngle** to define the nutation angle which is constant. To configure the rate of precession and spin rate, set **PrecessingRate** and **SpinRate** which are constant.

Note

The **PrecessingSpinner** model uses the cross product of the **BodySpinAxis** axis and the inertial x-axis as a reference for the initial attitude. To avoid an undefined attitude when the spin axis is aligned, or nearly aligned, with the inertial x-axis, a different reference vector is used in that case. In the event that the cross product of **BodySpinAxis** and the inertial x-axis is less than 1e-5, the inertial y-axis is used as the reference vector. For further details see the engineering/mathematical specifications.



The script example below shows how to configure a Spacecraft to have **PrecessingSpinner** attitude mode where the body z-axis spins with respect to the inertial z-axis. **PrecessionRate** is set to 1 deg./sec., **InitialPrecessionAngle** is set to 0 deg./sec., **SpinRate** is set to 2 deg./sec., **InitialSpinAngle** is set to 0 deg./sec., and **NutationAngle** is set to 30 deg.

```
Create Spacecraft aSat;
GMAT aSat.Attitude = PrecessingSpinner;
GMAT aSat.NutationReferenceVectorX = 0;
GMAT aSat.NutationReferenceVectorY = 0;
GMAT aSat.NutationReferenceVectorZ = 1;
GMAT aSat.BodySpinAxisX = 0;
GMAT aSat.BodySpinAxisY = 0;
GMAT aSat.BodySpinAxisZ = 1;
GMAT aSat.InitialPrecessionAngle = 0;
GMAT aSat.PrecessionRate = 1;
GMAT aSat.NutationAngle = 30;
GMAT aSat.InitialSpinAngle = 0;
GMAT aSat.SpinRate = 2;

Create OrbitView OrbitView1;
OrbitView1.Add = {aSat, Earth}
OrbitView1.ViewPointReference = Earth
OrbitView1.ViewPointVector = [ 30000 0 0 ]

Create Propagator aProp
aProp.MaxStep = 10

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedSecs = 12000.0}
```

Spacecraft Ballistic/Mass Properties

The physical properties of the spacecraft

Description

The **Spacecraft** ballistic and mass properties include the drag and SRP areas and coefficients as well as the spacecraft dry mass. These quantities are used primarily in orbital dynamics modelling. GMAT supports a spherical SRP model, and higher fidelity SRP file option.

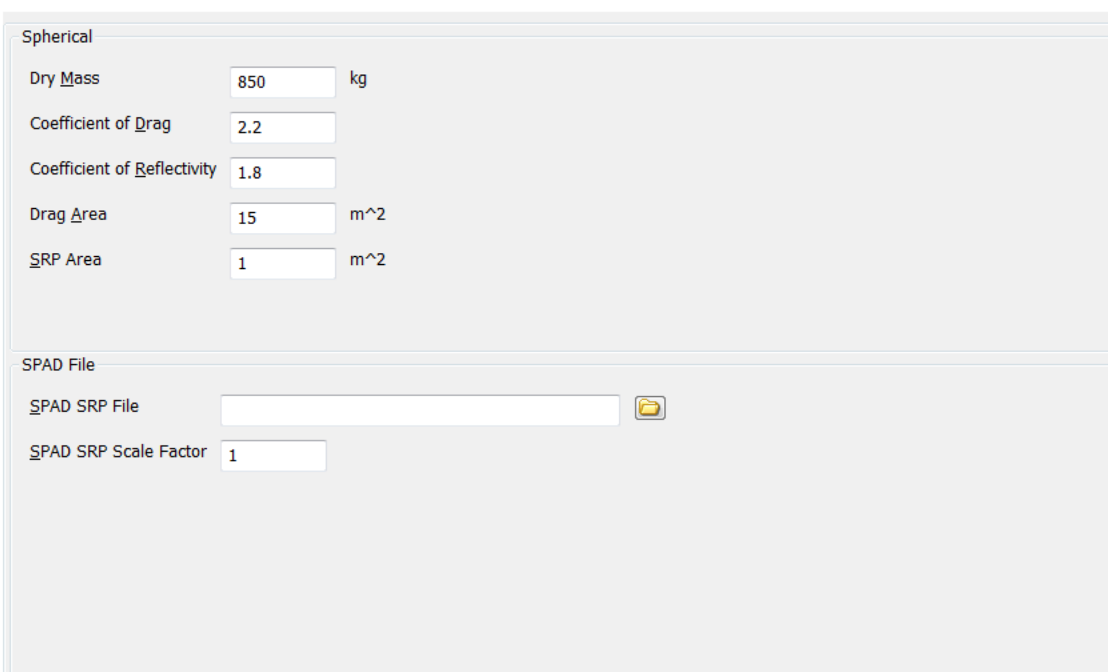
See Also: Propagate, Propagator,Spacecraft

Fields

Field	Description
Cd	The coefficent of drag used to compute the acceleration due to drag. **Data Type** Real **Allowed Values** Real >= 0 **Access** set, get **Default Value** 2.2 **Units** dimensionless **Interfaces** GUI, script
Cr	The coefficent of reflectivity used to compute the acceleration due toSRP. **Data Type** Real **Allowed Values** 0 <= Cr <= 2.0 **Access** set, get **Default Value** 1.8 **Units** dimensionless **Interfaces** GUI, script
Drag Area	The area used to compute acceleration due to atmospheric drag. **Data Type** Real **Allowed Values** Real > = 0 **Access** set, get **Default Value** 15 **Units** m^2 **Interfaces** GUI, script
DryMass	The dry mass of the **Spacecraft** (does not include fuel mass). **Data Type** Real **Allowed Values** Real >=0 **Access** set, get **Default Value** 850 **Units** kg **Interfaces** GUI, script

Field	Description
SPADSRPFile	Name (and optionally path information) of SPAD file. **Data Type** String **Allowed Values** valid path and SPAD file **Access** set **Default Value** N/A **Units** N/A **Interfaces** GUI, script
SPADSRPScaleFactor	Scale factor applied to SRP force when using a SPADModel in the propagation. **Data Type** Real **Allowed Values** Real >= 0 **Access** set **Default Value** 1 **Units** dimensionless **Interfaces** GUI, script
SRPArea	The area used to compute acceleration due to solar radiation pressure. **Data Type** Real **Allowed Values** Real > 0 **Access** set, get **Default Value** 1 **Units** m^2 **Interfaces** GUI, script

GUI



The GUI interface for ballistic and mass properties is contained on the **Ballistic/Mass** tab of the **Spacecraft** resource. You can enter physical properties such as the drag and SRP areas and coefficients and the **Spacecraft** dry mass which are used in orbital dynamics modelling. GMAT supports a spherical SRP model and a SPAD (Solar Pressure and Aerodynamic Drag) file.

Remarks

Configuring Ballistic and Mass Properties for the Spherical Model

GMAT supports a cannonball model for drag and SRP modeling. In the cannonball model, the area is assumed to be independent of the spacecraft's orientation with respect to the local velocity vector and the sun vector. For more details on the computation and configuration of drag and SRP models see the Force Model documentation.

Configuring Ballistic and Mass Properties for the SRP File

The (SPAD) SRP file can be used for high fidelity SRP modelling taking into account the physical properties of the spacecraft (shape and reflectivity) and the spacecraft attitude. SPAD stands for Solar Pressure and Aerodynamic Drag. SPAD files are tabulated data that contain the spacecraft area scaled by physical properties like Cr including specular, diffuse, and reflective properties. Data is expressed as a function of azimuth and elevation in the spacecraft body frame. Note: the azimuth and elevation tabulated on the file are the azimuth and elevation of the vector from the Sun, to the Spacecraft, expressed in the body frame. To compute the SRP acceleration, GMAT computes the sun vector's azimuth and elevation in the spacecraft body frame, and then interpolates the SPAD data using bi-linear interpolation. Note that this formulation results in an attitude dependent SRP acceleration. For more details on the computation and configuration of drag and SRP models see the Force Model documentation.

> **Caution**
>
> When using a SPAD SRP file, GMAT uses the attitude defined on the **Spacecraft** resource to compute the Sun's positon in the body frame. If the attitude uses a coordinate system with **Axes** set to **ObjectReferenced**, and those axes refer back to the **Spacecraft** orbit state (i.e. VNB or LVLH systems), GMAT holds the attitude constant over a given integration step. In those cases, we recommend carefully choosing a maximum step size small enough to ensure the resulting approximation is acceptable for your application.

A valid SPAD file header, and the first three lines of data are shown below for illustrative purposes. Note, GMAT does not use all values provide on the file and GMAT's usage of SPAD files is described in detail in the table below the example.

```
Version             : 4.21
System              : sphericalSat
Analysis Type       : Area
Pixel Size          : 5
Spacecraft Size     : 436.2
Pressure            : 1
Center of Mass      :  (50.9, 184.9, -49)
```

```
Current time       : May  7, 2009  15:53:38.00

Motion    : 1
  Name    : Azimuth
  Method  : Step
  Minimum : -180
  Maximum : 180
  Step    : 5
Motion    : 2
  Name    : Elevation
  Method  : Step
  Minimum : -90
  Maximum : 90
  Step    : 5
: END

Record count       : 2701

 AzimuthElevatio  Force(X)  Force(Y)  Force(Z)
 degrees degrees      m^2      m^2      m^2
 ------- ------- --------- --------- --------- ---------
 -180.00   -90.00 -0.00000000000000 -0.00000000000000 -8.94500000000000
 -180.00   -85.00 -0.77960811887780 -0.00000000000000 -8.91096157443066
 -180.00   -80.00 -1.55328294923069 -0.00000000000000 -8.80910535069420
```

A SPAD file contains three sections as illustrated below. Data specifications for items in each section are described in the tables below

A SPAD file header may contain many fields but only a few are used by GMAT as described below. Other fields are ignored.

Keyword	Required	Description and Supported Values
Analysis Type	Y	The SPAD software can creates files with Analysis Types of Solar Pressure, Area, and Drag. GMAT only supports the Area option. Example: Analysis Type : Area
Pressure	N	SPAD supports the ability to apply a pressure scale factor for SRP files. GMAT does not read this value, but the SRP properties on the file have been scaled by the Pressure factor. The value is usually "1". However, when not 1, it is possible to apply an SRP scale factor twice, once from the value applied in SPAD, and once from **SPADSRPScaleFactor**. Care should be taken to ensure that if the desired scale factor was applied during file creation that it is not reapplied in GMAT.

The SPAD file Motion Data section describes the data contained in the body of the file. The Motion Data fields used by GMAT are described below. Others are ingored.

Keyword	Required	Description and Supported Values
Motion	Y	Together, the Motion and Name fields specify the type of data in the first two columns of the body of the file. GMAT currently supports Azimuth and Elevation Motion only (no articulating appendages) and requires that the first Motion is Azimuth and the second Motion is Elevation as shown below. Examples: Motion : 1 Name : Azimuth and Motion : 2 Name : Elevation
Name	Y	Together, the Motion and Name fields specify the type of data in the first two columns of the body of the file. GMAT currently supports Azimuth and Elevation Motion only (no articulating appendages) and requires that the first Motion is Azimuth and the second Motion is Elevation as shown below. Examples: Motion : 1 Name : Azimuth and Motion : 2 Name : Elevation
Method	Y	The step size in the independent variable. The only supported value is Step. Example: Motion : 1 Method : Step

Keyword	Required	Description and Supported Values
Maximum	Y	The maximum value for an independent variable (Motion Type). For Azimuth, Maximum must be 180, and for Elevation Maximum must be 90. Example: Motion : 1 Name : Azimuth Maximum : 180 Motion : 2 Name : Elevation Maximum : 90
Minimum	Y	The minimum value for an independent variable. (Motion Type). For Azimuth, minimum must be -180, and for Elevation minimum must be -90. Example: Motion : 1 Name : Azimuth Minimum : -180 Motion : 2 Name : Elevation Minimum : -90
Step	Y	The step size for the independent variable (Motion Type). If Step does not divide evenly into the variable range, then errors may occur because the maximum and/or minimum values may not be on the file. Example: Motion : 1 Step : 15

Keyword	Required	Description and Supported Values
Record count	Y	Record count is the number of rows of data in the data segment. Record count = (360/(Azimuth Step) +1)*(180/(Elevation Step) +1). Example: Record count : 325

The SPAD file data block contains tabulated acceleration data as described below.

Keyword	Required	Description and Supported Values
Azimuth	Y	Azimuth data column. Must be first column in the data. Units must be degrees. Azimuth is the azimuth of the vector from spacecraft to sun, expressed in the body frame: atan2(ySun,xSun)). Example: AzimuthElevatio degrees degrees ------- ------- -180.00 -90.00 -180.00 -75.00 -180.00 -60.00
Elevation	N	Elevation data column. Must be second column in the data. Units must be degrees. Elevation is the elevation of the vector from spacecraft to sun, expressed in the body frame: atan2(zSun,sqrt(xSun^2 + ySun^2)). Example: AzimuthElevatio degrees degrees ------- ------- -180.00 -90.00 -180.00 -75.00 -180.00 -60.00

Keyword	Required	Description and Supported Values
Force(*)	N	Area vector columns. Must be columns 3-5 in the data. Quantities must be in base units of m^2,mm^2,cm^2,in^2,ft^2. If another unit is provided in the header lines, an exception is thrown. The area vector is the direction of the resulting SRP force, scaled by area and Cr properties. Example: See code listing above.

Total Mass Computation

The **TotalMass** property of a **Spacecraft** is a read-only property that is the sum of the **DryMass** value and the sum of the fuel mass in all attached fuel tanks. GMAT's propagators will not allow the total mass of a spacecraft to be negative. However, GMAT will allow the mass of a **FuelTank** to be negative. See the FuelTank documentation for details.

Examples

Configure physical properties for a spherical SRP model.

```
Create Spacecraft aSpacecraft
aSpacecraft.Cd        = 2.2
aSpacecraft.Cr        = 1.8
aSpacecraft.DragArea  = 40
aSpacecraft.SRPArea   = 35
aSpacecraft.DryMass   = 2000
Create Propagator aPropagator

BeginMissionSequence

Propagate   aPropagator(aSpacecraft, {aSpacecraft.ElapsedSecs = 600})
```

Configure a SPAD SRP model.

```
Create Spacecraft aSpacecraft;
aSpacecraft.DryMass   = 2000
aSpacecraft.SPADSRPFile = '..\data\vehicle\spad\SphericalModel.spo'
aSpacecraft.SPADSRPScaleFactor = 1;

Create ForceModel aFM;
aFM.SRP = On;
aFM.SRP.SRPModel = SPADFile

Create Propagator aProp;
aProp.FM = aFM;

BeginMissionSequence

Propagate aProp(aSpacecraft) {aSpacecraft.ElapsedDays = 0.2}
```

Spacecraft Epoch

The spacecraft epoch

Description

The epoch of a **Spacecraft** is the time and date corresponding to the specified orbit state. See the Spacecraft Orbit State section for interactions between the epoch, coordinate system, and spacecraft state fields.

See Also: Spacecraft

> **Caution**
>
> GMAT's Modified Julian Date (MJD) format differs from that of other software. The Modified Julian format is a constant offset from the full Julian date (JD):
>
> MJD = JD - offset
>
> GMAT uses a non-standard offset, as shown in the following table.

Epoch Type	**GMAT**	common
reference epoch	**05 Jan 1941 12:00:00.000**	17 Nov 1858 00:00:00.000
Modified Julian offset	**2430000.0**	2400000.5

Fields

Field	Description
DateFormat	The time system and format of the **Epoch** field. In the GUI, this field is called **EpochFormat**. **Data Type**: Enumeration **Allowed Values**: **A1ModJulian**, **TAIModJulian**, **UTCModJulian**, **TTModJulian**, **TDBModJulian**, **A1Gregorian**, **TAIGregorian**, **TTGregorian**, **UTCGregorian**, **TDBGregorian** **Access**: set only **Default Value**: **TAIModJulian** **Interfaces**: GUI, script

Field	Description
Epoch	The time and date corresponding to the specified orbit state. **Data Type**: Time **Allowed Values**: Gregorian: `04 Oct 1957 12:00:00.000` <= **Epoch** <= `28 Feb 2100 00:00:00.000` Modified Julian: **`6116.0`** <= **Epoch** <= **`58127.5`** **Access**: set only **Default Value**: 21545 **Interfaces**: GUI, script
A1ModJulian	The **Spacecraft** orbit epoch in the A.1 system and the Modified Julian format. **Data Type**: String **Allowed Values**: See **Epoch** **Access**: set, get (mission sequence only) **Default Value**: 21545.00000039794 **Units**: Days **Interfaces**: script
Epoch.A1ModJulian	The spacecraft orbit epoch in the A.1 system and the Modified Julian format. **Data Type**: String **Allowed Values**: See **Epoch** **Access**: set, get **Default Value**: 21545.00000039794 **Units**: Days **Interfaces**: none
CurrA1MJD	*This field has been deprecated and should no longer be used.* The current epoch in the **A1ModJulian** format. This field can only be used within the mission sequence. **Data Type**: Time **Allowed Values**: **`6116.0`** <= **CurrA1MJD** <= **`58127.5`** **Access**: get, set (mission sequence only) **Default Value**: converted equivalent of 21545 Modified Julian (TAI) **Interfaces**: script only

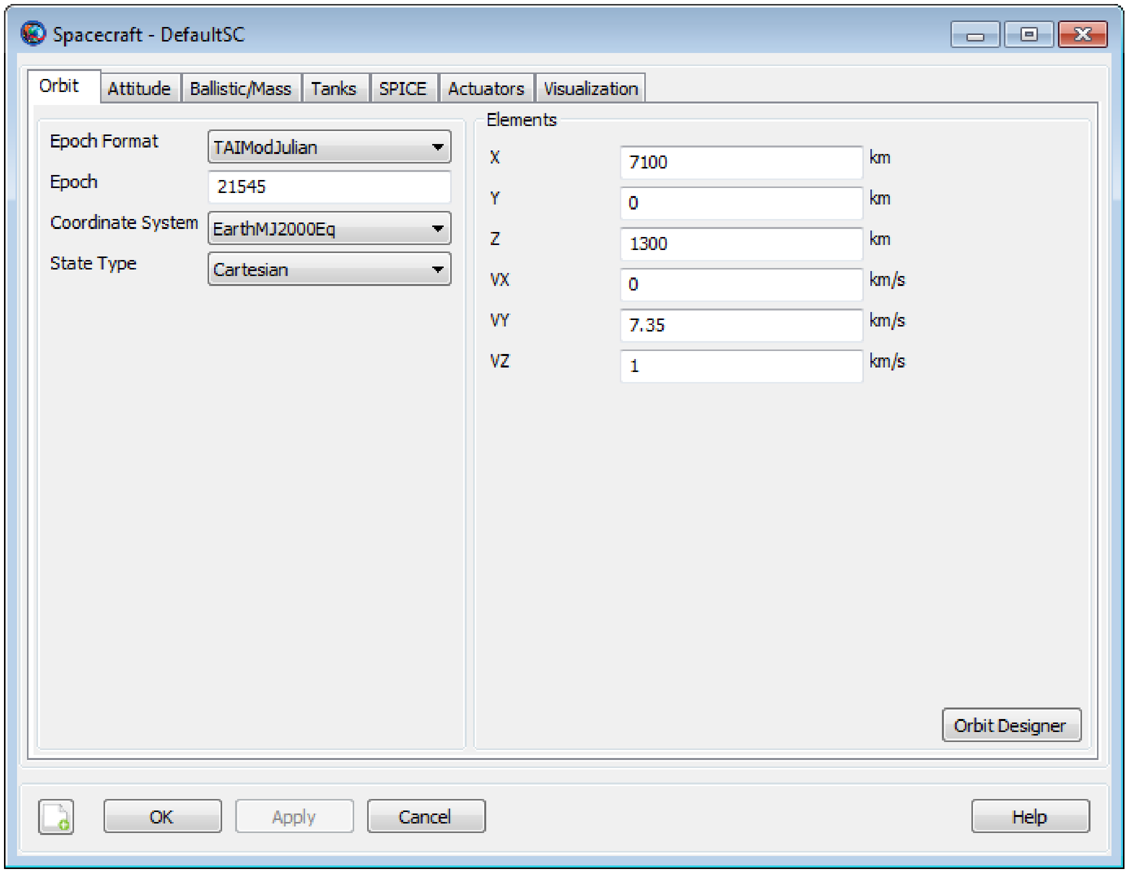
Field	Description
A1Gregorian	The **Spacecraft** orbit epoch in the A.1 system and the Gregorian format. **Data Type** String **Allowed Values** See **Epoch** **Access** set, get (mission sequence only) **Default Value** 01 Jan 2000 12:00:00.034 **Units** N/A **Interfaces** GUI, script
TAIGregorian	The **Spacecraft** orbit epoch in the TAI system and the Gregorian format. **Data Type** String **Allowed Values** See **Epoch** **Access** set, get (mission sequence only) **Default Value** 01 Jan 2000 12:00:00.000 **Units** Gregorian date **Interfaces** GUI, script
TAIModJulian	The **Spacecraft** orbit epoch in the TAI system and the Modified Julian format. **Data Type** String **Allowed Values** See **Epoch** **Access** set, get (mission sequence only) **Default Value** 21545 **Units** See A1ModJulian **Interfaces** GUI, script
TDBGregorian	The **Spacecraft** orbit epoch in the TDB system and the Gregorian format. **Data Type** String **Allowed Values** See **Epoch** **Access** set, get (mission sequence only) **Default Value** 01 Jan 2000 12:00:32.184 **Units** See A1Gregorian **Interfaces** GUI, script
TDBModJulian	The **Spacecraft** orbit epoch in the TDB system and the Modified Julian format. **Data Type** String **Allowed Values** See **Epoch** **Access** set, get (mission sequence only) **Default Value** 21545.00037249916 **Units** See A1ModJulian **Interfaces** GUI, script

Field	Description	
TTGregorian	The **Spacecraft** orbit epoch in the TT system and the Gregorian format.	
	Data Type	String
	Allowed Values	See **Epoch**
	Access	set, get (mission sequence only)
	Default Value	01 Jan 2000 12:00:32.184
	Units	See A1Gregorian
	Interfaces	GUI, script
TTModJulian	The **Spacecraft** orbit epoch in the TT system and the Modified Julian format.	
	Data Type	String
	Allowed Values	See **Epoch**
	Access	set, get (mission sequence only)
	Default Value	21545.0003725
	Units	See A1ModJulian
	Interfaces	GUI, script
UTCGregorian	The **Spacecraft** orbit epoch in the UTC system and the Gregorian format.	
	Data Type	String
	Allowed Values	See **Epoch**
	Access	set, get (mission sequence only)
	Default Value	01 Jan 2000 11:59:28.000
	Units	See A1Gregorian
	Interfaces	GUI, script
UTCModJulian	The **Spacecraft** orbit epoch in the UTC system and the Modified Julian format.	
	Data Type	String
	Allowed Values	See **Epoch**
	Access	set, get (mission sequence only)
	Default Value	21544.99962962963
	Units	See A1ModJulian
	Interfaces	GUI, script
Epoch.A1Gregorian	The **Spacecraft** orbit epoch in the A.1 system and the Gregorian format.	
	Data Type	String
	Allowed Values	See **Epoch**
	Access	set, get
	Default Value	01 Jan 2000 12:00:00.034
	Units	N/A
	Interfaces	GUI, script

Field	Description
Epoch.TAIGregorian	The **Spacecraft** orbit epoch in the TAI system and the Gregorian format. **Data Type** String **Allowed Values** See **Epoch** **Access** set, get **Default Value** DefaultValue **Units** 01 Jan 2000 12:00:00.000 **Interfaces** GUI, script
Epoch.TAIModJulian	The **Spacecraft** orbit epoch in the TAI system and the Modified Julian format. **Data Type** String **Allowed Values** See **Epoch.A1ModJulian** **Access** set, get **Default Value** 21545 **Units** See Epoch.A1ModJulian **Interfaces** GUI, script
Epoch.TDBGregorian	The **Spacecraft** orbit epoch in the TDB system and the Gregorian format. **Data Type** String **Allowed Values** See **Epoch** **Access** set, get **Default Value** 01 Jan 2000 12:00:32.184 **Units** See Epoch.A1Gregorian **Interfaces** GUI, script
Epoch.TDBModJulian	The **Spacecraft**orbit epoch in the TDB system and the Modified Julian format. **Data Type** String **Allowed Values** See **Epoch** **Access** set, get **Default Value** 21545.00037249916 **Units** See Epoch.A1ModJulian **Interfaces** GUI, script
Epoch.TTGregorian	The **Spacecraft** orbit epoch in the TT system and the Gregorian format. **Data Type** String **Allowed Values** See **Epoch** **Access** set, get **Default Value** 01 Jan 2000 12:00:32.184 **Units** See Epoch.A1Gregorian **Interfaces** GUI, script

Field	Description
Epoch.TTModJulian	The **Spacecraft**orbit epoch in the TT system and the Modified Julian format. **Data Type** String **Allowed Values** See **Epoch** **Access** set, get **Default Value** 21545.0003725 **Units** See Epoch.A1ModJulian **Interfaces** GUI, script
Epoch.UTCGregorian	The **Spacecraft**orbit epoch in the UTC system and the Gregorian format. **Data Type** String **Allowed Values** See **Epoch** **Access** set, get **Default Value** 01 Jan 2000 11:59:28.000 **Units** See Epoch.A1Gregorian **Interfaces** GUI, script
Epoch.UTCModJulian	The **Spacecraft** orbit epoch in the UTC system and the Modified Julian format. **Data Type** String **Allowed Values** Range **Access** See **Epoch** **Default Value** 21544.99962962963 **Units** See **Epoch.A1ModJulian** **Interfaces** GUI, script

GUI



A change in **EpochFormat** causes an immediate update to **Epoch** to reflect the chosen time system and format.

Remarks

GMAT supports five time systems or scales and two formats:

A.1	USNO atomic time; GMAT's internal time system
TAI	International Atomic Time
TDB	Barycentric Dynamical Time
TT	Terrestrial Time
UTC	Coordinated Universal Time

Gregorian	Text with the following format: `dd mmm yyyy HH:MM:SS.FFF` **`dd`** two-digit day of month **`mmm`** first three letters of month **`yyyy`** four-digit year **`HH`** two-digit hour **`MM`** two-digit minute **`SS`** two-digit second **`FFF`** three-digit fraction of second
Modified Julian	Floating-point number of days from a reference epoch. In GMAT, the reference epoch is 05 Jan 1941 12:00:00.000 (JD 2430000.0).

The epoch can be set in multiple ways. The default method is to set the **DateFormat** field to the desired time system and format, then set the **Epoch** field to the desired epoch. This method cannot be used to get the epoch value, such as on the right-hand side of an assignment statement.

```
aSat.DateFormat = UTCGregorian
aSat.Epoch = '18 May 2012 12:00:00.000'
```

An alternate method is to specify the **DateFormat** in the parameter name. This method works in both "get" and "set" modes.

```
aSat.Epoch.UTCGregorian = '18 May 2012 12:00:00.000'
Report aReport aSat.Epoch.UTCGregorian
```

A third method can be used in "get" mode everywhere, but in "set" mode only in the mission sequence (i.e. after the **BeginMissionSequence** command).

```
aSat.UTCGregorian = '18 May 2012 12:00:00.000'
Report aReport aSat.UTCGregorian
```

GMAT uses the A.1 time system in the Modified Julian format for its internal calculations. The system converts all other systems and formats on input and again at output.

Leap Seconds

When converting to and from the UTC time system, GMAT includes leap seconds as appropriate, according to the `tai-utc.dat` data file from the IERS. This file contains the conversion between TAI and UTC, including all leap seconds that have been added or announced.

GMAT applies the leap second as the last second before the date listed in the `tai-utc.dat` file, which historically has been either January 1 or July 1. In the Gregorian date format, the leap second appears as a "60^{th} second": for example, "31 Dec 2008 23:59:60.000". GMAT will correctly output this epoch, and will accept it as input. GMAT's Modified Julian format is based on an 86,400-second day, however, and will repeat the first second of the following day. Input of the leap second in Modified Julian format is not supported. (See Release Notes for a known bug related to this functionality).

For epochs prior to the first entry in the leap-second file, the UTC and TAI time systems are considered identical (i.e. zero leap seconds are added). For epochs after the last entry, the leap second count from the last entry is used.

The `tai-utc.dat` file is periodically updated by the IERS when new leap seconds are announced. The latest version of this file can always be found at http://maia.usno.navy.mil/ser7/tai-utc.dat. To replace it, download the latest version and replace GMAT's file in the location `<GMAT>/data/time/tai-utc.dat`, where `<GMAT>` is the install directory of GMAT on your system.

Examples

Setting the epoch for propagation

```
Create Spacecraft aSat
aSat.DateFormat = TAIModJulian
aSat.Epoch = 25562.5

Create ForceModel aFM
Create Propagator aProp
aProp.FM = aFM

BeginMissionSequence
Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

Plotting and reporting the epoch (syntax #1)

```
Create Spacecraft aSat
aSat.DateFormat = A1Gregorian
aSat.Epoch = '12 Jul 2015 08:21:45.921'

Create XYPlot aPlot
aPlot.XVariable = aSat.UTCModJulian
aPlot.YVariables = aSat.Earth.Altitude

Create Report aReport
aReport.Add = {aSat.UTCGregorian, aSat.EarthMJ2000Eq.ECC}
```

Plotting and reporting the epoch (syntax #2)

```
Create Spacecraft aSat
aSat.DateFormat = TTGregorian
aSat.Epoch = '01 Dec 1978 00:00:00.000'

Create XYPlot aPlot
aPlot.XVariable = aSat.Epoch.TTModJulian
aPlot.YVariables = aSat.Earth.RMAG

Create Report aReport
aReport.Add = {aSat.Epoch.A1Gregorian, aSat.Earth.RMAG}
```

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Spacecraft Hardware

Add hardware to a spacecraft

Description

The hardware fields allow you to attach pre-configured hardware models to a spacecraft. Current models include **FuelTank** and **Thruster**. Before you attach a hardware model to a **Spacecraf**t, you must first create the model.

See Also: FuelTank, Thruster

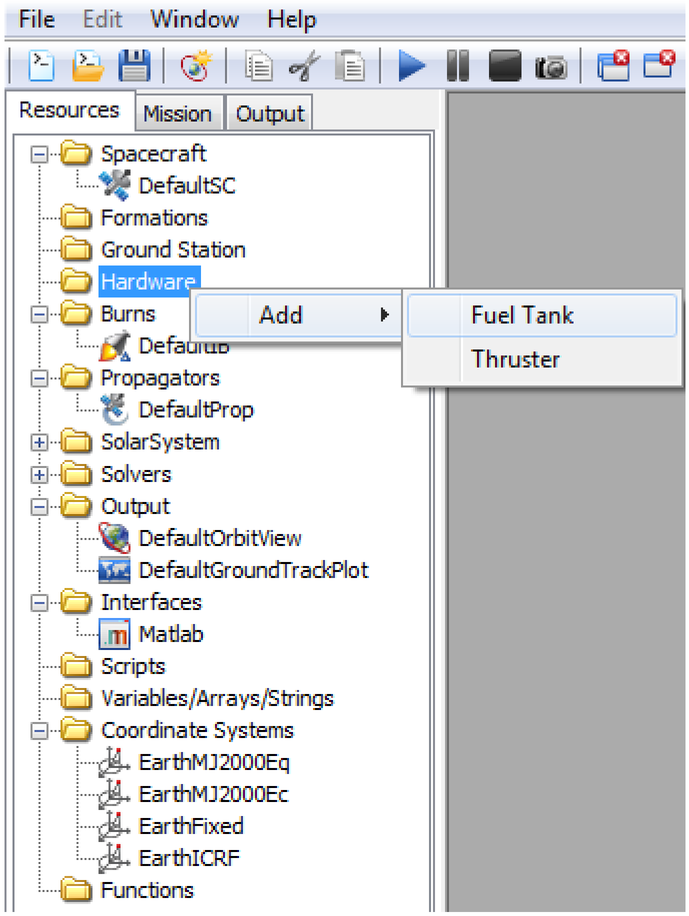
Fields

Field	Description
Tanks	This field is used to attach **FuelTank(s)** to a **Spacecraft**. In a script command, an empty list, e.g., `DefaultSC.Tanks={}`, is allowed and is used to indicate that no **FuelTank(s)** is attached to the spacecraft. **Data Type** Reference Array **Allowed Values** Any user-defined **FuelTank**. **Access** set **Default Value** N/A **Units** N/A **Interfaces** GUI, script.
Thrusters	This field is used to attach **Thruster(s)** to a **Spacecraft**. In a script command, an empty list, e.g., `DefaultSC.Thrusters={}`, is allowed and is used to indicate that no **Thrusters** are attached to the spacecraft. **Data Type** Reference Array **Allowed Values** Any user-defined **Thruster**. **Access** set **Default Value** N/A **Units** N/A **Interfaces** GUI, script

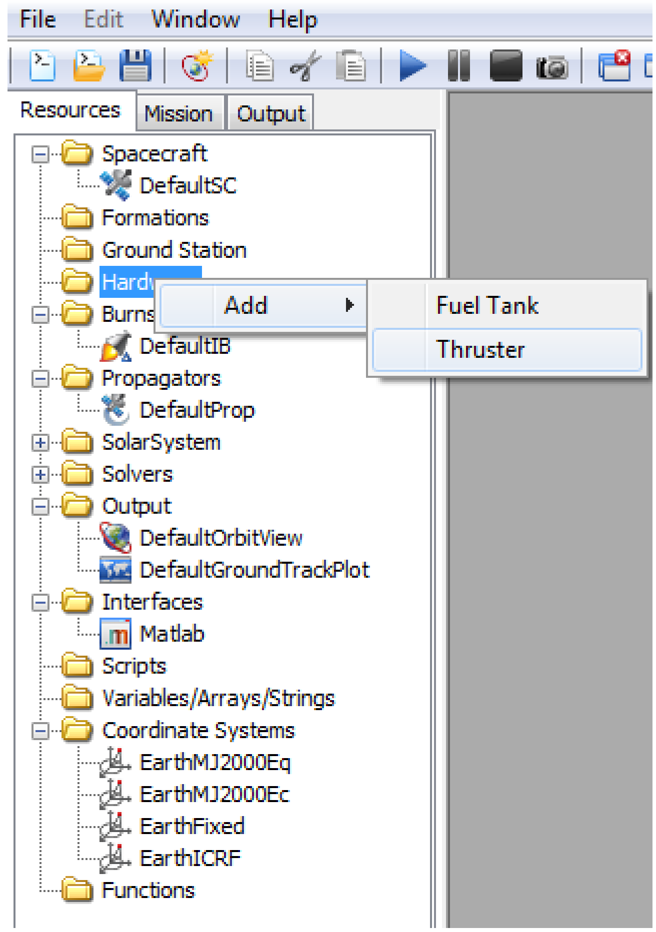
GUI

There are two spacecraft hardware items, the **FuelTank** and the **Thruster**, that can be attached to a Spacecraft. Here, we describe the method used to create and then attach these items to a **Spacecraft**. For details on how to configure the **FuelTank** and **Thruster** resources, see the help for the individual hardware item.

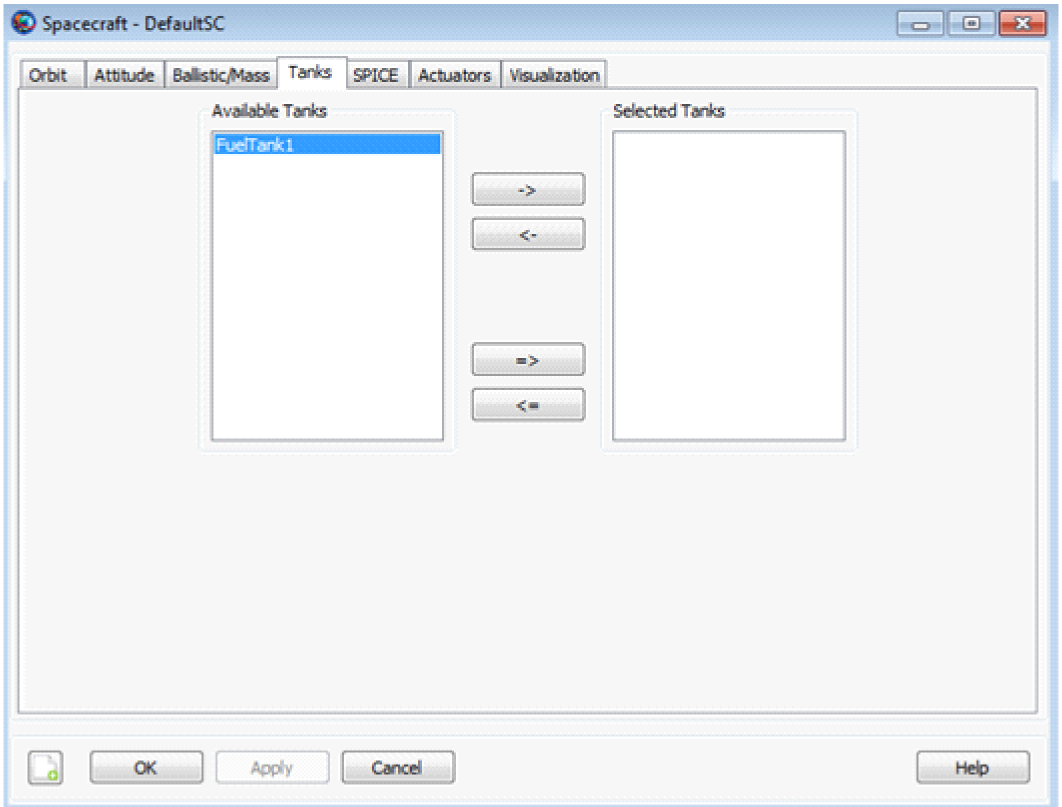
As shown below, to add a **FuelTank** to your script, highlight the **Hardware** resource and then right click to add a **FuelTank**.



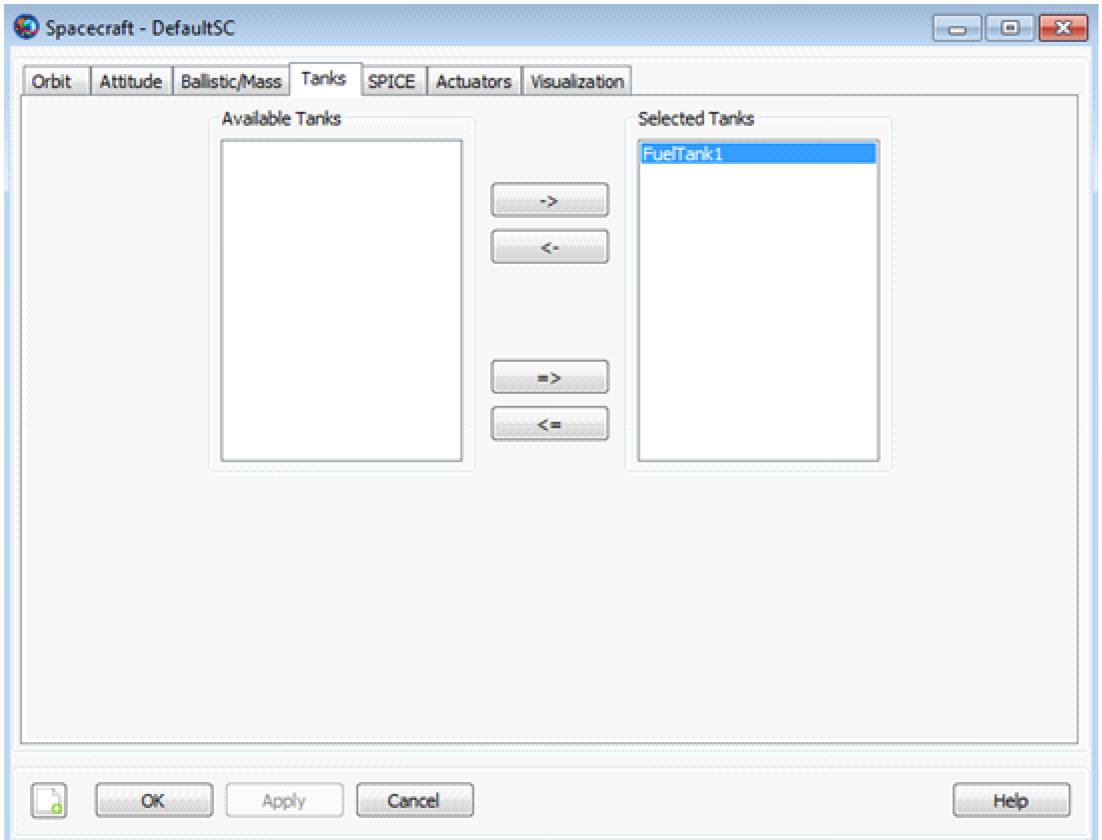
To add a **Thruster** to your script, highlight the **Hardware** resource and then right click to add a **Thruster**.



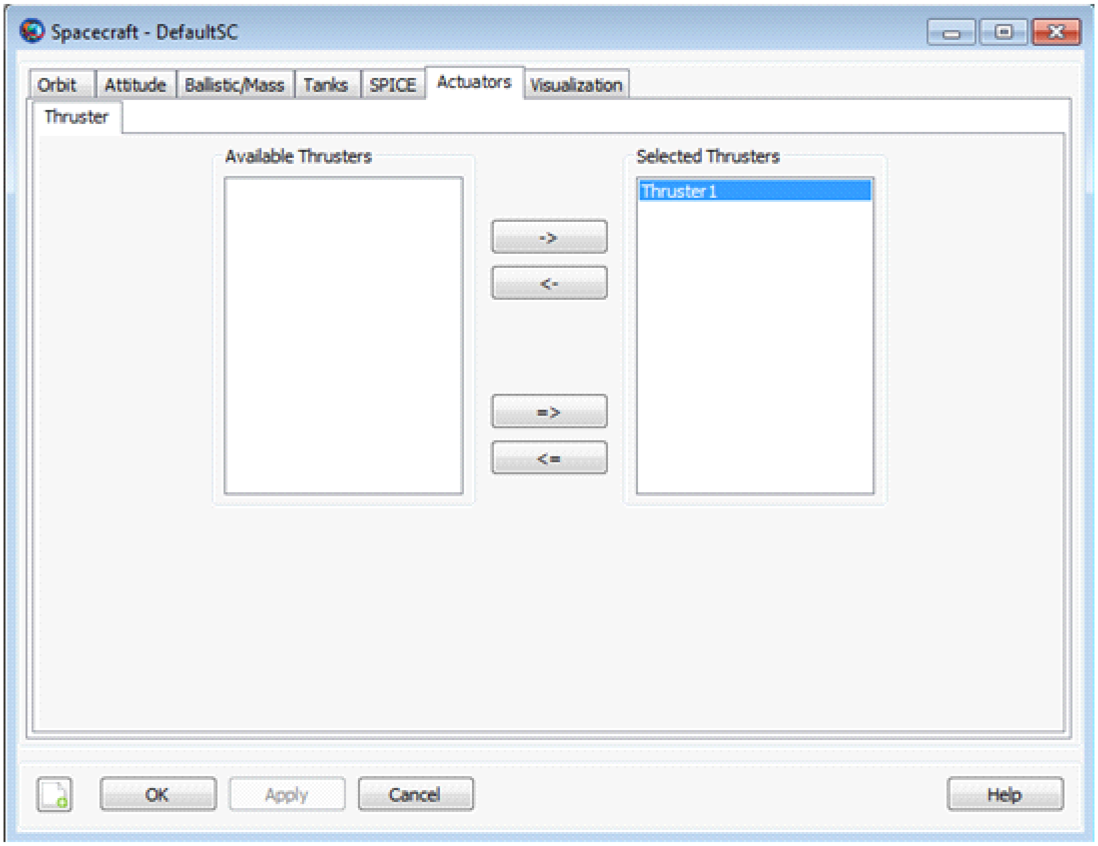
Thus far, we have created both a **FuelTank** and a **Thruster**. Next, we attach both the **FuelTank** and the **Thruster** to a particular **Spacecraft**. To do this, double click on the desired **Spacecraft** under the **Spacecraft** resource to bring up the associated GUI panel. Then click on the **Tanks** tab to bring up the following GUI display.



Next, select the desired **FuelTank** and use the right arrow button to attach the **FuelTank** to the **Spacecraft** as shown below. Then click the **Apply** button.



Similarly, to attach a **Thruster** to a **Spacecraft**, double click on the desired **Spacecraft** under the **Spacecraft** resource and then select the **Actuators** tab. Then select the desired **Thruster** and use the right arrow to attach the **Thruster** to the **Spacecraft** as shown below. Finally, click the **Apply** button.



Remarks

To actually use the **Thruster** to apply a finite burn to a **Spacecraft**, additional steps are required. For example, when you create the **Thruster** resource, you have to associate a **FuelTank** with the **Thruster**. For details on this and related matters, see the help for the **FuelTank**, **Thruster**, and **FiniteBurn** resources.

Examples

Create a default **Spacecraft**. Create **FuelTank** and **Thruster** resources and attach them to the **Spacecraft**.

```
% Create default Spacecraft FuelTank, and Thruster Resources
Create Spacecraft DefaultSC
Create FuelTank FuelTank1
Create Thruster Thruster1

%  Attach FuelTank and Thruster to the spacecraft
DefaultSC.Thrusters = {Thruster1}
DefaultSC.Tanks = {FuelTank1}

BeginMissionSequence
```

Spacecraft Orbit State

The orbital initial conditions

Description

GMAT supports a suite of state types for defining the orbital state, including **Cartesian** and **Keplerian**, among others. In addtion, you can define the orbital state in different coordinate systems, for example **EarthMJ2000Eq** and **EarthFixed**. GMAT provides three general state types that can be used with any coordinate system: **Cartesian**, **SphericalAZFPA**, and **SphericalRADEC**. There are three additional state types that can be used with coordinate systems centered at a celestial body: **Keplerian**, **ModifiedKeplerian**, and **Equinoctial**.

In the section called "Remarks" below, we describe each state type in detail including state-type definitions, singularities, and how the state fields interact with the **CoordinateSystem** and **Epoch** fields. There are some limitations when setting the orbital state during initialization, which are discussed in the section called "Remarks". We also include examples for setting each state type in commonly used coordinate systems.

See Also: Spacecraft, Propagator, and Spacecraft Epoch

Fields

Field	Description
AltEquinoctialP	A measure of the orientation of the orbit. AltEquinoctialP and AltEquinoctialQ together govern how an orbit is oriented. **AltEquinotialP** = sin(**INC**/2)*sin(**RAAN**). **Data Type**: Real **Allowed Values**: -1 ≤ **AltEquinoctialP** ≤ 1 **Access**: set, get **Default Value**: 0.08982062789020774 **Units**: (None) **Interfaces**: GUI, script
AltEquinoctialQ	A measure of the orientation of the orbit. AltEquinoctialP and AltEquinoctialQ together govern how an orbit is oriented. **AltEquinotialP** = sin(**INC**/2)*cos(**RAAN**). **Data Type**: Real **Allowed Values**: -1 ≤ **AltEquinoctialQ** ≤ 1 **Access**: set, get **Default Value**: 0.06674269576352432 **Units**: (None) **Interfaces**: GUI, script

Field	Description
AOP	The orbital argument of periapsis expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type** Real **Allowed Values** -∞ < **AOP** < ∞ **Access** set, get **Default Value** 314.1905515359921 **Units** deg. **Interfaces** GUI, script
AZI	The orbital velocity azimuth expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type** Real **Allowed Values** -∞ < **AZI** < ∞ **Access** set, get **Default Value** 82.37742168155043 **Units** deg. **Interfaces** GUI, script
BrouwerLongAOP **BrouwerShortAOP**	Brouwer-Lyddane long-term averaged (short-term averaged) mean argument of periapsis. **Data Type** Real **Allowed Values** -∞ < **BrouwerLongAOP/BrouwerShortAOP** < ∞ **Access** set, get **Default Value** Conversion from default Cartesian state **Units** deg **Interfaces** GUI, script
BrouwerLongECC **BrouwerShortECC**	Brouwer-Lyddane long-term averaged (short-term averaged) mean eccentricity. **Data Type** Real **Allowed Values** 0 ≤ **BrouwerLongECC/BrouwerShortECC** ≤ 0.99 **Access** set, get **Default Value** Conversion from default Cartesian state **Units** N/A **Interfaces** GUI, script

Field	Description	
BrouwerLongINC **BrouwerShortINC**	Brouwer-Lyddane long-term averaged (short-term averaged) mean inclination.	
	Data Type	Real
	Allowed Values	0 ≤ **BrouwerLongINC/BrouwerShortINC** ≤ 180
	Access	set, get
	Default Value	Conversion from default Cartesian state
	Units	deg
	Interfaces	GUI, script
BrouwerLongMA **BrouwerShortMA**	Brouwer-Lyddane long-term averaged (short-term averaged) mean MA (mean anomaly).	
	Data Type	Real
	Allowed Values	-∞ < **BrouwerLongMA/BrouwerShortMA** < ∞
	Access	set, get
	Default Value	Conversion from default Cartesian state
	Units	deg
	Interfaces	GUI, script
BrouwerLongRAAN **BrouwerShortRAAN**	Brouwer-Lyddane long-term averaged (short-term averaged) mean RAAN (right ascension of the ascending node).	
	Data Type	Real
	Allowed Values	-∞ < **BrouwerLongRAAN/BrouwerShortRAAN** < ∞
	Access	set, get
	Default Value	Conversion from default Cartesian state
	Units	deg
	Interfaces	GUI, script
BrouwerLongSMA **BrouwerShortSMA**	Long-term averaged (short-term averaged) mean semi-major axis.	
	Data Type	Real
	Allowed Values	**Brouwer*SMA** > 3000/(1-**Brouwer*ECC**)
	Access	set, get
	Default Value	Conversion from default Cartesian state
	Units	km
	Interfaces	GUI, script

Field	Description
CoordinateSystem	The coordinate system with respect to which the orbital state is defined. The **CoordinateSystem** field is dependent upon the **DisplayStateType** field. If the coordinate system chosen by the user does not have a gravitational body at the origin, then the state types **Keplerian**, **ModifiedKeplerian**, and **Equinoctial** are not permitted. **Data Type** String **Allowed Values** **CoordinateSystem** resource **Access** set **Default Value** **EarthMJ2000Eq** **Units** N/A **Interfaces** GUI, script
DEC	The declination of the orbital position expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type** Real **Allowed Values** -90 ≤ **DEC** ≤ 90 **Access** set, get **Default Value** 10.37584492005105 **Units** deg **Interfaces** GUI, script
DECV	The declination of orbital velocity expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type** Real **Allowed Values** -90 ≤ **DECV** ≤ 90 **Access** set, get **Default Value** 7.747772036108118 **Units** deg **Interfaces** GUI, script
Delaunayg	Delaunay "g" element, identical to **AOP**, expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type** Real **Allowed Values** -∞ < **Delaunayg** < ∞ **Access** set, get **Default Value** 314.1905515359921 **Units** deg **Interfaces** GUI, script

Field	Description
DelaunayG	Delaunay "G" element, the magnitude of the orbital angular momentum, expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type** Real **Allowed Values** $0 \leq$ **DelaunayG** $< \infty$ **Access** set, get **Default Value** 53525.52895581695 **Units** km^2/s **Interfaces** GUI, script
Delaunayh	Delaunay "h" element, identical to **RAAN**, expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type** Real **Allowed Values** $-\infty <$ **Delaunayh** $< \infty$ **Access** set, get **Default Value** 306.6148021947984 **Units** deg **Interfaces** GUI, script
DelaunayH	Delaunay "H" element, the z-component of the orbital angular momentum vector, expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type** Real **Allowed Values** $-\infty <$ **Delaunayl** $< \infty$ **Access** set, get **Default Value** 52184.99999999999 **Units** km^2/s **Interfaces** GUI, script
Delaunayl	Delaunay "ℓ" element, identical to the mean anomaly, expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type** Real **Allowed Values** $-\infty <$ **Delaunayl** $< \infty$ **Access** set, get **Default Value** 97.10782663991999 **Units** deg **Interfaces** GUI, script

Field	Description
DelaunayL	Delaunay "L" element, related to the two-body orbital energy, expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type**: Real **Allowed Values**: $0 \leq$ **DelaunayL** $< \infty$ **Access**: set, get **Default Value**: 53541.66590560955 **Units**: km^2/s **Interfaces**: GUI, script
DisplayStateType	The orbital state type displayed in the GUI. Allowed state types are dependent upon the selection of **CoordinateSystem**. For example, if the coordinate system does not have a celestial body at the origin, **Keplerian**, **ModifiedKeplerian**, and **Equinoctial** are not allowed options for **DisplayStateType**. **Data Type**: String **Allowed Values**: **Cartesian**, **Keplerian**, **ModifiedKeplerian**, **SphericalAZFPA**, **SphericalRADEC**, or **Equinoctial** **Access**: set **Default Value**: **Cartesian** **Units**: N/A **Interfaces**: GUI, script
ECC	The orbital eccentricity expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type**: Real **Allowed Values**: **ECC** < 0.9999999 or **ECC** > 1.0000001. If **ECC** > 1, **SMA** must be < 0 **Access**: set, get **Default Value**: 0.02454974900598137 **Units**: N/A **Interfaces**: GUI, script
EquinoctialH	A measure of the orbital eccentricity and argument of periapsis. **EquinoctialH** and **EquinoctialK** together govern how elliptic an orbit is and where the periapsis is located. **EquinotialH** = **ECC** * sin(**AOP** + **RAAN**) . **Data Type**: Real **Allowed Values**: -0.99999 < **EquinoctialH** < 0.99999, AND sqrt(**EquinoctialH**^2 + **EquinoctialK**^2) < 0.99999 **Access**: set, get **Default Value**: -0.02423431419337062 **Units**: dimless **Interfaces**: GUI, script

Field	Description
EquinoctialK	A measure of the orbital eccentricity and argument of periapsis. **EquinoctialH** and **EquinoctialK** together govern how elliptic an orbit is and where the periapsis is located. **EquinotialK** = **ECC** * cos(**AOP** + **RAAN**) . **Data Type** Real **Allowed Values** -0.99999 < **EquinoctialK** < 0.99999, AND sqrt(**EquinoctialH**^2 + **EquinoctialK**^2) < 0.99999 **Access** set, get **Default Value** -0.003922778585859663 **Units** dimless **Interfaces** GUI, script
EquinoctialP	A measure of the orientation of the orbit. **EquinoctialP** and **EquinoctialQ** together govern how an orbit is oriented. **EquinotialP** = **tan**(**INC**/2)*sin(**RAAN**). **Data Type** Real **Allowed Values** -∞ < **EquinoctialP** < ∞ **Access** set, get **Default Value** -0.09038834725719359 **Units** dimless **Interfaces** GUI, script
EquinoctialQ	A measure of the orientation of the orbit. **EquinoctialP** and **EquinoctialQ** together govern how an orbit is oriented. **EquinotialQ** = tan(**INC**/2)*cos(**RAAN**). **Data Type** Real **Allowed Values** -∞ < **EquinoctialQ** < ∞ **Access** set, get **Default Value** 0.06716454898232072 **Units** dimless **Interfaces** GUI, script
FPA	The orbital flight path angle expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type** Real **Allowed Values** 0 ≤ **FPA** ≤ 180 **Access** set, get **Default Value** 88.60870365370448 **Units** Deg. **Interfaces** GUI, script

Field	Description
Id	The spacecraft Id used in tracking data files. This field is only used for EstimationPlugin protype functionality. **Data Type** String **Allowed Values** String **Access** set **Default Value** SatId **Units** N/A **Interfaces** script
INC	The orbital inclination expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type** Real **Allowed Values** 0 ≤ **INC** ≤ 180 **Access** set, get **Default Value** 12.85008005658097 **Units** deg **Interfaces** GUI, script
IncomingBVAZI **OutgoingBVAZI**	**IncomingBVAZI/OutgoingBVAZI** is the B-vector azimuth at infinity of the incoming/outgoing asymptote measured counter-clockwise from south. If **C3Energy** < 0 the apsides vector is substituted for the outgoing/incoming asymptote. **Data Type** Real **Allowed Values** -∞ < **IncomingBVAZI/OutgoingBVAZI** < ∞ **Access** set, get **Default Value** Conversion from default Cartesian state **Units** deg **Interfaces** GUI, script
IncomingC3Energy **OutgoingC3Energy**	C3 energy. **C3Energy** = -mu/**SMA**. **IncomingC3Energy/OutgoingC3Energy** differ only in that they are associated with the **IncomingAsymptote** and **OutgoingAsymptote** state representations, respectively. **Data Type** Real **Allowed Values** **IncomingC3Energy** ≤ -1e-7 or **IncomingC3Energy** ≥ 1e-7 **OutgoingC3Energy** ≤ -1e-7 or **OutgoingC3Energy** ≥ 1e-7 **Access** set, get **Default Value** Conversion from default Cartesian state **Units** km^2/s^2 **Interfaces** GUI, script

Field	Description	
IncomingDHA **OutgoingDHA**	**IncomingDHA/OutgoingDHA** is the declination of the incoming/outgoing asymptote. If **C3Energy** < 0 the apsides vector is substituted for the incoming/outgoing asymptote..	
	Data Type	Real
	Allowed Values	-90° ≤ **IncomingDHA/OutgoingDHA** < 90°
	Access	set, get
	Default Value	Conversion from default Cartesian state
	Units	deg
	Interfaces	GUI, script
IncomingRadPer **OutgoingRadPer**	The orbital radius of periapsis. The radius of periapsis is the minimum distance (osculating) between the spacecraft and celestial body at the origin of coordinate system. **IncomingRadPer/OutgoingRadPer** differ from **RadPer** only in that they are associated with the **IncomingAsymptote** and **OutgoingAsymptote** state representations, respectively.	
	Data Type	Real
	Allowed Values	abs(**IncomingRadPer**) ≥ 1 meter. abs(**OutgoingRadPer**) ≥ 1 meter.
	Access	set, get
	Default Value	Conversion from default Cartesian state
	Units	km
	Interfaces	GUI, script
IncomingRHA **OutgoingRHA**	**IncomingRHA/OutgoingRHA** is the right ascension of the incoming/outgoing asymptote. If **C3Energy** < 0 the apsides vector is substituted for the incoming/outgoing asymptote.	
	Data Type	Real
	Allowed Values	-∞ < **IncomingRHA/OutgoingRHA** < ∞
	Access	set, get
	Default Value	Conversion from default Cartesian state
	Units	deg
	Interfaces	GUI, script
MLONG	A measure of the location of the spacecraft in it's orbit. **MLONG** = **AOP** + **RAAN** + **MA**.	
	Data Type	Real
	Allowed Values	-360 ≤ **MLONG** ≤ 360
	Access	set, get
	Default Value	357.9131803707105
	Units	deg.
	Interfaces	GUI, script

Field	Description	
ModEquinoctialF	Components of the eccentricity vector (with **ModEquinoctialG**). The eccentricity vector has a magnitude equal to the eccentricity and it points from the central body to perigee. **ModEquinoctialF** = **ECC** * cos(**AOP**+**RAAN**)	
	Data Type	Real
	Allowed Values	-∞ < **ModEquinoctialF** < ∞
	Access	set, get
	Default Value	-0.003922778585859663
	Units	(None)
	Interfaces	GUI, script
ModEquinoctialG	Components of eccentricity vector (with **ModEquinoctialF**). **ModEquinoctialG** = **ECC** * sin(**AOP**+**RAAN**)	
	Data Type	Real
	Allowed Values	-∞ < **ModEquinoctialG** < ∞
	Access	set, get
	Default Value	-0.02423431419337062
	Units	(None)
	Interfaces	GUI, script
ModEquinoctialH	Identical to **EquinoctialQ**.	
	Data Type	Real
	Allowed Values	-∞ < **ModEquinoctialH** < ∞
	Access	set, get
	Default Value	0.06716454898232072
	Units	(None)
	Interfaces	GUI, script
ModEquinoctialK	Idential to **EquinoctialP**.	
	Data Type	Real
	Allowed Values	-∞ < **ModEquinoctialK** < ∞
	Access	set, get
	Default Value	-0.09038834725719359
	Units	(None)
	Interfaces	GUI, script
NAIFId	The spacecraft Id used in SPICE kernels.	
	Data Type	String
	Allowed Values	String
	Access	set
	Default Value	-123456789
	Units	N/A
	Interfaces	GUI, script

Field	Description
OrbitSpiceKernelName	SPK Kernels for spacecraft orbit. SPK orbit kernels have extension ".BSP". This field cannot be set in the Mission Sequence. **Data Type** String array **Allowed Values** List of path and filenames. **Access** set **Default Value** No Default. The field is empty. **Units** N/A **Interfaces** GUI, script
PlanetodeticAZI	The orbital velocity azimuth expressed in the coordinate system chosen in the **CoordinateSystem** field. Unlike the **AZI** field, **PlanetodeticAZI** is associated with the **Planetodetic** state representation, which is only valid for coordinate systems with **BodyFixed** axes. **Data Type** Real **Allowed Values** $-\infty <$ **PlanetodeticAZI** $< \infty$ **Access** set, get **Default Value** 81.80908019114962 **Units** deg **Interfaces** GUI, script
PlanetodeticHFPA	The orbital horizontal flight path angle expressed in the coordinate system chosen in the **CoordinateSystem** field. **PlanetodeticHFPA** is only valid for coordinate systems with **BodyFixed** axes. **Data Type** Real **Allowed Values** $-90 \leq$ **PlanetodeticHFPA** ≤ 90 **Access** set, get **Default Value** 1.494615814842774 **Units** deg **Interfaces** GUI, script
PlanetodeticLAT	The planetodetic latitude expressed in the coordinate system chosen in the **CoordinateSystem** field. This field is only valid for coordinate systems with **BodyFixed** axes. **Data Type** Real **Allowed Values** $-90 \leq$ **PlanetodeticLAT** ≤ 90 **Access** set, get **Default Value** 10.43478253114861 **Units** deg **Interfaces** GUI, script

Field	Description
PlanetodeticLON	The planetodetic longitude expressed in the coordinate system chosen in the **CoordinateSystem** field. This field is only valid for coordinate systems with **BodyFixed** axes. **Data Type** Real **Allowed Values** -∞ < **PlanetodeticLON** < ∞ **Access** set, get **Default Value** 79.67188405807977 **Units** deg **Interfaces** GUI, script
PlanetodeticRMAG	The magnitude of the orbital position vector expressed in the coordinate system chosen in the **CoordinateSystem** field. Unlike the **RMAG** field, **PlanetodeticRMAG** is associated with the **Planetodetic** state representation, which is only valid for coordinate systems with **BodyFixed** axes. **Data Type** Real **Allowed Values** **PlanetodeticRMAG** ≥ 1e-10 **Access** set, get **Default Value** 7218.032973047435 **Units** km **Interfaces** GUI, script
PlanetodeticVMAG	The magnitude of the orbital velocity vector expressed in the coordinate system chosen in the **CoordinateSystem** field. Unlike the **VMAG** field, **PlanetodeticVMAG** is associated with the **Planetodetic** state representation, which is only valid for coordinate systems with **BodyFixed** axes. **Data Type** Real **Allowed Values** **PlanetodeticVMAG** ≥ 1e-10 **Access** set, get **Default Value** 6.905049647173787 **Units** km/s **Interfaces** GUI, script
RA	The right ascension of the orbital position expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type** Real **Allowed Values** -∞ < **RA** < ∞ **Access** set,get **Default Value** 0 **Units** deg **Interfaces** GUI, script

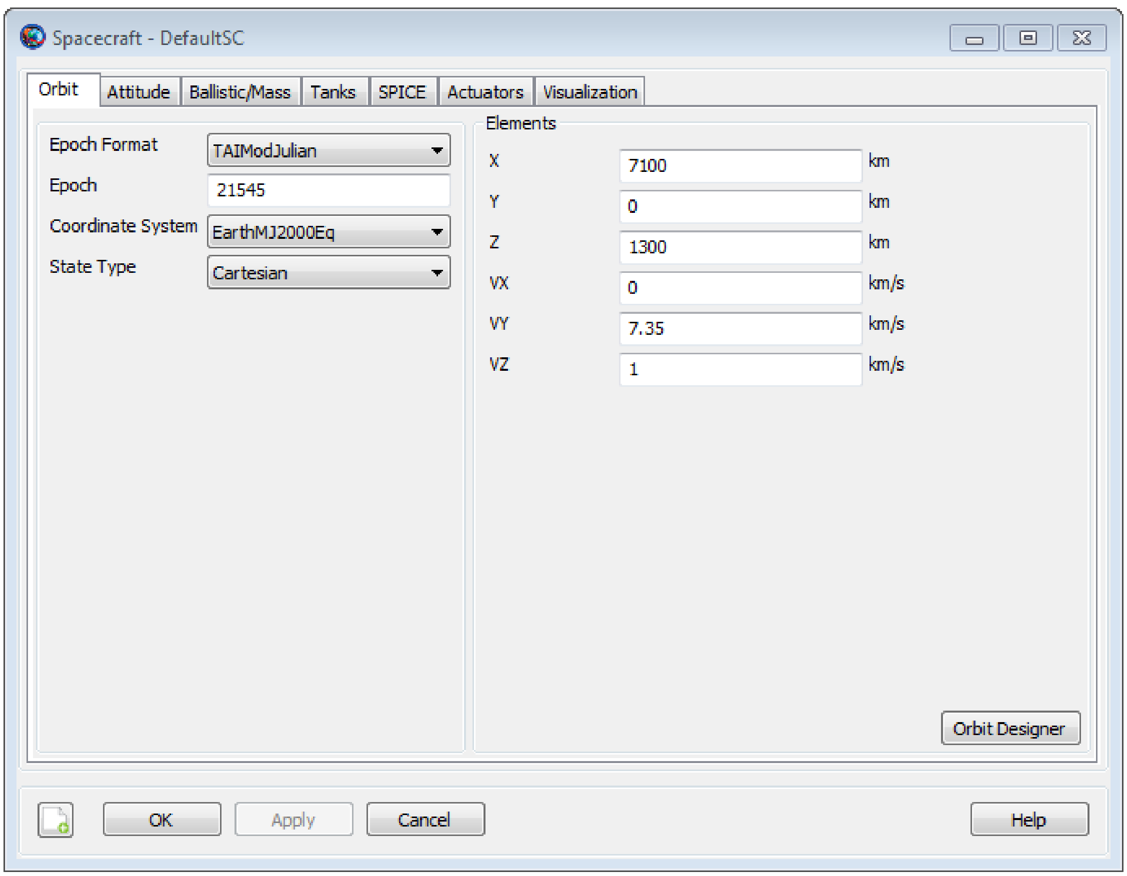
Field	Description
RAAN	The orbital right ascension of the ascending node expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type** Real **Allowed Values** -∞ < **RAAN** < ∞ **Access** set, get **Default Value** 306.6148021947984 **Units** deg **Interfaces** GUI, script
RadApo	The orbital radius of apoapsis expressed in the coordinate system chosen in the **CoordinateSystem** field. The radius of apoapsis is the maximum distance (osculating) between the **Spacecraft** and celestial body at the origin of **CoordinateSystem**. **Data Type** Real **Allowed Values** abs(**RadApo**) ≥ 1 meter. **Access** set, get **Default Value** 7368.49911046818 **Units** km **Interfaces** GUI, script
RadPer	The orbital radius of periapsis expressed in the coordinate system chosen in the **CoordinateSystem** field. The radius of periapsis is the minimum distance (osculating) between the **Spacecraft** and celestial body at the origin of **CoordinateSystem**. **Data Type** Real **Allowed Values** abs(**RadPer**) ≥ 1 meter. **Access** set, get **Default Value** 7015.378524789846 **Units** km **Interfaces** GUI, script
RAV	The right ascension of orbital velocity expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type** Real **Allowed Values** -∞ < **RAV** < ∞ **Access** set,get **Default Value** 90 **Units** deg **Interfaces** GUI, script

Field	Description	
RMAG	The magnitude of the orbital position vector expressed in the coordinate system chosen in the **CoordinateSystem** field.	
	Data Type	Real
	Allowed Values	**RMAG** ≥ 1e-10
	Access	set, get
	Default Value	7218.032973047435
	Units	km
	Interfaces	GUI, script
SemilatusRectum	Magnitude of the position vector when at true anomaly of 90 deg.	
	Data Type	Real
	Allowed Values	**SemilatusRectum** > 1e-7
	Access	set, get
	Default Value	7187.60430675539
	Units	km
	Interfaces	GUI, script
SMA	The orbital semi-major axis expressed in the coordinate system chosen in the **CoordinateSystem** field.	
	Data Type	Real
	Allowed Values	**SMA** < -0.001 m or **SMA** > 0.001 meter. If **SMA** < 0, then **ECC** must be > 1
	Access	set, get
	Default Value	7191.938817629013
	Units	km
	Interfaces	GUI, script
TA	The orbital true anomaly expressed in the coordinate system chosen in the **CoordinateSystem** field.	
	Data Type	Real
	Allowed Values	-∞ < **TA** < ∞
	Access	set, get
	Default Value	99.8877493320488
	Units	deg.
	Interfaces	GUI, script
TLONG	True longitude of the osculating orbit. **TLONG** = **RAAN** + **AOP** + **TA**	
	Data Type	Real
	Allowed Values	-∞ < **TLONG** < ∞
	Access	set, get
	Default Value	0.6931030628392251
	Units	deg
	Interfaces	GUI, script

Field	Description
VMAG	The magnitude of the orbital velocity vector expressed in the coordinate system chosen in the **CoordinateSystem** field. **Data Type** Real **Allowed Values** **VMAG** ≥ 1e-10 **Access** set, get **Default Value** 7.417715281675348 **Units** km/s **Interfaces** GUI, script
VX	The x-component of the **Spacecraft** velocity with respect to the coordinate system chosen in the spacecraft's **CoordinateSystem** field. **Data Type** Real **Allowed Values** -∞ < **VX** < ∞ **Access** set, get **Default Value** 0 **Units** km/s **Interfaces** GUI, script
VY	The y-component of the **Spacecraft** velocity with respect to the coordinate system chosen in the spacecraft's **CoordinateSystem** field. **Data Type** Real **Allowed Values** -∞ < **VY** < ∞ **Access** set, get **Default Value** 7.35 **Units** km/s **Interfaces** GUI, script
VZ	The z-component of the **Spacecraft** velocity with respect to the coordinate system chosen in the spacecraft's **CoordinateSystem** field. **Data Type** Real **Allowed Values** -∞ < **VZ** < ∞ **Access** set, get **Default Value** 1 **Units** km/s **Interfaces** GUI, script
X	The x-component of the **Spacecraft** position with respect to the coordinate system chosen in the spacecraft's **CoordinateSystem** field. **Data Type** Real **Allowed Values** -∞ < **X** < ∞ **Access** set,get **Default Value** 7100 **Units** km **Interfaces** GUI, script

Field	Description
Y	The y-component of the **Spacecraft** position with respect to the coordinate system chosen in the spacecraft's **CoordinateSystem** field. **Data Type** Real **Allowed Values** $-\infty < \mathbf{Y} < \infty$ **Access** set, get **Default Value** 0 **Units** km **Interfaces** GUI, script
Z	The z-component of the **Spacecraft** position with respect to the coordinate system chosen in the spacecraft's **CoordinateSystem** field. **Data Type** Real **Allowed Values** $-\infty < \mathbf{Z} < \infty$ **Access** set, get **Default Value** 1300 **Units** km **Interfaces** GUI, script

GUI



The **Spacecraft** orbit state dialog box allows you to set the epoch, coordinate system, and state type values for the **Spacecraft** orbital state. When you specify an orbital state, you define the state in the representation selected in the **StateType** menu, with respect to the coordinate system specified in the **CoordinateSystem** menu, at the epoch defined in the **Epoch** menu. If the selected **CoordinateSystem** is time varying, the epoch of the coordinate system is defined by the **Epoch** field, and changing the epoch changes the inertial representation of the orbital state.

A change in **Epoch Format** causes an immediate update to **Epoch** to reflect the chosen time system and format.

The **Keplerian**, **ModifiedKeplerian**, and **Equinoctial** state types cannot be computed if the **CoordinateSystem** does not have a central body at the origin, or if the **CoordinateSystem** references the current spacecraft (resulting in a circular reference). For example, if you have selected the **Keplerian** state type, coordinate systems for which the Keplerian elements cannot be computed do not appear in the **CoordinateSystem** menu. Similarly, if you have selected a **CoordinateSystem** that does not have a celestial body at the origin, Keplerian-based state types will not appear as options in the **StateType** menu. The **Planetodetic** state type cannot be selected untill the **CoordinateSystem** has **BodyFixed** axes.

Remarks

Cartesian State

The **Cartesian** state is composed of the position and velocity components expressed with respect to the selected **CoordinateSystem**.

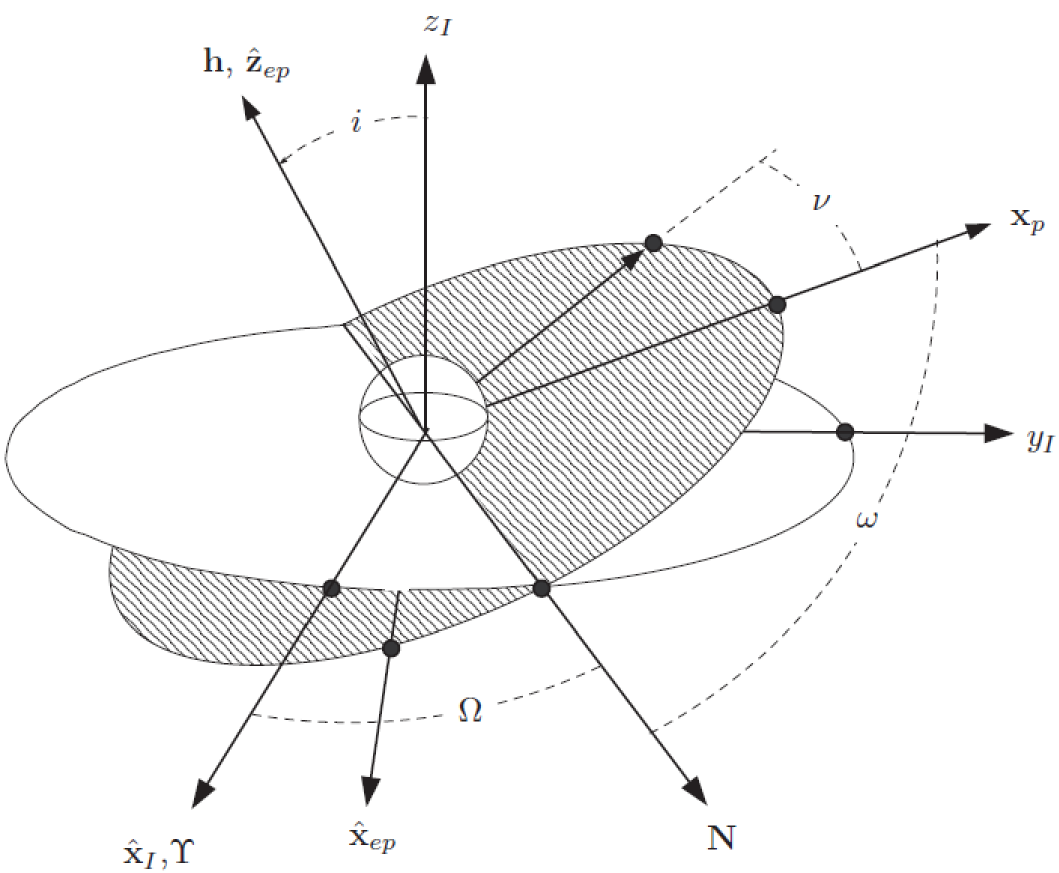
Keplerian and Modified Keplerian State Types

The **Keplerian** and **ModifiedKeplerian** state types use the osculating Keplerian orbital elements with respect to the selected **CoordinateSystem**. To use either the **Keplerian** or **ModifiedKeplerian** state type, the **Spacecraft**'s coordinate system must have a central body at the origin. The two representations differ in how the orbit size and shape are defined. The **Keplerian** state type is composed of the following elements: **SMA**, **ECC**, **INC**, **RAAN**, **AOP**, and **TA**. The **ModifiedKeplerian** state type is composed of the following elements: **RadApo**, **RadPer**, **INC**, **RAAN**, **AOP**, and **TA**. The tables and figures below describe each **Keplerian** state element in detail including singularities.

Geometry of the Keplerian Elements

Name	Description
SMA	**SMA** contains information on the type and size of an orbit. If **SMA** > 0 the orbit is elliptic. If **SMA** <0 the orbit is hyperbolic. **SMA** is infinite for parabolic orbits.
ECC	**ECC** contains information on the shape of an orbit. If **ECC** = 0, then the orbit is circular. If 0 < **ECC** < 1, the orbit is elliptical. If , **ECC** = 1 the orbit is parabolic. If **ECC** > 1 then the orbit is hyperbolic.
INC	**INC** is the angle between the orbit angular momentum vector and the z-axis. If **INC** < 90 deg., then the orbit is prograde. If **INC** > 90 deg, then the orbit is retrograde
RAAN	**RAAN** is defined as the angle between x-axis and the node vector measured counterclockwise. The node vector is defined as the cross product of the z-axis and orbit angular momentum vector. **RAAN** is undefined for equatorial orbits.

Name	Description
AOP	**AOP** is the angle between a vector pointing at periapsis and a vector pointing in the direction of the line of nodes. **AOP** is undefined for circular orbits.
TA	**TA** is defined as the angle between a vector pointing at periapsis and a vector pointing at the spacecraft. **TA** is undefined for circular orbits.



The **Keplerian** and **ModifiedKeplerian** state types have several singularities. The table below describes the different singularities and how each is handled in the state conversion algorithms.

Singularity	Comments and Behavior
ECC = 1	**SMA** is infinite and cannot be used to define the size of the orbit. GMAT requires **ECC** < 0.9999999 or **ECC** > 1.0000001 when setting **ECC** or when performing conversions. For transformations performed near these limits, loss of precision may occur.
ECC = 0	**AOP** is undefined. If **ECC** <= 1e-11, GMAT sets **AOP** to zero in the conversion from **Cartesian** to **Keplerian/ModKeplerian** and includes all orbital-plane angular displacement in the true anomaly.
SMA = 0	Results in a singular conic section. GMAT requires |**SMA**| > 1 meter when inputting **SMA**.

Singularity	Comments and Behavior
SMA = INF	**SMA** is infinite and another parameter is required to capture the size of the orbit. **Keplerian** elements are not supported.
INC = 0	**RAAN** is undefined. If **INC** < 6e-10, GMAT sets **RAAN** to 0 in the conversion from **Cartesian** to **Keplerian**/**ModKeplerian**. Then, if **ECC** < 1e-11, **AOP** is set to 0 and GMAT includes all angular displacement between the x-axis and the spacecraft in the true anomaly. If **ECC** ≥ 1e-11, then **AOP** is computed as the angle between the eccentricity vector and the x-axis.
INC = 180	**RAAN** is undefined. If **INC** > (180 - 6e-10), GMAT sets **RAAN** to 0 in the conversion from **Cartesian** to **Keplerian**/**ModKeplerian**. Then, if **ECC** < 1e-11, **AOP** is set to 0 and GMAT includes all angular displacement between the x-axis and the spacecraft in the true anomaly. If **ECC** ≥ 1e-11, then **AOP** is computed as the angle between the eccentricity vector and the x-axis.
RadPer = 0	Singular conic section. GMAT requires **RadPer** > 1 meter in state conversions.
RadApo = 0	Singular conic section. GMAT requires abs(**RadApo**) > 1 meter in state conversions.

Delaunay State Type

The conversion between **Delaunay** and **Cartesian** is performed passing through classical **Keplerian** state. Therefore, **Delaunay** state cannot represent parabolic orbits. Also, the **Delaunay** state cannot represent hyperbolic orbits because of the definition of **DelaunayL**, which is not a real value when **SMA** is negative. The table below describes the elements of the **Delaunay** state.

Element	Description
Delaunayl	The mean anomaly. It is related to uniform angular motion on a circle of radius **SMA**.
Delaunayg	See "Keplerian State" section, **AOP**
Delaunayh	See "Keplerian State" section, **RAAN**
DelaunayL	Related to the two-body orbital energy. **DelaunayL** = sqrt(mu***SMA**)
DelaunayG	Magnitude of the orbital angular momentum vector. **DelaunayG** = **DelaunayL***sqrt(1-**ECC**^2)
DelaunayH	The K component of the orbital angular momentum. **DelaunayH** = **DelaunayG** * cos(**INC**)

Singularities in the Delaunay Elements

Singularities in the **Delaunay** elements is the same as the **Keplerian** elements, because it uses the **Keplerian** elements during conversion. See "Keplerian State" section. The table below shows the additional singularities regarding the **Delaunay** state type.

Element	Description
ECC > 1	**DelaunayL** is not real for hyperbolic orbits by its definition.

Brouwer-Lyddane Mean State Type

The **BrouwerMeanShort** state represents short-term averaged mean motion under low-order zonal harmonics (i.e. J2-J5). Likewise, **BrouwerMeanLong** state represents long-term averaged mean motion under low-order zonal harmonics (i.e. J2-J5). GMAT uses JGM-2 zonal coefficients in Brouwer Mean states algorithms. Both are singular for near parabolic or hyperbolic orbits. To use **BrouwerMeanShort**/**BrouwerMeanLong** state type in GMAT, the central body must be the Earth. If the central body is the Earth, GMAT can calculate **BrouwerMeanShort**/**BrouwerMeanLong** state from the osculating state (**Cartesian**, **Keplerian**, etc.) and vice-versa.

Element	Description
BrouwerLongAOP **BrouwerShortAOP**	Brouwer-Lyddane long-term averaged (short-term averaged) mean argument of periapsis.
BrouwerLongMA **BrouwerShortMA**	Brouwer-Lyddane long-term averaged (short-term averaged) mean MA (mean anomaly).
BrouwerLongECC **BrouwerShortECC**	Brouwer-Lyddane long-term averaged (short-term averaged) mean eccentricity.
BrouwerLongINC **BrouwerShortINC**	Brouwer-Lyddane long-term averaged (short-term averaged) mean inclination.
BrouwerLongRAAN **BrouwerShortRAAN**	Brouwer-Lyddane long-term averaged (short-term averaged) mean RAAN (right ascension of the ascending node).
BrouwerLongSMA **BrouwerShortSMA**	Long-term averaged (short-term averaged) mean semi-major axis.

Singularities in the Brouwer-Lyddane Mean Elements

The table below shows the characteristics of singularities regarding **BrouwerMeanShort**/**BrouwerMeanLong** state and the implemented method to handle the singularities in GMAT state conversion algorithms. Note that because Brouwer-Lyddane mean elements involve an iterative solution, loss of precision may occur near singularities.

Element	Description
BrouwerSMA < 3000/(1-BrouwerECC)	Because Brouwer's formulation based on Earth's zonal harmonics, **BrouwerMeanShort** and **BrouwerMeanLong** cannot address orbits with mean perigee distance is smaller than Earth's radius, 3000 km because of numerical instability.

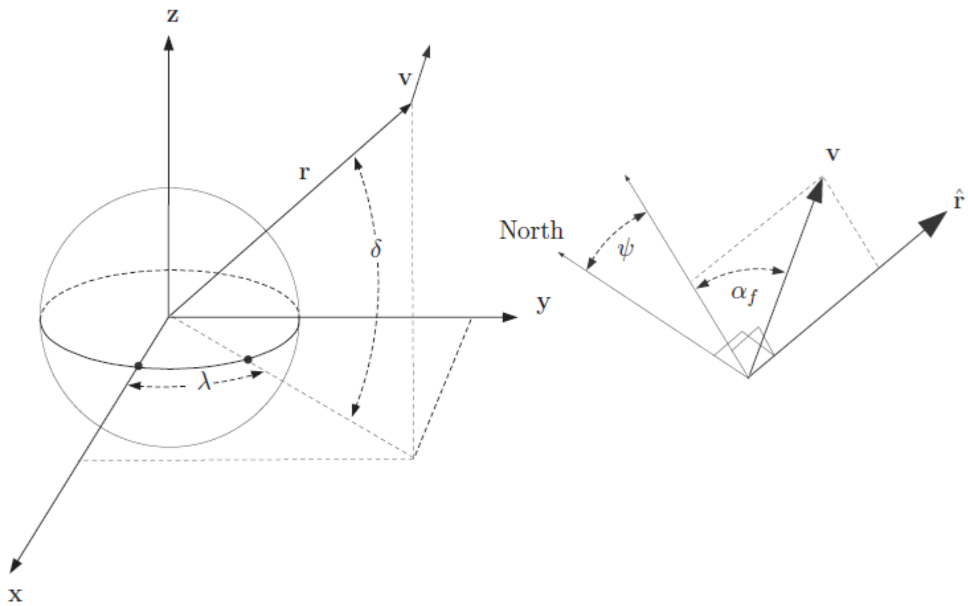
Element	Description
BrouwerLongINC= 63, BrouwerLongINC = 117	If given **BrouwerLongINC** (long-term averaged INC only) is close to i_c= 63 deg. or 117 deg., the algorithm is unstable because of singular terms (non-zero imaginary components). Thus, GMAT cannot calculate osculating elements.
BrouwerLongECC = 0, BrouwerLongECC ≥ 1	If **BrouwerECC** is larger than 0.9, or **BrouwerECC** is smaller than 1E-7, it has been reported that Cartesian to **BrouwerMean-Long** state does not converge statistically. For these cases, GMAT gives a warning message with the current conversion error.

Spherical State Types

The **SphericalAZFPA** and **SphericalRADEC** state types are composed of the polar coordinates of the spacecraft state expressed with respect to the selected **CoordinateSystem**. The two spherical representations differ in how the velocity is defined. The **SphericalRADEC** state type is composed of the following elements: **RMAG**, **RA**, **DEC**, **VMAG**, **RAV**, and **DECV**. The **SphericalAZFPA** state type is composed of the following elements: **RMAG**, **RA**, **DEC**, **VMAG**, **AZ**I and **FPA**. The tables and figures below describe each spherical state element in detail including singularities.

Geometry of the Spherical Elements

Name	Description
RMAG	The magnitude of the position vector.
RA	The right ascension which is the angle between the projection of the position vector into the xy-plane and the x-axis measured counterclockwise.
DEC	The declination which is the angle between tjhe position vector and the xy-plane.
VMAG	The magnitude of the velocity vector.
FPA	The vertical flight path angle. The angle measured from a plane normal to the postion vector to the velocity vector , measured in the plane formed by position vector and velocity vector.
AZI	The flight path azimuth. The angle measured from the vector perpendicular to the position vector and pointing north, to the projection of the velocity vector, into a plane normal to the position vector.
RAV	The right ascension of velocity. The angle between the projection of the velocity vector into the xy-plane and the x-axis measured counterclockwise.
DECV	The flight path azimuth. The angle between the velocity vector and the xy-plane.



Singularities in the Spherical Elements

Singularity	Comments and Behavior
RMAG = 0	Results in a singular conic section: declination and flight path angle are undefined. GMAT will not allow transformations if **RMAG** < 1e-10. For **RMAG** values greater than, but near 1e-10, loss of precision may occur in transformations.
VMAG = 0	Results in a singular conic section: velocity declination and flight path angle are undefined. GMAT will not allow transformations if **VMAG** < 1e-10.For **VMAG** values greater than, but near 1e-10, loss of precision may occur in transformations.

Planetodetic State Type

The **Planetodetic** state type is useful for specifying states relative to the surface of a central body. It is very similar to the spherical state types, but uses the central body's flattening in its definition. To use the **Planetodetic** state type, the spacecraft's coordinate system must have a celestial body at the origin, and must have **BodyFixed** axes.

Element	Description
PlanetodeticRMAG	Magnitude of the orbital radius vector.
PlanetodeticLON	Planetodetic longitude.
PlanetodeticLAT	Planetodetic latitude, using the **Flattening** of the central body.
PlanetodeticVMAG	Magnitude of the orbital velocity vector in the fixed frame.
PlanetodeticAZI	Orbital velocity azimuth in the fixed frame.
PlanetodeticHFPA	Horizontal flight path angle. **HFPA** = 90 - **VFPA**

Singularities in the Planetodetic Elements

Singularity	Comments and Behavior
PlanetodeticRMAG = 0	Results in a singular conic section: declination and flight path angle are undefined. GMAT will not allow transformations if **PlanetodeticRMAG** < 1e-10. For **PlanetodeticRMAG** values greater than, but near 1e-10, loss of precision may occur in transformations.
PlanetodeticVMAG = 0	Results in a singular conic section: velocity declination and flight path angle are undefined. GMAT will not allow transformations if **PlanetodeticVMAG** < 1e-10. For **PlanetodeticVMAG** values greater than, but near 1e-10, loss of precision may occur in transformations.

Equinoctial State Type

GMAT supports the **Equinoctial** state representation which is non-singular for elliptic orbits with inclinations less than 180 degrees. To use the **Equinoctial** state type, the spacecraft's coordinate system must have a central body at the origin.

Element	Description
SMA	See Keplerian section.
EquinoctialH	A measure of the orbital eccentricity and argument of periapsis. **EquinoctialH** and **EquinoctialK** together govern how elliptical an orbit is and where the periapsis is located. **EquinotialH** = **ECC** * sin(**AOP**).
EquinoctialK	A measure of the orbital eccentricity and argument of periapsis. **EquinoctialH** and **EquinoctialK** together govern how elliptical an orbit is and where the periapsis is located. **EquinotialK** = **ECC** * cos(**AOP**)
EquinoctialP	A measure of the orientation of the orbit. **EquinoctialP** and **EquinoctialQ** together govern how an orbit is oriented. **EquinotialP** = tan(**INC**/2)*sin(**RAAN**).
EquinoctialQ	A measure of the orientation of the orbit. **EquinoctialP** and **EquinoctialQ** together govern how an orbit is oriented. **EquinotialQ** = tan(**INC**/2)*cos(**RAAN**).
MLONG	A measure of the mean location of the spacecraft in its orbit. **MLONG** = **AOP** + **RAAN** + **MA**.

Singularities in the Equinoctial Elements

Element	Description
INC = 180	**RAAN** is undefined. If **INC** > 180 - 1.0e-11, GMAT sets **RAAN** to 0 degrees. GMAT does not support **Equinoctial** elements for true retrograde orbits.
ECC > 0.9999999	**Equinoctial** elements are not defined for parabolic or hyperbolic orbits.

Alternate Equinoctial State Type

The **AlternateEquinoctial** state type is a slight variation on the **Equinoctial** elements that uses sin(**INC**/2) instead of tan(**INC**/2) in the "P" and "Q" elements. Both representations have the same singularties.

Element	Description
SMA	See Keplerian section.
EquinoctialH	See Equinoctial section.
EquinoctialK	See Equinoctial section.
AltEquinoctialP	A measure of the orientation of the orbit. **AltEquinoctialP** and **AltEquinoctialQ** together govern how an orbit is oriented. **AltEquinotialP** = sin(**INC**/2)*sin(**RAAN**).
AltEquinoctialQ	A measure of the orientation of the orbit. **AltEquinoctialP** and **AltEquinoctialQ** together govern how an orbit is oriented. **AltEquinotialP** = sin(**INC**/2)*cos(**RAAN**).
MLONG	See Equinoctial section.

Modified Equinoctial State Type

The **ModifiedEquinoctial** state representation is non-singular for circular, elliptic, parabolic, and hyperbolic orbits. The only singularity is for retrograde equatorial orbits, because, like **Equinoctial** and **ModifiedEquinoctial**, GMAT does not support the retrograde factor.

Element	Description
SemilatusRectum	Magnitude of the position vector when at true anomaly of 90 deg **SemilatusRectum** = **SMA***(1-**ECC**^2)
ModEquinoctialF	Components of eccentricity vector (with **ModEquinoctialG**). Projection of eccentricity vector onto x. **ModEquinoctialF** = **ECC** * cos (**AOP**+**RAAN**)
ModEquinoctialG	Components of eccentricity vector (with **ModEquinoctialF**). Projection of eccentricity vector onto y. **ModEquinoctialG** = **ECC** * sin (**AOP**+**RAAN**)
ModEquinoctialH	Identical to **EquinoctialQ**.
ModEquinoctialK	Idential to **EquinoctialP**.
TLONG	A measure of the true location of the spacecraft in its orbit. **TLONG** = **AOP** + **RAAN** + **TA**.

Singularities in the Modified Equinoctial Elements

Element	Description
INC = 180	Similar to **Equinoctial** elements, there is singularity at **INC** = 180 deg. GMAT does not support **ModifiedEquinoctial** elements for retrograde equatorial orbits.

Hyperbolic Asymptote State Type

GMAT supports two related hyperbolic asymptote state types: **IncomingAsymptote** for defining the incoming hyperbolic asymptote, and **OutgoingAsymptote**, for defining the outgoing hyperbolic asymptote. Both representations are useful for defining flybys.

Element	Description
IncomingRadPer **OutgoingRadPer**	The orbital radius of periapsis. The radius of periapsis is the minimum distance (osculating) between the spacecraft and celestial body at the origin of coordinate system. **IncomingRadPer/OutgoingRadPer** differ from **RadPer** only in that they are associated with the **IncomingAsymptote** and **OutgoingAsymptote** state representations, respectively.
IncomingC3Energy **OutgoingC3Energy**	C3 energy. **C3Energy** = -mu/**SMA**. **IncomingC3Energy/OutgoingC3Energy** differ only in that they are associated with the **IncomingAsymptote** and **OutgoingAsymptote** state representations, respectively.
IncomingRHA **OutgoingRHA**	**IncomingRHA/OutgoingRHA** is the right ascension of the incoming/outgoing asymptote. If **C3Energy** < 0 the apsides vector is substituted for the incoming/outgoing asymptote.
IncomingDHA **OutgoingDHA**	**IncomingDHA/OutgoingDHA** is the declination of the incoming/outgoing asymptote. If **C3Energy** < 0 the apsides vector is substituted for the incoming/outgoing asymptote..
IncomingBVAZI **OutgoingBVAZI**	**IncomingBVAZI/OutgoingBVAZI** is the B-vector azimuth at infinity of the incoming/outgoing asymptote measured counter-clockwise from south. If **C3Energy** < 0 the apsides vector is substituted for the outgoing/incoming asymptote.
TA	See **Keplerian**.

Singularities in the Hyperbolic Asymptote Elements

Element	Description
IncomingC3Energy/ OutgoingC3Energy = 0	If **IncomingC3Energy/OutgoingC3Energy** = 0 the spacecraft has a parabolic orbit. Hyperbolic asymptote states do not support parabolic orbits. It must be avoided that -1E-7 ≤ **IncomingC3Energy/OutgoingC3Energy** ≤ 1E-7 by choosing a proper set of elements.
ECC = 0	For the case of circular orbits, **TA** is undefined. It must be avoided that **ECC** ≤ 1E-7 by choosing a proper set of elements. GMAT does not support hyperbolic asymptote representation for true circular orbits.
Asymptote vector parallel to z-axis	If the asymptote vector is parallel or antiparallel to coordinate system's z-direction, then the B-plane is undefined. It must be avoided by choosing either a proper coordinate system or set of elements.

State Component Interactions with the Spacecraft Coordinate System Field

When you define **Spacecraft** state elements such as **SMA**, **X**, or **DEC** for example, these values are set in coordinates defined by the **Spacecraft**'s **CoordinateSystem** field. For example, the following lines result in the X-component of the **Cartesian** state of **MySat** to be **`1000`**, in the **EarthFixed** system.

```
aSpacecraft.CoordinateSystem = EarthFixed
aSpacecraft.X = 1000
```

When the script lines above are executed in a script, GMAT converts the state to the specified coordinate system, in this case **EarthFixed**, sets the **X** component to **`1000`**, and then converts the state back to the internal inertial representation.

The following example sets **SMA** to **`8000`** in the **EarthMJ2000Eq** system, then sets **X** to **`6000`** in the Earth fixed system. (Note this is NOT allowed in initialization mode; see later remarks for more information).

```
aSpacecraft.CoordinateSystem = EarthMJ2000Eq
aSpacecraft.SMA = 8000
aSpacecraft.CoordinateSystem = EarthFixed
aSpacecraft.X = 6000
```

State Component Interactions with the Spacecraft Epoch Field

When you specify the **Spacecraft**'s epoch, you define the initial epoch of the spacecraft in the specified coordinate system. If your choice for the **Spacecraft**'s coordinate system is a time varying system such as the **EarthFixed** system, then you define the state in the **EarthFixed** system at that epoch. For example, the following lines would result in the cartesian state of **MySat** to be set to `[7000 0 1300 0 7.35 1]` in the **EarthFixed** system at `01 Dec 2000 12:00:00.000` UTC.

```
Create Spacecraft MySat
MySat.Epoch.UTCGregorian = '01 Dec 2000 12:00:00.000'
MySat.CoordinateSystem = EarthFixed
MySat.X = 7000
MySat.Y = 0
MySat.Z = 1300
MySat.VX = 0
MySat.VY = 7.35
MySat.VZ = 1
```

The corresponding **EarthMJ2000Eq** representation is

```
X  = -2320.30266
Y  = -6604.25075
Z  =  1300.02599
VX =  7.41609
VY = -2.60562
VZ =  0.99953
```

You can change the epoch of a **Spacecraft** in the mission sequence using a script line like this:

```
MySat.Epoch.TAIGregorian = '02 Dec 2000 12:00:00.000'
```

When the above line is executed in the mission sequence, GMAT converts the state to the specified coordinate system and then to the specified state type — in this case **EarthFixed** and **Cartesian** respectively — sets the epoch to the value of `02 Dec 2000 12:00:00.000`, and then converts the state back to the internal representation. This behavior is identical to that of the spacecraft orbit dialog box in the GUI. Because the coordinate system in this case is time varying, changing the spacecraft epoch has resulted in a change in the spacecraft's inertial state representation. After the epoch is changed to `02 Dec 2000 12:00:00.000`, the **EarthMJ2000Eq** state representation is now:

```
X  = -2206.35771
Y  = -6643.18687
Z  =  1300.02073
VX =  7.45981
VY = -2.47767
VZ =  0.99953
```

Scripting Limitations during Initialization

When setting the **Spacecraft** orbit state in a script, there are a few limitations to be aware of. In the initialization portion of the script (before the **BeginMissionSequence** command), you should set the epoch and coordinate system only once; multiple definitions of these parameters will result in either errors or warning messages and may lead to unexpected results.

Also when setting a state during initialization, you must set the orbit state in a set of fields corresponding to a single state type. For example, set the orbit state using the **X**, **Y**, **Z**, **VX**, **VY**, **VZ** fields (for the **Cartesian** state type) or the **SMA, ECC, INC, RAAN, AOP**, **TA** fields (for the **Keplerian** state type), but not a mixture of the two. If you need to mix state types, coordinate systems, or epochs to define the state of a spacecraft, you must set the state using scripting in the mission sequence (after the **BeginMissionSequence** command).

Shared State Components

Some state components, such as **SMA**, are shared among multiple state representations. In the mission sequence, GMAT does not require you to specify the state representation that you are setting; rather, you may specify a combination of elements from different representations.

For these shared components, GMAT defines a default representation for each, and uses that representation when setting or retrieving the value for the shared component. This is normally transparent, though it can have side effects if the default representation has singularities or numerical precision losses caused by the value being set or retrieved. The following table lists each shared state component and its default representation.

Field	Shared Between	Default Representation
AOP	Keplerian, ModifiedKeplerian	Keplerian
DEC	SphericalAZFPA, SphericalRADEC	SphericalAZFPA
EquinoctialH	AlternateEquinoctial, Equinoctial	Equinoctial
EquinoctialK	AlternateEquinoctial, Equinoctial	Equinoctial

Field	Shared Between	Default Representation
INC	Keplerian, ModifiedKeplerian	Keplerian
RA	SphericalAZFPA, SphericalRADEC	SphericalAZFPA
RAAN	Keplerian, ModifiedKeplerian	Keplerian
RMAG	SphericalAZFPA, SphericalRADEC	SphericalAZFPA
SMA	AlternateEquinoctial, Equinoctial, Keplerian	Keplerian
TA	IncomingAsymptote, OutgoingAsymptote, Keplerian, ModifiedKeplerian	Keplerian
VMAG	SphericalAZFPA, SphericalRADEC	SphericalAZFPA

As an example, consider the following mission sequence. Because GMAT executes each command sequentially, it uses the assigned state representation to calculation each component. For shared components, it uses the default representation for reach.

```
BeginMissionSequence
aSpacecraft.SMA = 20000      % conversion goes through Keplerian
aSpacecraft.RA = 30          % conversion goes through SphericalAZFPA
aSpacecraft.OutgoingDHA = 90 % conversion goes through OutgoingAsymptote
aSpacecraft.TA = 45          % conversion goes through Keplerian
```

Warning

When setting state parameters (especially in Keplerian-based representations) using non-default dependencies, be careful of the loss of precision caused by large translations in the intermediate orbit.

Examples

Define a **Spacecraft**'s Earth MJ2000Eq coordinates in the **Keplerian** representation:

```
Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = EarthMJ2000Eq
aSpacecraft.SMA  = 7100
aSpacecraft.ECC  = 0.01
aSpacecraft.INC  = 30
aSpacecraft.RAAN = 45
aSpacecraft.AOP  = 90
aSpacecraft.TA   = 270
```

Define a **Spacecraft**'s Earth fixed coordinates in the **Cartesian** representation:

```
Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = EarthFixed
aSpacecraft.X = 7100
aSpacecraft.Y = 0
aSpacecraft.Z = 1300
```

```
aSpacecraft.VX = 0
aSpacecraft.VY = 7.35
aSpacecraft.VZ = 1
```

Define a **Spacecraft**'s Moon centered coordinates in **ModifiedKeplerian** representation.

```
Create CoordinateSystem MoonInertial
MoonInertial.Origin = Luna
MoonInertial.Axes = BodyInertial

Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = MoonInertial
aSpacecraft.RadPer = 2100
aSpacecraft.RadApo = 2200
aSpacecraft.INC = 90
aSpacecraft.RAAN = 45
aSpacecraft.AOP = 45
aSpacecraft.TA = 180
```

Define a **Spacecraft**'s Rotating Libration Point coordinates in the **SphericalAZFPA** representation:

```
Create LibrationPoint ESL1
ESL1.Primary = Sun
ESL1.Secondary = Earth
ESL1.Point = L1

Create CoordinateSystem EarthSunL1CS
EarthSunL1CS.Origin = ESL1
EarthSunL1CS.Axes = ObjectReferenced
EarthSunL1CS.XAxis = R
EarthSunL1CS.ZAxis = N
EarthSunL1CS.Primary = Sun
EarthSunL1CS.Secondary = Earth

Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = EarthSunL1CS
aSpacecraft.DateFormat = UTCGregorian
aSpacecraft.Epoch = '09 Dec 2005 13:00:00.000'
aSpacecraft.RMAG = 1520834.130720907
aSpacecraft.RA = -111.7450242065574
aSpacecraft.DEC = -20.23326432189756
aSpacecraft.VMAG = 0.2519453702907011
aSpacecraft.AZI = 85.22478175803107
aSpacecraft.FPA = 97.97050698644287
```

Define a **Spacecraft**'s Earth-fixed coordinates in the **Planetodetic** representation:

```
Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = EarthFixed
aSpacecraft.PlanetodeticRMAG = 7218.032973047435
aSpacecraft.PlanetodeticLON = 79.67188405817301
aSpacecraft.PlanetodeticLAT = 10.43478253417053
aSpacecraft.PlanetodeticVMAG = 6.905049647178043
aSpacecraft.PlanetodeticAZI = 81.80908019170981
```

```
aSpacecraft.PlanetodeticHFPA = 1.494615714741736
```

Set a **Spacecraft**'s Earth MJ2000 ecliptic coordinates in the **Equinoctial** representation:

```
Create Spacecraft aSpacecraft
aSpacecraft.CoordinateSystem = EarthMJ2000Ec
aSpacecraft.SMA = 9100
aSpacecraft.EquinoctialH = 0.00905
aSpacecraft.EquinoctialK = 0.00424
aSpacecraft.EquinoctialP = -0.1059
aSpacecraft.EquinoctialQ = 0.14949
aSpacecraft.MLONG = 247.4528
```

Spacecraft Visualization Properties

The visual properties of the spacecraft

Description

The **Spacecraft Visualization Properties** lets you define a spacecraft model, translate the spacecraft in X,Y, Z directions or apply a fixed rotation to the attitude orientation of the model. You can also adjust the scale factor of the spacecraft model size. GMAT lets you set orbit colors via the spacecraft visualization properties as well. You can set colors to spacecraft orbital trajectories and any perturbing trajectories that are drawn during iterative processes. See Color documentation for discussion and examples on how to set orbital colors using **Spacecraft** object's **OrbitColor** and **TargetColor** fields. Also see the Fields section below to read more about these two fields. The Spacecraft visualization properties can be configured either through GMAT's GUI or the script interface.

See Also: OrbitView, Color

Fields

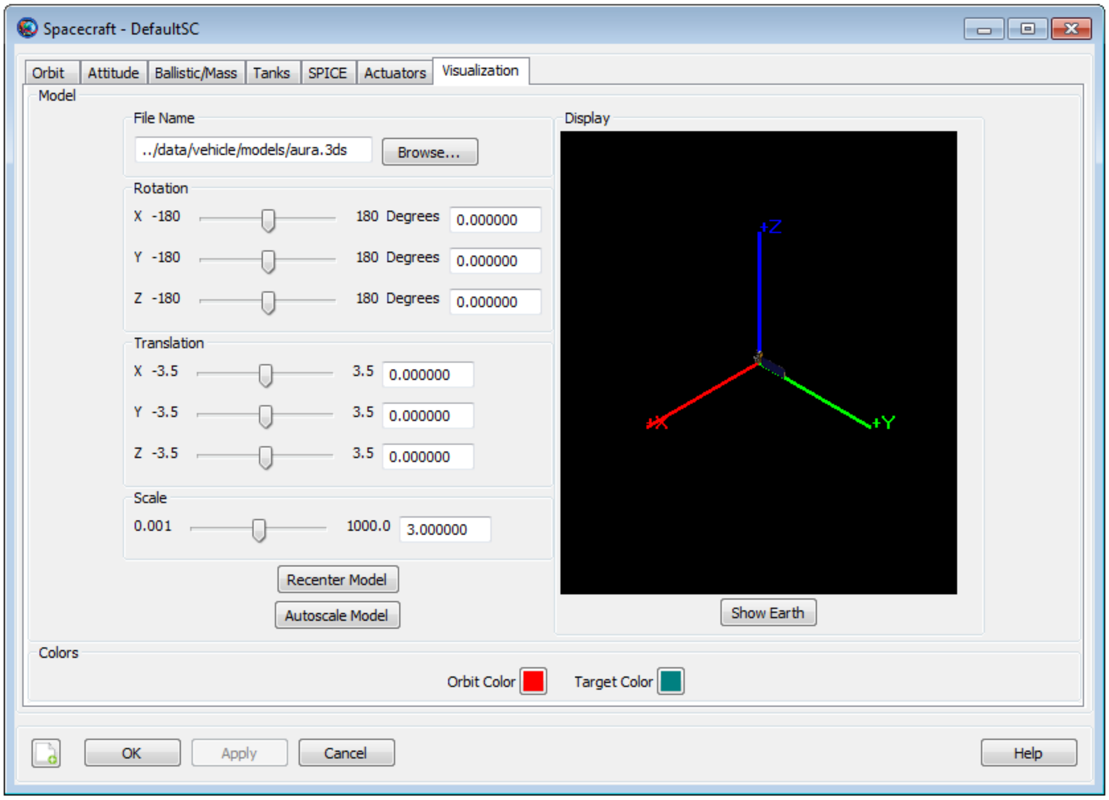
Field	Description
ModelOffsetX	This field lets you translate a spacecraft in +X or -X axis of central body's coordinate system. **Data Type**: Real **Allowed Values**: -3.5 <= Real <= 3.5 **Access**: set **Default Value**: 0.000000 **Units**: N/A **Interfaces**: GUI, script
ModelOffsetY	Allows you to translate a spacecraft in +Y or -Y axis of central body's coordinate system. **Data Type**: Real **Allowed Values**: -3.5 <= Real <= 3.5 **Access**: set **Default Value**: 0.000000 **Units**: N/A **Interfaces**: GUI, script
ModelOffsetZ	Allows you to translate a spacecraft in +Z or -Z axis of central body's coordinate system. **Data Type**: Real **Allowed Values**: -3.5 <= Real <= 3.5 **Access**: set **Default Value**: 0.000000 **Units**: N/A **Interfaces**: GUI, script

Field	Description
ModelRotationX	Allows you to perform a fixed rotation of spacecraft's attitude w.r.t X-axis of central body's coordinate system. **Data Type** Real **Allowed Values** -180 <= Real <= 180 **Access** set **Default Value** 0.000000 **Units** Deg. **Interfaces** GUI, script
ModelRotationY	Allows you to perform a fixed rotation of spacecraft's attitude w.r.t Y-axis of central body's coordinate system. **Data Type** Real **Allowed Values** -180 <= Real <= 180 **Access** set **Default Value** 0.000000 **Units** Deg. **Interfaces** GUI, script
ModelRotationZ	Allows you to perform a fixed rotation of spacecraft's attitude w.r.t Z-axis of central body's coordinate system. **Data Type** Real **Allowed Values** -180 <= Real <= 180 **Access** set **Default Value** 0.000000 **Units** Deg. **Interfaces** GUI, script
ModelScale	Allows you to apply a scale factor to the spacecraft model's size. **Data Type** Real **Allowed Values** 0.001 <= Real <= 1000 **Access** set **Default Value** 3.000000 **Units** N/A **Interfaces** GUI, script
ModelFile	Allows you to load spacecraft models that are in .3ds model formats. **Data Type** String **Allowed Values** . 3ds spacecraft model formats only **Access** set **Default Value** `../data/vehicle/models/aura.3ds` **Units** N/A **Interfaces** GUI, script

Field	Description
OrbitColor	Allows you to set available colors on spacecraft orbits. The spacecraft orbits are drawn using the **OrbitView** graphics displays. The colors can be identified through a string or an integer array. For example: Setting spacecraft's orbit color to red can be done in following two ways: `DefaultSC.OrbitColor = Red` or `DefaultSC.OrbitColor = [255 0 0]`. This field can be modified in the Mission Sequence as well. **Data Type** Integer Array or String **Allowed Values** Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255. **Access** set **Default Value** Red **Units** N/A **Interfaces** GUI, script
TargetColor	Allows you to set available colors on a spacecraft's perturbing trajectories during iterative processes such as Differential Correction or Optimization. The perturbing trajectories are drawn through the **OrbitView** resource. The target color can be identified through a string or an integer array. For example: Setting spacecraft's perturbing trajectories to yellow color can be done in following two ways: `DefaultSC.TargetColor = Yellow` or `DefaultSC.TargetColor = [255 255 0]` . This field can be modified in the Mission Sequence as well. **Data Type** Integer Array or String **Allowed Values** Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255. **Access** set **Default Value** Teal **Units** N/A **Interfaces** GUI, script

GUI

The figure below shows the default settings for the **Spacecraft Visualization Properties** resource:



The GUI interface for **Spacecraft Visualization Properties** is contained on the Visualization tab of the **Spacecraft** resource. You can configure visualization properties of the spacecraft and visualize the changes in the **Display** window.

Within the **Display** window, you can **Left** click and drag your mouse to change camera orientation. Camera orientation can be changed in **Up/Down/Left/Righ**t directions. You can also **Right** click and drag your mouse to zoom in and out of the **Display** window. **Right** click and moving the cursor in **Up** direction helps to zoom out and moving the cursor in **Down** direction helps to zoom in.

Remarks

Configuring Spacecraft Visualization Properties

GMAT lets you define any spacecraft model but currently GMAT supports only .3ds model format. Several .3ds spacecraft model formats are available here. You can also download more .3ds models by clicking here. Most of these models are in .3ds format, which can be read by most 3D programs.

GMAT lets you apply fixed rotation to the attitude orientation of the spacecraft model or translate the model in any of the X, Y and Z directions. You can also apply a scale factor to the selected spacecraft model to adjust the size of the model. Any changes that are made to the spacecraft model, attitude orientation, translation or scale size factor will also be displayed in **OrbitView** resource's graphics window. The configured spacecraft visualization properties will only show up in OrbitView graphics window after you have run the mission. See **OrbitView** resource's user-specification document to learn more about **OrbitView** graphics window.

Examples

This example shows you how to configure **Spacecraft Visualization Properties** resource. All values are non-default values.

```
Create Spacecraft aSat
aSat.ModelFile = '../data/vehicle/models/aura.3ds'
aSat.ModelOffsetX = 1.5
aSat.ModelOffsetY = -2
aSat.ModelOffsetZ = 3
aSat.ModelRotationX = 180
aSat.ModelRotationY = 180
aSat.ModelRotationZ = 90
aSat.ModelScale = 15

Create Propagator aProp

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth}

BeginMissionSequence
Propagate aProp(aSat) {aSat.ElapsedSecs = 9000}
```

String

A user-defined string variable

Description

The **String** resource is used to store a string value for use by commands in the Mission Sequence.

In the script environment, **String** resources are initialized to the string `'STRING_PARAMETER_UNDEFINED'` on creation. In the GUI environment, they're initialized to the empty string (`''`). String resources can be assigned using string literals or (in the Mission Sequence) other **String** resources, numeric **Variable** resources, or resource parameters that have string types.

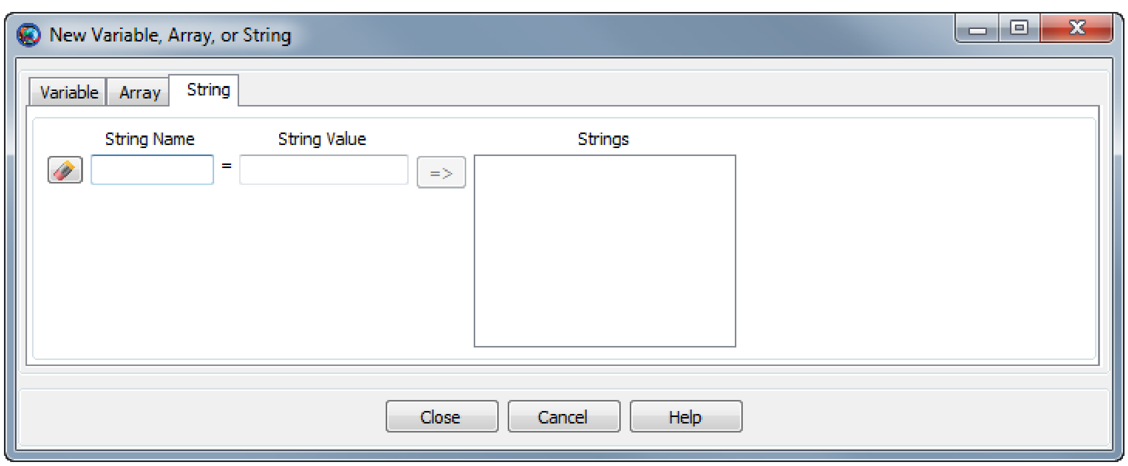
See Also: Array, Variable

Fields

The **String** resource has no fields; instead, the resource itself is set to the desired value.

Field	Description
`value`	The value of the string variable. **Data Type**: String **Allowed Values**: N/A **Access**: set, get **Default Value**: `''` (empty) (GUI) `'STRING_PARAMETER_UNDEFINED'` (script) **Units**: N/A **Interfaces**: GUI, script

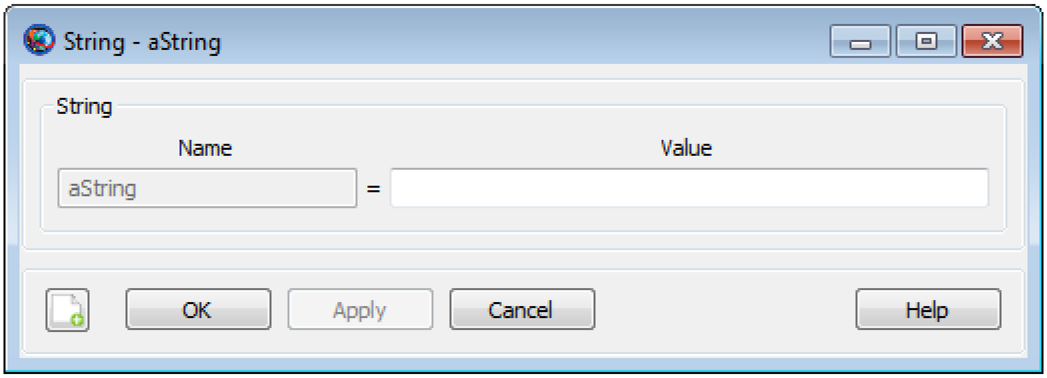
GUI



The GMAT GUI lets you create multiple **String** resources at once without leaving the window. To create a **String**:

1. In the **String Name** box, type the desired name of the string.
2. In the **String Value** box, type the initial value of the string. This is required and must be a literal string value. Quotes are not necessary when setting the value.
3. Click the **=>** button to create the string and add it to the list on the right.

You can create multiple **String** resources this way. To edit an existing string in this window, click it in the list on the right and edit the value. You must click the **=>** button again to save your changes.



You can also double-click an existing **String** in the resources tree in the main GMAT window. This opens the string properties box above that allows you to edit the value of that individual string.

Remarks

String resources can (in the Mission Sequence) be set using numeric **Variable** resources. The numeric value of the **Variable** is converted to a string during the assignment. The numeric value is converted to a string representation in either floating-point or scientific notation (whichever is more appropriate) with a maximum of 16 significant figures.

Examples

Creating a string and assigning it a literal value:

```
Create ReportFile aReport

Create String aStr
aStr = 'MyString'

BeginMissionSequence

Report aReport aStr
```

Thruster

A chemical thruster model

Description

The **Thruster** resource is a model of a chemical thruster which uses polynomials to model the thrust and specific impulse as a function of tank pressure and temperature. The **Thruster** model also allows you to specify properties such as a duty cycle and scale factor and to connect a **Thruster** with a **FuelTank**. You can flexibly define the direction of the thrust by specifying the thrust components in coordinate systems such as (locally defined) **SpacecraftBody** or **LVLH**, or by choosing any configured **CoordinateSystem** resource.

See Also: BeginFiniteBurn,FuelTank,FiniteBurn

Fields

The constants **Ci** below are used in the following equation to calculate thrust (in Newtons), F_T, as a function of pressure P (kPa) and temperature T (Celsius).

$$F_T(T,P) = C_1 + C_2 P + (C_3 + C_4 P + C_5 P^2 + C_6 P^{C_7}$$
$$+ C_8 P^{C_9} + C_{10} P^{C_{11}} + C_{12}(C_{13})^{C_{14} P}) \left(\frac{T}{T_{ref}}\right)^{1+C_{15}+C_{16}P}$$

The constants **Ki** below are used in the following equation to calculate ISP (in seconds), Isp, as a function of pressure P (kPa) and temperature T (Celsius).

$$I_{sp}(T,P) = K_1 + K_2 P + (K_3 + K_4 P + K_5 P^2 + K_6 P^{K_7}$$
$$+ K_8 P^{K_9} + K_{10} P^{K_{11}} + K_{12}(K_{13})^{K_{14} P}) \left(\frac{T}{T_{ref}}\right)^{1+K_{15}+K_{16}P}$$

Field	Description	
Axes	Allows the user to define a spacecraft centered set of axes for the **Thruster**. This field cannot be modified in the Mission Sequence	
	Data Type	Reference Array
	Allowed Values	**VNB**, **LVLH**, **MJ2000Eq**, **SpacecraftBody**
	Access	set
	Default Value	**VNB**
	Units	N/A
	Interfaces	GUI, script

Field	Description	
CoordinateSystem	Determines what coordinate system the orientation parameters, **Thrust-Direction1**, **ThrustDirection2**, and **ThrustDirection3** refer to. This field cannot be modified in the Mission Sequence.	
	Data Type	Reference Array
	Allowed Values	**Local**, **EarthMJ2000Eq**, **EarthMJ2000Ec**, **EarthFixed**, or any user defined system
	Access	set
	Default Value	**Local**
	Units	N/A
	Interfaces	GUI, script
C1	Thrust coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	10
	Units	N
	Interfaces	GUI, script
C2	Thrust coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	N/kPa
	Interfaces	GUI, script
C3	Thrust coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	N
	Interfaces	GUI, script
C4	Thrust coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	N/kPa
	Interfaces	GUI, script

Field	Description	
C5	Thrust coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	N/kPa^2
	Interfaces	GUI, script
C6	Thrust coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	N/kPa^{C7}
	Interfaces	GUI, script
C7	Thrust coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	None
	Interfaces	GUI, script
C8	Thrust coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	N/kPa^{C9}
	Interfaces	GUI, script
C9	Thrust coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	None
	Interfaces	GUI, script

Field	Description	
C10	Thrust coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	N/kPa^{C11}
	Interfaces	GUI, script
C11	Thrust coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	None
	Interfaces	GUI, script
C12	Thrust coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	N
	Interfaces	GUI, script
C13	Thrust coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	None
	Interfaces	GUI, script
C14	Thrust coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	1/kPa
	Interfaces	GUI, script

Field	Description
C15	Thrust coefficient. **Data Type** Real **Allowed Values** Real Number **Access** set, get **Default Value** 0 **Units** None **Interfaces** GUI, script
C16	Thrust coefficient. **Data Type** Real **Allowed Values** Real Number **Access** set, get **Default Value** 0 **Units** 1/kPa **Interfaces** GUI, script
DecrementMass	Flag which determines if the **FuelMass** is to be decremented as it used. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** true, false **Access** set **Default Value** false **Units** N/A **Interfaces** GUI, script
DutyCycle	Fraction of time that the thrusters are on during a maneuver. The thrust applied to the spacecraft is scaled by this amount. Note that this scale factor also affects mass flow rate. **Data Type** Real Number **Allowed Values** 0 <= Real <= 1 **Access** set, get **Default Value** 1 **Units** N/A **Interfaces** GUI, script
GravitationalAccel	Value of the gravitational acceleration used for the FuelTank/Thruster calculations. **Data Type** Real Number **Allowed Values** Real > 0 **Access** set, get **Default Value** 9.81 **Units** m/s^2 **Interfaces** GUI, script

Field	Description	
K1	ISP coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	300
	Units	s
	Interfaces	GUI, script
K2	ISP coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	s/kPa
	Interfaces	GUI, script
K3	ISP coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	s
	Interfaces	GUI, script
K4	ISP coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	s/kPa
	Interfaces	GUI, script
K5	ISP coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	s/kPa^2
	Interfaces	GUI, script

Field	Description	
K6	ISP coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	s/kPa^{C7}
	Interfaces	GUI, script
K7	ISP coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	None
	Interfaces	GUI, script
K8	ISP coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	s/kPa^{C9}
	Interfaces	GUI, script
K9	ISP coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	None
	Interfaces	GUI, script
K10	ISP coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	s/kPa^{C11}
	Interfaces	GUI, script

Field	Description	
K11	ISP coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	None
	Interfaces	GUI, script
K12	ISP coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	s
	Interfaces	GUI, script
K13	ISP coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	None
	Interfaces	GUI, script
K14	ISP coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	1/kPa
	Interfaces	GUI, script
K15	ISP coefficient.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	None
	Interfaces	GUI, script

Field	Description
K16	ISP coefficient. **Data Type** Real **Allowed Values** Real Number **Access** set, get **Default Value** 0 **Units** 1/kPa **Interfaces** GUI, script
Origin	This field, used in conjunction with the **Axes** field, allows the user to define a spacecraft centered set of axes for the **Thruster**. **Origin** has no affect when a **Local** coordinate system is used and the **Axes** are set to **MJ2000Eq** or **SpacecraftBody**. This field cannot be modified in the Mission Sequence. **Data Type** Reference Array **Allowed Values** **Sun**, **Mercury**, **Venus**, **Earth**, **Luna**, **Mars**,**Jupiter**, **Saturn**, **Uranus**, **Neptune**, **Pluto** **Access** set **Default Value** **Earth** **Units** N/A **Interfaces** GUI, script
Tank	**FuelTank** from which the **Thruster** draws propellant from. In a script command, an empty list, e.g., `Thruster1.Tank = {}`, is NOT allowed. Via the script, if you wish to indicate that no **FuelTank** is associated with a **Thruster**, do not include commands such as `Thruster1.Tank = ...` in your script. This field cannot be modified in the Mission Sequence. **Data Type** Reference Array **Allowed Values** User defined list of **FuelTank(s)**. **Access** set **Default Value** N/A **Units** N/A **Interfaces** GUI, script
ThrustDirection1	X component of the spacecraft thrust vector direction. **Data Type** Real **Allowed Values** Real Number **Access** set, get **Default Value** `1` **Units** N/A **Interfaces** GUI, script

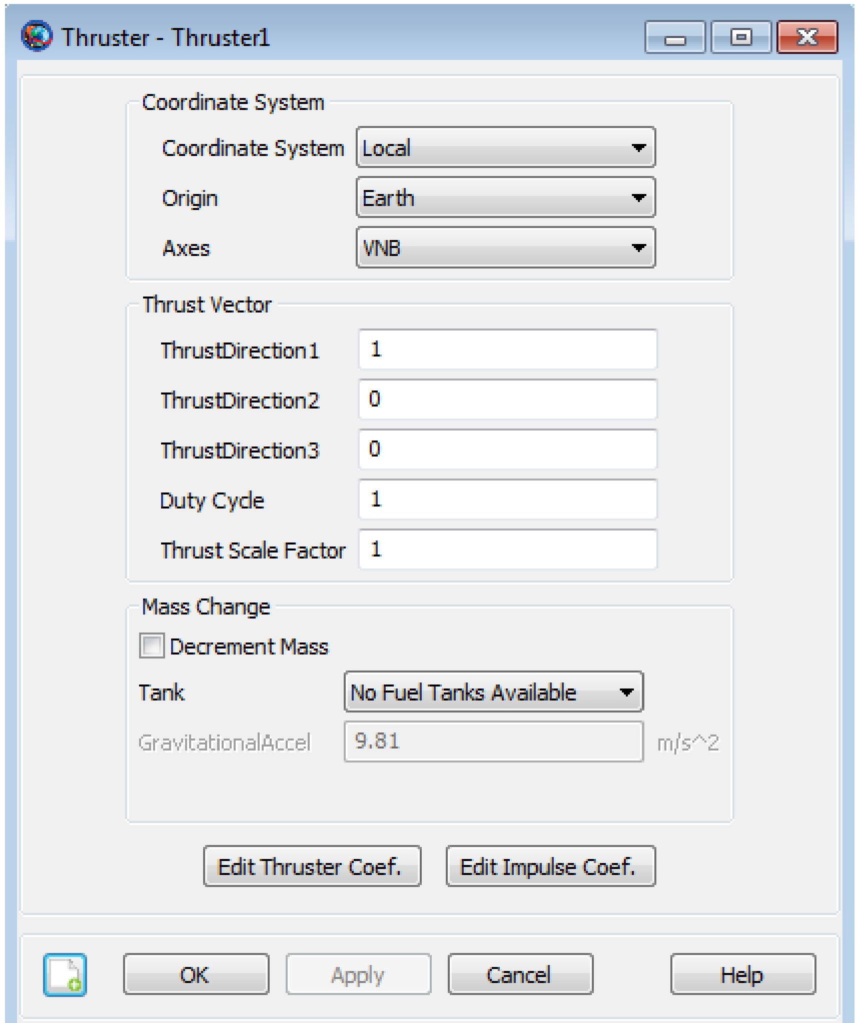
Field	Description	
ThrustDirection2	Y component of the spacecraft thrust vector direction.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	1
	Units	N/A
	Interfaces	GUI, script
ThrustDirection3	Z component of the spacecraft thrust vector direction.	
	Data Type	Real
	Allowed Values	Real Number
	Access	set, get
	Default Value	0
	Units	N/A
	Interfaces	GUI, script
ThrustScaleFactor	**ThrustScaleFactor** is a scale factor that is multiplied by the thrust vector, for a given thruster, before the thrust vector is added into the total acceleration. Note that the value of this scale factor does not affect the mass flow rate.	
	Data Type	Real Number
	Allowed Values	Real >= 0
	Access	set, get
	Default Value	1
	Units	N/A
	Interfaces	GUI, script

Interactions

Command or Resource	Description
BeginFiniteBurn/EndFiniteBurn command	Use these commands, which require a **Spacecraft** and a **FiniteBurn** name as input, to implement a finite burn.
FuelTank resource	This resource contains the fuel used to power the **Thruster** specified by the **FiniteBurn** resource.
FiniteBurn resource	When using the **BeginFiniteBurn/EndFiniteBurn** commands, you must specify which **FiniteBurn** resource to implement. The **FiniteBurn** resource specifies which **Thruster(s)** to use for the finite burn.
Spacecraft resource	When using the **BeginFiniteBurn/EndFiniteBurn** commands, you must specify which **Spacecraft** to apply the finite burn to.
Propagate command	In order to implement a non-zero finite burn, a **Propagate** statement must occurr within the **BeginFiniteBurn** and **EndFiniteBurn** statements.

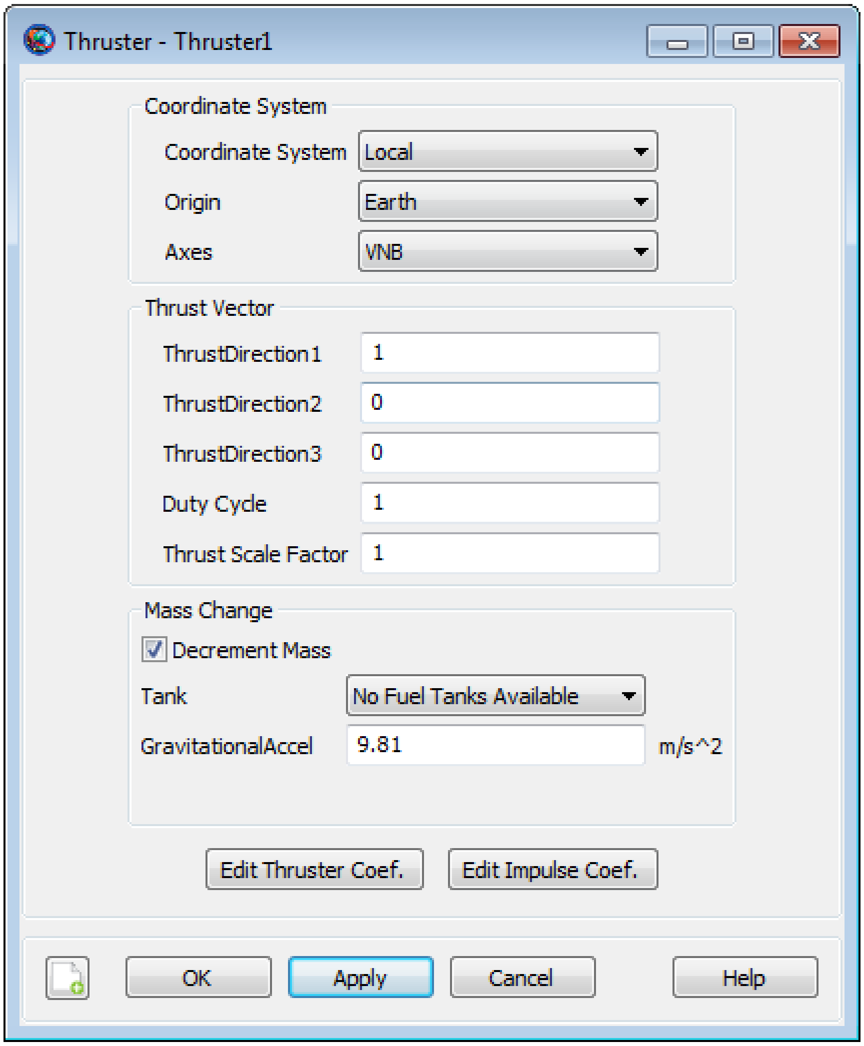
GUI

The **Thruster** dialog box allows you to specify properties of a **Thruster** including the **Coordinate System** of the thrust acceleration direction vector, the thrust magnitude and Isp coefficients, and choice of **FuelTank**. The layout of the **Thruster** dialog box is shown below.

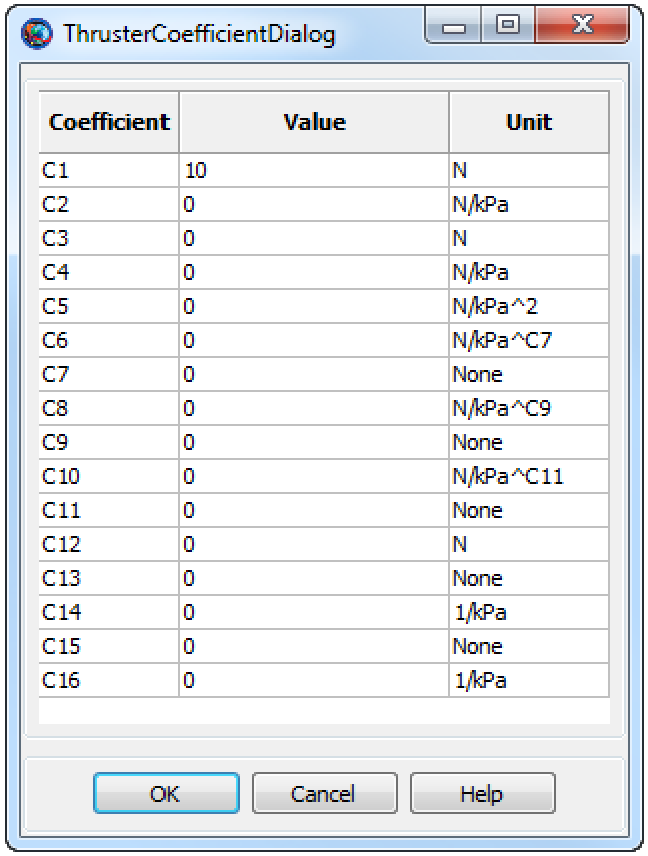


When configuring the **Coordinate System** field, you can choose between existing coordinate systems or use locally defined coordinate systems. The **Axes** field is only active if **Coordinate System** is set to **Local**. The **Origin** field is only active if **Coordinate System** is set to **Local** and **Axes** is set to either **VNB** or **LVLH**.

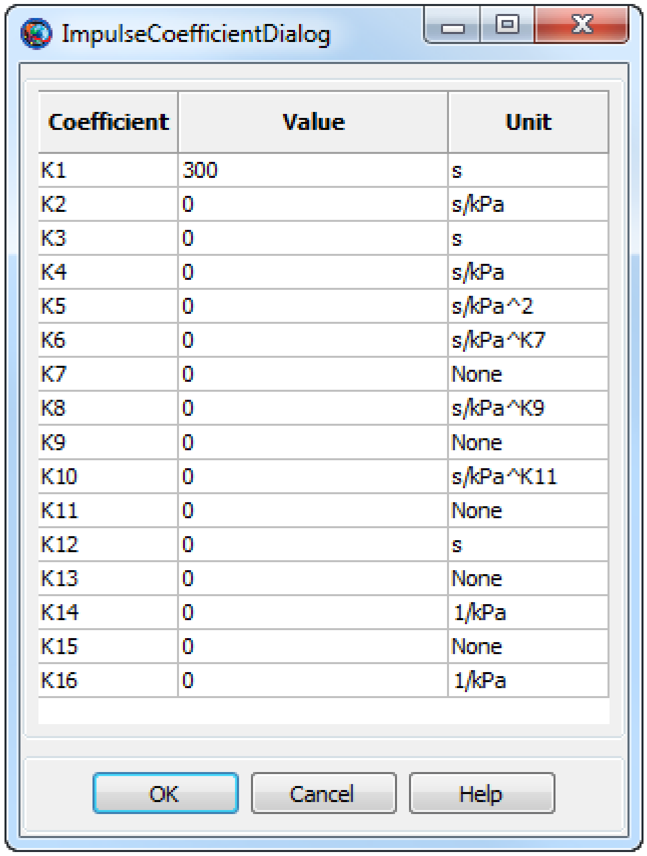
As shown below, if **Decrement Mass** is checked, then you can input the gravitational acceleration value used to calculate fuel use. The value of the gravitational acceleration input here only affects fuel use and does not affect the force model.



Selecting the **Edit Thruster Coef.** button brings up the following dialog box where you may input the coefficients for the **Thruster** polynomial.



Similarly, clicking the **Edit Impulse Coef.** button brings up the following dialog box where you may input the coefficients for the specific impulse (ISP) polynomial.



Coefficient	Value	Unit
K1	300	s
K2	0	s/kPa
K3	0	s
K4	0	s/kPa
K5	0	s/kPa^2
K6	0	s/kPa^K7
K7	0	None
K8	0	s/kPa^K9
K9	0	None
K10	0	s/kPa^K11
K11	0	None
K12	0	s
K13	0	None
K14	0	1/kPa
K15	0	None
K16	0	1/kPa

Remarks

Use of Thruster Resource in Conjunction With Maneuvers

A **Thruster** resource is used only in association with finite maneuvers. To implement a finite maneuver, you must first create both a **FuelTank** and a **FiniteBurn** resource. You must also associate a **FuelTank** with the **Thruster** resource and you must associate a **Thruster** with the **FiniteBurn** resource. The actual finite maneuver is implemented using the **BeginFiniteBurn**/**EndFiniteBurn** commands. See the **BeginFiniteBurn**/**EndFiniteBurn** command documentation for worked examples on how the **Thruster** resource is used in conjunction with finite maneuvers.

Thrust and ISP Calculation

Unscaled thrust, F_T, and Isp, as a function of Pressure, in kPa, and Temperature, in degrees Celsius, are calculated using the following polynomials.

$$F_T(T,P) = C_1 + C_2 P + (C_3 + C_4 P + C_5 P^2 + C_6 P^{C_7}$$
$$+C_8 P^{C_9} + C_{10} P^{C_{11}} + C_{12}(C_{13})^{C_{14}P}) \left(\frac{T}{T_{ref}}\right)^{1+C_{15}+C_{16}P}$$

$$I_{sp}(T,P) = K_1 + K_2 P + (K_3 + K_4 P + K_5 P^2 + K_6 P^{K_7}$$
$$+K_8 P^{K_9} + K_{10} P^{K_{11}} + K_{12}(K_{13})^{K_{14}P}) \left(\frac{T}{T_{ref}}\right)^{1+K_{15}+K_{16}P}$$

The thrust, T, output in Newtons, is scaled by the **Duty Cycle** and **Thrust Scale Factor**. The thrust acceleration direction vector (the direction of the actual acceleration not the thruster nozzle) is given by **ThrustDirection1-3** and is applied in the input **Coordinate System**. The Isp is output in seconds.

The mass flow rate and the thrust equations are shown below where F_T and Isp are defined above, f_d is the duty cycle, f_s is the thrust scale factor, R_{iT} is the rotation matrix from the thrust coordinate system to the inertial system, and T_d is the unitized thrust direction.

$$\dot{m} = f_d \frac{F_T(T,P)}{I_{sp}(T,P)g}$$

$$\mathbf{T} = f_s f_d F_T(T,P) \mathbf{R}_{iT} \hat{\mathbf{T}}_d$$

Local Coordinate Systems

Here, a Local coordinate system is defined as one that we configure "locally" using the **Thruster** resource interface as opposed to defining a coordinate system using the **Coordinate Systems** folder in the **Resources** Tree.

To configure a local coordinate system, you must specify the coordinate system of the input thrust acceleration direction vector, **ThrustDirection1-3**. If you choose a local coordinate system, the four choices available, as given by the **Axes** sub-field, are **VNB**, **LVLH**, **MJ2000Eq**, and **Spacecraft-Body**. **VNB** or Velocity-Normal-Binormal is a non-inertial coordinate system based upon the motion of the spacecraft with respect to the **Origin** sub-field. For example, if the **Origin** is chosen as Earth, then the X-axis of this coordinate system is the along the velocity of the spacecraft with respect to the Earth, the Y-axis is along the instantaneous orbit normal (with respect to the Earth) of the spacecraft, and the Z-axis completes the right-handed set.

Similarly, Local Vertical Local Horizontal or **LVLH** is also a non-inertial coordinate system based upon the motion of the spacecraft with respect to the **Origin** sub-field. Again, if we choose Earth as the origin, then the X-axis of this coordinate system is the position of the spacecraft with respect to the Earth, the Z-axis is the instantaneous orbit normal (with respect to the Earth) of the spacecraft, and the Y-axis completes the right-handed set.

MJ2000Eq is the J2000-based Earth-centered Earth mean equator inertial coordinate system. Note that the **Origin** sub-field is not needed to define this coordinate system.

SpacecraftBody is the attitude system of the spacecraft. Since the thrust is applied in this system, GMAT uses the attitude of the spacecraft, a spacecraft attribute, to determine the inertial thrust direction. Note that the **Origin** sub-field is not needed to define this coordinate system.

Caution When Setting the FuelTank Temperature and Reference Temperature

Note that both the thrust and ISP polynomials have terms that involve the ratio, (Temperature / Reference Temperature). For GMAT, this temperature ratio is calculated in Celsius units, and thus, there is a discontinuity when the Reference Temperature is equal to zero. For this reason, GMAT requires that the absolute value of the input Reference Temperature is greater than 0.01.

Note also that the form of the Thrust and ISP polynomial has some behavior, when the Reference Temperature is near 0 degrees Centigrade, that you need to be aware of. Because of the previously mentioned discontinuity, the polynomials do not vary smoothly when the Reference Temperature is near zero. For example, consider the two Reference Temperatures, -0.011 and + 0.011 degrees Centigrade. These two temperatures are close to each other in value and one might expect that they have roughly similar thrust and ISP values. This may not be the case, depending upon your choice of thrust/ISP coefficients, since the temperature ratios associated with the two Reference Temperatures have the same magnitude but different signs. You may choose to set the input Reference Temperature equal to the input Temperature, thus eliminating any dependence of thrust and ISP with temperature when using the currently implemented **FuelTank** model based upon Boyle's Law where the fuel Temperature does not change as fuel is depleted.

Examples

Create a default **FuelTank** and a **Thruster** that allows for fuel depletion, assign the **Thruster** the default **FuelTank**, and attach both the **Thruster** and **FuelTank** to a **Spacecraft**.

```
%  Create the FuelTank Resource
Create FuelTank FuelTank1
FuelTank1.AllowNegativeFuelMass = false
FuelTank1.FuelMass = 756
FuelTank1.Pressure = 1500
FuelTank1.Temperature = 20
FuelTank1.RefTemperature = 20
FuelTank1.Volume = 0.75
FuelTank1.FuelDensity = 1260
FuelTank1.PressureModel = PressureRegulated

%  Create a Thruster, that allows fuel depletion, and assign it a FuelTank
Create Thruster Thruster1
Thruster1.CoordinateSystem = Local
Thruster1.Origin = Earth
Thruster1.Axes = VNB
Thruster1.ThrustDirection1 = 1
Thruster1.ThrustDirection2 = 0
Thruster1.ThrustDirection3 = 0
Thruster1.DutyCycle = 1
Thruster1.ThrustScaleFactor = 1
Thruster1.DecrementMass = true
Thruster1.Tank = {FuelTank1}
```

```
Thruster1.GravitationalAccel = 9.810000000000001
Thruster1.C1 = 10
Thruster1.C2 = 0
Thruster1.C3 = 0
Thruster1.C4 = 0
Thruster1.C5 = 0
Thruster1.C6 = 0
Thruster1.C7 = 0
Thruster1.C8 = 0
Thruster1.C9 = 0
Thruster1.C10 = 0
Thruster1.C11 = 0
Thruster1.C12 = 0
Thruster1.C13 = 0
Thruster1.C14 = 0
Thruster1.C15 = 0
Thruster1.C16 = 0
Thruster1.K1 = 300
Thruster1.K2 = 0
Thruster1.K3 = 0
Thruster1.K4 = 0
Thruster1.K5 = 0
Thruster1.K6 = 0
Thruster1.K7 = 0
Thruster1.K8 = 0
Thruster1.K9 = 0
Thruster1.K10 = 0
Thruster1.K11 = 0
Thruster1.K12 = 0
Thruster1.K13 = 0
Thruster1.K14 = 0
Thruster1.K15 = 0
Thruster1.K16 = 0

%  Add the Thruster and the FuelTank to a Spacecraft
Create Spacecraft DefaultSC
DefaultSC.Tanks = {FuelTank1}
DefaultSC.Thrusters = {Thruster1}

BeginMissionSequence
```

Variable

A user-defined numeric variable

Description

The **Variable** resource is used to store a single numeric value for use by commands in the Mission Sequence. It can be used in place of a literal numeric value in most commands. **Variable** resources are initialized to zero on creation, and can be assigned using literal numeric values or (in the Mission Sequence) **Variable** resources, **Array** resource elements, resource parameters of numeric type, or **Equation** commands that evaluate to scalar numeric values.

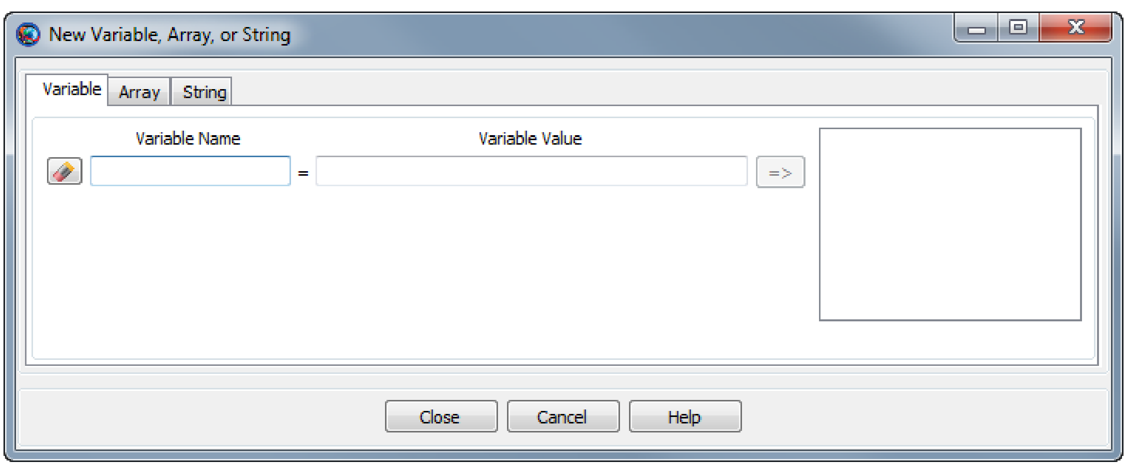
See Also: Array, String

Fields

The **Variable** resource has no fields; instead, the resource itself is set to the desired value.

Field	Description
`value`	The value of the variable. **Data Type** Real number **Allowed Values** -∞ < `value` < ∞ **Access** set, get **Default Value** 0.0 **Units** N/A **Interfaces** GUI, script

GUI

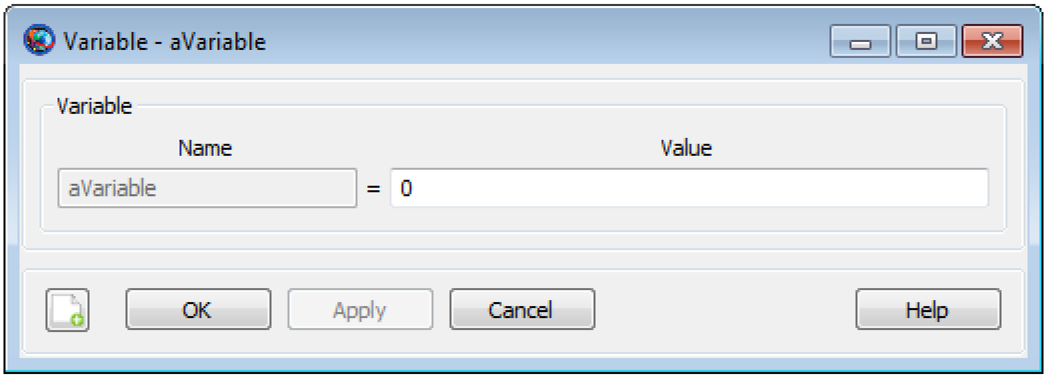


The GMAT GUI lets you create multiple **Variable** resources at once without leaving the window. To create a **Variable**:

1. In the **Variable Name** box, type the desired name of the variable.
2. In the **Variable Value** box, type the initial value of the variable. This is required and must be a literal numeric value.

3. Click the **=>** button to create the variable and add it to the list on the right.

You can create multiple **Variable** resources this way. To edit an existing variable in this window, click it in the list on the right and edit the value. You must click the **=>** button again to save your changes.



You can also double-click an existing variable in the resources tree in the main GMAT window. This opens the **Variable** properties box above that allows you to edit the value of that individual variable.

Remarks

GMAT **Variable** resources store a single numeric value. Internally, the value is stored as a double-precision real number, regardless of whether or not a fractional portion is present.

Examples

Creating a variable and assigning it a literal value:

```
Create ReportFile aReport

Create Variable aVar
aVar = 12

BeginMissionSequence

Report aReport aVar
```

Using variables in Mission Sequence commands:

```
Create Spacecraft aSat
Create ForceModel anFM
Create ReportFile aReport

Create Propagator aProp
aProp.FM = anFM

Create Variable i step totalDuration nSteps

BeginMissionSequence

step = 60
totalDuration = 24*60^2     % one day
```

```
nSteps = totalDuration / step

% Report Keplerian elements every 60 seconds for one day
For i=1:nSteps
   Propagate aProp(aSat) {aSat.ElapsedSecs = step}
   Report aReport aSat.TAIModJulian aSat.SMA aSat.ECC aSat.INC ...
      aSat.RAAN aSat.AOP aSat.TA
EndFor
```

VF13ad

The Sequential Quadratic Processor (SQP) optimizer, VF13ad

Description

The **VF13ad** optimizer is a SQP-based Nonlinear Programming solver available in the Harwell Subroutine Library. **VF13ad** performs nonlinear constrained optimization and supports both linear and nonlinear constraints. To use this solver, you must configure the solver options including convergence criteria, maximum iterations, and gradient computation method. In the mission sequence, you implement an optimizer such as VF13ad by using an **Optimize/EndOptimize** sequence. Within this sequence, you define optimization variables by using the **Vary** command, and define cost and constraints by using the **Minimize** and **NonlinearConstraint** commands respectively.

This resource cannot be modified in the Mission Sequence.

See Also: FminconOptimizer,Optimize,Vary, NonlinearConstraint, Minimize

Fields

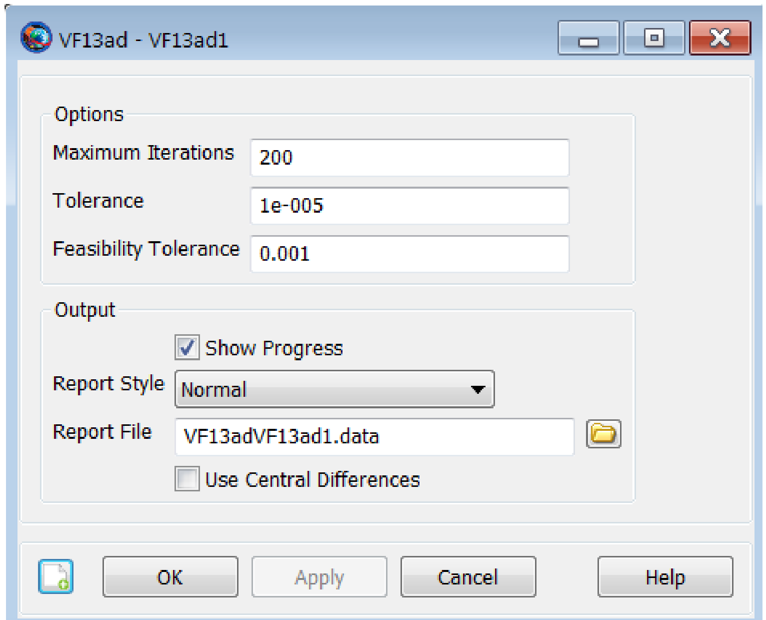
Field	Description
FeasibilityTolerance	Specifies the accuracy to which you want constraints to be satisfied. **Data Type**: Real **Allowed Values**: Real > 0 **Access**: set **Default Value**: 1e-3 **Units**: None **Interfaces**: GUI, script
MaximumIterations	Specifies the maximum allowable number of nominal passes through the Solver Control Sequence. **Data Type**: Integer **Allowed Values**: Integer > 0 **Access**: set **Default Value**: 200 **Units**: None **Interfaces**: GUI, script
ReportFile	Contains the path and file name of the report file. **Data Type**: String **Allowed Values**: Any user-defined file name **Access**: set **Default Value**: `VF13adVF13ad1.data` **Units**: None **Interfaces**: GUI, script

Field	Description	
ReportStyle	Determines the amount and type of data written to the message window and to the report specified by field **ReportFile** for each iteration of the solver (When **ShowProgress** is true). Currently, the **Normal**, **Debug**, and **Concise** options contain the same information: the values for the control variables, the constraints, and the objective function. In addition to this information, the **Verbose** option also contains values of the optimizer-scaled control variables.	
	Data Type	String
	Allowed Values	**Normal**, **Concise**, **Verbose**, **Debug**
	Access	set
	Default Value	**Normal**
	Units	None
	Interfaces	GUI, script
ShowProgress	Determines whether data pertaining to iterations of the solver is both displayed in the message window and written to the report specified by the **ReportFile** field. When **ShowProgress** is true, the amount of information contained in the message window and written in the report is controlled by the **ReportStyle** field.	
	Data Type	Boolean
	Allowed Values	`true`, `false`
	Access	set
	Default Value	`true`
	Units	None
	Interfaces	GUI, script
Tolerance	Specifies the measure the optimizer will use to determine when an optimal solution has been found based on the value of the goal set in a **Minimize** command.	
	Data Type	Real
	Allowed Values	Real > 0
	Access	set
	Default Value	1e-5
	Units	None
	Interfaces	GUI, script
UseCentralDifferences	Allows you to choose whether or not to use central differencing for numerically determining the derivative. For the default, 'false' value of this field, forward differencing is used to calculate the derivative.	
	Data Type	Boolean
	Allowed Values	`true`, `false`
	Access	set
	Default Value	`false`
	Units	None
	Interfaces	GUI, script

GUI

The **VF13ad** dialog box allows you to specify properties of a **VF13ad** such as as maximum iterations, cost function tolerance, feasibility tolerance, choice of reporting options, and choice of whether or not to use the central difference derivative method.

To create a **VF13ad** resource, navigate to the **Resources** tree, expand the **Solvers** folder, highlight and then right-click on the **Optimizers** sub-folder, point to **Add** and then select **VF13**ad. This will create a new **VF13ad** resource, VF13ad1. Double-click on VF13ad1 to bring up the **VF13ad** dialog box shown below.



Remarks

VF13ad Optimizer Availability

This optimizer is not included as part of the nominal GMAT installation and is only available if you have created and installed the VF13ad plug-in.

Resource and Command Interactions

The **VF13ad** resource can only be used in the context of optimization-type commands. Please see the documentation for **Optimize**, **Vary**, **NonlinearConstraint**, and **Minimize** for more information and worked examples.

Examples

Create a **VF13ad** resource named VF13ad1.

```
Create VF13ad VF13ad1
VF13ad1.ShowProgress = true
VF13ad1.ReportStyle = Normal
VF13ad1.ReportFile = 'VF13adVF13ad1.data'
```

```
VF13ad1.MaximumIterations = 200
VF13ad1.Tolerance = 1e-005
VF13ad1.UseCentralDifferences = false
VF13ad1.FeasibilityTolerance = 1e-003
```

For an example of how a **VF13ad** resource can be used within an Optimization sequence, see the **Optimize** command examples.

XYPlot

Plots data onto the X and Y axes of a graph

Description

The **XYPlot** resource allows you to plot data onto the X and Y axis of the graph. You can choose to plot any number of parameters as a function of a single independent variable. GMAT allows you to plot user-defined variables, array elements, or spacecraft parameters. You can create multiple **XY-Plots** by using either the GUI or script interface of GMAT. GMAT also provides the option of when to plot and stop plotting data to a XYPlot through the **Toggle On/Off** command. See the Remarks section below for detailed discussion of the interaction between an **XYPlot** resource and the **Toggle** command. GMAT's **Spacecraft** and **XYPlot** resources also interact with each other throughout the entire mission duration. Discussion of the interaction between **Spacecraft** and **XYPlot** resources can also be found in the Remarks section.

See Also: Toggle, Spacecraft

Fields

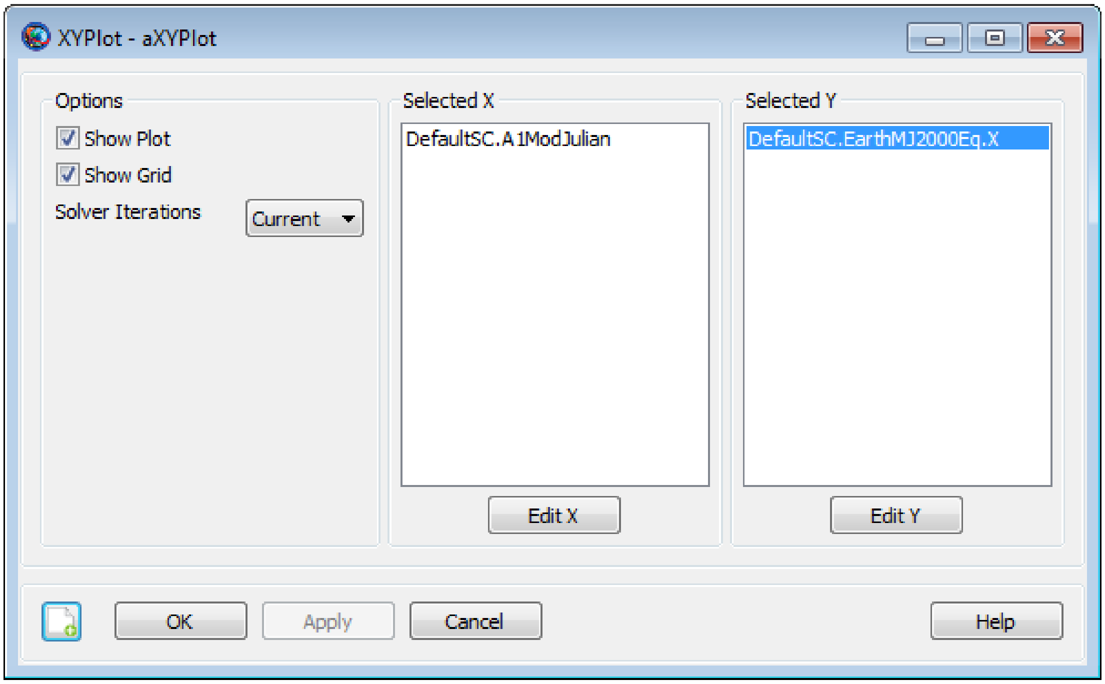
Field	Description
Maximized	Allows the user to maximize the **XYPlot** window. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** true,false **Access** set **Default Value** false **Units** N/A **Interfaces** script
UpperLeft	Allows the user to pan the **XYPlot** display window in any direction. First value in [0 0] matrix helps to pan the **XYPlot** window horizontally and second value helps to pan the window vertically. This field cannot be modified in the Mission Sequence. **Data Type** Real array **Allowed Values** Any Real number **Access** set **Default Value** [0 0] **Units** N/A **Interfaces** script

Field	Description
RelativeZOrder	Allows the user to select which **XYPlot** window to display first on the screen. The **XYPlot** with lowest **RelativeZOrder** value will be displayed last while **XYPlot** with highest **RelativeZOrder** value will be displayed first. This field cannot be modified in the Mission Sequence. **Data Type** Integer **Allowed Values** Integer ≥ 0 **Access** set **Default Value** 0 **Units** N/A **Interfaces** script
ShowGrid	When the **ShowGrid** field is set to **True**, then a grid is drawn on an xy-plot. When the **ShowGrid** field is set to **False**, then a grid is not drawn. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** True,False **Access** set **Default Value** True **Units** N/A **Interfaces** GUI, script
ShowPlot	Allows the user to turn off a plot for a particular run, without deleting the XYPlot resource, or removing it from the script. If you select **True**, then the plot will be shown. If you select **False**, then the plot will not be shown. This field cannot be modified in the Mission Sequence. **Data Type** Boolean **Allowed Values** True,False **Access** set **Default Value** True **Units** N/A **Interfaces** GUI, script
Size	Allows the user to control the display size of **XYPlot** window. First value in [0 0] matrix controls horizonal size and second value controls vertical size of **XYPlot** display window. This field cannot be modified in the Mission Sequence. **Data Type** Real array **Allowed Values** Any Real number **Access** set **Default Value** [0 0] **Units** N/A **Interfaces** script

Field	Description
SolverIterations	This field determines whether or not data associated with perturbed trajectories during a solver (**Targeter**, **Optimize**) sequence is displayed in the **XYPlot**. When **SolverIterations** is set to **All**, all perturbations/iterations are plotted in the **XYPlot**. When **SolverIterations** is set to **Current**, only the current solution or perturbation is plotted in **XYPlot**. When **SolverIterations** is set to **None**, only the final nominal run is plotted on the **XYPlot**. **Data Type**: Enumeration **Allowed Values**: **All**, **Current**, **None** **Access**: set **Default Value**: **Current** **Units**: N/A **Interfaces**: GUI, script
XVariable	Allows the user to define the independent variable for an **XYPlot**. Only one variable can be defined as an independent variable. For example, the line `MyXYPlot.XVariable = DefaultSC.A1ModJulian` sets the independent variable to be the epoch of **DefaultSC** in the A1 time system and modified Julian format. This field cannot be modified in the Mission Sequence. **Data Type**: Resource reference **Allowed Values**: **Variable**, **Array**, array element, **Spacecraft** parameter that evaluates to a real number **Access**: get, set **Default Value**: **DefaultSC.A1ModJulian** **Units**: N/A **Interfaces**: GUI, script
YVariable	Allows the user to add dependent variables to an xy-plot. All dependent variables are plotted on the y-axis vs the independent variable defined by **XVariable** field. The dependent variable(s) should always be included in curly braces. For example, `MyXYPlot.YVariables = {DefaultSC.EarthMJ2000Eq.Y, DefaultSC.EarthMJ2000Eq.Z}`. This field cannot be modified in the Mission Sequence. **Data Type**: Reference array **Allowed Values**: Any user variable, array element, or spacecraft parameter that evaluates to a real number **Access**: get, set **Default Value**: **DefaultSC.EarthMJ2000Eq.X** **Units**: N/A **Interfaces**: GUI, script

GUI

The figure below shows the default settings for the **XYPlot** resource:



Remarks

Behavior when using XYPlot Resource & Toggle Command

The **XYPlot** resource plots data onto the X and Y axis of the graph at each propagation step of the entire mission duration. If you want to report data to an **XYPlot** at specific points in your mission, then a **Toggle On**/**Off** command can be inserted into the mission sequence to control when the **XYPlot** is to plot data. When **Toggle Off** command is issued for a **XYPlot**, no data is plotted onto the X and Y axis of the graph until a **Toggle On** command is issued. Similarly when a **Toggle On** command is used, data is plotted onto the X and Y axis at each integration step until a **Toggle Off** command is used.

Below is an example script snippet that shows how to use **Toggle Off** and **Toggle On** commands while using the **XYPlot** resource. **Spacecraft's** position magnitude and semi-major-axis are plotted as a function of time.

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aXYPlot
aXYPlot.XVariable = aSat.ElapsedDays
aXYPlot.YVariables = {aSat.Earth.RMAG, aSat.Earth.SMA}

BeginMissionSequence

Toggle aXYPlot Off
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
Toggle aXYPlot On
Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

Behavior when using XYPlot & Spacecraft resources

Spacecraft resource contains information about spacecraft's orbit, its attitude, physical parameters (such as mass and drag coefficient) and any attached hardware, including thrusters and fuel tanks. **Spacecraft** resource interacts with **XYPlot** throughout the entire mission duration. The data retrieved from the spacecraft is what gets plotted onto the X and Y axis of the graph at each propagation step of the entire mission duration.

Behavior When Specifying Empty Brackets in XYPlot's YVariables Field

When using **XYPlot.YVariables** field, GMAT does not allow brackets to be left empty. The brackets must always be populated with values that you wish to plot against a variable in **XVariable** field. If brackets are left empty, then GMAT throws in an exception. Below is a sample script snippet that shows an example of empty brackets. If you were to run this script, then GMAT throws in an execption reminding you that brackets for **YVariables** field cannot be left empty.

```
Create Spacecraft aSat
Create Propagator aProp
Create XYPlot aXYPlot

aXYPlot.XVariable = aSat.ElapsedDays
aXYPlot.YVariables = {}

BeginMissionSequence
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
```

Behavior when Reporting Data in Iterative Processes

GMAT allows you to specify how data is plotted onto a plot during iterative processes such as differential correction or optimization. The **SolverIterations** field of an **XYPlot** resource supports three options which are described in the table below:

SolverIterations options	Description
Current	Shows only current iteration/perturbation in an iterative process and plots current iteration to a plot.
All	Shows all iterations/perturbations in an iterative process and plots all iterations/perturbations to a plot.
None	Shows only the final solution after the end of an iterative process and plots only that final solution to the plot.

Examples

Propagate an orbit and plot the spacecraft's altitude as a function of time at every integrator step:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aXYPlot
aXYPlot.XVariable = aSat.ElapsedSecs
```

```
aXYPlot.YVariables = {aSat.Earth.Altitude}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

Plotting data during an iterative process. Notice **SolverIterations** field is selected as **All**. This means all iterations/perturbations will be plotted.

```
Create Spacecraft aSat
Create Propagator aProp

Create ImpulsiveBurn TOI
Create DifferentialCorrector aDC

Create XYPlot aXYPlot
aXYPlot.SolverIterations = All
aXYPlot.XVariable = aSat.ElapsedDays
aXYPlot.YVariables = {aSat.Earth.RMAG}

BeginMissionSequence

Propagate aProp(aSat) {aSat.Earth.Periapsis}
Target aDC
 Vary aDC(TOI.Element1 = 0.24, {Perturbation = 0.001, Lower = 0.0, ...
 Upper = 3.14159, MaxStep = 0.5})
 Maneuver TOI(aSat)
 Propagate aProp(aSat) {aSat.Earth.Apoapsis}
 Achieve aDC(aSat.Earth.RMAG = 42165)
EndTarget
```

Commands

Table of Contents

Achieve

Specify a goal for a **Target** sequence

Script Syntax

```
Achieve SolverName (Goal = Arg1, [{Tolerance = Arg2}])
```

Description

The **Achieve** command is used in conjunction with the **Target** command as part of the **Target** sequence. The purpose of the **Achieve** command is to define a goal for the targeter (currently, the differential corrector is the only targeter available within a **Target** sequence) to achieve. To configure the **Achieve** command, you specify the goal object, its corresponding desired value, and an optional tolerance so the differential corrector can find a solution. The **Achieve** command must be accompanied and preceded by a **Vary** command in order to assist in the targeting process.

See Also: DifferentialCorrector, Target, Vary

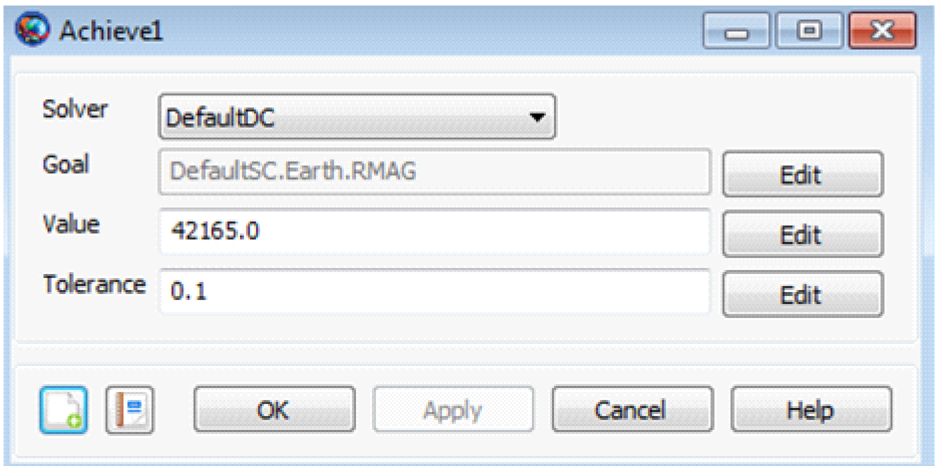
Options

Option	Description	
Arg1	Specifies the desired value for the **Goal** after the **DifferentialCorrector** has converged.	
	Accepted Data Types	Array, ArrayElement, Variable, String
	Allowed Values	Real Number, Array element, or Variable
	Default Value	42165
	Required	yes
	Interfaces	GUI, script
Arg2	Convergence tolerance for how close **Goal** equals **Arg1**	
	Accepted Data Types	Real Number, Array element, Variable, or any user-defined parameter > 0
	Allowed Values	Real Number, Array element, Variable, or any user-defined parameter > 0
	Default Value	0.1
	Required	no
	Interfaces	GUI, script
Goal	Allows you to select any single element user defined parameter, except a number, as a targeter goal.	
	Accepted Data Types	Object parameter, ArrayElement, Variable
	Allowed Values	**Spacecraft** parameter, **Array** element, **Variable**, or any other single element user defined parameter, excluding numbers
	Default Value	`DefaultSC.Earth.RMAG`
	Required	yes
	Interfaces	GUI, script

Option	Description	
SolverName	Specifies the **DifferentialCorrector** being used in the **Target** sequence	
	Accepted Data Types	String
	Allowed Values	Any user defined **DifferentialCorrector**
	Default Value	**DefaultDC**
	Required	yes
	Interfaces	GUI, script

GUI

You use an **Achieve** command, which is only valid within a **Target** sequence, to define your desired goal. More than one **Achieve** command may be used within a **Target** command sequence. The **Achieve** command dialog box, which allows you to specify the targeter, goal object, goal value, and convergence tolerance, is shown below.



Remarks

Command Interactions

A **Target** sequence must contain at least one **Vary** and one **Achieve** command.

Target command	An **Achieve** command only occurs within a **Target** sequence
Vary command	Associated with any **Achieve** command is at least one **Vary** command. The **Vary** command identifies the control variable used by the targeter. The goal specified by the **Achieve** command is obtained by varying the control variables.

Examples

As mentioned above, an **Achieve** command only occurs within a **Target** sequence. See the **Target** command help for examples showing the use of the **Achieve** command.

Assignment (=)

Set a variable or resource field to a value, possibly using mathematical expressions

Script Syntax

```
settable_item = expression
```

Description

The assignment command (in the GUI, the **Equation** command) allows you to set a resource field or parameter to a value, possibly using mathematical expressions. GMAT uses the assignment operator ('=') to indicate an assignment command. The assignment operator uses the following syntax, where LHS denotes the left-hand side of the operator, and RHS denotes the right-hand side of the operator:

```
LHS = RHS
```

In this expression, the left-hand side (*LHS*) is being set to the value of the right-hand side (*RHS*). The syntax of the *LHS* and *RHS* expressions vary, but both must evaluate to compatible data types for the command to succeed.

Left-hand side

The left-hand side of the assignment command must be a single item of any of the following types:

- allowed resource (e.g. **Spacecraft**, **Variable**, **Array**)
- resource field for allowed resources (e.g. **Spacecraft**.**Epoch**, **Spacecraft**.**DateFormat**)
- settable resource parameter (e.g. **Spacecraft**.**X**, **ReportFile**.**Precision**)
- **Array** or **Array** element

See the documentation for a particular resource to determine which fields and parameters can be set.

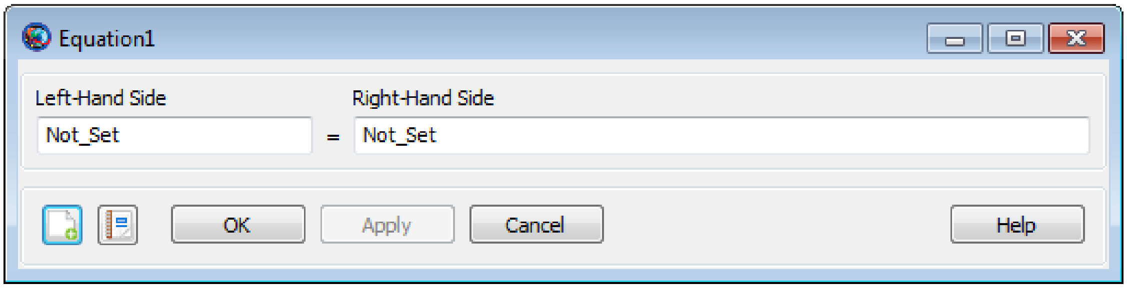
Right-hand side

The right-hand side of the assignment command can consist of any of the following:

- literal value
- resource (e.g. **Spacecraft**, **Variable**, **Array**)
- resource field (e.g. **Spacecraft**.**Epoch**, **Spacecraft**.**DateFormat**)
- resource parameter (e.g. **Spacecraft**.**X**, **Thruster**.**K1**)
- **Array** or **Array** element
- mathematical expression (see below)

MATLAB function calls are considered distinct from the assignment command. See the reference pages for more information.

GUI



The assignment command in the script language corresponds to the **Equation** command in the GUI. The **Equation** properties box allows you to input both sides of the expression into free-form text boxes. The default values on each side are "`Not_Set`"; these are placeholders only, and are not valid during the mission run. You can type into each box the same syntax described above for the script language. When you click **OK** or **Apply**, GMAT validates each side of the expression and provides feedback for any warnings or errors.

Remarks

Data type compatibility

In general, the data types of the left-hand side and the right-hand side must match after all expressions are evaluated. This means that a **Spacecraft** resource can only be set to another **Spacecraft** resource, numeric parameters can only be set to numeric values, and **String** resources can only be set to string values. Additionally, the dimension of **Array** instances must match for the command to succeed. For numeric quantities, the assignment command does not distinguish between integers and floating-point values.

Parameters

Parameters can be used on either side of an assignment command, but there may be certain restrictions.

On the right-hand side of the command, any parameter can be used. If a parameter accepts a dependency (such as **Spacecraft.*`CoordinateSystem`*.X**) and the dependency is omitted, a default dependency value will be used. For coordinate-system-dependent parameters, the default is **EarthMJ2000Eq**. For central-body-dependent parameters, the default is **Earth**.

On the left-hand side, only settable (writable) parameters can be used. Furthermore, no dependency can be specified, except in the special case that the dependencies on both sides of the assignment command are equivalent. On the left-hand side, the default values of omitted dependencies are automatically taken to be the current values of the **CoordinateSystem** field of the referenced **Spacecraft** and its origin.

These examples show valid and invalid usage of parameters:

```
Create Spacecraft aSat1 aSat2
aSat2.CoordinateSystem = 'EarthFixed'
Create Variable x
```

```
BeginMissionSequence
x = aSat1.EarthFixed.X       % Valid: Parameter with dependency on RHS
x = aSat1.EarthMJ2000Eq.X    % Valid: This and next statement are equiv.
x = aSat1.X                  % Valid: Default dep. value is EarthMJ2000Eq.

x = aSat1.Mars.Altitude      % Valid: Parameter with dependency on RHS
x = aSat1.Earth.Altitude     % Valid: This and next statement are equiv.
x = aSat1.Altitude           % Valid: Default dependency value is Earth.

aSat2.X = 1e5                % Valid: Default parameter value is EarthFixed.
aSat2.EarthMJ2000Eq.X = 1e5  % INVALID: Dependencies not allowed on LHS.
aSat2.EarthFixed.X = 1e5     % Valid: Special case because value = default.

aSat2.EarthMJ2000Eq.X = aSat1.EarthFixed.X    % INVALID: Dependency on LHS
aSat2.EarthMJ2000Eq.X = aSat1.EarthMJ2000Eq.X % INVALID: Dependency on LHS
aSat2.EarthFixed.X = aSat1.EarthFixed.X       % Valid: Special case

% DANGEROUS! Valid, but sets EarthMJ2000Eq RHS values to EarthFixed LHS param.
aSat2.X = aSat1.EarthMJ2000Eq.X

% DANGEROUS! RHS default is EarthMJ2000Eq, LHS default is current setting on
% aSat2 (EarthFixed in this case).
aSat2.X = aSat1.X
```

Mathematical Expressions

The assignment command supports the use of inline mathematical expressions on the right-hand side of the command. These expressions follow the general syntax rules of MATLAB expressions, and can use a variety of operators and built-in functions.

Parsing

Mathematical expressions are recognized by the presence of any of the operators or built-in functions described below. Before execution, all white space (e.g. spaces and tabs) is removed from the expression.

Data Types

Mathematical expressions operate on numeric values (integers or floating-point numbers). This includes the following:

- literal values
- numeric resources (**Variable**, **Array**)
- gettable resource parameters (e.g. **Spacecraft.X**, **Thruster.K1**)
- **Array** elements
- calculation parameters (e.g. **Spacecraft.OrbitPeriod**)
- nested mathematical expressions

Several of GMAT's operators and functions are vectorized, so they operate on full **Array** resources as well as scalar numeric values.

Operators

Vectorized operators	`+`	Addition or unary plus. `X+Y` adds `X` and `Y`. `X` and `Y` must have the same dimensions unless either is a scalar.
	`-`	Subtraction or unary minus. `-X` is the negative of `X`, where `X` can be any size. `X-Y` subtracts `Y` from `X`. `X` and `Y` must have the same dimensions unless either is a scalar.
	`*`	Multiplication. `X*Y` is the product of `X` and `Y`. If both `X` and `Y` are scalars, this is the simple algebraic product. If `X` is a matrix or vector and `Y` is a scalar, all elements of `X` are multiplied by `Y` (and vice versa). If both `X` and `Y` are non-scalar, `X*Y` performs matrix multiplication and the number of columns in `X` must equal the number of rows in `Y`.
	`'`	Transpose. `X'` is the transpose of `X`. If `X` is a scalar, `X'` is equal to `X`.
Scalar operators	`/`	Division. `X/Y` divides `X` by `Y`. If both `X` and `Y` are scalars, this is the simple algebraic quotient. If `X` is a matrix or vector, each element is divided by `Y`. `Y` must be a non-zero scalar quantity.
	`^`	Power. `X^Y` raises `X` to the `Y` power. `X` and `Y` must be scalar quantities. A special case is `X^(-1)`, which when applied to a square matrix `X`, returns the inverse of `X`.

When multiple expressions are combined, GMAT uses the following order of operations. Operations begin with those operators at the top of the list and and continue downwards. Within each level, operations proceed left-to-right.

1. parentheses `()`
2. transpose (`'`), power (`^`)
3. unary plus (`+`), unary minus (`-`)
4. multiplication (`*`), division (`/`)
5. addition (`+`), subtraction (`-`)

Built-in Functions

GMAT supports the following built-in functions in mathematical expressions. Such functions are either scalar, meaning they accept a single value only, or are matrix functions that operate on an entire matrix or vector.

Scalar functions	**`sin`**	Sine. In `Y = sin(X)`, `Y` is the sine of the angle `X`. `X` must be in radians. `Y` will be in the range [-1, 1].
	`cos`	Cosine. In `Y = cos(X)`, `Y` is the cosine of the angle `X`. `X` must be in radians. `Y` will be in the range [-1, 1].
	`tan`	Tangent. In `Y = tan(X)`, `Y` is the tangent of the angle `X`. `X` must be in radians. The tangent function is undefined at angles that normalize to π/2 or -π/2.
	`asin`	Arcsine. In `Y = asin(X)`, `Y` is the arcsine of `X`. `X` must be in the range [-1, 1], and `Y` will be in the range [-π/2, π/2].
	`acos`	Arccosine. In `Y = acos(X)`, `Y` is the arccosine of `X`. `X` must be in the range [-1, 1], and `Y` will be in the range [0, π].
	`atan`	Arctangent. In `Y = atan(X)`, `Y` is the arctangent of `X`. `Y` will be in the range (-π/2, π/2).
	`atan2`	Four-quadrant arctangent. In `A = atan2(Y, X)`, `A` is the arctangent of `Y/X`. `A` will be in the range (-π, π]. `atan2(Y, X)` is equivalent to `atan(Y/X)` except for the expanded range.
	`log`	Natural logarithm. In `Y = log(X)`, `Y` is the natural logarithm of `X`. `X` must be non-zero positive.
	`log10`	Common logarithm. In `Y = log10(X)`, `Y` is the common (base-10) logarithm of `X`. `X` must be non-zero positive.
	`exp`	Exponential. In `Y = exp(X)`, `Y` is exponential of `X` (e^X).
	`DegToRad`	Radian conversion. In `Y = DegToRad(X)`, `Y` is the angle `X` in units of radians. `X` must be an angle in degrees.
	`RadToDeg`	Degree conversion. In `Y = RadToDeg(X)`, `Y` is the angle `X` in units of degrees. `X` must be an angle in radians.
	`abs`	Absolute value. In `Y = abs(X)`, `Y` is the absolute value of `X`.
	`sqrt`	Square root. In `Y = sqrt(X)`, `Y` is the square root of `X`. `X` must be non-negative.
Matrix functions	**`norm`**	2-norm. In `Y = norm(X)`, `Y` is the 2-norm of `X`, where `X` must be a vector (i.e. one dimension must be 1). If `X` is a scalar, `Y` is equal to `X`.
	`det`	Determinant. In `Y = det(X)`, `Y` is the determinant of `X`. `X` must be a matrix or a scalar. If `X` is a matrix, the number of rows must equal the number of columns. If `X` is a scalar, `Y` is equal to `X`. For efficiency, GMAT's implementation of the determinant is currently limited to matrices 9×9 or smaller.
	`inv`	Inverse. In `Y = inv(X)`, `Y` is the inverse of `X`. `X` must be a matrix or a scalar. If `X` is a matrix, the number of rows must equal the number of columns. `X^(-1)` is an alternate syntax.

Examples

Evaluate a basic algebraic equation:

```
Create Variable A B C x y
x = 1
Create ReportFile aReport

BeginMissionSequence
```

```
A = 10
B = 20
C = 2

y = A*x^2 + B*x + C
Report aReport y
```

Matrix manipulation:

```
Create Array A[2,2] B[2,2] C[2,2] x[2,1] y[2,1]
Create ReportFile aReport

A(1,1) = 10
A(2,1) = 5
A(1,2) = .10
A(2,2) = 1

x(1,1) = 2
x(2,1) = 3

BeginMissionSequence

B = inv(A)
C = B'
y = C*x
Report aReport A B C x y
```

Cloning a resource:

```
Create Spacecraft Sat1 Sat2
Sat1.Cd = 1.87
Sat1.DryMass = 123.456

Create ReportFile aReport

BeginMissionSequence

Sat2 = Sat1
Report aReport Sat2.Cd Sat2.DryMass
```

Using built-in functions:

```
Create Variable pi x y1 y2 y3
Create Array A[3,3]
Create Spacecraft aSat
Create ReportFile aReport

BeginMissionSequence

pi = acos(-1)

aSat.TA = pi/4
x = pi/4
```

```
A(1,1) = pi/4

y1 = sin(x)
y2 = sin(aSat.TA)
y3 = sin(A(1,1))

Report aReport y1 y2 y3
```

BeginFiniteBurn

Model finite thrust maneuvers

Script Syntax

```
BeginFiniteBurn aFiniteBurn(aSpacecraft)
```

```
EndFiniteBurn aFiniteBurn(aSpacecraft)
```

Description

When you apply a **BeginFiniteBurn** command, you turn on the thruster configuration given in the specified **FiniteBurn** model. Similarly, when you apply an **EndFiniteBurn** command, you turn off the thruster configuration in the specified **FiniteBurn** model. After GMAT executes a **BeginFiniteBurn** command, all propagation for the spacecraft affected by the **FiniteBurn** object will include the configured finite thrust in the dynamics until an **EndFiniteBurn** line is executed for that configuration. In order to apply a non-zero finite burn , there must be a **Propagate** command between the **BeginFiniteBurn** and **EndFiniteBurn** commands.

To apply the **BeginFiniteBurn** and **EndFiniteBurn** commands, a **FiniteBurn** object must be configured. This object requires the configuration of **FuelTank** and **Thruster** models. See the Remarks section and the examples below for a more detailed explanation.

See Also: Spacecraft, Thruster, FuelTank, FiniteBurn

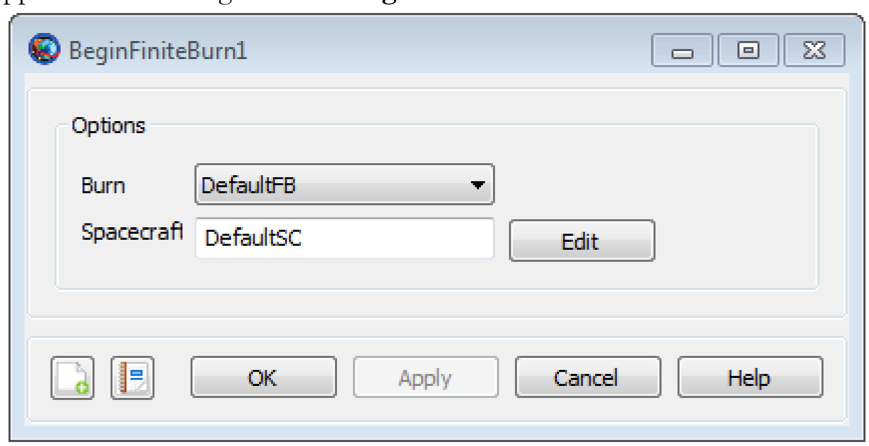
Options

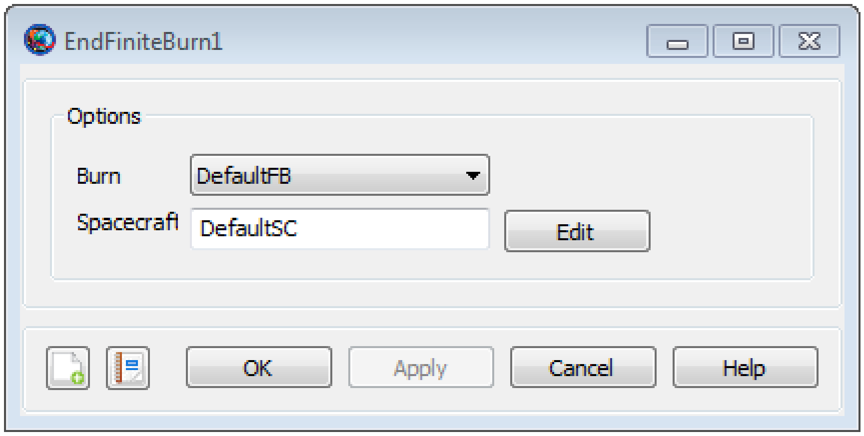
Option	Description
BeginFiniteBurn - Burn	Specifies the **FiniteBurn** object activated by the **BeginFiniteBurn** command. **Accepted Data Types** Reference Array **Allowed Values** **FiniteBurn** resource **Default Value** **DefaultFB** **Required** yes **Interfaces** GUI, script
BeginFiniteBurn - SpacecraftList	Specifies the **Spacecraft** (currently only a single **Spacecraft** can be in this list) acted upon by the **BeginFiniteBurn** command. The **Spacecraft** listed in **SpacecraftList** will have thrusters activated according to the configuration of the **FiniteBurn** object defined by the **Burn** field. **Accepted Data Types** Reference Array **Allowed Values** **Spacecraft** Objects **Default Value** **DefaultSC** **Required** yes **Interfaces** GUI, script

Option	Description
EndFiniteBurn - Burn	Specifies the **FiniteBurn** object de-activated by the **EndFiniteBurn** command. **Accepted Data Types** Reference Array **Allowed Values** **FiniteBurn** Object **Default Value** **DefaultFB** **Required** yes **Interfaces** GUI, script
EndFiniteBurn - SpacecraftList	Specifies the **Spacecraft** (currently only a single **Spacecraft** can be in this list) acted upon by the **EndFiniteBurn** command. **Spacecraft** listed in **SpacecraftList** will have thrusters de-activated according to the configuration of the **FiniteBurn** object defined by the **Burn** field. **Accepted Data Types** **Spacecraft** **Allowed Values** **Spacecraft** resource **Default Value** **DefaultSC** **Required** yes **Interfaces** GUI, script

GUI

The **BeginFiniteBurn** and **EndFiniteBurn** command dialog boxes allow you to implement a finite burn by specifying which finite burn model should be used and which spacecraft the finite burn should be applied to. The dialog boxes for **BeginFiniteBurn** and **EndFiniteBurn** are shown below.





Use the **Burn** menu to select the **FiniteBurn** model for the maneuver. Use the **Spacecraft** text box to select the spacecraft for the finite burn. You can either type the spacecraft name in the Spacecraft text box or click the **Edit** button and select the spacecraft using the **ParameterSelectDialog** box.

If you add a **BeginFiniteBurn** command or **EndFiniteBurn** command to the mission sequence, without first creating a **FiniteBurn** object, GMAT will create a default **FiniteBurn** object called **DefaultFB**. However, you will need to configure the required **FuelTank** and **Thruster** objects required for a **FiniteBurn** object before you can run the mission. See the Remarks section for detailed instructions.

Remarks

Configuring a Finite Burn

To use the **BeginFiniteBurn** and **EndFiniteBurn** commands in your mission sequence, you must configure a **FiniteBurn** object along with **FuelTank** and **Thruster** objects as shown in the examples below and as described in these steps:

1. Create and configure a **FuelTank** model.
2. Create a **Thruster** model:
   a. Set the parameters (direction, thrust, specific impulse, etc) for the thruster
   b. Configure the **Thruster** to use the **FuelTank** created in Step 1.
3. Add the **FuelTank** and **Thruster** created in the previous two steps to the **Spacecraft**.
4. Create a **FiniteBurn** model and configure it to use the **Thruster** created in Step 2.

Initial Thruster Status

When you configure the **Spacecraft**, **FuelTank**, **Thruster**, and **FiniteBurn** objects, GMAT initializes these objects with the thrusters turned off, so that no finite burns are active. You must use the **BeginFiniteBurn** command to turn on the thruster if you want to apply a finite burn during propagation.

Warning

Caution: If GMAT throws the error message “Propagator Exception: MassFlow is not a known propagation parameter on DefaultSC”, then you have not configured all of the required models to perform a finite burn. See detailed instructions above and examples to configure models required by the **EndFiniteBurn/BeginFiniteBurn** commands.

BeginFiniteBurn and EndFiniteBurn commands are NOT branch commands

The **BeginFiniteBurn** and **EndFiniteBurn** commands are NOT branch commands, meaning, a **BeginFiniteBurn** command can exist without an **EndFiniteBurn** command (however, this may result in depleting all the fuel in the spacecraft model). For behavior when fuel mass is fully depleted during a finite burn see the **FuelTank** object.

Similarly, since the **BeginFiniteBurn** and **EndFiniteBurn** commands are used to turn on or off the thrusters, applying the same command multiple times in a script without its inverse is the same as applying it once. In other words, if you do this:

```
BeginFiniteBurn aFiniteBurn(aSat)
BeginFiniteBurn aFiniteBurn(aSat)
BeginFiniteBurn aFiniteBurn(aSat)
```

The effect is the same as only applying the **BeginFiniteBurn** command one time. The same holds true for the **EndFiniteBurn** command.

Examples

Perform a finite burn while the spacecraft is between true anomaly of 300 degrees and 60 degrees.

```
%  Create objects
Create Spacecraft aSat
Create Thruster aThruster
Create FuelTank aTank
Create FiniteBurn aFiniteBurn
Create Propagator aPropagator

%  Configure the physical objects
aSat.Thrusters        = {aThruster}
aThruster.Tank        = {aTank}
aSat.Tanks            = {aTank}
aFiniteBurn.Thrusters = {aThruster}

BeginMissionSequence

%  Prop to TA = 300 then maneuver until TA = 60
Propagate aPropagator(aSat, {aSat.TA = 300})
BeginFiniteBurn aFiniteBurn(aSat)
Propagate aPropagator(aSat, {aSat.TA = 60})
EndFiniteBurn aFiniteBurn(aSat)
```

Perform a velocity direction maneuver firing the thruster for 2 minutes.

```
%  Create objects
Create Spacecraft aSat
Create Thruster aThruster
Create FuelTank aTank
Create FiniteBurn aFiniteBurn
Create Propagator aPropagator

%  Configure the physical objects
aThruster.CoordinateSystem = Local
aThruster.Origin = Earth
aThruster.Axes   = VNB
aThruster.ThrustDirection1 = 1
aThruster.ThrustDirection2 = 0
aThruster.ThrustDirection3 = 0

%  Configure the physical objects
aSat.Thrusters    = {aThruster}
aThruster.Tank    = {aTank}
aSat.Tanks        = {aTank}
aFiniteBurn.Thrusters = {aThruster}

BeginMissionSequence

%  Fire thruster for 2 minutes
BeginFiniteBurn aFiniteBurn(aSat)
Propagate aPropagator(aSat, {aSat.ElapsedSecs = 120})
EndFiniteBurn aFiniteBurn(aSat)
```

BeginMissionSequence

Begin the mission sequence portion of a script

Script Syntax

```
BeginMissionSequence
```

Description

The **BeginMissionSequence** command indicates the end of resource initialization and the beginning of the mission sequence portion of a GMAT script. It must appear once as the first command in the script, and must follow all resource creation lines.

See Also: Script Language

GUI

The **BeginMissionSequence** command is managed automatically when building mission sequences using the GUI mission tree. However, when editing the GMAT script directly, either with the GMAT script editor or with an external editor, you must insert the **BeginMissionSequence** command manually.

Remarks

The **BeginMissionSequence** is a script-only command that is not needed when working from the GUI. It indicates to GMAT that the portion of the script above the command consists of static resource initialization that can be performed in any order, and that the portion below the command consists of mission sequence commands that must be executed sequentially. This and other rules of the scripting language are discussed in detail in the script language reference.

Examples

A minimal GMAT script that propagates a spacecraft:

```
Create Spacecraft aSat
Create Propagator aProp

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

BeginScript

Execute free-form script commands

Script Syntax

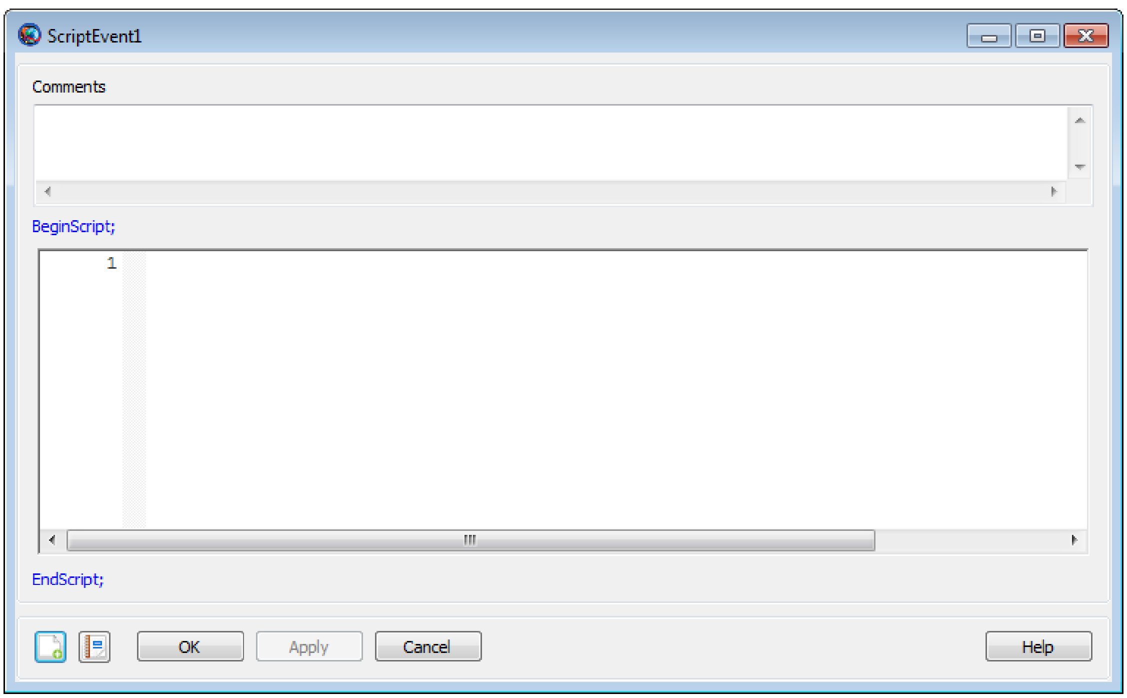
```
BeginScript
    [script statements]
    …
EndScript
```

Description

The **BeginScript** and **EndScript** commands (**ScriptEvent** in the GUI) allow you to write free-form script statements in the mission sequence without the statements being shown as individual commands in the GMAT GUI. This is useful as a way to group and label a complex sequence of statements as one unit, or to write small sequences of script statements when otherwise using the GUI to create the mission sequence. Within the script itself, there is no difference in the execution of statements within a **BeginScript**/**EndScript** block and those outside of it.

See Also: the section called “Script Editor”

GUI



The **ScriptEvent** GUI window divides the command into three parts: an initial comment, fixed **BeginScript** and **EndScript** commands, and the content of the block itself. The scripting window is a miniature version of the main script editor, and features line numbers, syntax highlighting, code folding, and all of the editing tools available in the full editor. See the the section called “Script Editor” documentation for more information. The **ScriptEvent** window performs script syntax validation when changes are applied. Nested **BeginScript**/**EndScript** blocks in the script language are collapsed into a single **ScriptEvent** when loaded into the GUI, and are saved to a single **BeginScript**/**EndScript** block when saved to a script.

Examples

Perform a calculation inside a **BeginScript**/**EndScript** block. When loaded into the GUI, the calculations within the **BeginScript**/**EndScript** block will be contained within a single **ScriptEvent** command.

```
Create Spacecraft aSat
Create Propagator aProp
Create ImpulsiveBurn aBurn
Create Variable a_init v_init
Create Variable a_transfer v_transfer_1 v_transfer_2
Create Variable a_target v_final mu
Create Variable dv_1 dv_2
mu = 398600.4415
a_target = 42164

BeginMissionSequence

% calculate Hohmann burns
BeginScript
    a_init = aSat.SMA
    v_init = aSat.VMAG
    a_transfer = (a_init + a_target) / 2
    v_transfer_1 = sqrt(2*mu/a_init - mu/a_transfer)
    v_transfer_2 = sqrt(2*mu/a_target - mu/a_transfer)
    v_final = sqrt(mu/a_target)
    dv_1 = v_transfer_1 - v_init
    dv_2 = v_final - v_transfer_2
EndScript

% perform burn 1
aBurn.Element1 = dv_1
Maneuver aBurn(aSat)

Propagate aProp(aSat) {aSat.Apoapsis}

% perform burn 2
aBurn.Element1 = dv_2
Maneuver aBurn(aSat)

Propagate aProp(aSat) {aSat.ElapsedSecs = aSat.OrbitPeriod}
```

CallMatlabFunction

Call a MATLAB function

Script Syntax

```
MatlabFunction()
MatlabFunction(input_argument[, input_argument]...)
[output_argument[, output_argument]...] = MatlabFunction
[output_argument[, output_argument]...] = ...
    MatlabFunction(input_argument[, input_argument]...)
```

Description

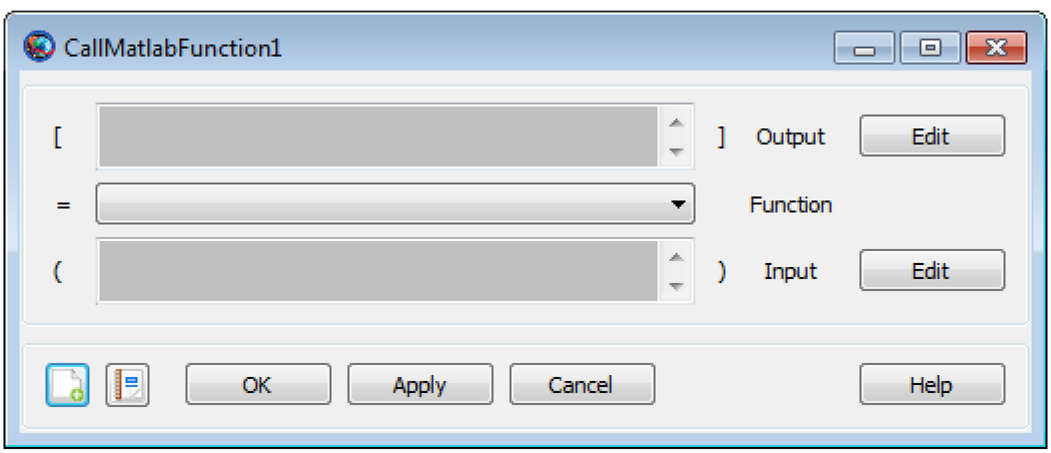
GMAT provides a special command that allows you to call a function written in the MATLAB language or provided with the MATLAB software. In the GUI, this is the **CallMatlabFunction** command.

In the syntax description, **MatlabFunction** is a **MatlabFunction** resource that must be declared during initialization. Arguments can be passed into and returned from the function, though some data-type limitations apply. See Remarks for details.

When a MATLAB function is called, GMAT opens a MATLAB command-line window in the background. This functionality requires that MATLAB be properly installed and configured on your system.

See Also: MatlabFunction, MATLAB Interface

GUI



The **CallMatlabFunction** GUI provides two input boxes for input and output arguments and a list to select a function to call.

The **Output** box lists all configured output argument parameters. These must be selected by clicking **Edit**, which displays a parameter selection window. See the Calculation Parameters reference for details on how to select a parameter.

The **Input** box is identical in behavior to **Output**, but lists all configured input arguments to the function. Arguments must be selected by clicking **Edit**. The **Function** list displays all functions that have been declared as **MatlabFunction** resources in the Resources tree. Select a function from the list to call it.

When the changes are accepted, GMAT does not perform any validation of input or output arguments. This validation is performed when the mission is run, when MATLAB has been started.

Remarks

The input arguments (*input_argument* values in the syntax description) can be any of the following types:

- resource parameter of real number type (e.g. ***Spacecraft*.X**)
- resource parameter of string type (e.g. ***Spacecraft*.UTCGregorian**)
- **Array**, **String**, or **Variable** resource
- **Array** resource element

The output arguments (*output_argument* values in the syntax description) can be any of the following types:

- resource parameter of real number type (e.g. ***Spacecraft*.X**)
- resource parameter of string type (e.g. ***Spacecraft*.UTCGregorian**)
- **Array**, **String**, or **Variable** resource
- **Array** resource element

Data type conversion is performed for the following data types when values are passed between MATLAB and GMAT. When data is passed from GMAT to MATLAB as input arguments, the following conversions occur.

GMAT	MATLAB
real number (e.g. **Spacecraft.X**, **Variable**, **Array** element)	double
string (e.g. ***Spacecraft*.UTCGregorian**, **String** resource)	char array
Array resource	double array

When data is passed from MATLAB to GMAT as output arguments, the following conversions occur.

MATLAB	GMAT
char array	string

MATLAB	GMAT
double	real number
double array	Array resource

Examples

Call a simple built-in MATLAB function:

```
Create MatlabFunction sinh
Create Variable x y

BeginMissionSequence

x = 1
[y] = sinh(x)
```

Call an external custom MATLAB function:

```
Create Spacecraft aSat
Create ImpulsiveBurn aBurn
Create Propagator aProp

Create MatlabFunction CalcHohmann
CalcHohmann.FunctionPath = 'C:\path\to\functions'

Create Variable a_target mu dv1 dv2
mu = 398600.4415

BeginMissionSequence

% calculate burns for circular Hohmann transfer (example)
[dv1, dv2] = CalcHohmann(aSat.SMA, a_target, mu)

% perform first maneuver
aBurn.Element1 = dv1
Maneuver aBurn(aSat)

% propagate to apoapsis
Propagate aProp(aSat) {aSat.Apoapsis}

% perform second burn
aBurn.Element1 = dv2
Maneuver aBurn(aSat)
```

Return the MATLAB search path and working directory:

```
Create MatlabFunction path pwd
Create String pathStr pwdStr
Create ReportFile aReport

BeginMissionSequence

[pathStr] = path
```

```
[pwdStr] = pwd

Report aReport pathStr
Report aReport pwdStr
```

ClearPlot

Allows you to clear all data from an XYPlot

Script Syntax

```
ClearPlot  OutputNames

OutputNames
  OutputNames is the list of subscribers whose data is to be
  cleared. When data of multiple subscribers is to be cleared,
  then they need to be separated by a space.
```

Description

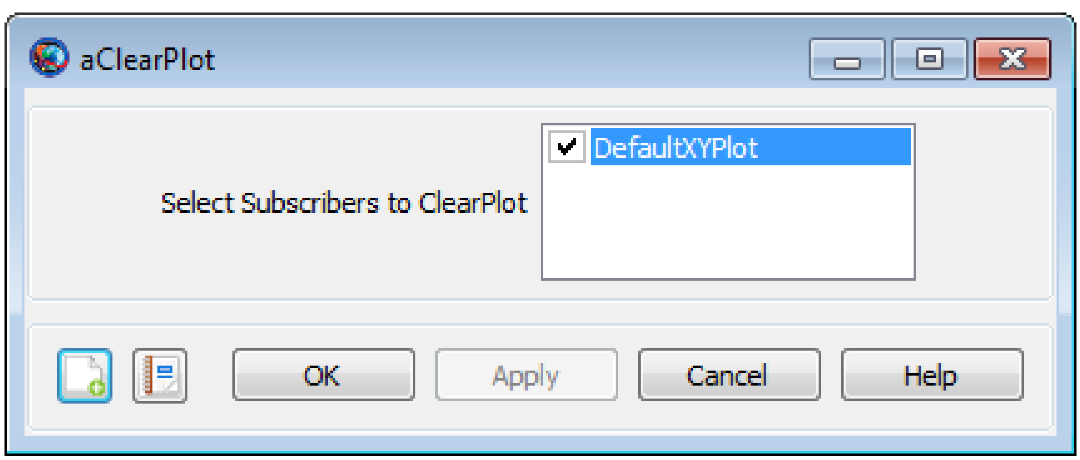
The **ClearPlot** command allows you to clear all data from an **XYPlot** after it has been plotted. The **ClearPlot** command works only for the **XYPlot** resource and data from multiple **XYPlot** resources can be cleared. **ClearPlot** command can be used through GMAT's GUI or the script interface.

Options

Option	Description	
OutputNames	The **ClearPlot** command allows the user to clear data from an **XYPlot** subscriber. When more than one subscriber is being used, the subscribers need to be separated by a space.	
	Accepted Data Types	Resource reference
	Allowed Values	**XYPlot** resource
	Default Value	**DefaultXYPlot**
	Required	yes
	Interfaces	GUI, script

GUI

Figure below shows default settings for **ClearPlot** command.



Remarks

GMAT allows you to insert **ClearPlot** command into the **Mission** tree at any location. This allows you to clear data output from an **XYPlot** at any point in your mission. The **XYPlot** subscriber plots data at each propagation step of the entire mission duration. If you want to report data to an **XYPlot** at specific points in your mission, then a **ClearPlot** command can be inserted into the mission sequence to control when a subscriber plots data. Refer to the Examples section below to see how **ClearPlot** command can be used in the **Mission** tree.

Examples

This example shows how to use **ClearPlot** command on multiple subscribers. Data from **XYPlot** subscribers is cleared after 2 days of the propagation:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aPlot1 aPlot2 aPlot3

aPlot1.XVariable = aSat.ElapsedSecs
aPlot1.YVariables = {aSat.EarthMJ2000Eq.X}

aPlot2.XVariable = aSat.ElapsedSecs
aPlot2.YVariables = {aSat.EarthMJ2000Eq.Y}

aPlot3.XVariable = aSat.ElapsedSecs
aPlot3.YVariables = {aSat.EarthMJ2000Eq.VX, aSat.EarthMJ2000Eq.VY, ...
aSat.EarthMJ2000Eq.VZ}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 2}
ClearPlot aPlot1 aPlot2 aPlot3
```

This example shows how to use **ClearPlot** command on a single subscriber. Data from **XYPlot** is cleared for the first 3 days of the propagation and only the data retrieved from last day of propagation is plotted:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aPlot1

aPlot1.XVariable = aSat.ElapsedDays
aPlot1.YVariables = {aSat.EarthMJ2000Eq.X, aSat.EarthMJ2000Eq.Y}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 3}
ClearPlot aPlot1
Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

EndFiniteBurn

Model finite thrust maneuvers in the mission sequence

Description

To implement a finite burn, you use a pair of commands, the **BeginFiniteBurn** command and the **EndFiniteBurn** command. The use of both of these commands is described in the BeginFiniteBurn command help.

For

Execute a series of commands a specified number of times

Script Syntax

```
For Index = Start:[Increment:]End
    [script statement]
    …
EndFor
```

Description

The **For** command is a control logic statement that executes a series of commands a specified number of times. The command argument must have one of the following forms:

Index = *Start*:*End*

This syntex increments **Index** from **Start** to **End** in steps of 1, repeating the script statements until **Index** is greater than **End**. If **Start** is greater than **End**, then the script statements do not execute.

Index = *Start*:*Increment*:*End*

This syntax increments **Index** from **Start** to **End** in steps of **Increment**, repeating the script statements until **Index** is greater than **End** if **Increment** is positive and less than **End** if **Increment** is negative. If **Start** is less than **End** and **Increment** is negative, or if **Start** is greater than **End** and **Increment** is positive, then the script statements do not execute.

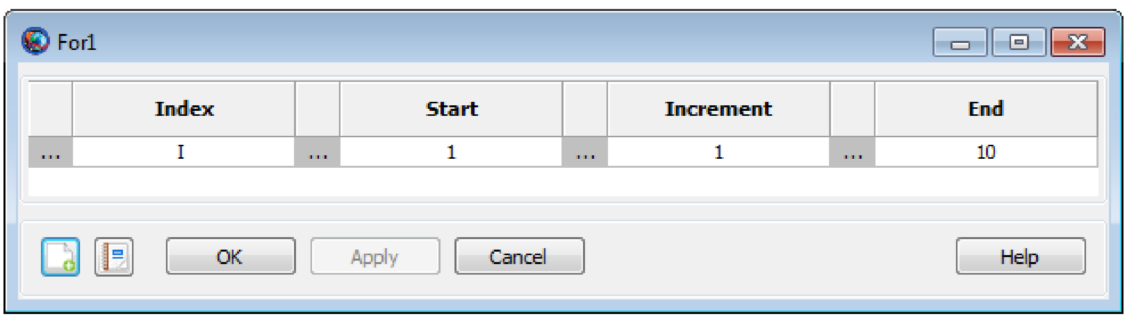
See Also: If, While

Options

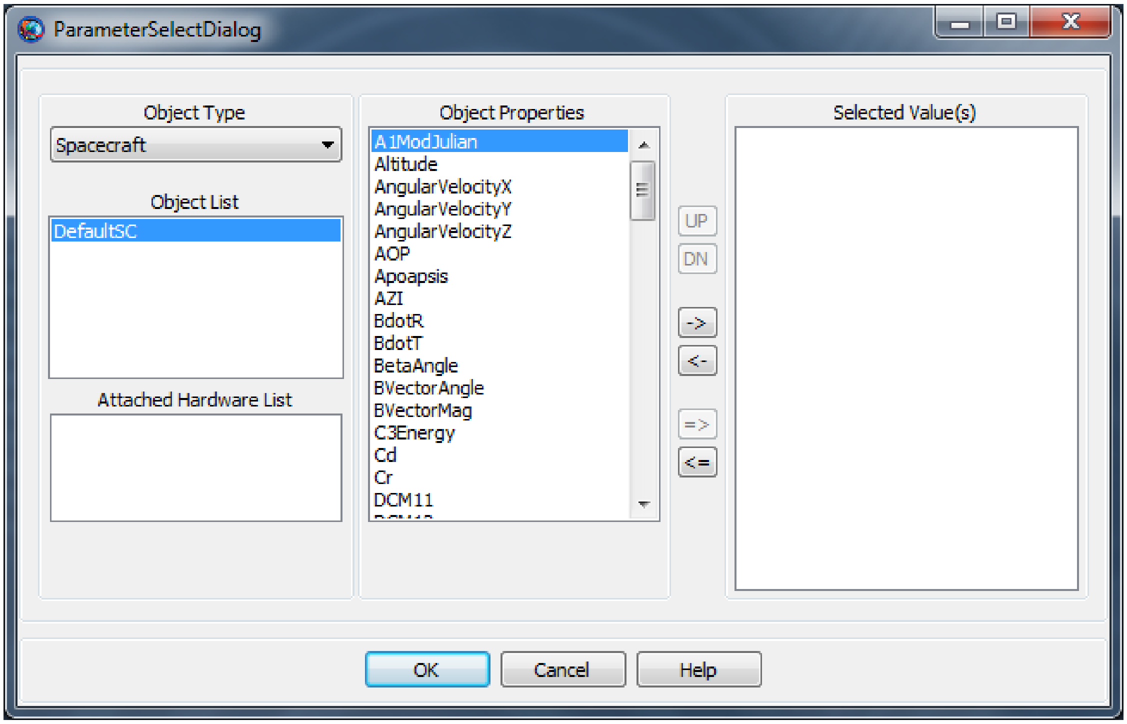
Option	Description	
Index	Independent variable in a for loop. **Index** is computed according to the arithmetic progression defined by the values for **Start**, **Increment**, and **End**.	
	Accepted Data Types	**Variable**
	Allowed Values	-∞ < **Index** < ∞
	Default Value	**Variable** named **I**
	Required	yes
	Interfaces	GUI, script
Start	Initial value for the **Index** parameter	
	Accepted Data Types	parameter
	Allowed Values	-∞ < **Start** < ∞
	Default Value	1
	Required	yes
	Interfaces	GUI, script

Option	Description
Increment	The **Increment** parameter is used to compute the arithmetic progression of the loop Index such that pass i through the loop is **Start** + i* **Increment** if the resulting value satisfies the constraint defined by **End**. **Accepted Data Types** parameter **Allowed Values** -∞ < **Increment** < ∞ **Default Value** 1 **Required** no **Interfaces** GUI
End	The **End** parameter is the upper (or lower if **Increment** is negative) bound for the **Index**. **Accepted Data Types** parameter **Allowed Values** -∞ < **End** < ∞ **Default Value** 10 **Required** yes **Interfaces** GUI, script

GUI



The **For** command GUI panel contains fields for all of its parameters: **Index**, **Start**, **Increment**, and **End**. To edit the values, click the field value you wish to change and type the new value (e.g. **5**, **`anArray(1,5)`**, or **`Spacecraft.X`**). Alternately, you can either right-click the field value or click the ellipses (**...**) button to the left of the field. This displays the **ParameterSelectDialog** window, which allows you to choose a parameter from a list.



Remarks

The values of the **Index**, **Start**, **Increment**, and **End** parameters can be any of the following types:

- Literal numeric value (e.g. 1, 15.2, -6)
- **Variable** resource
- **Array** resource element
- Resource parameter of numeric type (e.g. **Spacecraft.X**, **Thruster.K1**)

with the extra requirement that if a Resource parameter is used for **Index**, the parameter must be settable.

The index specification cannot contain mathematical operators or parentheses. After execution of the **For** loop, the value of **Index** retains its value from the last loop iteration. If the loop does not execute, the value of **Index** remains equal to its value before the loop was encountered.

Changes made to the index variable inside of a **For** loop are overwritten by the **For** loop statement. For example, the output from the following snippet:

```
For I = 1:1:3
    I = 100
    Report aReport I
EndFor
```

is:

```
100
100
100
```

Changes made to the the **Start**, **Increment**, and **End** parameters made inside of a loop do not affect the behavior of the loop. For example, the output from the following snippet:

```
J = 2
K = 2
L = 8
For I = J:K:L
    J = 1
    K = 5
    L = 100
    Report aReport I
EndFor
```

is:

```
2
4
6
8
```

Examples

Propagate a spacecraft to apogee 3 times:

```
Create Spacecraft aSat
Create Propagator aPropagator
Create Variable I

BeginMissionSequence

For I = 1:1:3
    Propagate aPropagator(aSat, {aSat.Apoapsis})
EndFor
```

Index into an array:

```
Create Variable I J
Create Array anArray[10,5]
BeginMissionSequence

For I = 1:10
    For J = 1:5
        anArray(I,J) = I*J
    EndFor
EndFor
```

If

Conditionally execute a series of commands

Script Syntax

```
If logical expression
    [script statement]
    …
EndIf
```

```
If logical expression
    [script statement]
    …
Else
    [script statement]
    …
EndIf
```

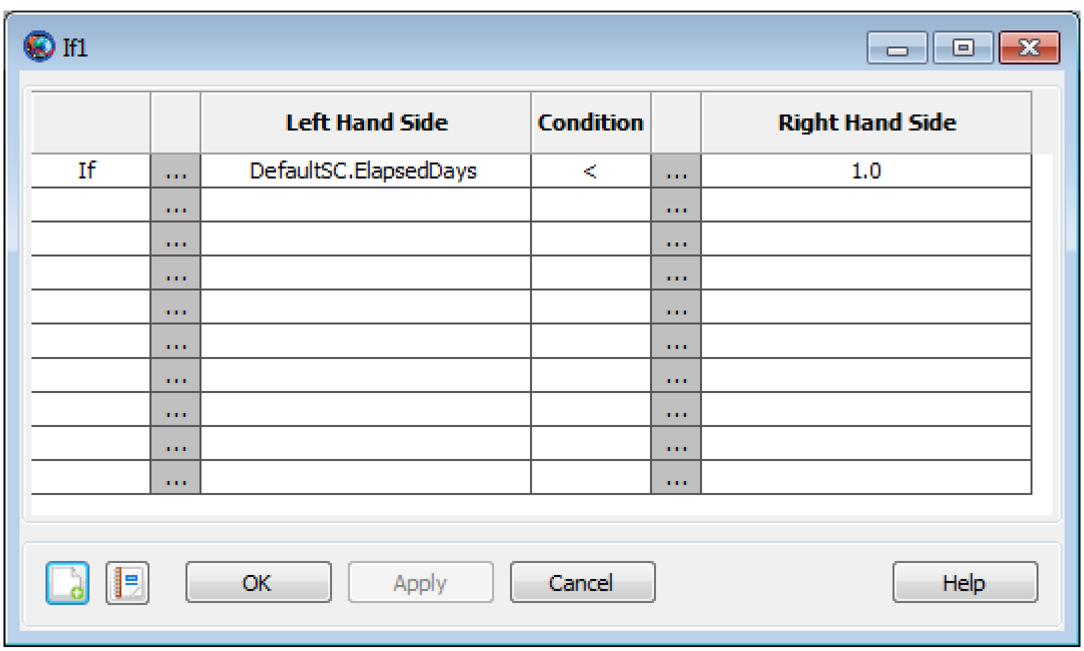
Description

The **If** command is a control logic statement that executes a series of commands if the value of the provided logical expression is true. The syntax of the logical expression is described in the script language reference.

The **If** command can optionally contain an **Else** clause that defines a series of commands to execute if the associated logical expression is false.

See Also: Script Language, For, While

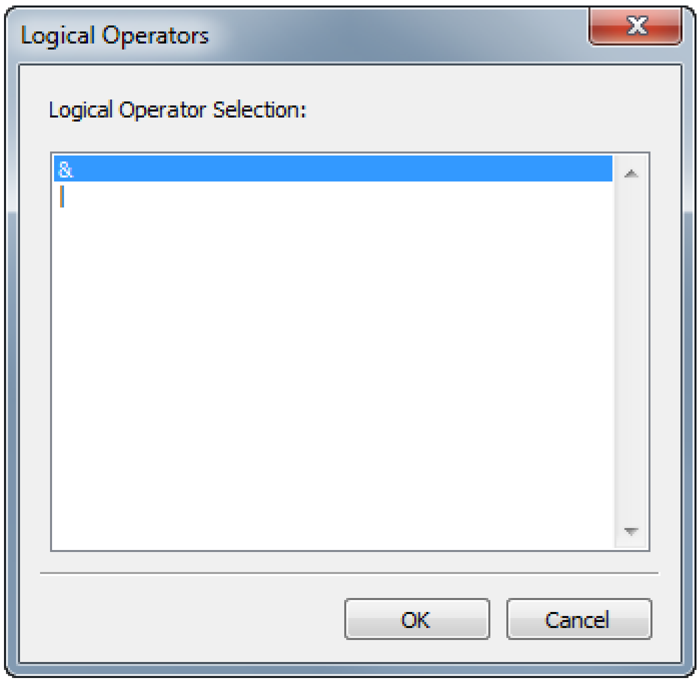
GUI



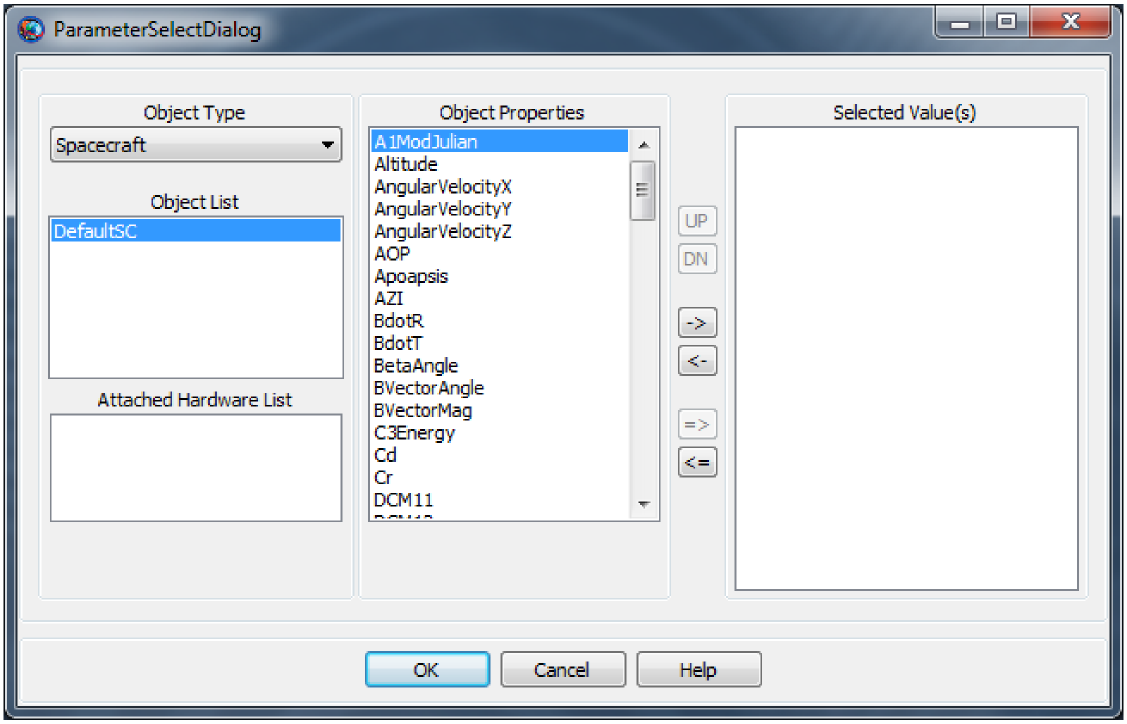
The **If** command GUI panel features a table in which you can build a complex logical expression. The rows of the table correspond to individual relational expressions in a compound logical expression (up to 10), and the columns correspond to individual elements of those expressions. The first line automatically contains a default statement:

```
If DefaultSC.ElapsedDays < 1.0
```

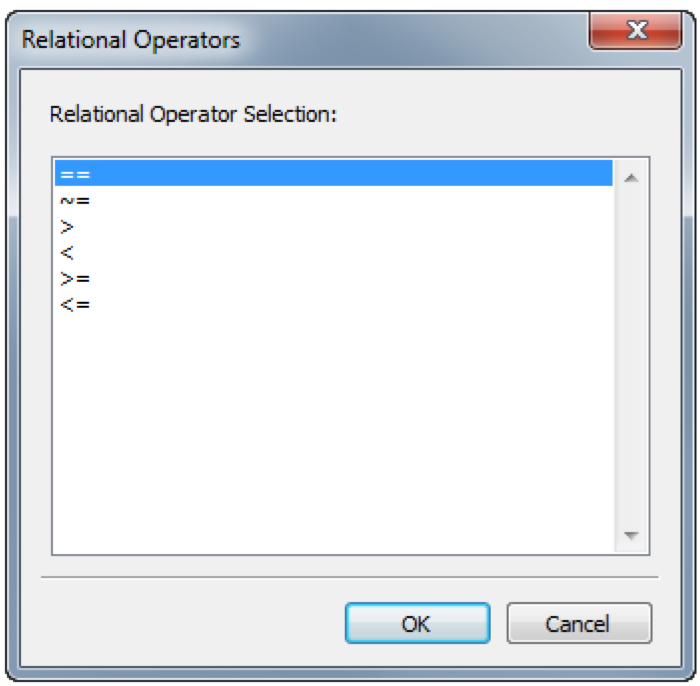
The first column of the first row contains a placeholder for the **If** command name. This cannot be changed. The first column of each additional row contains the logical operator (**&**, **|**) that joins the expression in that row with the one above it. To select a logical operator, double-click or right-click in the appropriate box in the table to display a selection window. Click the correct operator and click **OK** to select it.



The **Left Hand Side** column contains the left-hand side of each individual expression. Double-click the cell to type a parameter name. To set this value from a parameter selection list instead, either click "…" to the left of the cell you want to set, or right-click the cell itself. A **ParameterSelectDialog** window will appear that allows you to choose a parameter.



The **Condition** column contains the conditional operator (**==**, **~=**, **<**, etc.) that joins the left-hand and right-hand sides of the expression. To select a relational operator, double-click or right-click in the appropriate box in the table, and a selection window will appear. Click the correct operator and click **OK** to select it.



Finally, the **Right Hand Side** column contains the right-hand side of the expression. This value can be modified the same way as the **Left Hand Side** column.

When you are finished, click **Apply** to save your changes, or click **OK** to save your changes and close the window. The command will be validated when either button is clicked.

Examples

A simple **If** statement:

```
Create Spacecraft aSat
Create ForceModel aForceModel

Create Propagator aProp
aProp.FM = aForceModel

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1, aSat.Altitude = 300}
If aSat.Altitude < 301 & aSat.Altitude > 299
    % propagation stopped on altitude constraint
Else
    % propagation continued for 1 day
EndIf
```

Maneuver

Perform an impulsive (instantaneous) maneuver

Script Syntax

```
Maneuver BurnName (SpacecraftName)
```

Description

The **Maneuver** command applies a selected **ImpulsiveBurn** to a selected **Spacecraft**. To perform an impulsive maneuver using the **Maneuver** command, you must create an **ImpulsiveBurn**. If you wish to model fuel depletion, you must associate a specific **FuelTank** hardware object with this **ImpulsiveBurn** and attach the **FuelTank** to the desired **Spacecraft**. See the Remarks and example shown below for more details.

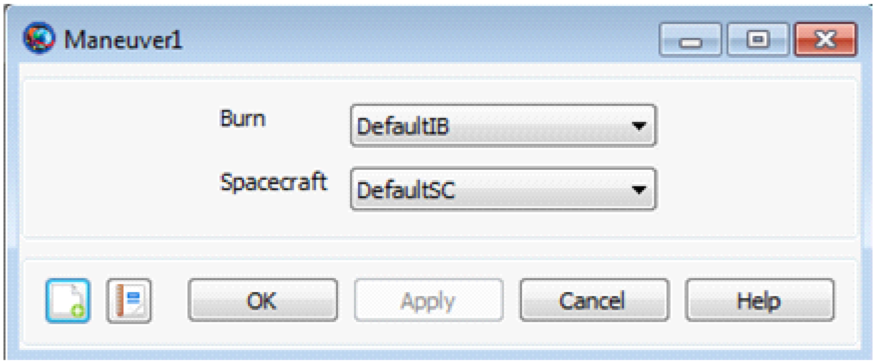
See Also: FuelTank, ImpulsiveBurn, Spacecraft

Options

Option	Description
ImpulsiveBurnName	Allows the user to select which **ImpulsiveBurn** to apply. As an example, to maneuver DefaultSC using DefaultIB, the script line would appear as Maneuver DefaultIB(DefaultSC). **Accepted Data Types**: Reference Array **Allowed Values**: Any **ImpulsiveBurn** existing in the resource treet **Default Value**: **DefaultIB** **Required**: yes **Interfaces**: GUI, script
SpacecraftName	Allows the user to select which **Spacecraft** to maneuver. The maneuver applied is specified by the **ImpulsiveBurnName** option above. **Accepted Data Types**: Reference Array **Allowed Values**: **Spacecraft** resource **Default Value**: **DefaultSC** **Required**: yes **Interfaces**: GUI, script

GUI

The **Maneuver** command dialog box, as shown below, allows you to select which previously created **ImpulsiveBurn** should be applied to which **Spacecraft**.



Remarks

Fuel Depletion

To model fuel depletion associated with your chosen **ImpulsiveBurn**, you must configure the **ImpulsiveBurn** object as follows:

- Set the **ImpulsiveBurn** parameter, **Decrement Mass**, equal to true.
- Select a **FuelTank** for the **ImpulsiveBurn** object and attach this selected **FuelTank** to the **Spacecraft**.
- Set values for the **ImpulsiveBurn** parameters, **Isp** and **GravitationalAccel**, which are used to calculate, via the Rocket Equation, the mass depleted.

Interactions

ImpulsiveBurn	The **Maneuver** command applies the specified **ImpulsiveBurn** to the specified Spacecraft.
FuelTank	The **FuelTank** specified by the **ImpulsiveBurn** object is (optionally) used to power the **ImpulsiveBurn**.
Spacecraft	This is the object that the **ImpulsiveBurn** is applied to.

Examples

Create a default **Spacecraft** and **FuelTank** and attach the **FuelTank** to the **Spacecraft**. Perform a 100 m/s impulsive maneuver in the Earth VNB-V direction.

```
%  Create default Spacecraft and FuelTank and attach the FuelTank
%  to the Spacecraft.
Create Spacecraft DefaultSC
Create FuelTank FuelTank1
DefaultSC.Tanks = {FuelTank1}

%  Set FuelTank1 parameters to default values
FuelTank1.AllowNegativeFuelMass = false
FuelTank1.FuelMass = 756
FuelTank1.Pressure = 1500
FuelTank1.Temperature = 20
FuelTank1.RefTemperature = 20
```

```
FuelTank1.Volume = 0.75
FuelTank1.FuelDensity = 1260
FuelTank1.PressureModel = PressureRegulated

%  Create ImpulsiveBurn associated with the created FuelTank
Create ImpulsiveBurn IB
IB.CoordinateSystem = Local
IB.Origin = Earth
IB.Axes = VNB
IB.Element1 = 0.1
IB.Element2 = 0
IB.Element3 = 0
IB.DecrementMass = true
IB.Tank = {FuelTank1}
IB.Isp = 300
IB.GravitationalAccel = 9.810000000000001

BeginMissionSequence
%  Apply impulsive maneuver to DefaultSC
Maneuver IB(DefaultSC)
```

MarkPoint

Allows you to add a special mark point character on an XYPlot

Script Syntax

```
MarkPoint  OutputNames

OutputNames
  OutputNames is the list of subscribers and a special mark point
  will be added to each subscriber's XYPlot. When mark points need
  to be added to multiple subscribers, then the subscribers need
  to be separated by a space.
```

Description

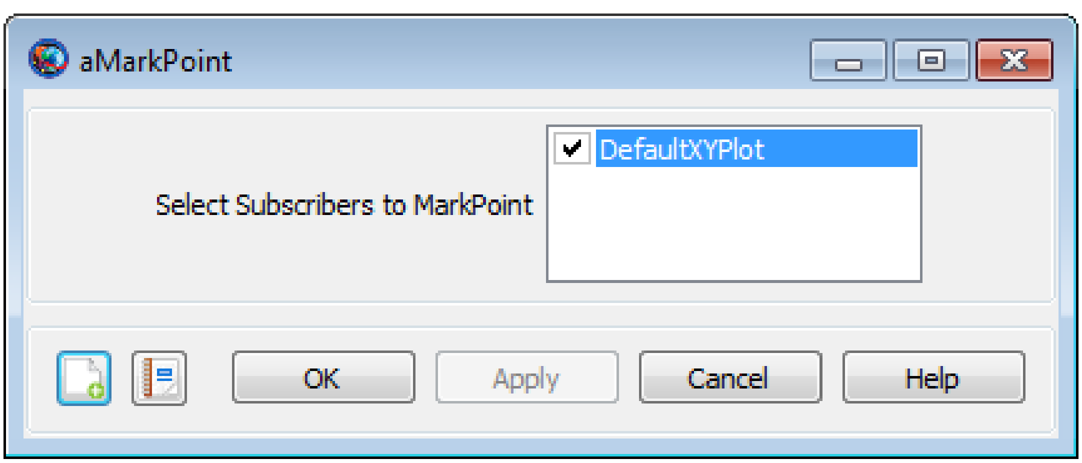
The **MarkPoint** command allows you to add a special mark point character to highlight a single data point on an **XYPlot**. **MarkPoint** command works only for **XYPlot** subscriber. This command also allows you to add special mark points on multiple **XYPlot** resources. **MarkPoint** command can be used through GMAT's GUI or the script interface.

Options

Option	Description
OutputNames	The **MarkPoint** command allows the user to add a special mark point character to highlight an individual data point on an **XYPlot**. **Accepted Data Types** Resource reference **Allowed Values** **XYPlot** resource **Default Value** **DefaultXYPlot** **Required** yes **Interfaces** GUI, script

GUI

Figure below shows default settings for **MarkPoint** command:



Remarks

GMAT allows you to insert **MarkPoint** command into the **Mission** tree at any location. This allows you to add special mark points on an **XYPlot** at any point in your mission. The **XYPlot** subscriber plots data at each propagation step of the entire mission duration. If you to want to place mark points on an **XYPlot** at specific points, then a **MarkPoint** command can be inserted into the mission sequence to control when mark points are placed onto an **XYPlot**. Refer to the Examples section below to see how **MarkPoint** command can be used in the **Mission** tree.

Examples

This example shows how to use **MarkPoint** command on multiple subscribers. Mark points are added on two **XYPlots** after every 0.2 days through an iterative loop:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aPlot1 aPlot2

aPlot1.XVariable = aSat.A1ModJulian
aPlot1.YVariables = {aSat.EarthMJ2000Eq.X}

aPlot2.XVariable = aSat.A1ModJulian
aPlot2.YVariables = {aSat.EarthMJ2000Eq.VX}

BeginMissionSequence;

While aSat.ElapsedDays < 1.0
 MarkPoint aPlot1 aPlot2
 Propagate aProp(aSat) {aSat.ElapsedDays = 0.2}
EndWhile
```

This example shows how to use **MarkPoint** on a single subscriber. In this example, mark points are placed on the **XYPlot** the moment spacecraft's altitude goes below 750 Km. Note that mark points are placed on the XYPlot at every integration step:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aPlot1

aPlot1.XVariable = aSat.A1ModJulian
aPlot1.YVariables = {aSat.Earth.Altitude}

BeginMissionSequence

While aSat.ElapsedDays < 2
 Propagate aProp(aSat)
 If aSat.Earth.Altitude < 750
 MarkPoint aPlot1
 EndIf
EndWhile
```

Minimize

Define the cost function to minimize

Script Syntax

```
Minimize OptimizerName (ObjectiveFunction)
```

Description

The **Minimize** command is used within an **Optimize/EndOptimize** Optimization sequence to define the objective function that you want to minimize.

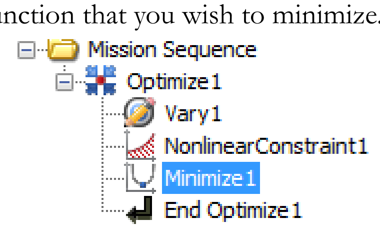
See Also: Vary, NonlinearConstraint, Optimize

Options

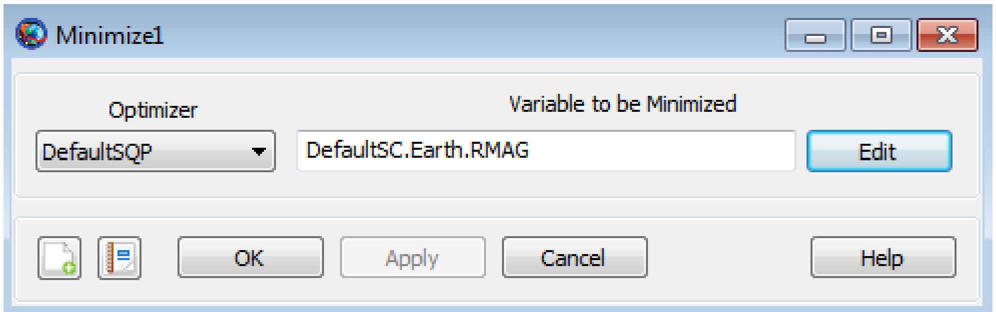
Option	Description	
ObjectiveFunction	Specifies the objective function that the optimizer will try to minimize.	
	Accepted Data Types	String
	Allowed Values	Spacecraft parameter, Array element, Variable, or any other single element user defined parameter, excluding numbers
	Default Value	`DefaultSC.Earth.RMAG`
	Required	yes
	Interfaces	GUI, script
OptimizerName	Specifies which optimizer to use to minimize the cost function	
	Accepted Data Types	Reference Array
	Allowed Values	Any **VF13ad** or **fminconOptimizer** resource
	Default Value	**DefaultSQP**
	Required	yes
	Interfaces	GUI, script

GUI

You use a **Minimize** command, within an **Optimize/EndOptimize** Optimization sequence as shown below, to define a cost function that you wish to minimize.



Double click on **Minimize1** to bring up the **Minimize** command dialog box shown below..



You must provide two inputs for the **Minimize** command dialog box above:

- Choice of optimizer.
- Object (and associated variable) to be minimized. You can input an object directly or you can click the **Edit** button to the right of this field to select the type of object from three possible choices, **Spacecraft**, **Variable**, or **Array**.

Remarks

Number of Vary, NonlinearConstraint, and Minimize Commands Within an Optimization Sequence

An Optimization sequence must contain one or more **Vary** commands. **Vary** commands must occur before any **Minimize** or **NonlinearConstraint** commands.

At most, a single **Minimize** command is allowed within an optimization sequence.

It is possible for an **Optimize/EndOptimize** optimization sequence to contain no **Minimize** commands. In this case, since every optimization sequence must contain (a) one or more **NonlinearConstraint** commands and/or (b) a single **Minimize** command, the optimization sequence must contain at least one **NonlinearConstraint** command.

Command Interactions

The **Minimize** command is only used within an **Optimize/EndOptimize** Optimization sequence. See the **Optimize** command documentation for a complete worked example using the **Minimize** command.

Vary command	Every Optimization sequence must contain at least one **Vary** command. **Vary** commands are used to define the control variables associated with an Optimization sequence.
NonlinearConstraint command	**NonlinearConstraint** commands are used to define the constraints (i.e., goals) associated with an Optimization sequence. Note that multiple **NonlinearConstraint** commands are allowed within an Optimization sequence.
Optimize command	A **Minimize** command can only occur within an **Optimize/EndOptimize** command sequence.

Examples

```
% Minimize the eccentricity of Sat, using SQP1
Minimize SQP1(Sat.ECC)

% Minimize the Variable DeltaV, using SQP1
Minimize SQP1(DeltaV)

% Minimize the first component of MyArray, using VF13ad1
Minimize VF13ad1(MyArray(1,1))
```

As mentioned above, the **Minimize** command only occurs within an **Optimize** sequence. See the **Optimize** command help for complete examples showing the use of the **Minimize** command.

NonlinearConstraint

Specify a constraint used during optimization

Script Syntax

```
NonlinearConstraint OptimizerName ({logical expression})
```

Description

The **NonlinearConstraint** command is used within an **Optimize**/**EndOptimize** optimization sequence to apply a linear or nonlinear constraint.

See Also: Vary, Optimize, Minimize

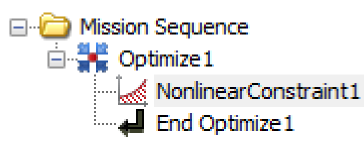
Options

Option	Description
LHS	Allows you to select any single element user defined parameter, except a number, to define the constraint variable. The constraint function is of the form **LHS Operator RHS** **Accepted Data Types**: String **Allowed Values**: Spacecraft parameter, Array element, Variable, or any other single element user defined parameter, excluding numbers **Default Value**: `DefaultSC.SMA` **Required**: yes **Interfaces**: GUI, script
Operator	logical operator used to specify the constraint function. The constraint function is of the form **LHS Operator RHS** **Accepted Data Types**: Reference Array **Allowed Values**: `>=`, `<=`, `=` **Default Value**: `=` **Required**: yes **Interfaces**: GUI, script
OptimizerName	Specifies the solver/optimizer object used to apply a constraint. **Accepted Data Types**: Reference Array **Allowed Values**: Any **VF13ad** or **fminconOptimizer** object. **Default Value**: **DefaultSQP** **Required**: yes **Interfaces**: GUI, script

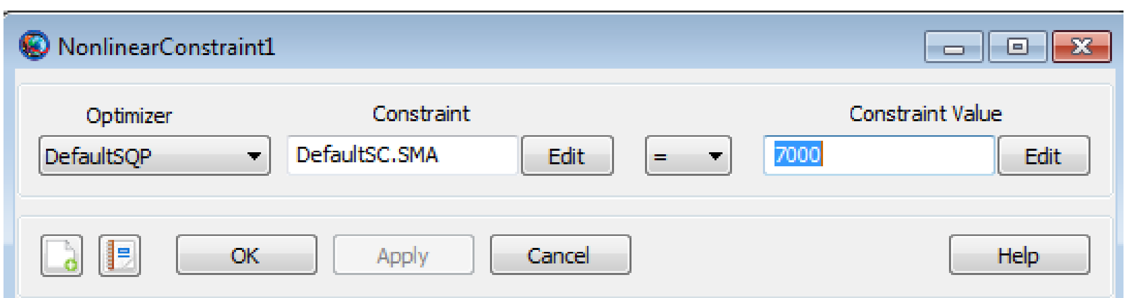
Option	Description
RHS	Allows you to select any single element user defined parameter, including a number, to specify the desired value of the constraint variable. The constraint function is of the form **LHS Operator RHS** **Accepted Data Types** String **Allowed Values** Spacecraft parameter, Array element, Variable, or any other single element user defined parameter, including numbers **Default Value** 7000 **Required** yes **Interfaces** GUI, script

GUI

You use a **NonlinearConstraint** command, within an Optimize/EndOptimize sequence as shown below, to define an equality or inequality constraint that you want to be satisfied at the end of the optimization process.



Double click on **NonlinearConstraint1** to bring up the **NonlinearConstraint** command dialog box, shown below.



You must provide four inputs for the **NonlinearConstraint** command dialog box above:

- Choice of **Optimizer**.
- **Constraint** Object. Click the **Edit** button to the right of this field to select the type of constraint object from three possible choices, **Spacecraft**, **Variable**, or **Array**.
- Logical operator. Select one from three choices, =, <=, or >=.
- **Constraint Value**.

Note that Inputs 2-4 define a logical expression. In the example above, we have: `DefaultSC.SMA = 7000`

Remarks

Number of Vary, NonlinearConstraint, and Minimize Commands Within an Optimization Sequence

An Optimization sequence must contain one or more **Vary** commands. **Vary** commands must occur before any **Minimize** or **NonlinearConstraint** commands.

Multiple **NonlinearConstraint** commands are allowed. There is exactly one **NonlinearConstraint** command for every constraint.

It is possible for an **Optimize/EndOptimize** optimization sequence to contain no **NonlinearConstraint** commands. In this case, since every optimization sequence must contain (a) one or more **NonlinearConstraint** commands and/or (b) a single **Minimize** command, the optimization sequence must contain a single **Minimize** command.

Command Interactions

The **Minimize** command is only used within an **Optimize/EndOptimize** Optimization sequence. See the **Optimize** command documentation for a complete worked example using the **NonlinearConstraint** command.

Optimize command	**NonlinearConstraint** commands can only occur within an **Optimize/EndOptimize** command sequence.
Vary command	Every Optimization sequence must contain at least one **Vary** command. **Vary** commands are used to define the control variables associated with an Optimization sequence.
Minimize command	A **Minimize** command is used within an Optimization sequence to define the objective function that will be minimized. Note that an optimization sequence is allowed to contain, at most, one **Minimize** command. (An Optimization sequence is not required to contain a **Minimize** command)

Examples

```
% Constrain SMA of Sat to be 7000 km, using SQP1
NonlinearConstraint SQP1( Sat.SMA = 7000 )

% Constrain SMA of Sat to be less than or equal to 7000 km,
% using SQP1
NonlinearConstraint SQP1( Sat.SMA <= 7000 )

% Constrain the SMA of Sat to be greater than or equal to 7000 km,
% using VF13ad1
NonlinearConstraint VF13ad1( Sat.SMA >= 7000 )
```

As mentioned above, the **NonlinearConstraint** command only occurs within an **Optimize** sequence. See the **Optimize** command help for complete examples showing the use of the **NonlinearConstraint** command.

Optimize

Solve for condition(s) by varying one or more parameters

Script Syntax

```
Optimize SolverName [{[SolveMode = value], [ExitMode = value]}]
      Vary command …
      script statement …
      NonlinearConstraint command …
      Minimize command …
EndOptimize
```

Description

The **Optimize** command in GMAT allows you to solve optimization problems by using a solver object. Currently, you can choose from one of two available solvers, the **FminconOptimizer** solver object available to all GMAT users with access to the Matlab optimization toolbox and the **VF13ad** solver object plug-in that you must install yourself.

You use the **Optimize** and **EndOptimize** commands to define an **Optimize** sequence to determine, for example, the maneuver components required to raise orbit apogee to 42164 km while simultaneously minimizing the DeltaV required to do so. **Optimize** sequences in GMAT are applicable to a wide variety of problems and this is just one example. Let's define the quantities that you don't know precisely, but need to determine, as the Control Variables. We define the conditions that must be satisfied as the Constraints and we define the quantity to be minimized (e.g., DeltaV) as the Objective function. An **Optimize** sequence numerically solves a boundary value problem to determine the value of the Control Variables required to satisfy the Constraints while simultaneously minimizing the Objective function. As was the case for the **Target**/**EndTarget** command sequence, you define your control variables by using **Vary** commands. You define the constraints that must be satisfied by using the **NonlinearConstraint** command and you define the objective function to be minimized by using the **Minimize** command. The **Optimize**/**EndOptimize** sequence is an advanced command. The examples later in this section give a more detailed explanation.

See Also: Vary, NonlinearConstraint, Minimize, VF13ad

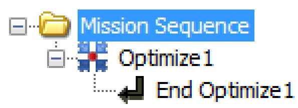
Options

Option	Description
ApplyCorrections	The **ApplyCorrections** GUI button replaces the initial guess values specified in the **Vary** commands with those computed by the optimizer during a run. If the **Optimize** sequence converged, the converged values are applied. If the **Optimize** sequence did not converge, the last calculated values are applied. There is one situation where the action specified above, where the initial guess values specified in the **Vary** commands are replaced, does not occur. This happens when the initial guess value specified in the **Vary** command is given by a variable. **Accepted Data Types** N/A **Allowed Values** N/A **Default Value** N/A **Required** no **Interfaces** GUI, script
ExitMode	Controls the initial guess values for **Optimize** sequences nested in control flow. If **ExitMode** is set to `SaveAndContinue`, the solution of an **Optimize** sequence is saved and used as the initial guess for the next time this Optimize sequence is run. The rest of the mission sequence is then executed. If **ExitMode** is set to **DiscardAndContinue**, then the solution is discarded and the initial guess values specified in the **Vary** commands are used for each **Optimize** sequence execution. The rest of the mission sequence is then executed. If **ExitMode** is set to **Stop**, the **Optimize** sequence is executed, the solution is discarded, and the rest of the mission sequence is not executed. **Accepted Data Types** Reference Array **Allowed Values** **DiscardAndContinue**,**SaveAndContinue**, **Stop** **Default Value** **DiscardAndContinu**e **Required** no **Interfaces** GUI, script
SolveMode	Specifies how the optimization loop behaves during mission execution. When **SolveMode** is set to **Solve**, the optimization loop executes and attempts to solve the optimization problem. When **SolveMode** is set to **RunInitialGuess**, the Optimizer does not attempt to solve the optimization problem and the commands in the **Optimize** sequence execute using the initial guess values defined in the **Vary** commands. **Accepted Data Types** Reference Array **Allowed Values** **Solve**, **RunInitialGuess** **Default Value** **Solve** **Required** no **Interfaces** GUI, script

Option	Description	
SolverName	Specifies the solver/optimizer object used in the **Optimize** sequence	
	Accepted Data Types	Reference Array
	Allowed Values	Any **VD13ad** or **FminconOptimizer** resource
	Default Value	**DefaultSQP**
	Required	yes
	Interfaces	GUI, script

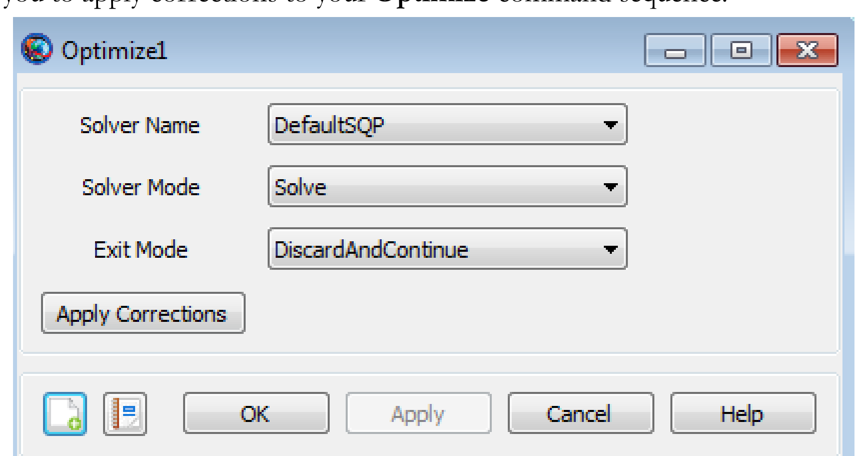
GUI

The **Optimize** command allows you to use an optimization process to solve problems. To solve a given problem, you need to create a so-called **Optimize** sequence which we now define. When you add an **Optimize** command to the mission sequence, an **EndOptimize** command is automatically added as shown below.



In the example above, the **Optimize** command sequence is defined as all of the commands between the **Optimize1** and **EndOptimize1** commands, inclusive. Although not shown above, an **Optimize** command sequence must contain a **Vary** command which is used to define the control variables that can be varied in order to help solve our problem. An **Optimize** command must also contain a **Minimize** command and/or one or more **NonlinearConstraint** commands. You use a **Minimize** command to define a cost function that you wish to minimize and you use the **NonlinearConstraint** command to define either an equality or inequality constraint that you want to be satisfied at the end of the optimization process.

Double click on the **Optimize1** command above to open the **Optimize** command dialog box, shown below, which allows you to specify your choice of Solver (i.e., your choice of optimizer), **Solver Mode**, and **Exit Mode**. As described in the Remarks section, the **Optimize** command dialog box also allows you to apply corrections to your **Optimize** command sequence.



Remarks

Content of an Optimize/EndOptimize Sequence

An **Optimize/EndOptimize** sequence must contain at least one **Vary** command and at least one of the following commands: **NonlinearConstraint** and **Minimize**. See the **Vary**, **NonlinearConstraint**, and **Minimize** command sections for details on the syntax for those commands. The first **Vary** command must occur before the first **NonlinearConstraint** or **Minimize** command. Each **Optimize** command field in the curly braces is optional. You can omit the entire list and the curly braces and the default values will be used for **Optimize** configuration fields such as **SolveMode** and **ExitMode**.

Relation to Target/EndTarget Command Sequence

There are some functional similarities between the **Target/EndTarge**t and **Optimize/EndOptimize** command sequences. In both cases, we define Control Variables and Constraints. For both **Target** and **Optimize** sequences, we use the **Vary** command to define the Control Variables. For the **Target** sequence, we use the **Achieve** command to define the constraints whereas, for an **Optimize** sequence, we use the **NonlinearConstraint** command. The big difference between the **Target** and **Optimize** sequences is that the **Optimize** sequence allows for the minimization of an Objective function through the use of the **Minimize** command.

Command Interactions

Vary command	Every **Optimize** sequence must contain at least one **Vary** command. **Vary** commands are used to define the control variables associated with an **Optimize** sequence.
NonlinearConstraint command	**NonlinearConstraint** commands are used to define the constraints associated with an **Optimize** sequence. Note that multiple **NonlinearConstraint** commands are allowed within an **Optimize** sequence.
Minimize command	A **Minimize** command is used within an **Optimize** sequence to define the Objective function that will be minimized. Note that an **Optimize** sequence is allowed to contain, at most, one **Minimize** command. (An **Optimize** sequence is not required to contain a **Minimize** command)

Examples

Use an **Optimize** sequence with the fmincon solver object to find the point, (x, y), on the unit circle with the smallest y value. Note that the use of the **FminconOptimizer** solver assumes you have access to the Matlab optimization toolbox.

```
Create FminconOptimizer SQP1
SQP1.MaximumIterations = 50
Create Variable x y Circle

BeginMissionSequence
Optimize SQP1
  Vary SQP1(x = 1)
  Vary SQP1(y = 1)
  Circle = x*x + y*y
```

```
  NonlinearConstraint SQP1(Circle = 1)
  Minimize SQP1(y)
EndOptimize
```

Similar to the example given in the **Target** command Help, use an **Optimize** sequence to raise orbit apogee. In the **Target** command example, we had one control variable, the velocity component of an **ImpulsiveBurn** object, and the single constraint that the position vector magnitude at orbit apogee equals 42164. For this example, we keep this control variable and constraint but we now add a second control variable, the true anomaly of where the burn occurs. In addition, we ask the optimizer to minimize the Delta-V cost of the burn. As expected, the best (DV minimizing) orbit location to perform an apogee raising burn is near perigee (i.e., nearTA = 0). In this example, since the force model in use in not perfectly two body Keplerian, the optimal TA value obtained is close to but not exactly 0. Note that the use of the **VF13ad** solver object in this example assumes that you have installed this optional plug-in. Finally, report the convergence status to a file.

```
Create Spacecraft aSat
Create Propagator aPropagator
Create ImpulsiveBurn aBurn
Create VF13ad VF13ad1
VF13ad1.Tolerance = 1e-008
Create OrbitView EarthView
EarthView.Add = {Earth, aSat}
EarthView.ViewScaleFactor = 5
Create Variable ApogeeRadius DVCost
Create ReportFile aReport

BeginMissionSequence
Optimize VF13ad1
  Vary VF13ad1(aSat.TA = 100, {MaxStep = 10})
  Vary VF13ad1(aBurn.Element1 = 1, {MaxStep = 1})
  Maneuver aBurn(aSat)
  Propagate aPropagator(aSat) {aSat.Apoapsis}
  GMAT ApogeeRadius = aSat.RMAG
  NonlinearConstraint VF13ad1(ApogeeRadius=42164)
  GMAT DVCost = aBurn.Element1
  Minimize VF13ad1(DVCost)
EndOptimize
Report aReport VF13ad1.SolverStatus VF13ad1.SolverState
```

PenUpPenDown

Allows you to stop or begin drawing data on a plot

Script Syntax

```
PenUp  OutputNames

OutputNames
  OutputNames is the list of subscribers that
  PenUp command operates on. When PenUp
  command is used on multiple subscribers, then the subscribers
  need to be separated by a space.

PenDown OutputNames

OutputNames
  OutputNames is the list of subscribers
  that PenDown command operates on.
  When PenDown command is used on multiple subscribers, then the
  subscribers need to be separated by a space.
```

Description

The **PenUp** and **PenDown** commands allow you to stop or begin drawing data on a plot. The **PenUp** and **PenDown** commands operate on **XYPlot**, **OrbitView** and **GroundTrackPlot** subscribers. GMAT allows you to insert **PenUp** and **PenDown** commands into the **Mission** tree at any location. This allows you to stop or begin drawing data output on a plot at any point in your mission. The **PenUp** and **PenDown** commands can be used through GMAT's GUI or the script interface.

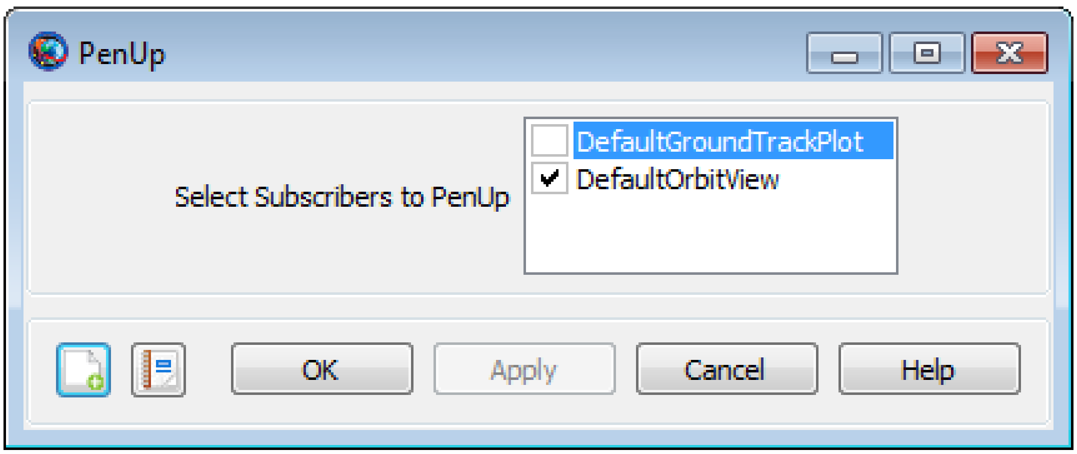
Options

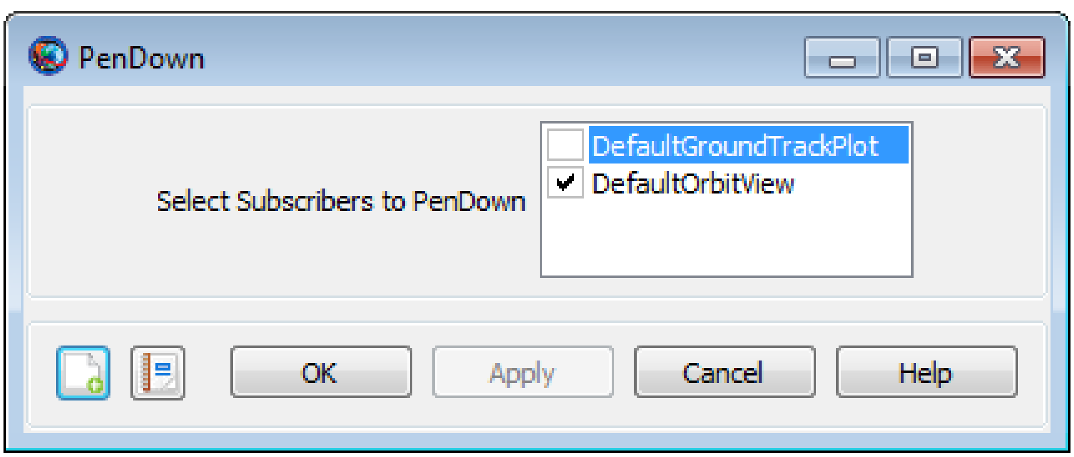
Option	Description	
OutputNames	When a **PenUp** command is issued for a plot, no data is drawn to that plot until a **PenDown** command is issued for that plot	
	Accepted Data Types	Resource reference
	Allowed Values	**XYPlot**, **OrbitView** or **GroundTrackPlot** resources
	Default Value	**DefaultOrbitview**
	Required	yes
	Interfaces	GUI, script

Option	Description
OutputNames	When a **PenDown** command is issued for a plot, data is drawn for each integration step until a **PenUp** command is issued for that plot. **Accepted Data Types**: Resource reference **Allowed Values**: **XYPlot**, **OrbitView** or **GroundTrackPlot** resources **Default Value**: **DefaultOrbitview** **Required**: yes **Interfaces**: GUI, script

GUI

Figures below show default settings for **PenUp** and **PenDown** commands:





Remarks

XYPlot, **OrbitView** and **GroundTrackPlot** subscribers plot data at each integration step of the entire mission duration. If you want to plot data at specific points in your mission, then a **PenUp** and **PenDown** command can be inserted into the mission sequence to control when a subscriber plots data. For example, when a **PenUp** command is issued for **XYPlot**, **OrbitView** or **GroundTrack-**

Plot, no data is drawn to that plot until a **PenDown** command is issued for that same plot. Similarly, when a **PenDown** command is issued for any of the three **subscribers**, then data is drawn for each integration step until a **PenUp** command is issued for that specific subscriber. Refer to the Examples section below to see how **PenUp** and **PenDown** commands can be used in the **Mission** tree.

Examples

This example shows how to use **PenUp** and **PenDown** commands on multiple subscribers. **PenUp** and **PenDown** commands are used on **XYPlot**, **OrbitView** and **GroundTrackPlot**. Data is drawn to the plots for first day of the propagation, turned off for second day of propagation and then data is drawn for third day of the propagation:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aPlot
aPlot.XVariable = aSat.ElapsedDays
aPlot.YVariables = {aSat.Earth.SMA}

Create OrbitView anOrbitViewPlot
anOrbitViewPlot.Add = {aSat, Earth}

Create GroundTrackPlot aGroundTrackPlot
aGroundTrackPlot.Add = {aSat, Earth}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}
PenUp aGroundTrackPlot anOrbitViewPlot aPlot
Propagate aProp(aSat) {aSat.ElapsedDays = 1}
PenDown aGroundTrackPlot anOrbitViewPlot aPlot
Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

This example shows how to use **PenUp** and **PenDown** commands on a single **XYPlot** subscriber. Data is drawn to the plot for one-third of the day, turned off for second one-third of the day and then data is drawn again for last one-third of the day:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aPlot1
aPlot1.XVariable = aSat.ElapsedDays
aPlot1.YVariables = {aSat.Earth.Altitude}

Create Variable I
I = 0

BeginMissionSequence

While aSat.ElapsedDays < 1.0

 Propagate aProp(aSat) {aSat.ElapsedSecs = 60}
 If I == 480
```

```
 PenUp aPlot1
 EndIf

 If I == 960
 PenDown aPlot1
 EndIf

 GMAT I = I +1

EndWhile
```

Propagate

Propagates spacecraft to a requested stopping condition

Script Syntax

The **Propagate** command is a complex command that supports multiple **Propagators**, multiple **Spacecraft**, and multiple stopping conditions. In the syntax definition below, **SatList** is a comma separated list of spacecraft and **StopList** is a comma separated list of stopping conditions. The general syntax of the **Propagate** command is:

```
Propagate [Mode] [BackProp] Propagator1Name(SatList1,{StopList1})...
                 Propagator2Name(SatList2,{StopList2}

or

Propagate [Mode] [BackProp] Propagator1Name(SatList1)...
                 Propagator2Name(SatList2){StopList}
```

Most applications propagate a single **Spacecraft**, forward, to a single stopping condition. In that case, the syntax simplifies to:

```
Propagate PropagatorName(SatName,{StopCond});

or

Propagate PropagatorName(SatName){StopCond};
```

In GMAT, syntax for setting orbit color on a **Propagate** command for a single **Spacecraft** propagating forward to a single stopping condition can be done by either identifying orbit color through ColorName or via RGB triplet value:

```
Propagate PropagatorName(SatName),{StopCond, OrbitColor = ColorName};

or

Propagate PropagatorName(SatName),{StopCond, OrbitColor = [RGB triplet value]};
```

Description

The **Propagate** command controls the time evolution of spacecraft. GMAT allows you to propagate single **Spacecraft**, multiple non-cooperative **Spacecraft**, and **Formations** in a single **Propagate** command. The **Propagate** command is complex and controls the following aspects of the temporal modelling of spacecraft:

- The **Spacecraft** to be propagated
- The model(s) used for the propagation (numerical integration, ephemeris interpolation)
- The condition(s) to be satisfied at the termination of propagation
- The direction of propagation (forwards or backwards in time)
- The time synchronization of multiple **Spacecraft**
- Propagation of STM and computation of state Jacobian (A-matrix)
- Setting unique colors on different **Spacecraft** trajectory segments through **Propagate** commands

See Also: Propagator, Spacecraft, Formation, Color

Options

Option	Description	
Mode	Optional flag to time-synchronize propagation of **Spacecraft** performed by multiple **Propagators** in a single **Propagate** command. See the section called "Remarks" for more details.	
	Accepted Data Types	String
	Allowed Values	**Synchronized**
	Default Value	Not used
	Required	no
	Interfaces	GUI, script
BackProp	Optional flag to propagate all **Spacecraft** in a **Propagate** command backwards in time.	
	Accepted Data Types	String
	Allowed Values	**BackProp**
	Default Value	Not used
	Required	no
	Interfaces	GUI, script
StopList	A comma separated list of stopping conditions. Stopping conditions must be parameters of propagated **Spacecraft** in **SatList**. See the section called "Remarks" for more details.	
	Accepted Data Types	Reference array
	Allowed Values	Valid list of stopping conditions
	Default Value	**ElapsedSecs = 12000**
	Required	no
	Interfaces	GUI, script
SatList	A comma separated list of **Spacecraft**. For SPK type **Propagators**, the **Spacecraft** must be configured with valid SPK kernels.	
	Accepted Data Types	Resource array
	Allowed Values	Valid list of spacecraft and/or formations
	Default Value	**DefaultSC**
	Required	yes
	Interfaces	GUI, script

Option	Description
PropagatorName	A propagator name. **Accepted Data Types** **Propagator** **Allowed Values** Valid **Propagator** name **Default Value** **DefaultProp** **Required** yes **Interfaces** GUI, script
StopTolerance	Tolerance on the stopping condition root location. See the section called “Remarks” for more details. **Accepted Data Types** Real **Allowed Values** Real number > 0 **Default Value** 0.0000001 **Required** no **Interfaces** GUI, script
STM	Optional flag to propagate the orbit STM. STM propagation only occurs for numerical integrator type propagators. **Accepted Data Types** String **Allowed Values** **STM** **Default Value** Not used **Required** no **Interfaces** GUI, script
AMatrix	The Jacobian of the orbital acceleration. The partial of the first order acceleration vector with respect to the state vector. **Accepted Data Types** String **Allowed Values** **AMatrix** **Default Value** Not used **Required** no **Interfaces** GUI, script

Option	Description
OrbitColor	Sets orbit color on a **Propagate** command. Default color on **Propagate** segment is seeded from color that is set on **Spacecraft.OrbitColor** field. To set unique colors on **Propagate** command in script mode: Enter ColorName or RGB triplet value for the color of your choice. In GUI mode, select unique color of your choice on the **Propagate** command by clicking on Orbit Color Selectbox. For Example: Setting yellow color on **Propagate** segment in script mode can be done in either of the following two ways: `Propagate DefaultProp(DefaultSC) {DefaultSC.Earth.Apoapsis, OrbitColor = Yellow}` or `Propagate DefaultProp(DefaultSC) {DefaultSC.Earth.Apoapsis, OrbitColor = [255 255 0]}`. **Accepted Data Types**: Integer Array or String **Allowed Values**: Any color available from the Orbit Color Picker in GUI. Valid predefined color name or RGB triplet value between 0 and 255. **Default Value**: Default color on **Propagate** command is color that is first set on **Spacecraft.OrbitColor** field. Default color on **Spacecraft.OrbitColor** is Red. Therefore default color for **Propagate** command is Red. **Required**: no **Interfaces**: GUI, script

GUI

Introduction

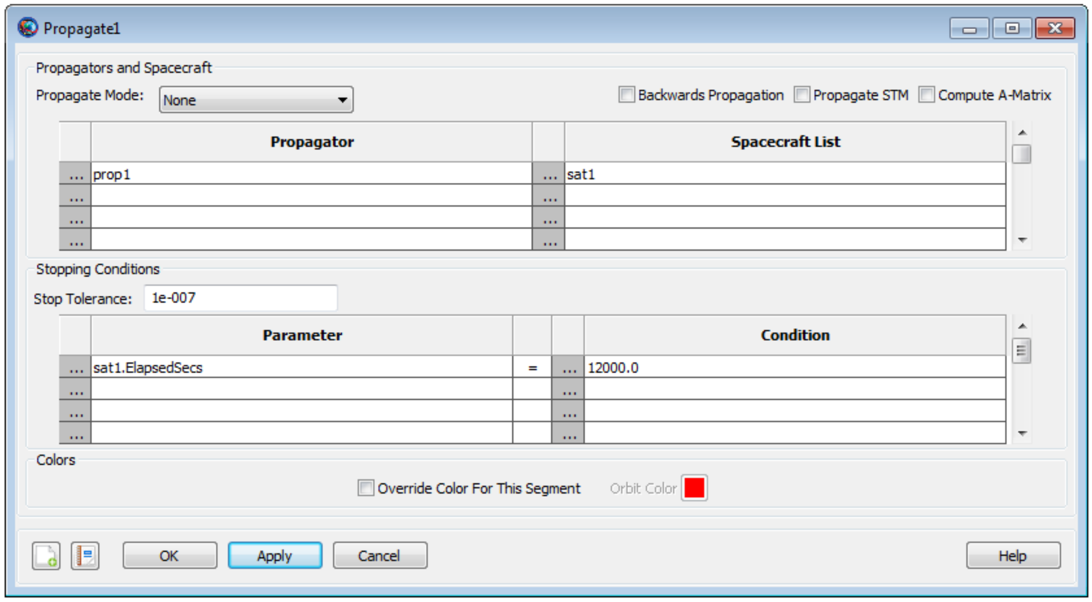
The **Propagate** command GUI provides an interface to assign **Spacecraft** to **Propagators** used for propagation and to define a set of conditions to terminate propagation. The GUI also allows you to define the direction of propagation, the synchronization mode for multiple spacecraft, and whether or not to propagate the STM and compute the A-Matrix.

To follow the examples below, you can load the following script snippet or create a new mission with three spacecraft (named **sat1**, **sat2**, and **sat3**) and two propagators (named **prop1** and **prop2**).

```
Create Spacecraft sat1 sat2 sat3
Create Propagator prop1 prop2
BeginMissionSequencer
```

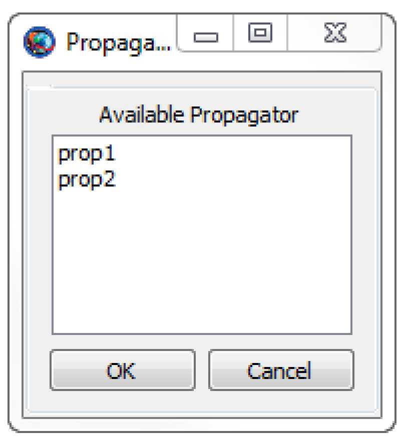
Defining Spacecraft and Propagators

To demonstrate how to define a set of propagators and **Spacecraft** for propagation, you will set up a **Propagate** command to propagate a **Spacecraft** named **sat1** using a **Propagator** named **prop1** and **Spacecraft** named **sat2** and **sat3** using a **Propagator** named **prop2**. You will configure the command to propagate for 1 day or until **sat2** reaches periapsis, whichever happens first. You will need to configure GMAT as described in the the section called "Introduction" section and add a new **Propagate** command to your mission sequence. GMAT auto-populates the **Propagate** command GUI with the first **Propagator** in the GUI list and the first **Spacecraft** when you add a new **Propagate** command so you should start from this point.

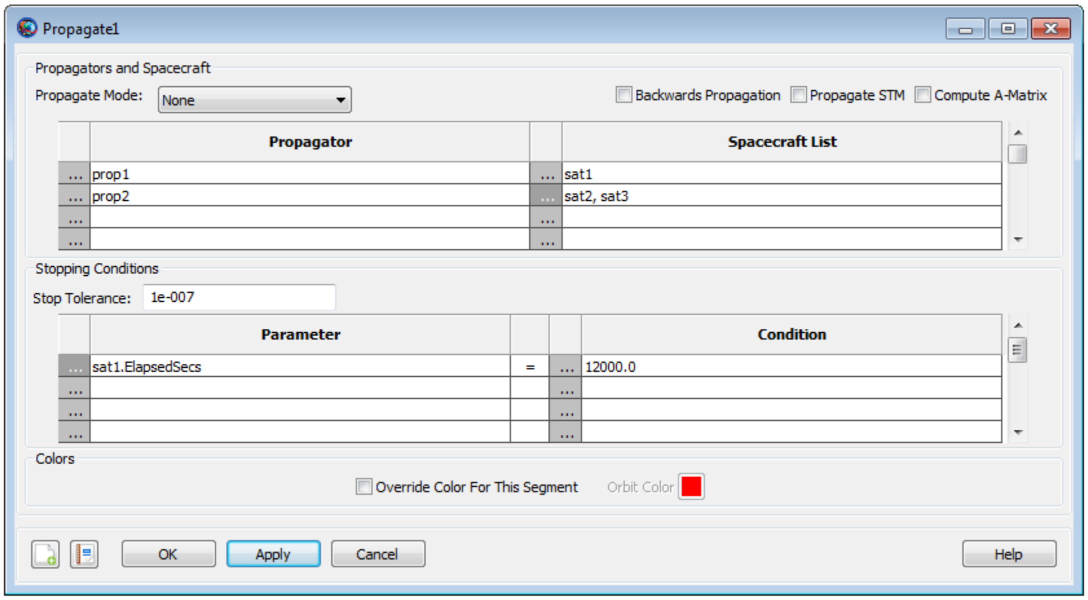


To add a second **Propagator** to propagate **sat2** and **sat3** using **prop2**:

1. In the **Propagator** list, click the ellipsis button in the second row to open the **Propagator Select Dialog**.



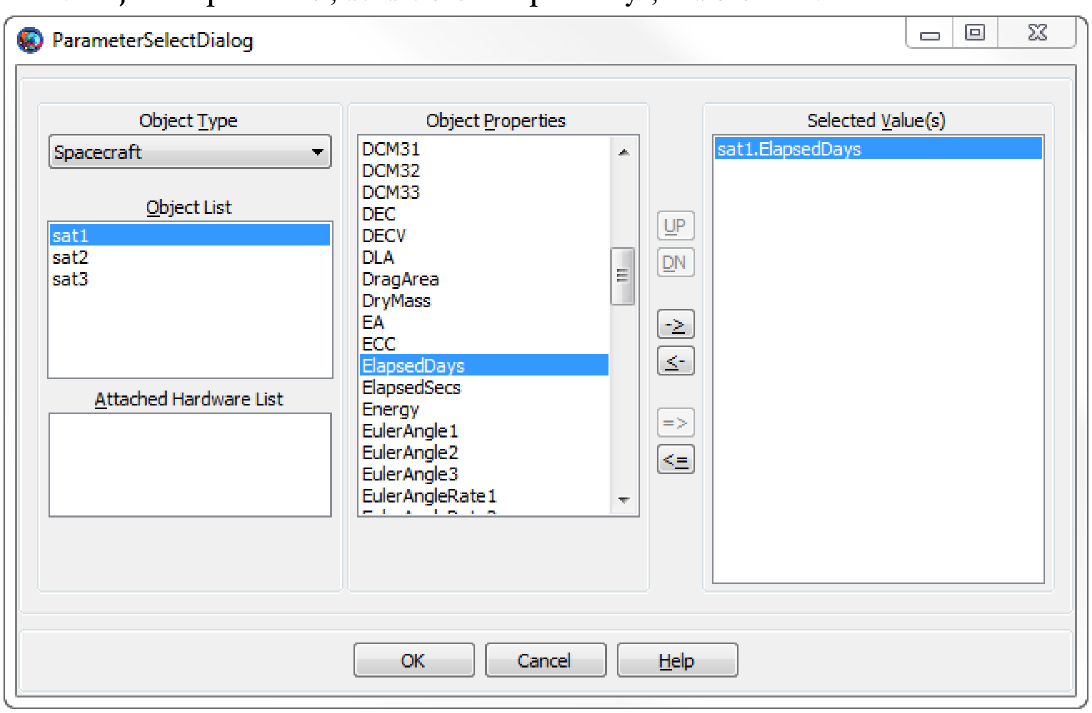
2. In the **Available Propagators** list, click on **prop2**, and click **OK**.
3. In the **Spacecraft List**, click the ellipsis button in the second row to open the **Space Object Select** dialog.
4. Click the right-arrow twice to add **sat2** and **sat3** to the list of selected spacecraft and click **Ok**.



Stopping conditions

Continuing with the example above, now you will configure GMAT to propagate for one elapsed day or until **sat2** reaches periapsis.

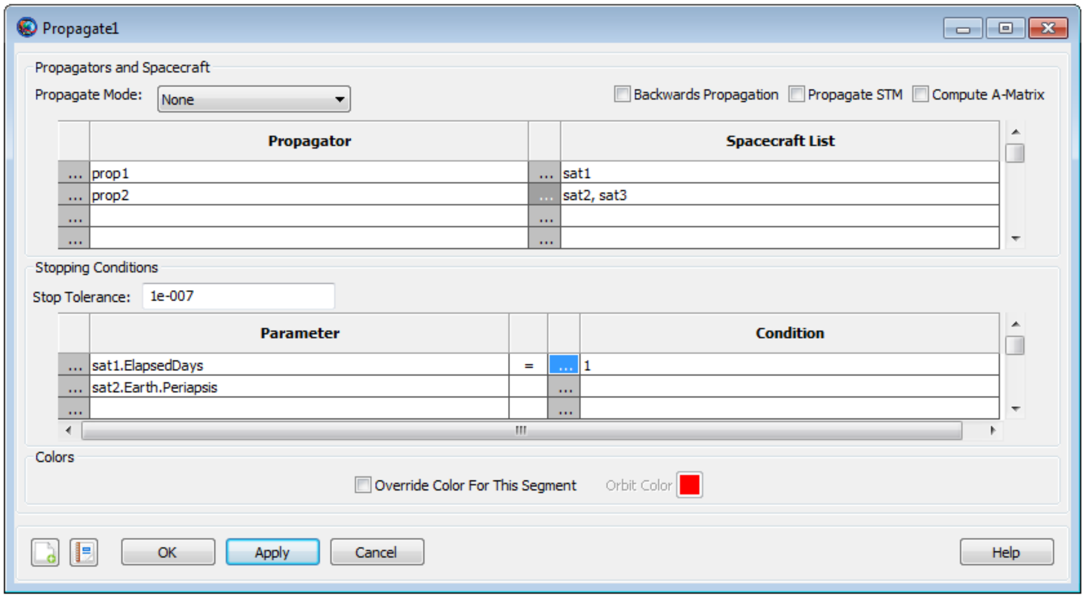
1. In the **Parameter** list, click the ellipsis button in the first row to bring up the **Parameter Select Dialog**.
2. In the **ObjectProperties** list, double click **ElapsedDays**, and click **OK**.



3. In the **Condition** list, double click the first row containing `12000`, type `1`, and click OK.

4. In the **Parameter** list, click the ellipsis button in the second row to bring up the **Parameter Select Dialog**.
5. In the **Object** list, click **Sat2**.
6. In the **ObjectProperties** list, double click **Periapsis** and click **OK**.

The **Propagate1** dialog should now look like the image below.



Remarks

Introduction

The **Propagate** command documentation below describes how to propagate single and multiple **Spacecraft** to desired conditions forward and backwards in time. To streamline the script examples, the objects **numSat**, **spkSat**, **numProp**, and **spkProp** are assumed to be configured as shown below. GMAT is distributed with the SPK kernels used in the examples.

```
Create Spacecraft spkSat;
spkSat.Epoch.UTCGregorian    = '02 Jun 2004 12:00:00.000'
spkSat.NAIFId                = -123456789;
spkSat.OrbitSpiceKernelName = {'..\data\vehicle\ephem\spk\GEOSat.bsp'};

Create Spacecraft numSat
numSat.Epoch.UTCGregorian = '02 Jun 2004 12:00:00.000'

Create Propagator spkProp;
spkProp.Type       = SPK;
spkProp.StartEpoch = FromSpacecraft

Create Propagator numProp
numProp.Type = PrinceDormand78

BeginMissionSequence
```

How to Propagate a Single Spacecraft

`Note:` See the the section called "Introduction" section for a script snippet to configure GMAT to execute the examples in this section.

The **Propagate** command provides a simple interface to propagate a **Spacecraft** to a stopping condition or to take a single propagation step. To propagate a single **Spacecraft** you must specify the desired **Propagator**, the **Spacecraft** to propagate, and if desired, the stopping condition. The **Propagate** command supports numerical integrator and ephemeris type propagators. For single **Spacecraft** propagation, the syntax is the same regardless of propagator type. For example, to propagate a **Spacecraft** using a numerical integrator, you can use the following script snippet:

```
Propagate numProp(numSat){numSat.Periapsis}
% or
Propagate numProp(numSat,{numSat.Periapsis})
```

To propagate a single **Spacecraft** using a **Propagator** configured to use an SPK kernel use the following:

```
Propagate spkProp(spkSat){spkSat.TA = 90}
% or
Propagate spkProp(spkSat,{spkSat.TA = 90})
```

To take a single propagation step, simply omit the stopping conditions as shown below. The **Propagator** will take a step based on its step size control algorithm. See the Propagator documentation for more information on step size control.

```
Propagate numProp(numSat)
% or
Propagate spkProp(spkSat)
```

How to Propagate Multiple Spacecraft

The **Propagate** command allows you to propagate multiple **Spacecraft** by including a list of **Spacecraft** in a single **Propagator**, by including a **Formation** in a **Propagator**, and/or by including multiple **Propagators** in a single command. For example purposes, here is a script snippet that propagates multiple **Spacecraft**.

```
Propagate Synchronized Prop1(Sat1,Sat2) Prop2(Sat3,Sat4)...
Prop3(aFormation){Sat1.Earth.Periapsis}
```

In the script line above **Sat1** and **Sat2** are propagated using **Prop1**; **Prop2** is used to propagate **Sat3** and **Sat4**; all **Spacecraft** added to **aFormation** are propagated using **Prop3**. The **Propagate** command configured above propagates all **Spacecraft** until **Sat1** reaches Earth periapsis.

All **Spacecraft** propagated by the same **Propagator** are time synchronized during propagation. By time synchronization, we mean that all **Spacecraft** are propagated across the same time step. The **Synchronized** keyword tells GMAT to keep **Spacecraft** propagated by different **Propagators** synchronized in time during propagation. Time synchronization among multiple **Propagators** is performed by taking a single step for all **Spacecraft** controlled by the first **Propagator** (**Prop1** in the above example), and then stepping all other **Propagators** to that time. When the **Synchronized** keyword is omitted, **Spacecraft** propagated by different **Propagators** are not synchronized in time.

In that case, each **Propagator** takes steps determined by its step size control algorithm without regard to the other **Propagators** in the **Propagate** command. Time synchronization is particularly useful if you need ephemeris files for multiple spacecraft with consistent time tags, or if you are visualizing multiple spacecraft in an **OrbitView**.

> **Warning**
>
> Caution: When using a **Propagator** configured to use SPK kernels, you can only have one **Spacecraft** per **Propagator**.
>
> This is supported:
>
> ```
> Propagate numProp(numSat) spkProp(spkSat1) spkProp(spkSat2)
> ```
>
> This is NOT supported!
>
> ```
> Propagate numProp(numSat) spkProp(spkSat1,spkSat2)
> ```

Behavior of Stopping Conditions

GMAT allows you to define a set of stopping conditions when propagating **Spacecraft** that define conditions that must be satisfied at the termination of the **Propagate** command. For example, it is often useful to propagate to an orbital location such as Apogee. When no stopping condition is provided, the **Propagate** command takes a single step. When given a set of stopping conditions, the **Propagate** command propagates the **Spacecraft** to the condition that occurs first in elapsed propagation time and terminates propagation. There are several ways to define stopping conditions via the script interface. One is to include a comma separated list of stopping conditions with each **Propagator** like this.

```
Propagate Prop1(Sat1,{Sat1.Periapsis}) Prop2(Sat2,{Sat2.Periapsis})
```

A second approach is to define a comma separated list of stopping conditions at the end of the **Propagate** command like this.

```
Propagate Prop1(Sat1) Prop2(Sat2) {Sat1.Periapsis,Sat2.Periapsis}
```

Note that the above two methods result in the same stopping epoch. When you provide a set of stopping conditions, regardless of where in the command the stopping condition is defined, GMAT builds a list of all conditions and tracks them until the first condition occurs.

The **Propagate** command currently requires that the left hand side of a stopping condition is a valid **Spacecraft** parameter. For example, the first line in the following example is supported and the second line is not supported.

```
Propagate Prop1(Sat1) {Sat1.TA = 45}  % Supported
Propagate Prop1(Sat1) {45 = Sat1.TA}  % Not supported
```

GMAT supports special built-in stopping conditions for apoapsis and periapsis like this:

```
Propagate Prop1(Sat1) {Sat1.Apoapsis}
Propagate Prop1(Sat1) {Sat1.Mars.Periapsis}
```

You can define the tolerance on the stopping condition by including the **StopTolerance** keyword in the **Propagate** command as shown below. In this example, GMAT will propagate until the true anomaly of **Sat1** is 90 degrees to within +/- 1e-5 degrees.

```
Propagate Prop1(Sat1) {Sat1.TA = 90, StopTolerance = 1e-5}
```

Warning

Caution: GMAT currently propagates **Spacecraft** to a time quantization of a few microseconds. Depending upon the rate of the stopping condition function, it may not be possible to locate the stopping condition to the requested **StopTolerance**. In that case, GMAT throws a warning to alert you that the tolerance was not satisfied and provides information on the achieved stopping value and the requested tolerance.

Note: GMAT does not currently support tolerances on a per stopping condition basis. If you include **StopTolerance** multiple times in a single **Propagate** command, GMAT uses the last value provided.

The **Propagate** command uses an algorithm called the First Step Algorithm (FSA) when back-to-back propagations occur and both propagations have at least one stopping condition that is the same in both commands. For example:

```
Propagate prop1(Sat1) {Sat1.TA = 90}
Propagate prop1(Sat1) {Sat1.TA = 90, StopTolerance = 1e-4}
```

The **FSA** determines the behavior of the first step when the last propagation performed on a **Spacecraft** was terminated using a stopping condition listed in the current command. If the error in the stopping condition at the initial epoch of the second **Propagate** command is less than SafetyFactor***StopTolerance**, the propagate command will take one integration step before attempting to locate the stopping condition again. In the FSA, SafetyFactor = 10, and the **StopTolerance** is from the second **Propagate** command. Continuing with the example above, if abs(TA_Achieved - TA_Desired) < 1e-3 -- where TA_Achieved is the TA after the first **Propagate** command and TA_Desired is the requested value of TA in the second **Propagate** command -- then the **Propagate** command will take one step before attempting to locate the stopping condition. The first step algorithm works the same way for forward propagation, backwards propagation, and changing propagation directions.

Warning

Caution: It is possible to specify a **StopTolerance** that cannot be satisfied by the stopping condition root locators and in that case, a warning is thrown. However, subsequent **Propagate** commands using the same stopping conditions may not behave as desired. For the FSA algorithm to work as designed, you must provide **StopTolerance** values that are achievable.

How to Propagate Backwards

To propagate backwards using the script interface, include the keyword **BackProp** between the **Propagate** command and the first **Propagator** in the command as shown below. All **Propagators** in the command will propagate backwards.

```
Propagate Synchronized BackProp Prop1(Sat1,Sat2) Prop2(Sat3,Sat4)...
          Prop3(aFormation){Sat1.Earth.Periapsis}

Propagate Backprop numProp(numSat){numSat.Periapsis}
```

How to Propagate the STM and Compute the Jacobian (A-matrix)

GMAT propagates the STM for all **Spacecraft** propagated using numerical integrators by including the `STM` keyword in a **Propagate** command as shown below. If the STM keyword is included anywhere in a **Propagate** command, the STM is propagated for all spacecraft using numerical propagators.

```
Propagate Backprop numProp(numSat,'STM'){numSat.Periapsis}
```

GMAT does not currently support propagating the STM when propagating **Formation** resources or when using SPK type propagators.

Limitations of the Propagate Command

- When using an SPK-type **Propagator**, only a single **Spacecraft** can be propagated by a given **Propagator**.
- GMAT does not currently support propagating the STM when propagating **Formation** objects.
- When computing the A-matrix during propagation, the A-matrix values are only accessible via the C-Interface.

Setting Colors on the Propagate Command

GMAT allows you to assign unique colors to **Spacecraft** trajectory segments by setting orbital colors on each **Propagate** command. If you do not set unique colors on each **Propagate** command, then by default, the color on each propagate segment is seeded from color that is set on **Spacecraft.OrbitColor** field. See the Options section for **OrbitColor** option that lets you set colors on the **Propagate** command. Also see Color documentation for discussion and examples on how to set unique colors on orbital trajectory segments through GMAT's **Propagate** command.

Examples

Propagate a single **Spacecraft** to Earth periapsis

```
Create Spacecraft numSat
numSat.Epoch.UTCGregorian = '02 Jun 2004 12:00:00.000'

Create Propagator numProp
numProp.Type = PrinceDormand78

BeginMissionSequence

Propagate numProp(numSat) {numSat.Earth.Periapsis}
```

Propagate a single **Spacecraft** for one day.

```
Create Spacecraft numSat
numSat.Epoch.UTCGregorian = '02 Jun 2004 12:00:00.000'
```

```
Create Propagator numProp
numProp.Type = PrinceDormand78

BeginMissionSequence

Propagate numProp(numSat) {numSat.ElapsedDays = 1}
```

Propagate a single **Spacecraft** backwards to true anomaly of 90 degrees.

```
Create Spacecraft numSat
numSat.Epoch.UTCGregorian = '02 Jun 2004 12:00:00.000'

Create Propagator numProp
numProp.Type = PrinceDormand78

BeginMissionSequence

Propagate BackProp numProp(numSat) {numSat.TA = 90}
```

Propagate two **Spacecraft**, each using a different **Propagator**, but keep the **Spacecraft** synchronized in time. Propagate until either **Spacecraft** reaches a mean anomaly of 45 degrees.

```
Create Spacecraft aSat1 aSat2
aSat1.Epoch.UTCGregorian = '02 Jun 2004 12:00:00.000'
aSat2.Epoch.UTCGregorian = '02 Jun 2004 12:00:00.000'
aSat2.TA = 0;

Create Propagator aProp1
aProp1.Type = PrinceDormand78
Create Propagator aProp2
aProp2.Type = PrinceDormand78

BeginMissionSequence

Propagate Synchronized aProp1(aSat1) aProp2(aSat2) ...
                      {aSat1.MA = 45,aSat2.MA = 45}
```

Report

Allows you to write data to a text file

Script Syntax

```
Report  ReportName  DataList

ReportName
  ReportName option allows you to specify the
  ReportFile for data output.
DataList
  DataList option allows you to output data to the Filename
  specified by the ReportName. Multiple objects can be written
  in the DataList when they are separated by spaces.
```

Description

The **Report** command allows you to report data at specific points in your mission sequence. GMAT allows you to insert **Report** command into the **Mission** tree at any location. **Report** command can be used through GMAT's GUI or via the script interface. The parameters reported by **Report** command are placed into a report file that can be accessed at the end of the mission run.

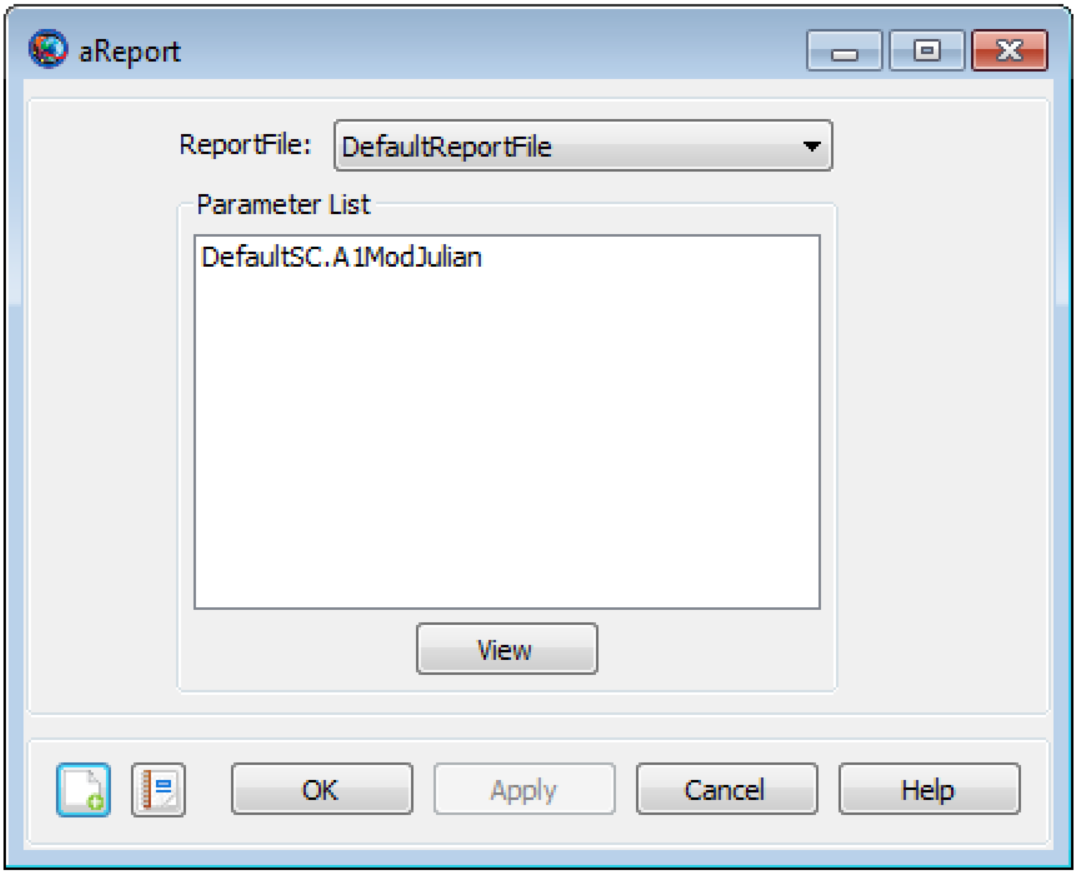
See Also: ReportFile

Options

Option	Description
ReportName	The **ReportName** option allows the user to specify the **ReportFile** for data output. **Accepted Data Types**: Resource reference **Allowed Values**: **ReportFile** resource **Default Value**: **DefaultReportFile** **Required**: yes **Interfaces**: GUI, script
DataList	The **DataList** option allows the user to output data to the file name that is specified by the **ReportName**. Multiple objects can be in the **DataList** when they are separated by spaces. **Accepted Data Types**: Reference array **Allowed Values**: **Spacecraft**, **ImpulsiveBurn** reportable parameters, **Array**, Array Element, **Variable**, or a **String**. **Default Value**: **DefaultSC.A1ModJulian** **Required**: yes **Interfaces**: GUI, script

GUI

Figure below shows default settings for **Report** command:



Remarks

Report command can be used to report data to a report file at specific points in your mission. If you want data to be reported at each propagation step of the entire mission duration, then you should not use **Report** command. Instead you should use **ReportFile** resource. See **ReportFile** resource section of the User's Guide to learn about the syntax that allows you to report data at each raw integrator steps.

Examples

Propagate an orbit for two days and report epoch and selected orbital elements to a report file using the **Report** command.

```
Create Spacecraft aSat
Create ReportFile aReport

Create Propagator aProp

BeginMissionSequence

```

```
Report aReport aSat.UTCGregorian aSat.Earth.SMA aSat.Earth.ECC ...
aSat.EarthMJ2000Eq.RAAN
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
Report aReport aSat.UTCGregorian aSat.Earth.SMA aSat.Earth.ECC ...
aSat.EarthMJ2000Eq.RAAN
```

Report user-defined parameters such as variables, array elements and a string to a report file using the **Report** command.

```
Create ReportFile aReport

Create Variable aVar aVar2
aVar = 100
aVar2 = 2000

Create Array aArray[2,2]
aArray(1, 1) = 2
aArray(1, 2) = 3
aArray(2, 1) = 4
aArray(2, 2) = 5

Create String aString
aString = 'GMAT is awesome'

BeginMissionSequence

Report aReport aVar aVar2 aArray(1,1) aArray(1,2) aArray(2,1) ...
aArray(2,2) aString
```

While spacecraft propagates for less than a day, report spacecraft's true anomaly, eccentricity and altitude after every 3600 seconds using the **Report** command:

```
Create Spacecraft aSat
Create ReportFile aReport
Create Propagator aProp

BeginMissionSequence

While aSat.ElapsedDays < 1
 Propagate aProp(aSat) {aSat.ElapsedSecs = 3600 }
 Report aReport aSat.Earth.TA aSat.Earth.ECC aSat.Earth.Altitude
EndWhile
```

Set

Configure a resource from a data interface

Script Syntax

```
Set destination source (options)
```

Description

The **Set** command retrieves data from `source` according to `options` and populates `destination`. Time systems, time formats, state types, and coordinate systems are automatically converted to those required by `destination`.

See Also: FileInterface, Spacecraft

Options

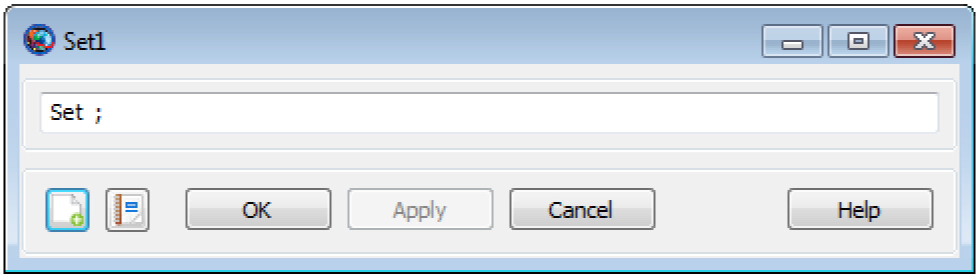
Option	Description	
`destination`	The resource to populate from the data source.	
	Accepted Data Types	**Spacecraft**
	Allowed Values	any **Spacecraft** resource
	Default Value	(None)
	Required	yes
	Interfaces	GUI, script
`source`	The data source from which to obtain data.	
	Accepted Data Types	**FileInterface**
	Allowed Values	any **FileInterface** resource
	Default Value	(None)
	Required	yes
	Interfaces	GUI, script
`options`	Options specific to the chosen `source`. See the following sections for details.	

The following options are available when `source` is a **FileInterface** and the **Format** is "`TVHF_ASCII`":

`Data={keyword[, keyword, ...]}`

Comma-separated list of values to retrieve from the file. Defaults to `'All'`, which retrieves all available elements. The available keywords are documented in the "TVHF_ASCII" section of the FileInterface reference.

GUI



The **Set** GUI is a very simple text box that lets you type the command directly. By default, it has no arguments, so you must finish the command yourself.

Examples

Read a TVHF file and use it to configure a spacecraft.

```
Create Spacecraft aSat
Create FileInterface tvhf
tvhf.Filename = 'statevec.txt'
tvhf.Format = 'TVHF_ASCII'

BeginMissionSequence

Set aSat tvhf
```

Read a TVHF file and use it to set only the epoch and the Cartesian state.

```
Create Spacecraft aSat
Create FileInterface tvhf
tvhf.Filename = 'statevec.txt'
tvhf.Format = 'TVHF_ASCII'

BeginMissionSequence

Set aSat tvhf (Data = {'Epoch', 'CartesianState'})
```

Stop

Stop mission execution

Description

The **Stop** command stops execution of the current mission at the point that the command is encountered and returns control to the GMAT interface. The effect is similar to that of the **Stop** button on the GUI toolbar.

GUI

The **Stop** command can be inserted into and deleted from Mission tree, but the command has no GUI panel of its own.

Remarks

The **Stop** command stops execution of the current mission, not the GMAT application. All data displayed to the point, at which the script was stopped (e.g. **OrbitView** windows, **GroundTrackPlot** windows), remain available for manipulation. Using the **Stop** command within a loop or solver structure will stop execution at the first iteration during which the command is encountered.

Examples

Stopping the execution of a script between commands:

```
Create Spacecraft aSat
Create ForceModel aForceModel
Create Propagator aProp
aProp.FM = aForceModel

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 30};
Stop
Propagate aProp(aSat) {aSat.ElapsedDays = 30};
```

Stopping the execution of a solver structure for further investigation:

```
Create FuelTank aTank
Create ForceModel aForceModel
Create DifferentialCorrector aDC

Create Spacecraft aSat
aSat.Tanks = {aTank}

Create Propagator aProp
aProp.FM = aForceModel

Create ImpulsiveBurn anIB
anIB.DecrementMass = true
```

```
anIB.Tanks = {aTank}

BeginMissionSequence

Target aDC
Vary aDC(anIB.Element1 = 0.5)
Maneuver anIB(aSat)
Propagate aProp(aSat) {aSat.Periapsis}
If aSat.aTank.FuelMass < 10
Stop
EndIf
Achieve aDC(aSat.Altitude = 1000)
```

Target

Solve for condition(s) by varying one or more parameters

Script Syntax

```
Target SolverName [{[SolveMode = value], [ExitMode = value]}]
      Vary command …
      script statement …
      Achieve command …
EndTarget
```

> **Note**
>
> See the section called "Remarks" and the section called "Description" for this complex command. Multiple **Vary** and **Achieve** commands are permitted. Script statements can appear anywhere in the **Target** sequence.

Description

The **Target** and **EndTarget** commands are used to define a **Target** sequence to determine, for example, the maneuver components required to raise the orbit apogee to 42164 km. Another common targeting example is to determine the parking orbit orientation required to align a lunar transfer orbit with the moon. **Target** sequences in GMAT are general and these are just examples. Let's define the quantities whose values you don't know precisely, but need to determine, as the *control variables*. Define the conditions that must be satisfied as the *constraints*. A **Target** sequence numerically solves a boundary value problem to determine the value of the control variables required to satisfy the constraints. You define your control variables by using **Vary** commands and you define the problems constraints using **Achieve** commands. The **Target/EndTarget** sequence is an advanced command. The examples later in this section give additional details.

See also: DifferentialCorrector,Vary,Achieve,Optimize,

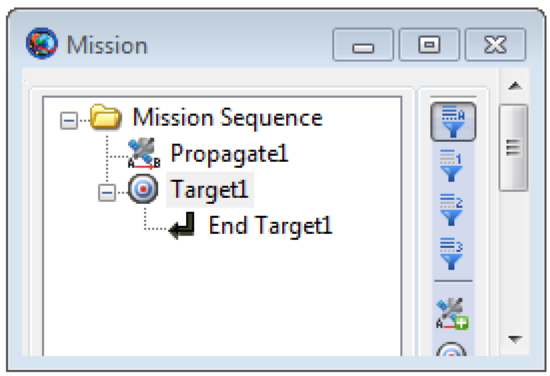
Options

Option	Description
ApplyCorrections	This GUI button replaces the initial guess values specified in the **Vary** commands. If the **Target** sequence converged, the converged values are applied. If the **Target** sequence did not converge, the last calculated values are applied. There is one situation where the action specified above, where the initial guess values specified in the **Vary** commands are replaced, does not occur. This happens when the initial guess value specified in the **Vary** command is given by a variable. See the Remarks section of the help for additional details. **Accepted Data Types**: N/A **Allowed Values**: N/A **Default Value**: N/A **Required**: no **Interfaces**: GUI
ExitMode	Controls the initial guess values for **Target** sequences nested in control flow. If **ExitMode** is set to **SaveAndContinue**, the solution of a **Target** sequence is saved and used as the initial guess for the next **Target** sequence execution. The rest of the mission sequence is then executed. If **ExitMode** is set to **DiscardAndContinue**, then the solution is discarded and the initial guess values specified in the **Vary** commands are used for each **Target** sequence execution. The rest of the mission sequence is then executed. If **ExitMode** is set to **Stop**, the **Target** sequence is executed, the solution is discarded, and the rest of the mission sequence is not executed. **Accepted Data Types**: Reference Array **Allowed Values**: **DiscardAndContinue**, **SaveAndContinue**, **Stop** **Default Value**: **DiscardAndContinue** **Required**: no **Interfaces**: GUI, script
SolveMode	Specifies how the **Target** sequence behaves during mission execution. When **SolveMode** is set to **Solve**, the **Target** sequence executes and attempts to solve the boundary value problem satisfying the targeter constraints (i.e, goals). When **SolveMode** is set to **RunInitialGuess**, the targeter does not attempt to solve the boundary value problem and the commands in the **Target** sequence execute using the initial guess values defined in the **Vary** commands. **Accepted Data Types**: Reference Array **Allowed Values**: **Solve**, **RunInitialGuess** **Default Value**: **Solve** **Required**: no **Interfaces**: GUI, script

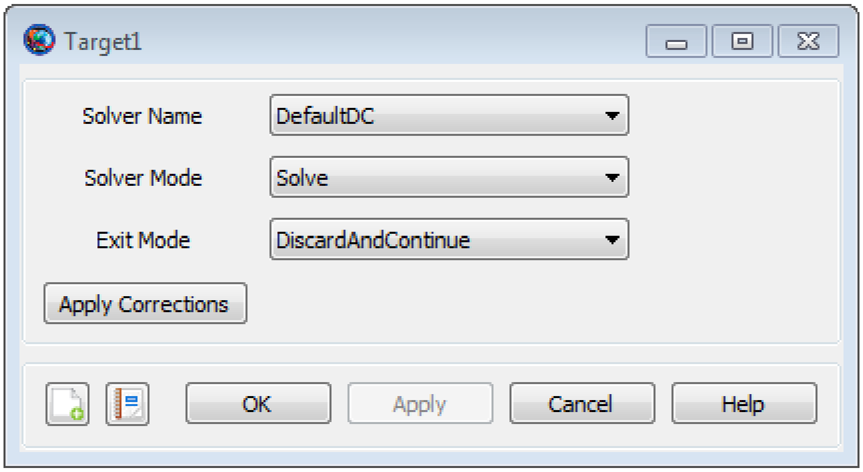
Option	Description	
SolverName	Identifies the **DifferentialCorrector** used for a **Target** sequence.	
	Accepted Data Types	**DifferentialCorrector**
	Allowed Values	Any user-defined or default **Differential-Corrector**
	Default Value	**DefaultDC**
	Required	yes
	Interfaces	GUI, script

GUI

The **Target** command allows you to use a differential correction process to solve problems. To solve a given problem, you need to create a so-called **Target** sequence which we now define. When you add a **Target** command to the mission sequence, an **EndTarget** command is automatically added as shown below.



In the example above, the **Target** command sequence is defined as all of the commands between the **Target1** and **End Target1** commands, inclusive. Although not shown above, a **Target** command sequence must contain both a **Vary** command and an **Achieve** command. The **Vary** command is used to define the control variables which can be varied in order to achieve a certain goal. The **Achieve** command is used to define the desired goal. In order for the **Target** aequence to be well formed, there must be at least one **Vary** command before any **Achieve** commands, so that the variable defined in the **Vary** command can affect the goal specified in the subsequent **Achieve** commands. Double click on **Target1** command above to bring up the **Target** command dialog box, shown below, which allows you to specify your choice of **Solver** (i.e., your choice of **DifferentialCorrector**), **Solver Mode**, and **Exit Mode**. As described in the Remarks section, the **Target** command dialog box also allows you to apply corrections to your **Target** command sequence.



Remarks

Content of a Target/EndTarget Sequence

A **Target/EndTarget** sequence must contain at least one **Vary** command and at least one **Achieve** Command. See the **Vary** and **Achieve** command sections for details on the syntax for those commands. The First **Vary** command must occur before the first **Achieve** command. **Target** commands must be be coupled with one and only one **EndTarget** command. Each **Targe**t command field in the curly braces is optional. You can omit the entire list and the curly braces and the default values will be used for **Target** configuration fields such as **SolveMode** and **ExitMode**.

Use of a Target/EndTarget Sequence

GMAT **Target** sequences can solve square problems (the number of Control Variables equals the number of constraints), over-determined problems (the number of Control Variables is less than the number of constraints) and under-determined problems (the number of Control Variables is greater than the number of constraints). In any of these cases, there may not be a solution and the type of solution found depends on the selection of the targeter (currently, only differential correctors are supported). Assuming a solution to the problem exists and assuming certain mathematical conditions are satisfied, there is often one solution for a square problem and many solutions to an under-determined problem. Problems with more goals (i.e., constraints) than variables may not have a solution. If your problem is under-determined, consider using an **Optimize** sequence to find an optimal solution in the space of feasible solutions.

> **Caution**
>
> If you configure a **Target** sequence and get the error “Rmatrix error: matrix is singular”, then your control variables defined in the **Vary** commands do not affect the constraints defined in the **Achieve** commands. A common mistake in this case is that you forgot to apply a maneuver.

Note on Using Apply Corrections

After the **Target** sequence has been run, you may choose to apply corrections by navigating to the **Mission** tree, right-clicking the **Target** command to bring up the **Target** window, and clicking the

Apply Corrections button. The **Apply Corrections** button replaces the initial guess values specified in the **Vary** commands . If the **Target** sequence converged, the converged values are applied. If the **Target** sequence did not converge, the last calculated values are applied. Note that the **Apply Corrections** feature is only currently available through the GUI interface.

There is one situation where the action specified above, where the initial guess values specified in the **Vary** commands are replaced, does not occur. This happens, as illustrated in the example below, when the initial guess value specified in the **Vary** command is given by a variable. In this situation, the **Apply Corrections** button has no affect since GMAT does not allow variables to be overwritten.

```
Create Variable InitialGuess_BurnDuration BurnDuration
Create DifferentialCorrector aDC
BeginMissionSequence
Target aDC
Vary aDC(BurnDuration = InitialGuess_BurnDuration)
Achieve aDC(BurnDuration = 10) % atypical Achieve command for
                               % illustrative purposes only
EndTarget
```

Command Interactions

Vary command	Every **Target** sequence must contain at least one **Vary** command. **Vary** commands are used to define the control variables associated with a **Target** sequence.
Achieve command	Every **Target** sequence must contain at least one **Achieve** command. **Achieve** commands are used to define the goals associated with a **Target** sequence.

Examples

Use a **Target** sequence to solve for a root of an algebraic equation. Here we provide an initial guess of 5 for the Control Variable (or independent variable) x, and solve for the value of x that satisfies the Constraint y = 0, where y :=3*x^3 + 2*x^2 - 4*x + 8. After executing this example you can look in the message window to see the solution for the variable x. You can easily check that the value obtained does indeed satisfy the constraint.

```
Create Variable x y
Create DifferentialCorrector aDC

BeginMissionSequence

Target aDC
  Vary aDC(x = 5)
  y = 3*x^3 + 2*x^2 - 4*x + 8
  Achieve aDC(y = 0,{Tolerance = 0.0000001})
EndTarget
```

Use a **Target** sequence to raise orbit apogee. Here the control variable is the velocity component of an **ImpulsiveBurn** object. The Constraint is that the position vector magnitude at orbit apogee is 42164. Report the convergence status to a file.

```
Create Spacecraft aSat
Create Propagator aPropagator
Create Variable I
```

```
Create ImpulsiveBurn aBurn
Create DifferentialCorrector aDC
Create OrbitView EarthView
EarthView.Add = {Earth,aSat}
EarthView.ViewScaleFactor = 5

Create ReportFile aReport

BeginMissionSequence
Target aDC
   Vary aDC(aBurn.Element1 = 1.0, {Upper = 3})
   Maneuver aBurn(aSat)
   Propagate aPropagator(aSat,{aSat.Apoapsis})
   Achieve aDC(aSat.RMAG = 42164)
EndTarget
Report aReport aDC.SolverStatus aDC.SolverState
```

Similar to the previous example, we use a **Target** sequence to raise orbit apogee except that this time we use a finite burn. Here the control variable is the duration of the Velocity component of a **FiniteBurn** object. The Constraint is that the position vector magnitude at orbit apogee is 12000. Additional detail on the example below can be found in the Target Finite Burn to Raise Apogee tutorial.

```
Create Spacecraft DefaultSC
Create Propagator DefaultProp
Create Thruster Thruster1
GMAT Thruster1.C1 = 1000
GMAT Thruster1.DecrementMass = true
Create FuelTank FuelTank1
GMAT Thruster1.Tank = {FuelTank1}
Create FiniteBurn FiniteBurn1
GMAT FiniteBurn1.Thrusters = {Thruster1}
GMAT DefaultSC.Tanks = {FuelTank1}
GMAT DefaultSC.Thrusters = {Thruster1}
Create Variable BurnDuration
Create DifferentialCorrector DC1

BeginMissionSequence

Propagate DefaultProp(DefaultSC) {DefaultSC.Earth.Periapsis}
Target DC1
  Vary DC1(BurnDuration = 200, {Upper = 10000})
  BeginFiniteBurn FiniteBurn1(DefaultSC)
  Propagate DefaultProp(DefaultSC){DefaultSC.ElapsedSecs=BurnDuration}
  EndFiniteBurn FiniteBurn1(DefaultSC)
  Propagate DefaultProp(DefaultSC) {DefaultSC.Earth.Apoapsis}
  Achieve DC1(DefaultSC.Earth.RMAG = 12000)
EndTarget
```

Toggle

Allows you to turn data output off or on

Script Syntax

```
Toggle  OutputNames  Arg

OutputNames
  OutputNames is the list of subscribers that are to be toggled.
  When multiple subscribers are being toggled in the OutputNames,
  then they need to be separated by a space.
Arg
  Arg option allows you to turn off or on the data output to
  the selected subscribers listed in the OutputNames.
```

Description

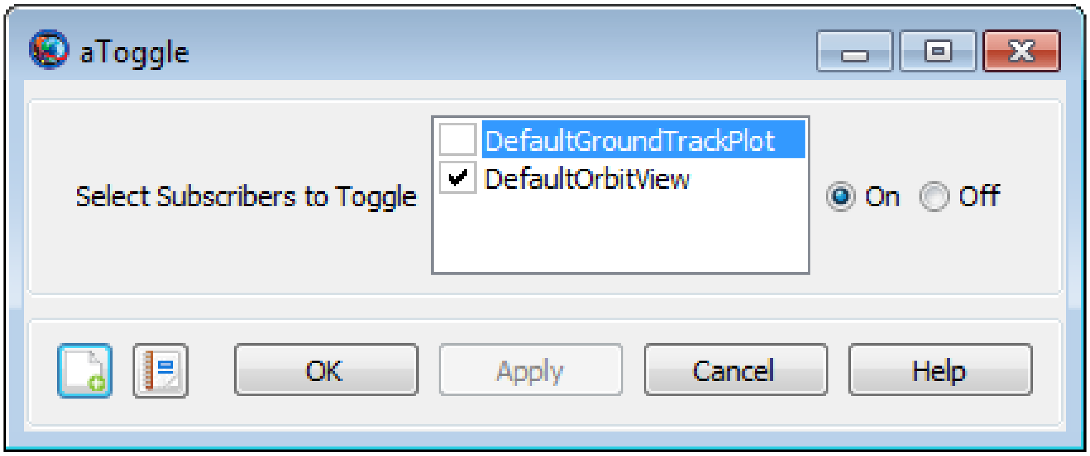
The **Toggle** command allows you to turn data output off or on for the subscribers that you select such as **ReportFile**, **XYPlot**, **OrbitView**, **GroundTrackPlot** and **EphemerisFile**. GMAT allows you to insert **Toggle** command into the **Mission** tree at any location and data output can be turned off or on at any point in your mission. **Toggle** command can be used through GMAT's GUI or the script interface.

Options

Option	Description
OutputNames	The **Toggle** option allows the user to assign subscribers such as **ReportFile**, **XYPlot**, **OrbitView**, **GrounTrackPlot** or **EphemerisFile** to be toggled. When more than one subscriber is being toggled, they need to be separated by a space. **Accepted Data Types** Resource reference **Allowed Values** **ReportFile**, **XYPlot**, **OrbitView**, **GroundTrackPlot** or **EphemerisFile** resources **Default Value** **DefaultOrbitView** **Required** yes **Interfaces** GUI, script
Arg	The **Arg** option allows the user to turn off or on the data output to the selected subscriber. **Accepted Data Types** Boolean **Allowed Values** On, Off **Default Value** On **Required** yes **Interfaces** GUI, script

GUI

Figure below shows default settings for **Toggle** command:



Remarks

The subscribers such as **ReportFile**, **XYPlot**, **OrbitView**, **GroundTrackPlot** and **EphemerisFile** report or plot data at each propagation step of the entire mission duration. If you want to report data to any of these subscribers at specific points in your mission, then a **Toggle On/Off** command can be inserted into the mission sequence to control when a subscriber reports or plots data. For example, when a **Toggle Off** command is issued for a **XYPlot**, no data is plotted onto the X and Y axis of the graph until a **Toggle On** command is issued. Similarly when a **Toggle On** command is used, data is plotted onto the X and Y axis at each integration step until a **Toggle Off** command is used.

Examples

This example shows how to use **Toggle Off** and **Toggle On** commands while using the **XYPlot** resource. Spacecraft's position magnitude and semi-major-axis are plotted as a function of time. **XYPlot** is turned off for the first 2 days of the propagation:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aPlot
aPlot.XVariable = aSat.ElapsedDays
aPlot.YVariables = {aSat.Earth.RMAG, aSat.Earth.SMA}

BeginMissionSequence

Toggle aPlot Off
Propagate aProp(aSat) {aSat.ElapsedDays = 2}
Toggle aPlot On
Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

This example shows how to use **Toggle Off** and **Toggle On** commands while using the **ReportFile** resource. Spacecraft's cartesian position vector is reported to the report file. Report file is turned off for the first day of the propagation:

```
Create Spacecraft aSat
Create Propagator aProp

Create ReportFile aReport
aReport.Filename = 'ReportFile1.txt'
aReport.Add = {aSat.ElapsedDays aSat.EarthMJ2000Eq.X ...
aSat.EarthMJ2000Eq.Y aSat.EarthMJ2000Eq.Z}

BeginMissionSequence

Toggle aReport Off
Propagate aProp(aSat) {aSat.ElapsedDays = 1}
Toggle aReport On
Propagate aProp(aSat) {aSat.ElapsedDays = 4}
```

This example shows how to toggle multiple subscribers. **Toggle Off** and **Toggle On** commands are used on multiple subscribers like **ReportFile**, **XYPlot** and **EphemerisFile**. Subscribers are turned off for first 3 days of the propagation:

```
Create Spacecraft aSat
Create Propagator aProp

Create ReportFile aReport
aReport.Filename = 'ReportFile1.txt'
aReport.Add = {aSat.ElapsedDays aSat.EarthMJ2000Eq.X ...
aSat.EarthMJ2000Eq.Y aSat.EarthMJ2000Eq.Z}

Create XYPlot aPlot
aPlot.XVariable = aSat.ElapsedDays
aPlot.YVariables = {aSat.Earth.RMAG, aSat.Earth.SMA}

Create EphemerisFile aEphemerisFile
aEphemerisFile.Spacecraft = aSat

BeginMissionSequence

Toggle aReport aPlot aEphemerisFile Off
Propagate aProp(aSat) {aSat.ElapsedDays = 3}
Toggle aReport aPlot aEphemerisFile On
Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

Vary

Specifies variables used by a solver

Script Syntax

```
Vary SolverName(<UserSelectedControl>=InitialGuess,
[{[Perturbation=Arg1], [MaxStep=Arg2],
[Lower=Arg3], [Upper=Arg4],
[AdditiveScalefactor=Arg5], [MultiplicativeScalefactor=Arg6]}])
```

Description

The **Vary** command is used in conjunction with either the **Target** or the **Optimize** command. The **Vary** command defines the control variable used by the targeter or optimizer. The **Target** or **Optimize** sequence then varies these control variables until certain desired conditions are met. Every **Target** or **Optimize** sequence must contain at least one **Vary** command.

See Also: DifferentialCorrector, FminconOptimizer, VF13ad, Target, Optimize

Options

Option	Description	
AdditiveScaleFactor	Number used to nondimensionalize the independent variable. The solver sees only the nondimensional form of the variable. The nondimensionalization is performed using the following equation: xn = m (xd + a). (xn is the non-dimensional parameter. xd is the dimensional parameter. a= additive scale factor. m= multiplicative scale factor.) Note the nondimensionalization process occurs after the perturbation to the control variable has been applied. Thus, xd represents a perturbed control variable.	
	Accepted Data Types	Real Number, Array element, Variable, or any user defined parameter
	Allowed Values	Real Number, Array element, Variable, or any user defined parameter
	Default Value	0
	Required	no
	Interfaces	GUI, script

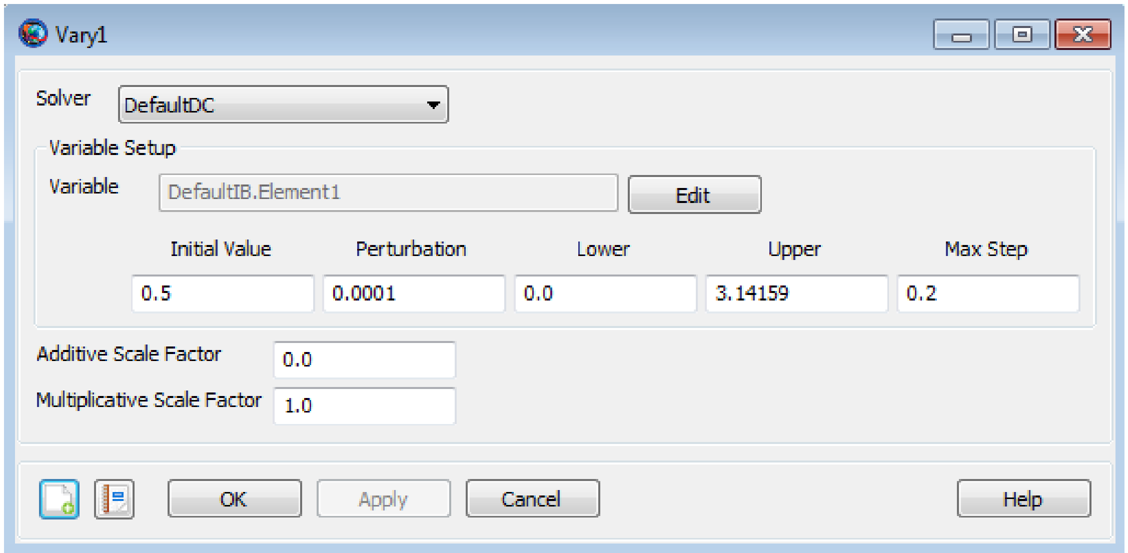
Option	Description
InitialGuess	Specifies the initial guess for the selected **Variable** **Accepted Data Types**: Real Number, Array element, Variable, or any user-defined parameter that obeys the conditions for the selected Variable object **Allowed Values**: Real Number, Array element, Variable, or any user-defined parameter that obeys the conditions for the selected Variable object **Default Value**: 0.5 **Required**: yes **Interfaces**: GUI, script
Lower	The **Lower** option (only used for the Differential Corrector and fmincon solvers) is used to set the lower bound of the control **Variable**. **Lower** must be less than **Uppe**r. **Accepted Data Types**: Real Number, Array element, Variable, or any user defined parameter **Allowed Values**: Real Number, Array element, Variable, or any user defined para- meter (Upper > Lower) **Default Value**: 0 **Required**: no **Interfaces**: GUI, script
MaxStep	The **MaxStep** option (only used for the **DifferentialCorrector** and **VF13ad** solvers) is the maximum allowed change in the control variable during a single iteration of the solver. **Accepted Data Types**: Real Number, Array element, Variable, or any user defined parameter > 0 **Allowed Values**: Real Number, Array element, Variable, or any user defined parameter > 0 **Default Value**: 0.2 **Required**: no **Interfaces**: GUI, script

Option	Description
MultiplicativeScaleFactor	Number used to nondimensionalize the independent variable. The solver sees only the nondimensional form of the variable. The nondimensionalization is performed using the following equation: xn = m (xd + a). (xn is the non-dimensional parameter. xd is the dimensional parameter. a= additive scale factor. m= multiplicative scale factor.) Note the nondimensionalization process occurs after the perturbation to the control variable has been applied. Thus, xd represents a perturbed control variable. **Accepted Data Types**: Real Number, Array element, Variable, or any user defined parameter **Allowed Values**: Real Number, Array element, Variable, or any user defined parameter > 0 **Default Value**: 1 **Required**: no **Interfaces**: GUI, script
Perturbation	The **Perturbation** option (only used for the **DifferentialCorrector** and **VF13ad** solvers) is the perturbation step sized used to calculate the finite difference derivative **Accepted Data Types**: Real Number, Array element, Variable, or any user defined parameter **Allowed Values**: Real Number, Array element, Variable, or any user defined parameter != 0 **Default Value**: 0.0001 **Required**: no **Interfaces**: GUI, script
SolverName	Allows you to choose which solver to assign to the **Vary** command. In the context of a **Target** sequence, you will choose a **DifferentialCorrector** object. In the context of an **Optimize** sequence, you will choose either a **FminconOptimizer** or **VF13ad** object. **Accepted Data Types**: Solver (either an Optimizer or a Targeter) **Allowed Values**: Any user defined Optimizer or Targeter **Default Value**: `DefaultDC` in a **Target** sequence and `DefaultSQP` in an **Optimize** sequence **Required**: yes **Interfaces**: GUI, script

Option	Description
Upper	The **Upper** option (only used for the **DifferentialCorrector** and **FminconOptimizer** solvers) is used to set the upper bound of the control **Variable**. **Lower** must be less than **Upper**. **Accepted Data Types**: Real Number, Array element, Variable, or any user defined parameter **Allowed Values**: Real Number, Array element, Variable, or any user defined para- meter (Upper > Lower) **Default Value**: 3.14159 **Required**: no **Interfaces**: GUI, script
UserSelectedControl	Allows you to select any single element user-defined parameter, except a number, to vary. For example, `DefaultIB.V`, `DefaultIB.N`, `DefaultIB.Element1`, `DefaultSC.TA`, `Array(1,1)`, and **Variable** are all valid values. The three element burn vector or multidimensional Arrays are not valid values. **Accepted Data Types**: Parameter, Array element, **Variable**, or any other single element user-defined parameter, excluding numbers. Note that the variable chosen must be settable in the **Mission** tree. **Allowed Values**: Spacecraft parameter, Array element, **Variable**, or any other single element user-defined parameter, excluding numbers **Default Value**: `DefaultIB.Element1` **Required**: yes **Interfaces**: GUI, script

GUI

The **Vary** command, only valid within either a **Target** or an **Optimize** sequence, is used to define the control variables which will be used to solve a problem. The **Vary** command dialog box is shown below.



The **Vary** command dialog box allows you to specify

- Choice of **Solver** (a differential corrector if using a **Target** sequence or an optimizer if using an **Optimize** sequence).
- Control **Variable** object. To define the control **Variable** used in the **Vary** command, click the **Edit** button to bring up the **ParameterSelectDialog** as shown below. Use the arrow to select the desired object and then click **OK**.
- **Initial Value** for the control variable object.
- **Perturbation** Step size used as part of the finite differencing algorithm. As noted in the Remarks section, this field is only used if the solver chosen is a differential corrector or a VF13AD optimizer.
- **Lower** allowed limit for the converged control variable object. As noted in the Remarks section, this field is only used if the solver chosen is a differential corrector or a fmincon optimizer.
- **Upper** allowed limit for the converged control variable object. As noted in the Remarks section, this field is only used if the solver chosen is a differential corrector or a fmincon optimizer.
- Maximum step size (**Max Step**), per iteration, for the control variable object. As noted in the Remarks section, this field is only used if the solver chosen is a differential corrector or a VF13AD optimizer.
- **Additive Scale Factor** used to scale the control variable object.
- **Multiplicative Scale Factor** used to scale the control variable object.

Remarks

Vary Command Options

The **Vary** command is designed to work with all three of the GMAT targeters and optimizers (Differential Corrector, fmincon, and VF13AD). The solvers, which are developed by different parties, all work slightly differently and thus have different needs. The table below shows which command options are available for a given solver.

	Differential Corrector	fmincon	VF13AD
SolverName	X	X	X

	Differential Corrector	fmincon	VF13AD
Variable	X	X	X
InitialGuess	X	X	X
AdditiveScaleFactor	X	X	X
MultiplicativeScaleFactor	X	X	X
Lower	X	X	
Upper	X	X	
Perturbation	X		X
MaxStep	X		X

The **Vary** syntax allows you to specify the value of an option even if a particular solver would not use the information.

Vary Command Accepts Repeated Parameters

As shown in the example below, the **Vary** command accepts repeated parameters.

```
Vary DefaultDC(ImpulsiveBurn1.Element1 = 2, ...
{Perturbation = 1e99, Perturbation = .001})
```

The accepted best practice is not to repeat parameters in any given command. However, for the **Vary** command, if you accidentally sets the same parameter multiple times, the last setting takes precedence. Thus, in the example above, the perturbation step size is set to 0.001.

Use of Thruster Parameters in a Vary Command

If you wish to use thruster parameters, such as thrust direction, in a **Vary** command, then you must reference the cloned (child) object directly. In the example below, we first show syntax, using the parent object that does not work. We then show the correct syntax using the cloned (child) object.

```
%Referencing the parent object, thruster1, does not work.
Vary DC1(thruster1.ThrustDirection1 = 0.4)
Vary DC1(thruster1.ThrustDirection2 = 0.5)

%Referencing the cloned (child) object, Sc.thruster1, does work.
Vary DC1(Sc.thruster1.ThrustDirection1 = 0.4)
Vary DC1(Sc.thruster1.ThrustDirection2 = 0.5)
```

Command Interactions

Target command	A **Vary** command only occurs within a **Target** or **Optimize** sequence.
Optimize command	A **Vary** command only occurs within a **Target** or **Optimize** sequence.
Achieve command	The **Achieve** command, used as part of a **Target** sequence, specifies the desired result or goal (obtained by using the **Vary** command to vary the control variables).

NonlinearConstraint command	The **NonlinearConstraint** command, used as part of an **Optimize** sequence, specifies the desired result or goal (obtained by using the **Vary** command to vary the control variables).
Minimize command	The **Minimize** command, used as part of an **Optimize** sequence, specifies the desired quantity to be minimized (obtained by using the **Vary** command to vary the control variables).

Examples

As mentioned above, the **Vary** command only occurs within either a **Target** or an **Optimize** sequence. See the **Target** and **Optimize** command help for examples showing the use of the **Vary** command.

While

Execute a series of commands repeatedly while a condition is met

Script Syntax

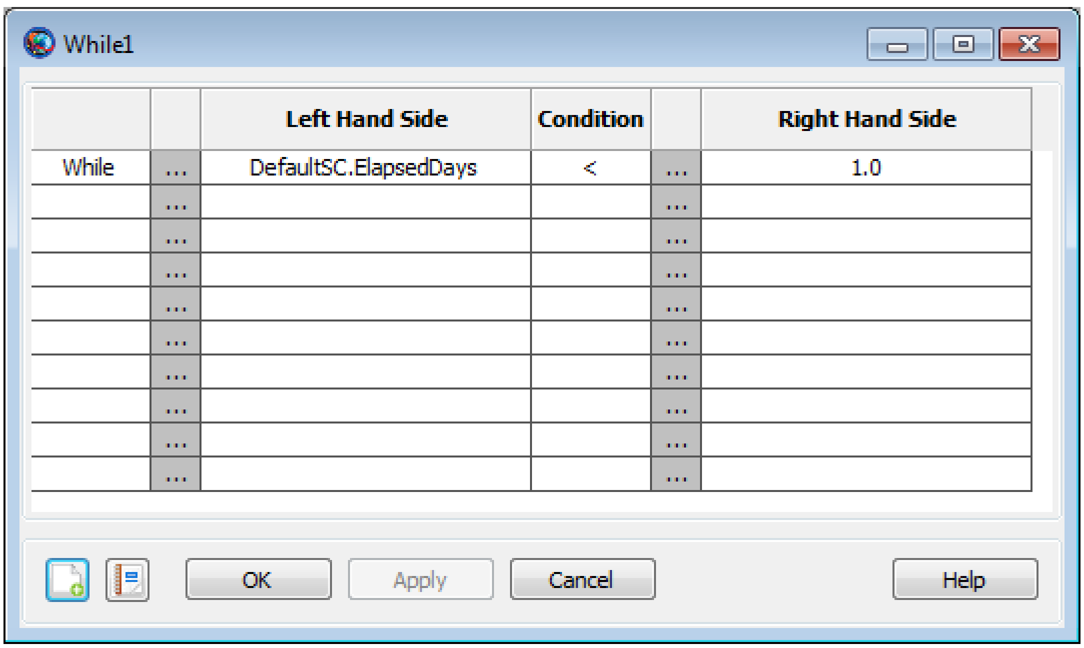
```
While logical expression
    [script statement]
    …
EndWhile
```

Description

The **While** command is a control logic statement that executes a series of commands repeatedly as long as the value of the provided logical expression is true. The logical expression is evaluated before every iteration of the loop. If the expression is initially false, the loop is never executed. The syntax of the expression is described in the script language reference.

See Also: Script Language, For, If

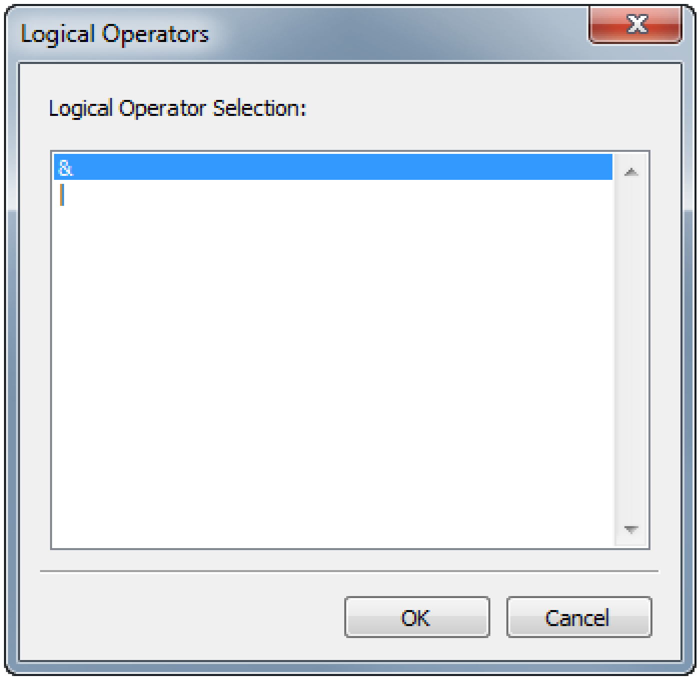
GUI



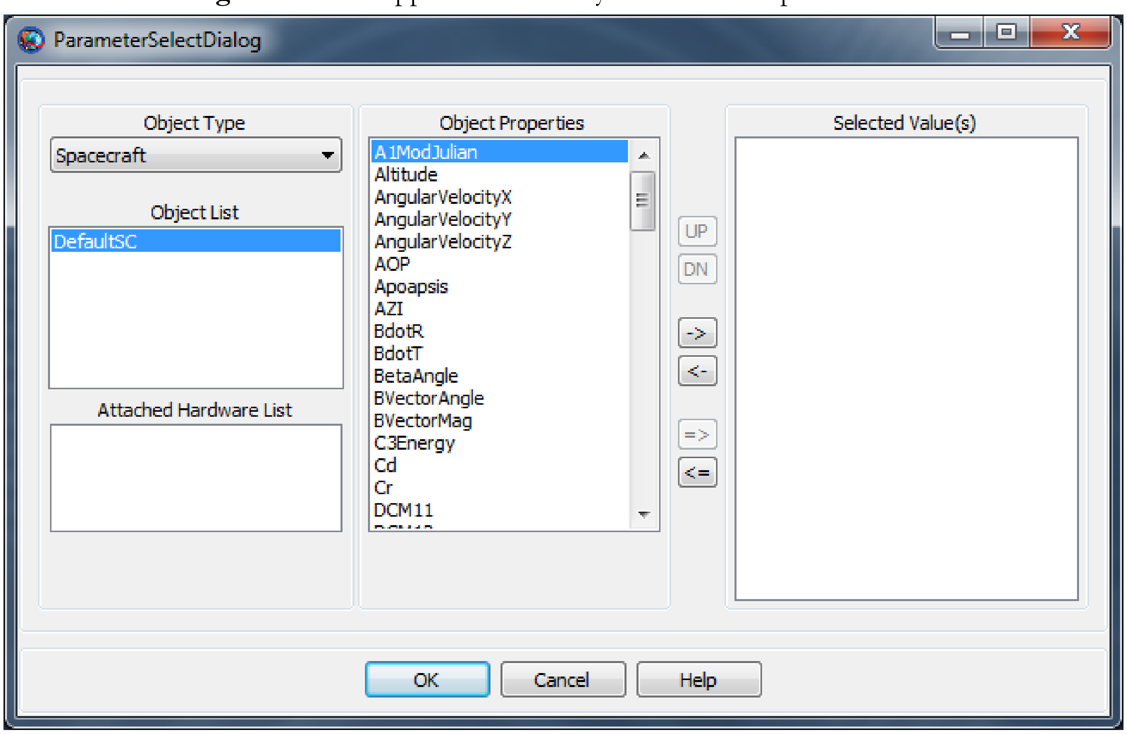
The **While** command GUI panel features a table in which you can build a complex logical expression. The rows of the table correspond to individual relational expressions in a compound logical expression, and the columns correspond to individual elements of those expressions. The first line automatically contains a default statement:

```
While DefaultSC.ElapsedDays < 1.0
```

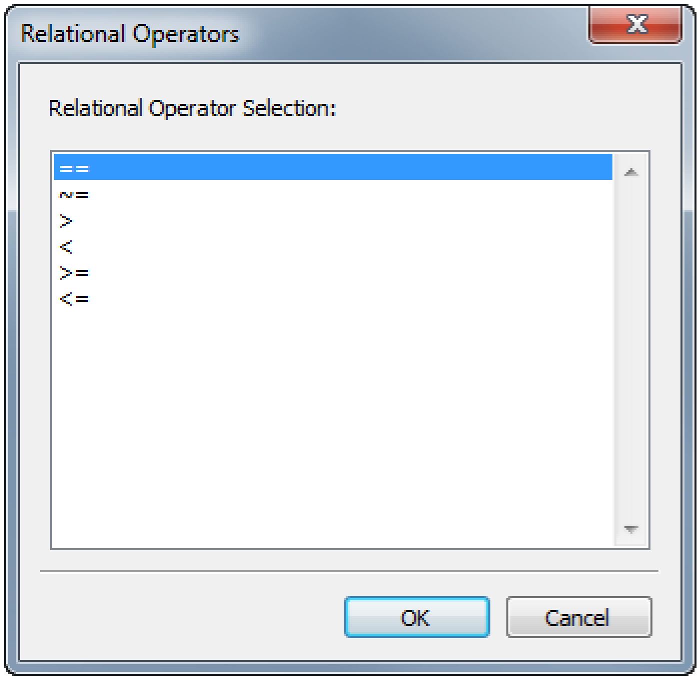
The first column of the first row contains a placeholder for the **While** command name. This cannot be changed. The first column of each additional row contains the logical operator (**&**, **|**) that joins the expression in that row with the one above it. To select a logical operator, double-click or right-click in the appropriate box in the table, and a selection window will appear. Click the correct operator and click **OK** to select it.



The **Left Hand Side** column contains the left-hand side of each individual relational expression. Double-click the cell to type a parameter name. To set this value from a parameter selection list instead, either click "…" to the left of the cell you want to set, or right-click the cell itself. A **ParameterSelectDialog** window will appear that allows you to choose a parameter.



The **Condition** column contains the conditional operator (**==**, **~=**, **<**, etc.) that joins the left-hand and right-hand sides of the expression. To select a relational operator, double-click or right-click in the appropriate box in the table, and a selection window will appear. Click the correct operator and click **OK** to select it.



Finally, the **Right Hand Side** column contains the right-hand side of the expression. This value can be modified the same way as the **Left Hand Side** column.

When you are finished, click **Apply** to save your changes, or click **OK** to save your changes and close the window. The command will be validated when either button is clicked.

Examples

Propagate a spacecraft until it reaches a predefined altitude, reporting data at each periapsis crossing:

```
Create Spacecraft aSat
aSat.SMA = 6800
aSat.ECC = 0

Create ForceModel aForceModel
aForceModel.Drag.AtmosphereModel = MSISE90

Create Propagator aProp
aProp.FM = aForceModel

Create ReportFile aReport

BeginMissionSequence

While aSat.Altitude > 300
    Propagate aProp(aSat) {aSat.Periapsis}
    Report aReport aSat.TAIGregorian aSat.Altitude
```

```
EndWhile
```

System

Table of Contents

Calculation Parameters

Resource properties available for use by commands and output

Description

Parameters are named resource properties that can be used to obtain data for use by Mission Sequence commands or by output resources. Some parameters, such as the **Altitude** parameter of **Spacecraft**, are calculated values that can only be used to retrieve data. They cannot be set directly. Others, such as the **Element1** parameter of **ImpulsiveBurn**, share the same name as a resource field and can be used both to set data and retrieve it. Parameters are distinguished from resource fields by their extra functionality: fields are static resource properties that are usually set in initialization (or in the GUI Resources tree), while parameters can be calculated on the fly and used in plots, reports, and mathematical expressions.

Parameters are classified as one of four types: central-body-dependent parameters, coordinate-system-dependent parameters, attached-hardware parameters, and standalone parameters. Standalone parameters are the simplest type, as they have no dependencies. The **ElapsedSecs** parameter of **Spacecraft** is an example of this; it is simply referenced as `Spacecraft.ElapsedSecs`.

Central-body-dependent parameters, as the name suggests, have a value that is dependent on the chosen celestial body. The **Altitude** parameter of **Spacecraft** is an example of this. To reference this parameter, you must specify a central body, such as `Spacecraft.Mars.Altitude`. Any built-in central body or user-defined **Asteroid**, **Comet**, **Moon**, or **Planet** is valid as a dependency.

Likewise, coordinate-system-dependent parameters have a value that is dependent on the chosen coordinate system. The **DEC** parameter of **Spacecraft** is an example of this. To reference this parameter, you must specify the name of a **CoordinateSystem** resource, such as `Spacecraft.EarthFixed.DEC`. Any default or user-defined **CoordinateSystem** resource is valid as a dependency.

If a dependency is used when retrieving the value of the parameter, as in the following line, the value of **Altitude** is calculated at Mars before setting it to the variable `x`. If the dependency is omitted, **Earth** and **EarthMJ2000Eq** are assumed unless noted otherwise.

```
x = DefaultSC.Mars.Altitude
```

If a dependency is used when setting the value of a parameter, the value of the parameter is first converted based on the value of the dependency, then the value is set. For example, in the following line, the value of **SMA** is first calculated at Mars, then it is set to the value `10000` in that context. If the dependency is omitted when setting the value, the default is assumed to be the central body or coordinate system of the parent resource (in this case, **DefaultSC**).

```
DefaultSC.Mars.SMA = 10000
```

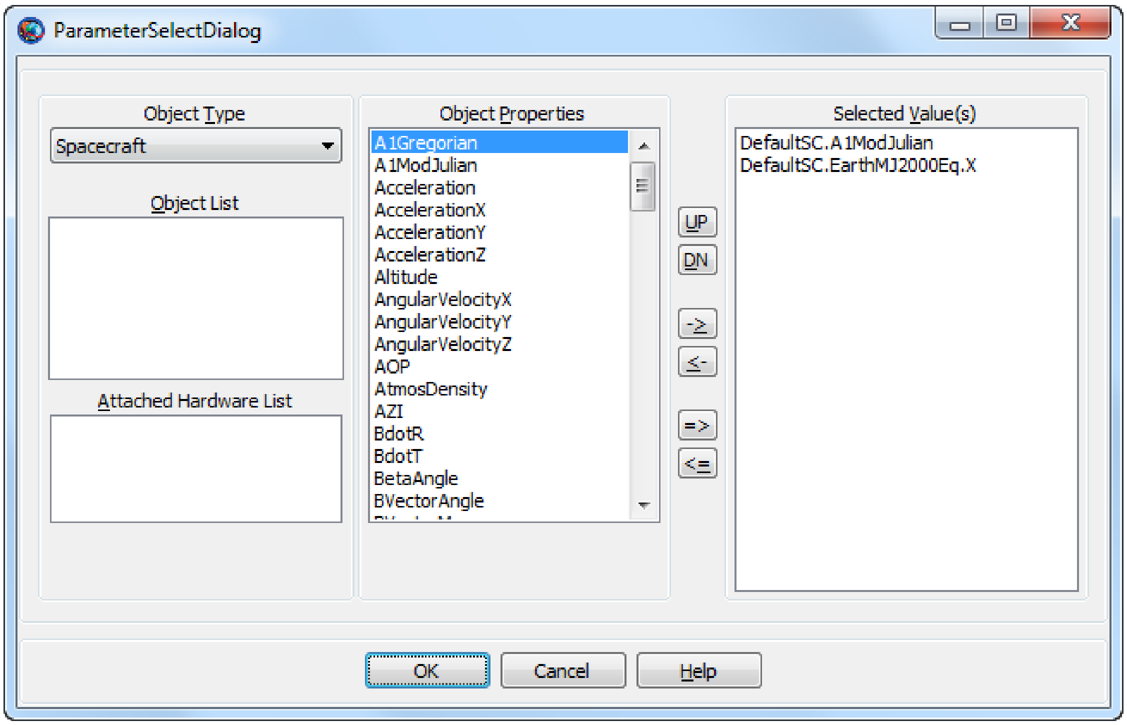
Attached-hardware parameters have no dependencies, but are themselves dependent on being attached to a **Spacecraft**. **FuelTank** and **Thruster** parameters are examples of this. The **FuelMass** parameter of **FuelTank** cannot be referenced without first attaching the **FuelTank** to a **Spacecraft**. Then, the parameter can be referenced as: `Spacecraft.FuelTank.FuelMass`.

The individual parameters are resource-specific, and are documented in the tables below. The GUI has a parameter selection interface that is common to all parameters. This interface is documented in GUI, below.

See Also: Array, FuelTank, ImpulsiveBurn, Spacecraft, String, Thruster, Variable

GUI

Parameters can be used as input in several places throughout GMAT, such as the **ReportFile** and **XYPlot** resources and the **If/Else**, **Propagate**, and **Report** commands. In the GUI, all of these use a common interface called the **ParameterSelectDialog** that allows for interactive parameter selection. A basic **ParameterSelectDialog** window looks like the following:



The **ParameterSelectDialog** window is used to build a parameter, along with any dependencies, for use in a command or resource. Some resources and commands have different requirements for the types of parameters that can be used, so the **ParameterSelectDialog** can take slightly different forms, depending on where it's used. This section will describe the generic interface, then mention any resource- or command-specific exceptions.

General Usage

The first step in choosing a parameter is to select the object (or resource) type from the **Object Type** list in the upper left. Five types can appear in this list: **Spacecraft**, **ImpulsiveBurn**, **Variable**, **Array**, and **String**.

Once you've selected a type, The **Object List** box is populated with all existing resources of that type. Use this list to choose the specific resource you'd like to reference.

If the **Spacecraft** type is selected, the **Attached Hardware List** appears below the **Object List**. This list displays any hardware (such as **FuelTank** resources) attached to the selected **Spacecraft**.

If the **Array** type is selected, **Row** and **Col** boxes appear. Use these to specify a row and column to select an individual array element, or check **Select Entire Object** to choose the entire array.

Once a resource is selected, the **Object Properties** list is populated with all available parameters provided by that resource. Some resources, such as instances of **Variable** or **Array**, are themselves parameters, so this list remains empty.

Parameters with different dependency types are commingled in the **Object Properties** list. When you select one, the appropriate dependency (if any) appears below the list. For example, after selecting the **Spacecraft AOP** parameter, a **CoordinateSystem** list appears. After selecting the **Spacecraft Apoapsis** parameter, a **Central Body** list appears. And after selecting the Spacecraft Cd parameter, no dependency list appears. To select a range of parameters from the **Object Properties** list, hold down the Shift key while selecting the second endpoint of the range. To select multiple individual parameters, hold down the **Ctrl** key while making each selection.

To select a parameter, select the appropriate **Object Type**, the specific resource from the **Object List** or **Attached Hardware List**, the desired parameter from the **Object Properties list**, and the required dependency, and add it to the **Selected Value(s)** list on the right. There are six buttons available to control this list:

- **UP**: Move the selected item in the **Selected Value(s)** list up one position (if allowed).
- **DN**: Move the selected item in the **Selected Value(s)** list down one position (if allowed).
- **->**: Add the selected item in the **Object Properties** list to the **Selected Value(s)** list.
- **<-**: Remove the selected item in the **Selected Value(s)** list.
- **=>**: Add all items to the **Selected Value(s)** list.
- **<=**: Remove all items from the **Selected Value(s**) list.

When finished, the **Selected Value(s)** list contains the final selected parameters. Click **OK** to accept the selection.

The ordering of the **Selected Value(s)** list is significant in certain circumstances (such as in the **Add** field of **ReportFile**), but not in others. See the documentation for each resource or command for details.

Special Considerations

Some resources and commands (such as the **Propagate** command **Parameter** argument) only accept a single parameter as input; in this context the **ParameterSelectDialog** only allows one parameter in the **Selected Value(s)** list and does not allow use of the **UP**, **DN**, and **=>** buttons.

In some instances (such as in the **Vary** command), only parameters that are also fields (and so can be set in the **Mission Sequence**) can be used. In this case only the allowed parameters will be shown in the **Object Properties** list.

In the **Propagate** command **Parameter** argument, only parameters of **Spacecraft** can be used. In this case only **Spacecraft** will be shown in the **Object Type** list.

Parameters

Spacecraft

Parameter	Settable	Plottable	Description
A1Gregorian	Y	N	Spacecraft epoch in the A.1 system and the Gregorian format. **Data Type** String **Dependency** (None) **Units** (N/A)
A1ModJulian	Y	Y	Spacecraft epoch in the A.1 system and the Modified Julian format. **Data Type** Real **Dependency** (None) **Units** d
Acceleration	N	Y	The total acceleration with respect to the inertial system computed using the **ForceModel** selected for the dependency. **Data Type** Real **Dependency** **ForceModel** **Units** km/s^2
AccelerationX	N	Y	The x-component of acceleration with respect to the inertial system computed using the **ForceModel** selected for the dependency. **Data Type** Real **Dependency** **ForceModel** **Units** km/s^2
AccelerationY	N	Y	The y-component of acceleration with respect to the inertial system computed using the **ForceModel** selected for the dependency. **Data Type** Real **Dependency** **ForceModel** **Units** km/s^2
AccelerationZ	N	Y	The z-component of acceleration with respect to the inertial system computed using the **ForceModel** selected for the dependency. **Data Type** String **Dependency** **ForceModel** **Units** km/s^2

Parameter	Settable	Plottable	Description
AltEquinoctialP	Y	Y	See **Spacecraft.AltEquinoctialP** **Data Type** Real **Dependency** **CoordinateSystem** **Units** (None)
AltEquinoctialQ	Y	Y	See **Spacecraft.AltEquinoctialQ** **Data Type** Real **Dependency** **CoordinateSystem** **Units** (None)
Altitude	N	Y	Distance to the plane tangent to the surface of the specified celestial body at the sub-satellite point. GMAT assumes the body is an ellipsoid. **Data Type** Real **Dependency** **CelestialBody** **Units** km
AngularVelocityX	Y	Y	See **Spacecraft.AngularVelocityX** **Data Type** Real **Dependency** (None) **Units** deg/s
AngularVelocityY	Y	Y	See **Spacecraft.AngularVelocityY** **Data Type** Real **Dependency** (None) **Units** deg/s
AngularVelocityZ	Y	Y	See **Spacecraft.AngularVelocityZ** **Data Type** Real **Dependency** (None) **Units** deg/s
AOP	Y	Y	See **Spacecraft.AOP** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** $0° \leq$ **AOP** $< 360°$ **Units** deg
Apoapsis	N	Y	A parameter that equals zero when the spacecraft is at orbit apoapsis. This parameter can only be used as a stopping condition in the **Propagate** command. **Data Type** Real **Dependency** **CelestialBody** **Units** (None)

Parameter	Settable	Plottable	Description
AtmosDensity	N	Y	The atmospheric density at the current **Spacecraft** epoch and location computed using the **ForceModel** selected for the dependency. **Data Type** String **Dependency** **ForceModel** **Units** kg/km^3
AZI	Y	Y	See **Spacecraft.AZI** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** -180° ≤ **AZI** ≤ 180° **Units** deg
BdotR	N	Y	B-plane B·R magnitude. GMAT computes the B-plane coordinates in the coordinate system specified in the dependency. In many implementations, the B-plane coordinates are computed in a pseudo-rotating coordinate system where the ω×r term is not applied when transforming velocity vectors. GMAT does apply the ω×r term in the velocity transformation. When computing B-plane coordinates in inertial systems, this term is identically zero. For rotating systems such as the Sun-Earth body-body rotating system, the effect of including ω×r is small but noticeable when comparing results between systems. When the rotation of the selected coordinate system is "fast", the values may differ significantly. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km
BdotT	N	Y	B-plane B·T magnitude. See the **BdotR** parameter for notes on this calculation. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km

Parameter	Settable	Plottable	Description
BetaAngle	N	Y	Beta angle (or phase angle) between the orbit normal vector and the vector from the celestial body to the sun. **Data Type** Real **Dependency** **CelestialBody** **Output Range** -90° ≤ **BetaAngle** ≤ 90° **Units** deg
BrouwerLongAOP	Y	Y	See **Spacecraft.BrouwerLongAOP**. **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** 0° ≤ **BrouwerLongAOP** ≤ 360° **Units** deg
BrouwerLongECC	Y	Y	See **Spacecraft.BrouwerLongECC**. **Data Type** Real **Dependency** **CoordinateSystem** **Units** (None)
BrouwerLongINC	Y	Y	See **Spacecraft.BrouwerLongINC**. **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** 0° ≤ **BrouwerLongINC** ≤ 180° **Units** deg
BrouwerLongMA	Y	Y	See **Spacecraft.BrouwerLongMA**. **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** 0° ≤ **BrouwerLongMA** ≤ 360° **Units** deg
BrouwerLongRAAN	Y	Y	See **Spacecraft.BrouwerLongRAAN**. **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** 0° ≤ **BrouwerLongRAAN** ≤ 360° **Units** deg
BrouwerLongSMA	Y	Y	See **Spacecraft.BrouwerLongSMA**. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km

Parameter	Settable	Plottable	Description
BrouwerShortAOP	Y	Y	See **Spacecraft.BrouwerShortAOP**. **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** 0° ≤ **BrouwerShortAOP** ≤ 360° **Units** deg
BrouwerShortECC	Y	Y	See **Spacecraft.BrouwerShortECC**. **Data Type** Real **Dependency** **CoordinateSystem** **Units** (None)
BrouwerShortINC	Y	Y	See **Spacecraft.BrouwerShortINC**. **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** 0° ≤ **BrouwerShortINC** ≤ 180° **Units** deg
BrouwerShortMA	Y	Y	See **Spacecraft.BrouwerShortMA**. **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** 0° ≤ **BrouwerShortMA** ≤ 360° **Units** deg
BrouwerShortRAAN	Y	Y	See **Spacecraft.BrouwerShortRAAN**. **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** 0° ≤ **BrouwerShortRAAN** ≤ 360° **Units** deg
BrouwerShortSMA	Y	Y	See **Spacecraft.BrouwerShortSMA**. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km

Parameter	Settable	Plottable	Description
BVectorAngle	N	Y	B-plane angle between the B vector and the T unit vector. See the **BdotR** parameter for notes on this calculation. **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** -180° ≤ **BVectorAngle** ≤ 180° **Units** deg
BVectorMag	N	Y	B-plane B vector magnitude. See the **BdotR** parameter for notes on this calculation. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km
C3Energy	N	Y	C_3 (characteristic) energy. **Data Type** Real **Dependency** **CelestialBody** **Units** MJ/kg (km^2/s^2)
Cd	Y	Y	See **Spacecraft.Cd** **Data Type** Real **Dependency** (None) **Units** (None)
Cr	Y	Y	See **Spacecraft.Cr** **Data Type** Real **Dependency** (None) **Units** (None)
CurrA1MJD	Y	Y	*Deprecated*. Spacecraft epoch in the A.1 system and the Modified Julian format. **Data Type** Real **Dependency** (None) **Units** d
DCM11	Y	Y	See **Spacecraft.DCM11** **Data Type** Real **Dependency** (None) **Units** (None)
DCM12	Y	Y	See **Spacecraft.DCM12** **Data Type** Real **Dependency** (None) **Units** (None)

Parameter	Settable	Plottable	Description
DCM13	Y	Y	See **Spacecraft.DCM13** **Data Type** Real **Dependency** (None) **Units** (None)
DCM21	Y	Y	See **Spacecraft.DCM21** **Data Type** Real **Dependency** (None) **Units** (None)
DCM22	Y	Y	See **Spacecraft.DCM22** **Data Type** Real **Dependency** (None) **Units** (None)
DCM23	Y	Y	See **Spacecraft.DCM23** **Data Type** Real **Dependency** (None) **Units** (None)
DCM31	Y	Y	See **Spacecraft.DCM31** **Data Type** Real **Dependency** (None) **Units** (None)
DCM32	Y	Y	See **Spacecraft.DCM32** **Data Type** Real **Dependency** (None) **Units** (None)
DCM33	Y	Y	See **Spacecraft.DCM33** **Data Type** Real **Dependency** (None) **Units** (None)
DEC	Y	Y	See **Spacecraft.DEC** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** -90° ≤ **DEC** ≤ 90° **Units** deg

Parameter	Settable	Plottable	Description
DECV	Y	Y	See **Spacecraft.DECV** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** $-90° \leq$ **DECV** $\leq 90°$ **Units** deg
Delaunayg	Y	Y	See **Spacecraft.Delaunayg**. **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** $0° \leq$ **Delaunayg** $< 360°$ **Units** deg
DelaunayG	Y	Y	See **Spacecraft.DelaunayG**. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km^2/s
Delaunayh	Y	Y	See **Spacecraft.Delaunayh**. **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** $0° \leq$ **Delaunayh** $< 360°$ **Units** deg
DelaunayH	Y	Y	See **Spacecraft.DelaunayH**. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km^2/s
Delaunayl	Y	Y	See **Spacecraft.Delaunayl**. **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** $0° \leq$ **Delaunayl** $< 360°$ **Units** deg
DelaunayL	Y	Y	See **Spacecraft.DelaunayL**. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km^2/s
DLA	N	Y	Declination of the outgoing hyperbolic asymptote. **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** $-90° \leq$ **DLA** $\leq 90°$ **Units** deg

Parameter	Settable	Plottable	Description
DragArea	Y	Y	See **Spacecraft.DragArea** **Data Type** Real **Dependency** (None) **Units** m^2
DryMass	Y	Y	See **Spacecraft.DryMass** **Data Type** Real **Dependency** (None) **Units** kg
EA	N	Y	Eccentric anomaly. **Data Type** Real **Dependency** **CelestialBody** **Output Range** $0° \leq$ **EA** $< 360°$ **Units** deg
ECC	Y	Y	See **Spacecraft.ECC** **Data Type** Real **Dependency** **CelestialBody** **Output Range** **Units** (None)
ElapsedDays	N	Y	See **Spacecraft.ElapsedDays** **Data Type** Real **Dependency** (None) **Units** d
ElapsedSecs	N	Y	See **Spacecraft.ElapsedSecs** **Data Type** Real **Dependency** (None) **Units** s
Energy	N	Y	Specific orbital energy. **Data Type** Real **Dependency** **CelestialBody** **Units** MJ/kg (km^2/s^2)
EquinoctialH	Y	Y	See **Spacecraft.EquinoctialH** **Data Type** Real **Dependency** **CoordinateSystem** **Units** (None)

Parameter	Settable	Plottable	Description
EquinoctialK	Y	Y	See **Spacecraft.EquinoctialK** **Data Type** Real **Dependency** **CoordinateSystem** **Units** (None)
EquinoctialP	Y	Y	See **Spacecraft.EquinoctialP** **Data Type** Real **Dependency** **CoordinateSystem** **Units** (None)
EquinoctialQ	Y	Y	See **Spacecraft.EquinoctialQ** **Data Type** Real **Dependency** **CoordinateSystem** **Units** (None)
EulerAngle1	Y	Y	See **Spacecraft.EulerAngle1** **Data Type** Real **Dependency** (None) **Output Range** $0° \leq$ **EulerAngle1** $< 360°$ **Units** deg
EulerAngle2	Y	Y	See **Spacecraft.EulerAngle2** **Data Type** Real **Dependency** (None) **Output Range** $0° \leq$ **EulerAngle2** $< 360°$ **Units** deg
EulerAngle3	Y	Y	See **Spacecraft.EulerAngle3** **Data Type** Real **Dependency** (None) **Output Range** $0° \leq$ **EulerAngle3** $< 360°$ **Units** deg
EulerAngleRate1	Y	Y	See **Spacecraft.EulerAngleRate1** **Data Type** Real **Dependency** (None) **Units** deg/s
EulerAngleRate2	Y	Y	See **Spacecraft.EulerAngleRate2** **Data Type** Real **Dependency** (None) **Units** deg/s

Parameter	Settable	Plottable	Description
EulerAngleRate3	Y	Y	See **Spacecraft.EulerAngleRate3** **Data Type** Real **Dependency** (None) **Units** deg/s
FPA	Y	Y	See **Spacecraft.FPA** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** $0° \le$ **FPA** $\le 180°$ **Units** deg
HA	N	Y	Hyperbolic anomaly. **Data Type** Real **Dependency** **CelestialBody** **Output Range** $-\infty <$ **HA** $< \infty$ **Units** deg
HMAG	N	Y	Magnitude of the angular momentum vector. **Data Type** Real **Dependency** **CelestialBody** **Units** km^2/s
HX	N	Y	X component of the angular momentum vector. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km^2/s
HY	N	Y	Y component of the angular momentum vector. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km^2/s
HZ	N	Y	Z component of the angular momentum vector. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km^2/s
INC	Y	Y	See **Spacecraft.INC** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** $0° \le$ **INC** $\le 180°$ **Units** deg

Parameter	Settable	Plottable	Description
IncomingBVAZI	Y	Y	See **Spacecraft.IncomingBVAZI** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** 0° ≤ **IncomingBVAZI** < 360° **Units** deg
IncomingC3Energy	Y	Y	See **Spacecraft.IncomingC3Energy**. **Data Type** Real **Dependency** **CelestialBody** **Units** MJ/kg (km^2/s^2)
IncomingDHA	Y	Y	See **Spacecraft.IncomingDHA** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** -90° ≤ **IncomingDHA** ≤ 90° **Units** deg
IncomingRadPer	Y	Y	See **Spacecraft.IncomingRadPer** **Data Type** Real **Dependency** **CelestialBody** **Units** km
IncomingRHA	Y	Y	See **Spacecraft.IncomingRHA** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** 0° ≤ **IncomingRHA** < 360° **Units** deg
Latitude	N	Y	Planetodetic latitude. **Data Type** Real **Dependency** **CelestialBody** **Output Range** -90° ≤ **Latitude** ≤ 90° **Units** deg
Longitude	N	Y	Planetodetic longitude. **Data Type** Real **Dependency** **CelestialBody** **Output Range** -180° ≤ **Longitude** ≤ 180° **Units** deg

Parameter	Settable	Plottable	Description
LST	N	Y	Local sidereal time of the spacecraft from the celestial body's inertial x-axis. **Data Type** Real **Dependency** **CelestialBody** **Output Range** $0° \le$ **LST** $< 360°$ **Units** deg
MA	N	Y	Mean anomaly. **Data Type** Real **Dependency** **CelestialBody** **Output Range** $0° \le$ **MA** $< 360°$ **Units** deg
MHA	N	Y	Angle between celestial body's body-fixed and inertial axes. For Earth, this is the Greenwich Hour Angle. **Data Type** Real **Dependency** **CelestialBody** **Output Range** $0° \le$ **MHA** $< 360°$ **Units** deg
MLONG	Y	Y	See **Spacecraft.MLONG** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** $0° \le$ **MLONG** $< 360°$ **Units** deg
MM	N	Y	Mean motion. **Data Type** Real **Dependency** **CelestialBody** **Output Range** **Units** rad/s
ModEquinoctialF	Y	Y	See **Spacecraft.ModEquinoctialF** **Data Type** Real **Dependency** **CoordinateSystem** **Units** (None)
ModEquinoctialG	Y	Y	See **Spacecraft.ModEquinoctialG** **Data Type** Real **Dependency** **CoordinateSystem** **Units** (None)

Parameter	Settable	Plottable	Description
ModEquinoctialH	Y	Y	See **Spacecraft.ModEquinoctialH** **Data Type** Real **Dependency** **CoordinateSystem** **Units** (None)
ModEquinoctialK	Y	Y	See **Spacecraft.ModEquinoctialK** **Data Type** Real **Dependency** **CoordinateSystem** **Units** (None)
MRP1	Y	Y	See **Spacecraft.MRP1** **Data Type** Real **Dependency** (None) **Units** (None)
MRP2	Y	Y	See **Spacecraft.MRP2** **Data Type** Real **Dependency** (None) **Units** (None)
MRP3	Y	Y	See **Spacecraft.MRP3** **Data Type** Real **Dependency** (None) **Units** (None)
OrbitPeriod	N	Y	Osculating orbit period. **Data Type** Real **Dependency** **CelestialBody** **Units** s
OrbitSTM	N	N	State transition matrix with respect to the origin-independent MJ2000Eq axes. **Data Type** Array (6×6) **Dependency** (None) **Units** (None)
OrbitSTMA	N	N	Upper-left quadrant of the state transition matrix, with respect to the origin-independent MJ2000Eq axes. **Data Type** Array (3×3) **Dependency** (None) **Units** (None)

Parameter	Settable	Plottable	Description
OrbitSTMB	N	N	Upper-right quadrant of the state transition matrix, with respect to the origin-independent MJ2000Eq axes. **Data Type** Array (3×3) **Dependency** (None) **Units** (None)
OrbitSTMC	N	N	Lower-left quadrant of the state transition matrix, with respect to the origin-independent MJ2000Eq axes. **Data Type** Array (3×3) **Dependency** (None) **Units** (None)
OrbitSTMD	N	N	Lower-right quadrant of the state transition matrix, with respect to the origin-independent MJ2000Eq axes. **Data Type** Array (3×3) **Dependency** (None) **Units** (None)
OutgoingBVAZI	Y	Y	See **Spacecraft.OutgoingBVAZI** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** 0° ≤ **OutgoingBVAZI** < 360° **Units** deg
OutgoingC3Energy	Y	Y	See **Spacecraft.OutgoingC3Energy**. **Data Type** Real **Dependency** **CelestialBody** **Units** MJ/kg (km^2/s^2)
OutgoingDHA	Y	Y	See **Spacecraft.OutgoingDHA** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** -90° ≤ **OutgoingRHA** ≤ 90° **Units** deg
OutgoingRadPer	Y	Y	See **Spacecraft.OutgoingRadPer** **Data Type** Real **Dependency** **CelestialBody** **Units** km

Parameter	Settable	Plottable	Description
OutgoingRHA	Y	Y	See **Spacecraft.OutgoingRHA** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** 0° ≤ **OutgoingRHA** < 360° **Units** deg
Periapsis	N	Y	A parameter that equals zero when the spacecraft is at orbit periapsis. This parameter can only be used as a stopping condition in the **Propagate** command. **Data Type** Real **Dependency** **CelestialBody** **Units** (None)
PlanetodeticAZI	Y	Y	See **Spacecraft.PlanetodeticAZI**. This parameter must be used with a **CoordinateSystem** with **BodyFixed** axes. **Data Type** Real **Dependency** **CoordinateSystem** (with **BodyFixed** axes) **Output Range** -180° ≤ **PlanetodeticAZI** ≤ 180° **Units** deg
PlanetodeticHFPA	Y	Y	See **Spacecraft.PlanetodeticHFPA**. This parameter must be used with a **CoordinateSystem** with **BodyFixed** axes. **Data Type** Real **Dependency** **CoordinateSystem** (with **BodyFixed** axes) **Output Range** -90° ≤ **PlanetodeticHFPA** ≤ 90° **Units** deg
PlanetodeticLAT	Y	Y	See **Spacecraft.PlanetodeticLAT**. This parameter must be used with a **CoordinateSystem** with **BodyFixed** axes. **Data Type** Real **Dependency** **CoordinateSystem** (with **BodyFixed** axes) **Output Range** -180° ≤ **PlanetodeticLAT** ≤ 180° **Units** deg

Parameter	Settable	Plottable	Description
PlanetodeticLON	Y	Y	See **Spacecraft.PlanetodeticLON**. This parameter must be used with a **CoordinateSystem** with **BodyFixed** axes. **Data Type** Real **Dependency** **CoordinateSystem** (with **BodyFixed** axes) **Output Range** -180° ≤ **PlanetodeticLON** ≤ 180° **Units** deg
PlanetodeticRMAG	Y	Y	See **Spacecraft.PlanetodeticRMAG**. This parameter must be used with a **CoordinateSystem** with **BodyFixed** axes. **Data Type** Real **Dependency** **CoordinateSystem** (with **BodyFixed** axes) **Units** km
PlanetodeticVMAG	Y	Y	See **Spacecraft.PlanetodeticVMAG**. This parameter must be used with a **CoordinateSystem** with **BodyFixed** axes. **Data Type** Real **Dependency** **CoordinateSystem** (with **BodyFixed** axes) **Units** km/s
Q1	N	Y	See **Spacecraft.Q1** **Data Type** Real **Dependency** (None) **Units** (None)
Q2	N	Y	See **Spacecraft.Q2** **Data Type** Real **Dependency** (None) **Units** (None)
Q3	N	Y	See **Spacecraft.Q3** **Data Type** Real **Dependency** (None) **Units** (None)
Q4	N	Y	See **Spacecraft.Q4** **Data Type** Real **Dependency** (None) **Units** (None)

Parameter	Settable	Plottable	Description
Quaternion	Y	N	Attitude quaternion. **Data Type** Array (1×4) **Dependency** (None) **Units** (None)
RA	Y	Y	See **Spacecraft.RA** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** -180° ≤ **RA** ≤ 180° **Units** deg
RAAN	Y	Y	See **Spacecraft.RAAN** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** 0° ≤ **RAAN** < 360° **Units** deg
RadApo	Y	Y	See **Spacecraft.RadApo** **Data Type** Real **Dependency** **CelestialBody** **Units** km
RadPer	Y	Y	See **Spacecraft.RadPer** **Data Type** Real **Dependency** **CelestialBody** **Units** km
RAV	Y	Y	See **Spacecraft.RAV** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** -180° ≤ **RAV** ≤ 180° **Units** deg
RLA	N	Y	Right ascension of the outgoing hyperbolic asymptote. **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** -180° ≤ **RLA** ≤ 180° **Units** deg
RMAG	Y	Y	See **Spacecraft.RMAG** **Data Type** Real **Dependency** **CelestialBody** **Units** km

Parameter	Settable	Plottable	Description
SemilatusRectum	Y	Y	See **Spacecraft.SemilatusRectum** **Data Type** Real **Dependency** **CelestialBody** **Units** km
SemilatusRectum	N	Y	Semilatus rectum of the osculating orbit. **Data Type** Real **Dependency** **CelestialBody** **Units** km
SMA	Y	Y	See **Spacecraft.SMA** **Data Type** Real **Dependency** **CelestialBody** **Units** km
SRPArea	Y	Y	See **Spacecraft.SRPArea** **Data Type** Real **Dependency** (None) **Units** m^2
TA	Y	Y	See **Spacecraft.TA**. **Data Type** Real **Dependency** **CelestialBody** **Output Range** $0° \leq$ **TA** $< 360°$ **Units** deg
TAIGregorian	Y	N	Spacecraft epoch in the TAI system and the Gregorian format. **Data Type** String **Dependency** (None) **Units** (N/A)
TAIModJulian	Y	Y	Spacecraft epoch in the TAI system and the Modified Julian format. **Data Type** Real **Dependency** (None) **Units** d
TDBGregorian	Y	N	Spacecraft epoch in the TDB system and the Gregorian format. **Data Type** String **Dependency** (None) **Units** (N/A)

Parameter	Settable	Plottable	Description
TDBModJulian	Y	Y	Spacecraft epoch in the TDB system and the Modified Julian format. **Data Type** Real **Dependency** (None) **Units** d
TLONG	Y	Y	See **Spacecraft.TLONG** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** $0° \leq$ **TLONG** $< 360°$ **Units** deg
TotalMass	N	Y	Total mass, including fuel mass from attached **FuelTank** resources. **Data Type** Real **Dependency** (None) **Units** kg
TTGregorian	Y	N	Spacecraft epoch in the TT system and the Gregorian format. **Data Type** String **Dependency** (None) **Units** (N/A)
TTModJulian	Y	Y	Spacecraft epoch in the TT system and the Modified Julian format. **Data Type** Real **Dependency** (None) **Units** d
UTCGregorian	Y	N	Spacecraft epoch in the UTC system and the Gregorian format. **Data Type** String **Dependency** (None) **Units** (N/A)
UTCModJulian	Y	Y	Spacecraft epoch in the UTC system and the Modified Julian format. **Data Type** Real **Dependency** (None) **Units** d

Parameter	Settable	Plottable	Description
VelApoapsis	N	Y	Scalar velocity at apoapsis. **Data Type** Real **Dependency** **CelestialBody** **Units** km/s
VelPeriapsis	N	Y	Scalar velocity at periapsis. **Data Type** Real **Dependency** **CelestialBody** **Units** km/s
VMAG	Y	Y	See **Spacecraft.VMAG** **Data Type** Real **Dependency** **CoordinateSystem** **Output Range** **Units** km/s
VX	Y	Y	See **Spacecraft.VX** **Data Type** Real **Dependency** **CoordinateSystem** **Units** km/s
VY	Y	Y	See **Spacecraft.VY** **Data Type** Real **Dependency** **CoordinateSystem** **Units** km/s
VZ	Y	Y	See **Spacecraft.VZ** **Data Type** Real **Dependency** **CoordinateSystem** **Units** km/s
X	Y	Y	See **Spacecraft.X** **Data Type** Real **Dependency** **CoordinateSystem** **Units** km
Y	Y	Y	See **Spacecraft.Y** **Data Type** Real **Dependency** **CoordinateSystem** **Units** km
Z	Y	Y	See **Spacecraft.Z** **Data Type** Real **Dependency** **CoordinateSystem** **Units** km

FuelTank

FuelTank parameters are accessible only after attaching the **FuelTank** resource to a **Spacecraft**, like so:

```
Create FuelTank aTank
Create Spacecraft aSat
aSat.Tanks = {aTank}
```

Then, **FuelTank** parameters are accessible by specifying the **FuelTank** name as the parameter dependency:

```
Create ReportFile aReport
aReport.Add = {aSat.aTank.FuelMass}
```

Parameter	Settable	Plottable	Description
FuelDensity	Y	Y	See **FuelTank.FuelDensity** **Data Type** Real **Dependency** (None) **Units** kg/m^3
FuelMass	Y	Y	See **FuelTank.FuelMass** **Data Type** Real **Dependency** (None) **Units** kg
Pressure	Y	Y	See **FuelTank.Pressure** **Data Type** Real **Dependency** (None) **Units** kPa
RefTemperature	Y	Y	See **FuelTank.RefTemperature** **Data Type** Real **Dependency** (None) **Units** °C
Temperature	Y	Y	See **FuelTank.Temperature** **Data Type** Real **Dependency** (None) **Units** °C
Volume	Y	Y	See **FuelTank.Volume** **Data Type** Real **Dependency** (None) **Units** m^3

Space Point Parameters

All Resources that have coordinates in space have Cartesian position and velocity parameters, so you can access ephemeris information. This includes all built-in solar system bodies and other Resources such as **CelestialBody**,**Planet**, **Moon**, **Asteroid**, **Comet**, **Barycenter**, **LibrationPoint**, and **GroundStation** :

- *CelestialBody.CoordinateSystem*.X
- *CelestialBody.CoordinateSystem*.Y
- *CelestialBody.CoordinateSystem*.Z
- *CelestialBody.CoordinateSystem*.VX
- *CelestialBody.CoordinateSystem*.VY
- *CelestialBody.CoordinateSystem*.VZ

Note that to use these parameters, you must first set the epoch of the Resource to the desired epoch at which you want the data. See the following example:

```
Create ReportFile rf

BeginMissionSequence

Luna.Epoch.A1ModJulian = 21545
Report rf Luna.EarthMJ2000Eq.X Luna.EarthMJ2000Eq.Y Luna.EarthMJ2000Eq.Z ...
       Luna.EarthMJ2000Eq.VX Luna.EarthMJ2000Eq.VY Luna.EarthMJ2000Eq.VZ
```

Note

Spacecraft parameters are treated slightly different than Space Point parameters primarily because **Spacecraft** Cartesian state parameters are settable, and all other Space Point Cartesian parameters are only gettable. When requesting state information for Space Points other than **Spacecraft**, the coordinates are computed based on the model configured for that Resource. Additionally, not all epoch configuration options supported for **Spacecraft** are supported for Space Points (i.e. **Epoch** and **DateFormat**).

Parameter	Settable	Plottable	Description
A1Gregorian	Y	N	Resource epoch in the A.1 system and the Gregorian format. **Data Type** String **Dependency** (None) **Units** (N/A)
A1ModJulian	Y	Y	Resource epoch in the A.1 system and the Modified Julian format. **Data Type** Real **Dependency** (None) **Units** d

Parameter	Settable	Plottable	Description
TAIGregorian	Y	N	Resource epoch in the TAI system and the Gregorian format. **Data Type** String **Dependency** (None) **Units** (N/A)
TAIModJulian	Y	Y	Resource epoch in the TAI system and the Modified Julian format. **Data Type** Real **Dependency** (None) **Units** d
TDBGregorian	Y	N	Resource epoch in the TDB system and the Gregorian format. **Data Type** String **Dependency** (None) **Units** (N/A)
TDBModJulian	Y	Y	Resource epoch in the TDB system and the Modified Julian format. **Data Type** Real **Dependency** (None) **Units** d
TTGregorian	Y	N	Resource epoch in the TT system and the Gregorian format. **Data Type** String **Dependency** (None) **Units** (N/A)
TTModJulian	Y	Y	Resource epoch in the TT system and the Modified Julian format. **Data Type** Real **Dependency** (None) **Units** d
UTCGregorian	Y	N	Resource epoch in the UTC system and the Gregorian format. **Data Type** String **Dependency** (None) **Units** (N/A)

Parameter	Settable	Plottable	Description
UTCModJulian	Y	Y	Resource epoch in the UTC system and the Modified Julian format. **Data Type** Real **Dependency** (None) **Units** d
VX	N	Y	The x-component of velocity with respect to the **CoordinateSystem** chosen as the dependency. When no dependency is selected, **EarthMJ2000Eq** is used. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km/s
VY	N	Y	The y-component of velocity with respect to the **CoordinateSystem** chosen as the dependency. When no dependency is selected, **EarthMJ2000Eq** is used. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km/s
VZ	N	Y	The z-component of velocity with respect to the **CoordinateSystem** chosen as the dependency. When no dependency is selected, **EarthMJ2000Eq** is used. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km/s
X	N	Y	The x-component of position with respect to the **CoordinateSystem** chosen as the dependency. When no dependency is selected, **EarthMJ2000Eq** is used. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km
Y	N	Y	The y-component of position with respect to the **CoordinateSystem** chosen as the dependency. When no dependency is selected, **EarthMJ2000Eq** is used. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km

Parameter	Settable	Plottable	Description
Z	N	Y	The z-component of position with respect to the **CoordinateSystem** chosen as the dependency. When no dependency is selected, **EarthMJ2000Eq** is used. **Data Type** Real **Dependency** **CoordinateSystem** **Units** km

Thruster

Thruster parameters are accessible only after attaching the **Thruster** resource to a **Spacecraft**, like so:

```
Create Thruster aThruster
Create Spacecraft aSat
aSat.Thrusters = {aThruster}
```

Then, **Thruster** parameters are accessible by specifying the **Thruster** name as the parameter dependency:

```
Create ReportFile aReport
aReport.Add = {aSat.aThruster.DutyCycle}
```

Parameter	Settable	Plottable	Description
C1	Y	Y	See **Thruster.C1** **Data Type** Real **Dependency** (None) **Units** N
C2	Y	Y	See **Thruster.C2** **Data Type** Real **Dependency** (None) **Units** N/kPa
C3	Y	Y	See **Thruster.C3** **Data Type** Real **Dependency** (None) **Units** N
C4	Y	Y	See **Thruster.C4** **Data Type** Real **Dependency** (None) **Units** N/kPa

Parameter	Settable	Plottable	Description
C5	Y	Y	See **Thruster.C5** **Data Type** Real **Dependency** (None) **Units** N/kPa^2
C6	Y	Y	See **Thruster.C6** **Data Type** Real **Dependency** (None) **Units** N/kPa^{C7}
C7	Y	Y	See **Thruster.C7** **Data Type** Real **Dependency** (None) **Units** (None)
C8	Y	Y	See **Thruster.C8** **Data Type** Real **Dependency** (None) **Units** N/kPa^{C9}
C9	Y	Y	See **Thruster.C9** **Data Type** Real **Dependency** (None) **Units** (None)
C10	Y	Y	See **Thruster.C10** **Data Type** Real **Dependency** (None) **Units** N/kPa^{C11}
C11	Y	Y	See **Thruster.C11** **Data Type** Real **Dependency** (None) **Units** (None)
C12	Y	Y	See **Thruster.C12** **Data Type** Real **Dependency** (None) **Units** N
C13	Y	Y	See **Thruster.C13** **Data Type** Real **Dependency** (None) **Units** (None)

Parameter	Settable	Plottable	Description
C14	Y	Y	See **Thruster.C14** **Data Type** Real **Dependency** (None) **Units** 1/kPa
C15	Y	Y	See **Thruster.C15** **Data Type** Real **Dependency** (None) **Units** (None)
C16	Y	Y	See **Thruster.C16** **Data Type** Real **Dependency** (None) **Units** 1/kPa
DutyCycle	Y	Y	See **Thruster.DutyCycle** **Data Type** Real **Dependency** (None) **Units** (None)
GravitationalAccel	Y	Y	See **Thruster.GravitationalAccel** **Data Type** Real **Dependency** (None) **Units** m/s^2
K1	Y	Y	See **Thruster.K1** **Data Type** Real **Dependency** (None) **Units** s
K2	Y	Y	See **Thruster.K2** **Data Type** Real **Dependency** (None) **Units** s/kPa
K3	Y	Y	See **Thruster.K3** **Data Type** Real **Dependency** (None) **Units** s
K4	Y	Y	See **Thruster.K4** **Data Type** Real **Dependency** (None) **Units** s/kPa

Parameter	Settable	Plottable	Description
K5	Y	Y	See **Thruster.K5** **Data Type** Real **Dependency** (None) **Units** s/kPa^2
K6	Y	Y	See **Thruster.K6** **Data Type** Real **Dependency** (None) **Units** s/kPa^{C7}
K7	Y	Y	See **Thruster.K7** **Data Type** Real **Dependency** (None) **Units** (None)
K8	Y	Y	See **Thruster.K8** **Data Type** Real **Dependency** (None) **Units** s/kPa^{C9}
K9	Y	Y	See **Thruster.K9** **Data Type** Real **Dependency** (None) **Units** (None)
K10	Y	Y	See **Thruster.K10** **Data Type** Real **Dependency** (None) **Units** s/kPa^{C11}
K11	Y	Y	See **Thruster.K11** **Data Type** Real **Dependency** (None) **Units** (None)
K12	Y	Y	See **Thruster.K12** **Data Type** Real **Dependency** (None) **Units** s
K13	Y	Y	See **Thruster.K13** **Data Type** Real **Dependency** (None) **Units** (None)

Parameter	Settable	Plottable	Description
K14	Y	Y	See **Thruster.K14** **Data Type** Real **Dependency** (None) **Units** 1/kPa
K15	Y	Y	See **Thruster.K15** **Data Type** Real **Dependency** (None) **Units** (None)
K16	Y	Y	See **Thruster.K16** **Data Type** Real **Dependency** (None) **Units** 1/kPa
ThrustDirection1	Y	Y	See **Thruster.ThrustDirection1** **Data Type** Real **Dependency** (None) **Units** (None)
ThrustDirection2	Y	Y	See **Thruster.ThrustDirection2** **Data Type** Real **Dependency** (None) **Units** (None)
ThrustDirection3	Y	Y	See **Thruster.ThrustDirection3** **Data Type** Real **Dependency** (None) **Units** (None)
ThrustScaleFactor	Y	Y	See **Thruster.ThrustScaleFactor** **Data Type** Real **Dependency** (None) **Units** (None)

ImpulsiveBurn

To compute **ImpulsiveBurn** parameters, GMAT requires that an **ImpulsiveBurn** has been executed using a **Maneuver** command like this:

```
Maneuver myImpulsiveBurn(mySat)
```

In the case that an **ImpulsiveBurn** has not been applied, GMAT will output zeros for the **ImpulsiveBurn** components and issue a warning.

We recommended that you evaluate **ImpulsiveBurn** parameters immediately after the **ImpulsiveBurn** is applied using the **Maneuver** command like this:

```
Maneuver myImpulsiveBurn(mySat)
myVar =  mySat.MyCoordinateSystem.Element1
```

The above usage avoids issues that may occur if the **ImpulsiveBurn** coordinate system is time varying, and the **ImpulsiveBurn** parameters are requested after further manipulation of the participants using other commands (such as **Propagate**). In that case, it is possible that the participants are no longer at the epoch of the maneuver, and unexpected results can occur due to epoch mismatches.

Parameter	Settable	Plottable	Description
B	Y	Y	See **ImpulsiveBurn.B** **Data Type** Real **Dependency** (None) **Units** (None)
Element1	Y	Y	See **ImpulsiveBurn.Element1** **Data Type** Real **Dependency** **CoordinateSystem** **Units** (None)
Element2	Y	Y	See **ImpulsiveBurn.Element2** **Data Type** Real **Dependency** **CoordinateSystem** **Units** (None)
Element3	Y	Y	See **ImpulsiveBurn.Element3** **Data Type** Real **Dependency** **CoordinateSystem** **Units** (None)
N	Y	Y	See **ImpulsiveBurn.N** **Data Type** Real **Dependency** (None) **Units** (None)
V	Y	Y	See **ImpulsiveBurn.V** **Data Type** Real **Dependency** (None) **Units** (None)

Solver

Solver parameters allow you to query a **Solver** for its convergence state to determine if the **Solver** converged. There are both string and numeric parameters which are described in further detail in the table below the following usage example using solver parameters before and after a **Target** sequence.

```
Create Spacecraft aSat
Create Propagator aPropagator
```

```
Create ImpulsiveBurn aBurn
Create DifferentialCorrector aDC
Create OrbitView EarthView
EarthView.Add = {Earth,aSat}
EarthView.ViewScaleFactor = 5

Create ReportFile aReport

BeginMissionSequence
Report aReport aDC.SolverStatus aDC.SolverState
Target aDC
   Vary aDC(aBurn.Element1 = 1.0, {Upper = 3})
   Maneuver aBurn(aSat)
   Propagate aPropagator(aSat,{aSat.Apoapsis})
   Achieve aDC(aSat.RMAG = 42164)
EndTarget
Report aReport aDC.SolverStatus aDC.SolverState
```

Parameter	Settable	Plottable	Description
SolverStatus	N	N	The **SolverStatus** parameter contains the state of a **Solver**. If the **Solver** has not executed, **SolverStatus** is **Initialized**. If the **Solver** has executed and converged, **SolverStatus** is **Converged**. If the **Solver** is iterating, **SolverStatus** is **Running**. If the **Solver** has executed and reached the maximum number of iterations before convergence, **SolverStatus** is **ExceededIterations**. If the **Solver** has executed and failed to converge, but did not exceed the maximum iterations, **SolverStatus** is **DidNotConverge**. **Data Type** String **Dependency** (None) **Units** (None)
SolverState	N	Y	The **SolverState** parameter contains the state of a **Solver**. If the solver has not executed, **SolverState** is 0. If the **Solver** has executed and converged, **SolverState** is **1**. If the **Solver** is iterating, **SolverState** is 0. If the **Solver** has executed and reached the maximum number of iterations before convergence, **SolverState** is **-1**. If the **Solver** has executed and failed to converge, but did not exceed the maximum iterations, **SolverState** is **-2**. **Data Type** Integer **Dependency** (None) **Units** (None)

Array, String, Variable

Array, **String**, and **Variable** resources are themselves parameters, and can be used as any other parameter would. All of these are writable parameters, though only **Variable** resources and individual elements of **Array** resources can be plotted.

Examples

Using parameters in the Mission Sequence:

```
Create Spacecraft aSat
Create Propagator aProp
Create ReportFile aReport
Create Variable i

BeginMissionSequence

% propagate for 100 steps
For i=1:100
Propagate aProp(aSat)
% write four parameters (one standalone, three coordinate-system-dependent) to a file
Report aReport aSat.TAIGregorian aSat.EarthFixed.X aSat.EarthFixed.Y aSat.EarthFixed.Z
EndFor
```

Using parameters as plot data:

```
Create Spacecraft aSat
Create Propagator aProp

Create XYPlot aPlot
aPlot.XVariable = aSat.TAIModJulian
aPlot.YVariables = {aSat.Earth.Altitude, aSat.Earth.ECC}

Create Variable i

BeginMissionSequence

% propagate for 100 steps
For i=1:100
    Propagate aProp(aSat)
EndFor
```

Using parameters as stopping conditions:

```
Create Spacecraft aSat
aSat.SMA = 6678

Create ForceModel anFM
anFM.Drag.AtmosphereModel = MSISE90

Create Propagator aProp
aProp.FM = anFM

BeginMissionSequence
```

```
Propagate aProp(aSat) {aSat.Earth.Altitude = 100, aSat.ElapsedDays = 365}
```

Color

Color support in GMAT resources and commands

Description

GMAT lets you assign different colors to orbital trajectory segments that are drawn by **Spacecraft**, **CelestialBody**, **LibrationPoint** and **Barycenter** resources. You can also assign unique colors to **Spacecraft** orbital trajectory segments by setting colors through the **Propagate** command. The orbital trajectories of these resources are drawn using the **OrbitView** 3D graphics resource. Additionally, GMAT allows you set colors on **GroundStation** facilities that are drawn on a spacecraft's ground track plot created by **GroundTrackPlot** 2D graphics resource.

In addition to setting colors on orbital trajectory segments of the following five resources and single command: **Spacecraft**, **CelestialBody**, **LibrationPoint**, **Barycenter**, **GroundStation** and **Propagate**, GMAT also allows you to assign colors to perturbing trajectories that may be drawn by the above five resources. These perturbing trajectories are drawn during iterative processes such as differential correction or optimization. The above five resources and single **Propagate** command each have a common field called **OrbitColor**. The **OrbitColor** field is used to set colors on orbital trajectory segments drawn by these resources and single command. Similarly, these five resources also have a common field called **TargetColor**. The **Propagate** command does not have a **TargetColor** field. The **TargetColor** field of these five resources can be used to set colors on perturbing trajectories that may be drawn during iterative processes.

You can set colors on the above five resources and **Propagate** command either via the GUI or script interface of GMAT. Setting colors on these five resources and single command via the GUI mode is very easy: After opening any of the five resources or **Propagate** command, you can choose colors for **OrbitColor** field by clicking on any available colors from Orbit Color selectbox. Similarly, for the five resources, you can select colors for the **TargetColor** field by choosing any available colors from the Target Color selectbox. See the GUI section below that walks you through an example of how to select colors through the GUI mode.

There are two ways to set colors on both **OrbitColor** and **TargetColor** fields via GMAT's script mode. The available colors are identified through a string or a three digit integer array. You can input color of your choice by either entering a color's ColorName or its corresponding RGB triplet value. The table below shows a list of 75 colors that are available for you to select from. Each row of the table lists an available color's ColorName and an equivalent RGB triplet value. Refer to the Fields section of the above five resources and **Propagate** command's Options section to learn more about **OrbitColor** and **TargetColor** fields and how to set colors. Also see the Remarks section below for additional script snippets that show how to assign colors through either ColorName or RGB triplet value input method for the above five resources and single command.

ColorName	Equivalent RGB Triplet Value
Aqua	0 255 255
AquaMarine	127 55 212
Beige	245 245 220
Black	0 0 0
Blue	0 0 255

ColorName	Equivalent RGB Triplet Value
BlueViolet	138 43 226
Brown	165 42 42
CadetBlue	95 158 160
Coral	255 127 80
CornflowerBlue	100 149 237
Cyan	0 255 255
DarkBlue	0 0 139
DarkGoldenRod	184 134 11
DarkGray	169 169 169
DarkGreen	0 100 0
DarkOliveGreen	85 107 47
DarkOrchid	153 50 204
DarkSlateBlue	72 61 139
DarkSlateGray	47 79 79
DarkTurquoise	0 206 209
DimGray	105 105 105
FireBrick	178 34 34
ForestGreen	34 139 34
Fuchsia	255 0 255
Gold	255 215 0
GoldenRod	218 165 32
Gray	128 128 128
Green	0 128 0
GreenYellow	173 255 47
IndianRed	205 92 92
Khaki	240 230 140
LightBlue	173 216 230
LightGray	211 211 211
Lime	0 255 0
LimeGreen	50 205 50
LightSteelBlue	176 196 222
Magenta	255 0 255
Maroon	128 0 0
MediumAquaMarine	102 205 170
MediumBlue	0 0 205

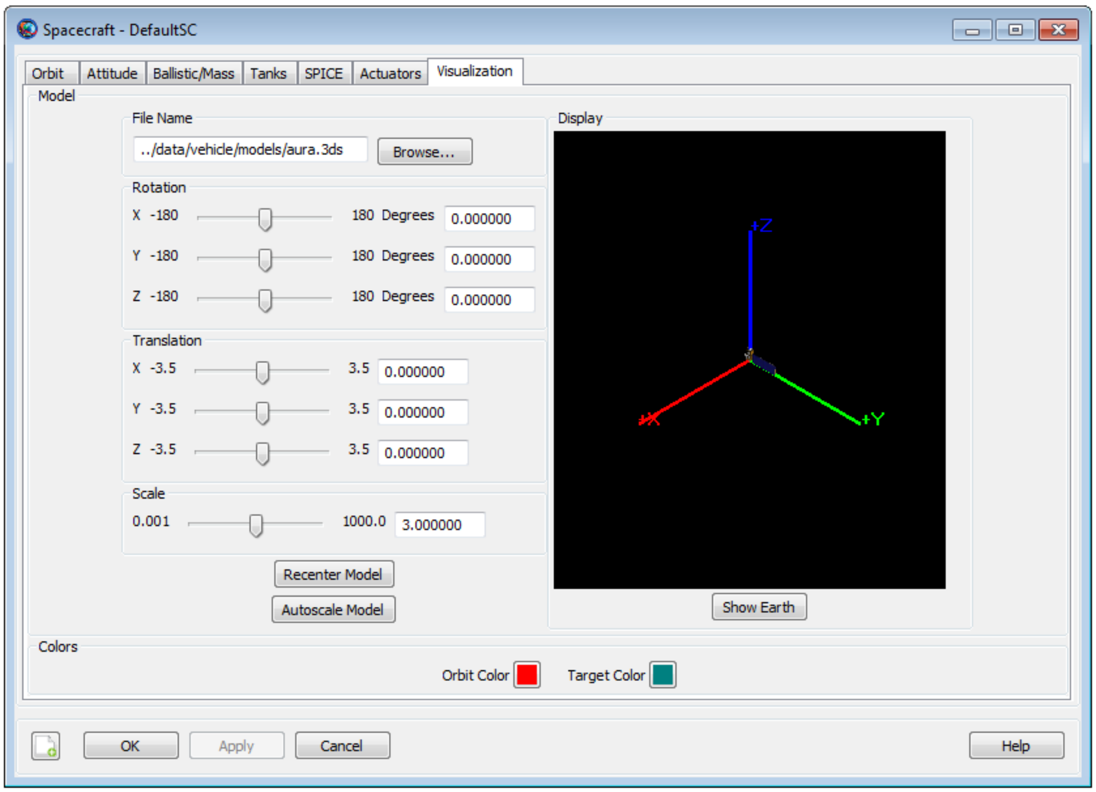
ColorName	Equivalent RGB Triplet Value
MediumOrchid	186 85 211
MediumSeaGreen	60 179 113
MediumSpringGreen	0 250 154
MediumTurquoise	72 209 204
MediumVioletRed	199 21 133
MidnightBlue	25 25 112
Navy	0 0 128
Olive	128 128 0
Orange	255 165 0
OrangeRed	255 69 0
Orchid	218 112 214
PaleGreen	152 251 152
Peru	205 133 63
Pink	255 192 203
Plum	221 160 221
Purple	128 0 128
Red	255 0 0
SaddleBrown	244 164 96
Salmon	250 128 114
SeaGreen	46 139 87
Sienna	160 82 45
Silver	192 192 192
SkyBlue	135 206 235
SlateBlue	106 90 205
SpringGreen	0 255 127
SteekBlue	70 130 180
Tan	210 180 140
Teal	0 128 128
Thistle	216 191 216
Turquoise	64 224 208
Violet	238 130 238
Wheat	245 222 179
White	255 255 255
Yellow	255 255 0
YellowGreen	154 205 50

See Also: Spacecraft Visualization Properties, CelestialBody, LibrationPoint, Barycenter, GroundStation, Propagate

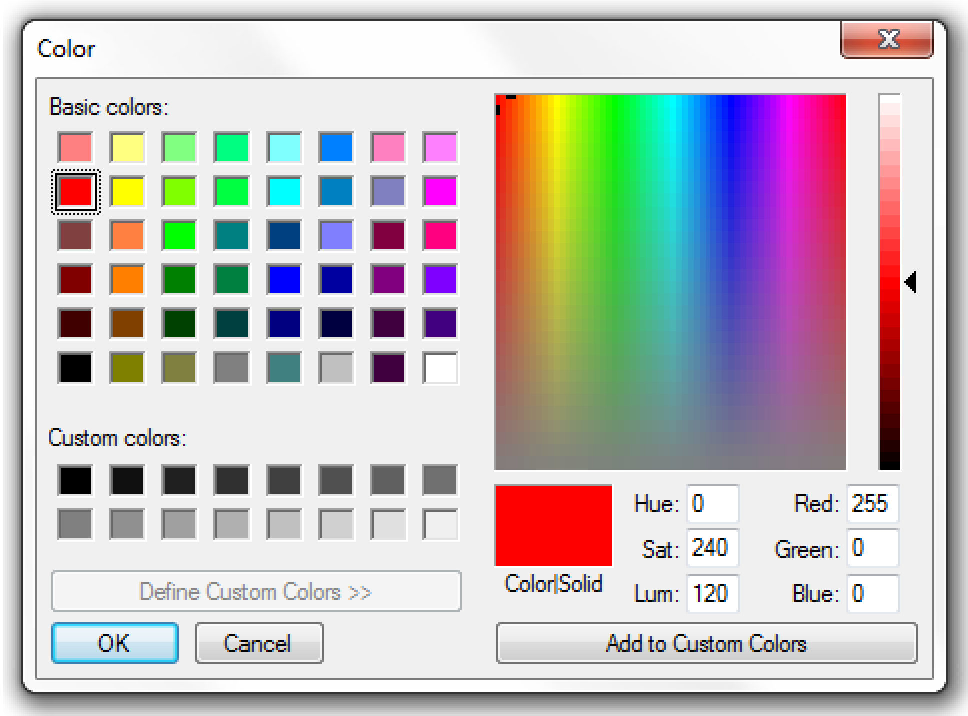
GUI

Setting colors on **Spacecraft**, **GroundStation**, **CelestialBody**, **LibrationPoint** and **Barycenter** resources' **OrbitColor** and **TargetColor** fields via GMAT's GUI mode is very easy. Since the procedure for setting colors on these five resources is the same, hence only one GUI example is given below using the **Spacecraft** resource:

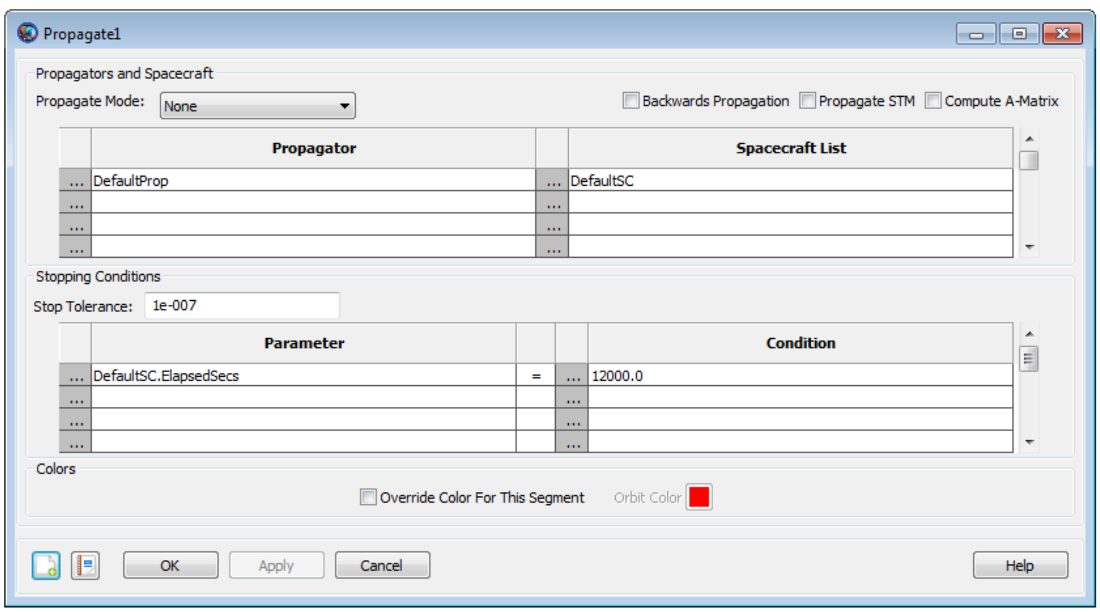
After opening the **Spacecraft** resource, click on Visualization tab.



In the Visualization window, you will see Orbit Color and Target Color Select boxes. You can choose colors for **OrbitColor** and **TargetColor** fields by clicking on the Orbit Color and Target Color select boxes respectively. For example, clicking either on the Orbit Color or Target Color select box opens the Color panel seen below. Using this Color panel, you can select basic colors, create custom colors of your choice and add custom colors to the list of available colors.

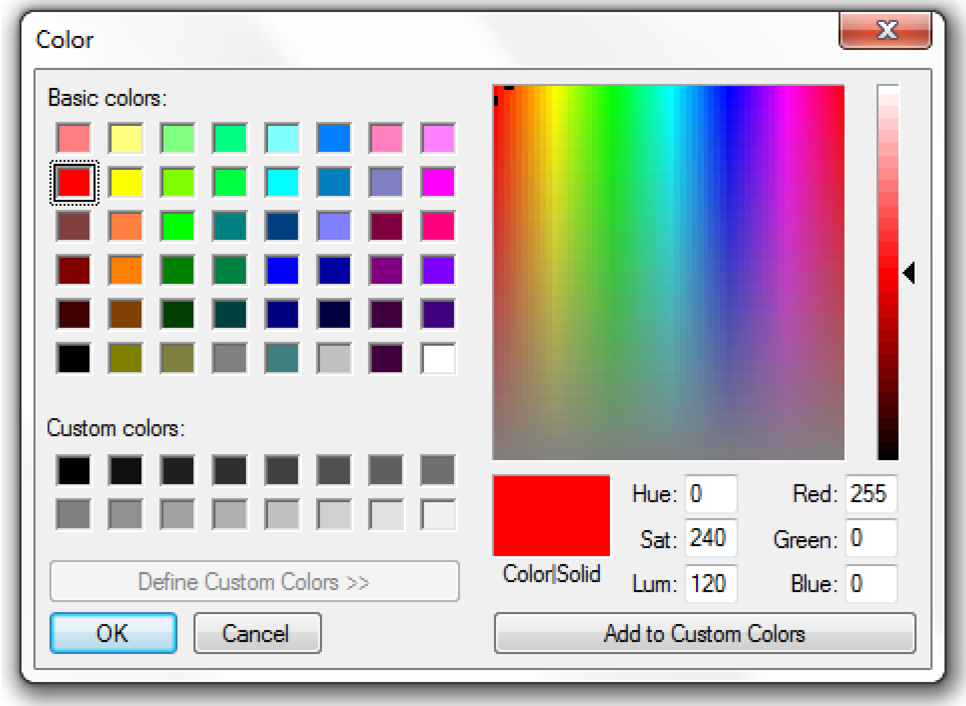


Selecting colors on **Propagate** command's **OrbitColor** option through the GUI mode is also very easy. Open any **Propagate** command. Below is screenshot of GMAT's default **Propagate** command:



In GMAT, the default orbit color on any **Propagate** command is the color that is set on **Spacecraft** resource's **OrbitColor** field (i.e. **Spacecraft.OrbitColor**). Whenever you do not set a unique color on the **Propagate** command's **OrbitColor** option, hence the color on the **Propagate** command will always be the color that is set on **Spacecraft** object's **OrbitColor** field.

To set your own unique colors to the **Propagate** command, click and check the **Override Color For This Segment** box. This makes the Orbit Color select box active. Clicking on the Orbit Color select box opens the Color panel shown below:



Using this Color panel, you can select basic colors, create custom colors of your choice and add custom colors to the list of available colors and set them on the **Propagate** command's **OrbitColor** option.

Remarks

Configuring Orbit and Target Colors on Spacecraft Resource

You can set unique colors of your choice on orbital trajectories of a **Spacecraft** by assigning colors to **Spacecraft** object's **OrbitColor** field. As long as you do not reset or reassign orbit color on the **Propagate** command, then all spacecraft trajectory colors that GMAT draws will be the same color that you first set on **Spacecraft** object's **OrbitColor** field. The default color on **Spacecraft** object's **OrbitColor** field is set to red. With this default setting of red color to **OrbitColor** field, all **Spacecraft** trajectories will be drawn in red color as long as you do not reset orbit color on any of the **Propagate** commands. Now for example, if you want all **Spacecraft** orbital trajectories to be drawn in yellow color alone, the script snippet below demonstrates two acceptable methods of setting yellow color to **Spacecraft** object's **OrbitColor** field:

```
Create Spacecraft aSat
aSat.OrbitColor = Yellow       % ColorName method
% or
aSat.OrbitColor = [255 255 0]  % RGB triplet value method
```

Similarly, setting colors of your choice on spacecraft's perturbing trajectories that may be drawn during iterative processes such as differential correction or optimization can be done by assigning unique colors to **Spacecraft** object's **TargetColor** field. Setting colors on the **TargetColor** field is only useful when you want to assign colors on perturbed trajectories generated during iterative processes. Both **OrbitColor** and **TargetColor** fields of **Spacecraft** object can also be used and modified in the Mission Sequence as well. The example script snippet below shows two acceptable methods of setting blue violet color to **Spacecraft** resource's **TargetColor** field:

```
Create Spacecraft aSat
aSat.TargetColor = BlueViolet    % ColorName method
% or
aSat.TargetColor = [138 43 226]  % RGB triplet value method
```

The list of available colors that you can set on **Spacecraft** object's **OrbitColor** and **TargetColor** fields are tabulated in the table in Description section. You can assign colors either via the ColorName or RGB triplet value input method. Also see the Examples section below for complete sample scripts that show how to use **Spacecraft** object's **OrbitColor** and **TargetColor** fields.

Setting Colors on Ground Station Resource

GMAT allows you to set unique colors of your choice on **GroundStation** object's **OrbitColor** or **TargetColor** fields. The list of available colors that you can set are tabulated in the table in Description section. You can assign colors either via the ColorName or RGB triplet value method. The custom ground station facility that you create shows up on the ground track plot of a spacecraft that is drawn on a 2D texture map of a central body. The colors that are assigned on **GroundStation** object's **TargetColor** field are only used whenever **GroundStation** object is drawn during iterative processes such as differential correction or optimization. The script snippet below shows how to set colors on **GroundStation's OrbitColor** and **TargetColor** fields using either the ColorName or RGB method:

```
Create GroundStation aGroundStation
aGroundStation.OrbitColor = Aqua           % ColorName method
% or
aGroundStation.OrbitColor = [0 255 255]    % RGB method
```

```
Create GroundStation aGroundStation
aGroundStation.TargetColor = Black     % ColorName method
% or
aGroundStation.TargetColor = [0 0 0]   % RGB method
```

See the Examples section below for complete sample script that shows how to use **GroundStation** object's **OrbitColor** field.

Configuring Orbit and Target Colors on Celestial Body Resource

GMAT allows you to set available colors to orbits of built-in or custom-defined celestial bodies. GMAT contains built-in models for the Sun, the 8 planets, Earth's moon, and Pluto. You can create a custom **CelestialBody** resource to model a planet, asteroid, comet, or moon. The orbit colors on **CelestialBody** objects are set through the **OrbitColor** field. You can also set colors to a celestial body's perturbing trajectories that are generated during iterative processes such as differential correction or optimization. This is done by setting colors to **CelestialBody** object's **TargetColor** field. Setting colors on the **TargetColor** field is only useful when you want to assign colors on perturbed trajectories that are generated during iterative processes. The list of available colors that you can set on **OrbitColor** and **TargetColor** fields are tabulated in the table shown in the Description section.

To assign colors, you can either use the ColorName or RGB triplet value method. Both **OrbitColor** and **TargetColor** fields of the **CelestialBody** object can also be used and modified in the Mission Sequence as well. The script snippet below shows how to set colors on **OrbitColor** and **TargetColor** fields on a custom-built celestial body using either the ColorName or RGB method:

```
Create CelestialBody aPlanet
aPlanet.OrbitColor = CornflowerBlue   % ColorName method
% or
aPlanet.OrbitColor = [100 149 237]    % RGB method
```

```
Create CelestialBody aPlanet
aPlanet.TargetColor = DarkBlue     % ColorName method
% or
aPlanet.TargetColor = [0 0 139]    % RGB method
```

See the Examples section below for complete sample scripts that show how to use **CelestialBody** object's **OrbitColor** field

Configuring Orbit and Target Colors on Libration Point Resource

GMAT lets you set available colors on an orbit that is drawn by a libration point. In order to see orbital trajectory that a libration point draws in space, you must draw the Lagrange points in an inertial space. The orbit colors on **LibrationPoint** resources are set through the **OrbitColor** field. GMAT also allows you to set colors on a libration point's perturbing trajectories that are drawn during iterative processes such as differential correction or optimization. Setting colors on perturbing libration point trajectories is done via the **TargetColor** field. Setting colors on the **TargetColor** field is only useful whenever perturbed libration point trajectories are generated during iterative processes. The available colors that can be set on **OrbitColor** and **TargetColor** fields are tabulated in the table shown in the Description section. You can either use the ColorName or RGB triplet value method to assign colors on **OrbitColor** and **TargetColor** fields. These two fields of **LibrationPoint** resource can also be used and modified to set colors in the Mission Sequence as well. The script snippet below shows how to set colors on **OrbitColor** and **TargetColor** fields using either the ColorName or RGB method:

```
Create LibrationPoint ESL1
ESL1.OrbitColor = Magenta            % ColorName method
% or
ESL1.OrbitColor = [255 0 255]        % RGB method
```

```
Create LibrationPoint ESL1
ESL1.TargetColor = Orchid            % ColorName method
% or
ESL1.TargetColor = [218 112 214]     % RGB method
```

See the Examples section below for complete sample script that shows how to use **LibrationPoint** object's **OrbitColor** field.

Configuring Orbit and Target Colors on Barycenter Resource

In GMAT, you can assign available colors on an orbit that is drawn by a barycenter point. Since a barycenter is a center of mass of a set of celestial bodies, hence in order to see its orbital trajectory, the barycenters must be plotted in an inertial space. You can set orbit colors on GMAT's both built-in **SolarSystemBarycenter** resource or custom barycenters that you create through the **Barycenter** object. The orbit colors on **Barycenter** resources are set through the **OrbitColor** field. GMAT also allows you to set colors on a barycenter's perturbing trajectories that are drawn during iterative processes such as differential correction or optimization. Setting colors on perturbing barycenter trajectories is done via the **TargetColor** field. Setting colors on the **TargetColor** field is only useful whenever you want to set different colors on the perturbing trajectories. The available colors that can be set on OrbitColor and **TargetColor** fields are tabulated in the table shown in the Description section. You can either use the ColorName or RGB triplet value color input method to assign colors on **OrbitColor** and **TargetColor** fields. These two fields of **Barycenter** resource can also be used and modified in the Mission Sequence as well. The script snippet below shows how to set colors on **OrbitColor** and **TargetColor** fields using either the ColorName or RGB method:

```
Create Barycenter EarthMoonBarycenter
EarthMoonBarycenter.OrbitColor = Violet         % ColorName method
% or
EarthMoonBarycenter.OrbitColor = [238 130 238]  % RGB method
```

```
Create Barycenter EarthMoonBarycenter
EarthMoonBarycenter.TargetColor = Silver         % ColorName method
% or
EarthMoonBarycenter.TargetColor = [192 192 192]  % RGB method
```

See the Examples section below for complete sample script that shows how to use **Barycenter** object's **OrbitColor** field.

Configuring Orbit Colors on Propagate Command

In GMAT, you can set unique colors on different **Spacecraft** trajectory segments by setting orbital colors on **Propagate** commands. If you do not select unique colors on each **Propagate** command, then by default, the color on all **Propagate** commands is seeded from color that is set on **Spacecraft** object's **OrbitColor** field. You can set orbit colors on each **Propagate** command through the **OrbitColor** option. The available colors that can be set on **Propagate** command's **OrbitColor** option are tabulated in the table shown in the Description section. You can either use the ColorName or RGB triplet value input method to assign colors on **OrbitColor** option. The script snippet below shows how to set colors on **OrbitColor** option using either the ColorName or RGB method:

```
% ColorName method:
Propagate aProp(aSat) {aSat.ElapsedSecs = 500, OrbitColor = Gold}
% or RGB method:
Propagate aProp(aSat) {aSat.ElapsedSecs = 500, OrbitColor = [255 215 0]}
```

See the Examples section below for complete sample scripts that show how to use **Propagate** command's **OrbitColor** option.

Examples

Set non-default sky blue color to **Spacecraft** object's **OrbitColor** field through both ColorName and RGB triplet value methods. Both methods draw spacecraft orbital trajectory in sky blue color. Note: Since orbit color was not re-set in the **Propagate** command, hence entire spacecraft orbital trajectory is drawn in sky blue color:

```
Create Spacecraft aSat
aSat.OrbitColor = SkyBlue   % ColorName method
```

```
Create Propagator aProp

Create OrbitView anOrbitView
GMAT anOrbitView.Add = {aSat, Earth}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}

% or

Create Spacecraft aSat
aSat.OrbitColor = [135 206 235]   % RGB triplet value method
Create Propagator aProp

Create OrbitView anOrbitView
GMAT anOrbitView.Add = {aSat, Earth}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 1}
```

Set unique colors on **Spacecraft** object's **OrbitColor** field multiple times through combination of both ColorName and RGB method. Notice that **Spacecraft.OrbitColor** is used and modified in the Mission Sequence as well:

```
Create Spacecraft aSat
aSat.OrbitColor = Yellow   % ColorName method
Create Propagator aProp

Create OrbitView anOrbitView
GMAT anOrbitView.Add = {aSat, Earth}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedSecs = 1000}
aSat.OrbitColor = Green   % ColorName method
Propagate aProp(aSat) {aSat.ElapsedSecs = 1000}
aSat.OrbitColor = [255 165 0 ]   % RGB value for Orange
Propagate aProp(aSat) {aSat.ElapsedSecs = 2000}
```

Set non-default yellow color on **Spacecraft** object's **TargetColor** field. Setting color on the **TargetColor** field is only useful when perturbed trajectories are generated during iterative processes such as differential correction. Note yellow color was set via the ColorName method. It could've been also set through the RGB triplet value method as well.

```
Create Spacecraft aSat
aSat.OrbitColor = Red       % Default OrbitColor
aSat.TargetColor = Yellow  % ColorName method

Create Propagator aProp

Create ImpulsiveBurn TOI
```

```
Create DifferentialCorrector aDC

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth}
anOrbitView.SolverIterations = All
anOrbitView.ViewScaleFactor = 2


BeginMissionSequence

Propagate aProp(aSat) {aSat.Earth.Periapsis}

Target aDC;
Vary aDC(TOI.Element1 = 0.24, {Perturbation = 0.001, Lower = 0.0, ...
 Upper = 3.14159, MaxStep = 0.5})
 Maneuver TOI(aSat);
 Propagate aProp(aSat) {aSat.Earth.Apoapsis}
 Achieve aDC(aSat.Earth.RMAG = 20000)
EndTarget

Propagate aProp(aSat) {aSat.ElapsedDays = 0.25}
```

Set non-default colors on multiple **GroundStation** objects through the **OrbitColor** field. The colors are assigned through combination of both ColorName and RGB input methods:

```
Create Spacecraft aSat
Create Propagator aProp

Create GroundStation aGroundStation aGroundStation2 aGroundStation3

aGroundStation.StateType = Spherical
aGroundStation.Latitude = 45
aGroundStation.OrbitColor = Black

aGroundStation2.StateType = Spherical
aGroundStation2.Longitude = 20
aGroundStation2.OrbitColor = [165 42 42]  % RGB value for Brown

aGroundStation3.StateType = Spherical
aGroundStation3.Latitude = 30
aGroundStation3.Longitude = 45
aGroundStation3.OrbitColor = [255 127 80]  % RGB value for Coral

Create GroundTrackPlot aGroundTrackPlot
aGroundTrackPlot.Add = {aSat, aGroundStation, aGroundStation2, ...
aGroundStation3 }

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 0.25 }
```

Set non-default colors on built-in celestial body orbits. In this example, **CelestialBody** object's **OrbitColor** field is assigned colors through mixture of both ColorName and RGB triplet value methods. By default, GMAT sets **Spacecraft** orbit color to red:

```
Create Spacecraft aSat
aSat.CoordinateSystem = SunMJ2000Ec
aSat.DisplayStateType = Keplerian
aSat.SMA = 150000000

Mercury.OrbitColor = Orange
Venus.OrbitColor = [255 255 0]  % RGB value for Yellow
Earth.OrbitColor = Cyan
Mars.OrbitColor = [0 128 0]  % RGB value for Green

Create CoordinateSystem SunMJ2000Ec
SunMJ2000Ec.Origin = Sun
SunMJ2000Ec.Axes = MJ2000Ec

Create ForceModel aFM
aFM.CentralBody = Sun
aFM.PointMasses = {Sun}

Create Propagator aProp
aProp.FM = aFM

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth, Venus, Mars, Mercury}
anOrbitView.CoordinateSystem = SunMJ2000Ec
anOrbitView.ViewPointReference = Sun
anOrbitView.ViewPointVector = [0 0 150000000]
anOrbitView.ViewDirection = Sun
anOrbitView.ViewScaleFactor = 6
anOrbitView.ViewUpCoordinateSystem = SunMJ2000Ec

BeginMissionSequence
Propagate aProp(aSat) {aSat.ElapsedDays = 150}
```

Set unique non-default orbit colors on built-in **CelestialBody** object's **OrbitColor** field multiple times through combination of both ColorName and RGB triplet value methods. Notice that **CelestialBody.OrbitColor** is used and modified in the Mission Sequence as well:

```
Create Spacecraft aSat
aSat.CoordinateSystem = SunMJ2000Ec
aSat.DisplayStateType = Keplerian
aSat.SMA = 150000000

Mars.OrbitColor = Orange

Create CoordinateSystem SunMJ2000Ec
SunMJ2000Ec.Origin = Sun
SunMJ2000Ec.Axes = MJ2000Ec

Create ForceModel aFM
aFM.CentralBody = Sun
aFM.PointMasses = {Sun}

Create Propagator aProp
aProp.FM = aFM
```

```
aProp.MaxStep = 20000

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Mars}
anOrbitView.CoordinateSystem = SunMJ2000Ec
anOrbitView.ViewPointReference = Sun
anOrbitView.ViewPointVector = [0 0 150000000]
anOrbitView.ViewDirection = Sun
anOrbitView.ViewScaleFactor = 6
anOrbitView.ViewUpCoordinateSystem = SunMJ2000Ec

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 150}
Mars.OrbitColor = [255 255 0]  % RGB value for Yellow
Propagate aProp(aSat) {aSat.ElapsedDays = 150}
Mars.OrbitColor = Cyan
Propagate aProp(aSat) {aSat.ElapsedDays = 150}
Mars.OrbitColor = [0 128 0]   % RGB value for Green
Propagate aProp(aSat) {aSat.ElapsedDays = 150}
```

Set unique non-default orbit colors on Earth-Sun L1 libration point orbit. ESL1 libration point is plotted in an inertial space in order to see its orbit around sun.The orbit colors on **LibrationPoint** object's **OrbitColor** field are set multiple times through combination of both ColorName and RGB triplet value input methods. Notice that in this example, **LibrationPoint.OrbitColor** is also set in the Mission Sequence as well. By default, GMAT sets **Spacecraft** orbit color to red:

```
Create Spacecraft aSat
aSat.CoordinateSystem = SunMJ2000Ec
aSat.DisplayStateType = Keplerian
aSat.SMA = 150000000

Create LibrationPoint ESL1
ESL1.OrbitColor = Orange
ESL1.Primary = Sun
ESL1.Secondary = Earth
ESL1.Point = L1

Create CoordinateSystem SunMJ2000Ec
SunMJ2000Ec.Origin = Sun
SunMJ2000Ec.Axes = MJ2000Ec

Create ForceModel aFM
aFM.CentralBody = Sun
aFM.PointMasses = {Sun}

Create Propagator aProp
aProp.FM = aFM

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, ESL1}
anOrbitView.CoordinateSystem = SunMJ2000Ec
anOrbitView.ViewPointReference = Sun
anOrbitView.ViewPointVector = [0 0 150000000]
```

```
anOrbitView.ViewDirection = Sun
anOrbitView.ViewScaleFactor = 3
anOrbitView.ViewUpCoordinateSystem = SunMJ2000Ec

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 75}
ESL1.OrbitColor = [255 255 0]  % RGB value for Yellow
Propagate aProp(aSat) {aSat.ElapsedDays = 75}
ESL1.OrbitColor = Cyan
Propagate aProp(aSat) {aSat.ElapsedDays = 75}
ESL1.OrbitColor = [0 128 0]   % RGB value for Green
Propagate aProp(aSat) {aSat.ElapsedDays = 75}
```

Set unique non-default orbit colors on Earth-Moon barycenter. The Earth Moon barycenter had to be plotted in an inertial space in order to see its orbit around the sun. The orbit colors on **Barycenter** object's **OrbitColor** field are set multiple times through combination of both ColorName and RGB triplet value input methods. Notice that in this example, **Barycenter.OrbitColor** is also set in the Mission Sequence as well. By default, GMAT sets **Spacecraft** orbit color to red:

```
Create Spacecraft aSat
aSat.CoordinateSystem = SunMJ2000Ec
aSat.DisplayStateType = Keplerian
aSat.SMA = 150000000

Create Barycenter EarthMoonBarycenter
EarthMoonBarycenter.OrbitColor = Cyan
EarthMoonBarycenter.BodyNames = {Earth, Luna}

Create CoordinateSystem SunMJ2000Ec
SunMJ2000Ec.Origin = Sun
SunMJ2000Ec.Axes = MJ2000Ec

Create ForceModel aFM
aFM.CentralBody = Sun
aFM.PointMasses = {Sun}

Create Propagator aProp
aProp.FM = aFM

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, EarthMoonBarycenter}
anOrbitView.CoordinateSystem = SunMJ2000Ec
anOrbitView.ViewPointReference = Sun
anOrbitView.ViewPointVector = [0 0 150000000]
anOrbitView.ViewDirection = Sun
anOrbitView.ViewScaleFactor = 4
anOrbitView.ViewUpCoordinateSystem = SunMJ2000Ec

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedDays = 75}
EarthMoonBarycenter.OrbitColor = [255 255 0]  % RGB value for Yellow
Propagate aProp(aSat) {aSat.ElapsedDays = 75}
```

```
EarthMoonBarycenter.OrbitColor = Orange
Propagate aProp(aSat) {aSat.ElapsedDays = 75}
EarthMoonBarycenter.OrbitColor = [250 128 114]   % RGB value for Salmon
Propagate aProp(aSat) {aSat.ElapsedDays = 75}
```

Set unique colors on spacecraft's various trajectory segments through **Propagate** command's **OrbitColor** option. The colors are set through combination of both ColorName and RGB input methods. Notice that although by default, red color is set on **aSat.OrbitColor** field, however since orbit color has been reset on all **Propagate** commands, hence red color is never drawn:

```
Create Spacecraft aSat
aSat.OrbitColor = Red
aSat.X = 10000

Create Propagator aProp

Create OrbitView anOrbitView
GMAT anOrbitView.Add = {aSat, Earth}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedSecs = 1000, OrbitColor = Yellow}
Propagate aProp(aSat) {aSat.ElapsedSecs = 1000, OrbitColor = Cyan}
Propagate aProp(aSat) {aSat.ElapsedSecs = 1000, OrbitColor = [154 205 50]}
Propagate aProp(aSat) {aSat.ElapsedSecs = 1000, OrbitColor = [255 0 255]}
```

Set colors on spacecraft's various trajectory segments through **Propagate** command's **OrbitColor** option. This time, colors are only set through ColorName input method. Default color set on **aSat.OrbitColor** field is red. Notice that the orbit color has been reset on only the first three **Propagate** commands. However since **OrbitColor** option has not been used on the last **Propagate** command, therefore the trajectory drawn by the last **Propagate** command is in red color which is the color assigned on **aSat.OrbitColor** field:

```
Create Spacecraft aSat
aSat.OrbitColor = Red
aSat.X = 10000

Create Propagator aProp

Create OrbitView anOrbitView
GMAT anOrbitView.Add = {aSat, Earth}

BeginMissionSequence

Propagate aProp(aSat) {aSat.ElapsedSecs = 1000, OrbitColor = Orange}
Propagate aProp(aSat) {aSat.ElapsedSecs = 1000, OrbitColor = Blue}
Propagate aProp(aSat) {aSat.ElapsedSecs = 1000, OrbitColor = Yellow}
Propagate aProp(aSat) {aSat.ElapsedSecs = 1000}
```

Set colors on **Propagate** commands when used with **Target** resource and during differential correction iterative process. This time, since colors have been set on all **Propagate** commands, hence default color of red which is set on **aSat.OrbitColor** field is never plotted. Also notice that although **aSat.TargetColor** is set to Yellow, but since **anOrbitView.SolverIterations** is set to None, hence perturbed trajectories that are drawn during iterative process are not plotted and only final solution is plotted

```
Create Spacecraft aSat
aSat.OrbitColor = Red
aSat.TargetColor = Yellow

Create Propagator aProp

Create ImpulsiveBurn TOI

Create DifferentialCorrector aDC

Create OrbitView anOrbitView
anOrbitView.Add = {aSat, Earth}
anOrbitView.SolverIterations = None %Set to 'All' to see perturbations
anOrbitView.ViewScaleFactor = 2


BeginMissionSequence

Propagate aProp(aSat) {aSat.Earth.Periapsis, OrbitColor = Salmon}

Target aDC;
Vary aDC(TOI.Element1 = 0.24, {Perturbation = 0.001, Lower = 0.0, ...
 Upper = 3.14159, MaxStep = 0.5})
 Maneuver TOI(aSat);
 Propagate aProp(aSat) {aSat.Earth.Apoapsis, OrbitColor = Blue}
 Achieve aDC(aSat.Earth.RMAG = 20000)
EndTarget

Propagate aProp(aSat) {aSat.Earth.Periapsis, OrbitColor = Orange}
```

Command-Line Usage

Starting the `GMAT` application from the command line

Synopsis

`GMAT` [*`option`*...] [*`script_file`*]

Description

The GMAT command starts the GMAT graphical interface. If run with no arguments, GMAT starts with the default mission loaded. If *`script_file`* is specified, and is a valid path to a GMAT script, GMAT loads the script and remains open, but does not run it.

Options

`-h`, `--help`
: Start GMAT and display command-line usage information in the message window.

`-m`, `--minimize`
: Start GMAT with a minimized interface.

`-r`, `--run`
: Automatically run the specified script after loading.

`-v`, `--version`
: Start GMAT and display version information in the message window.

`-x`, `--exit`
: Exit GMAT after running the specified script. This option has no effect if specified alone.

Examples

Start GMAT and run the script `MyScript.script`:

```
GMAT MyScript.script
```

Run a script with the interface minimized, and exit afterwards:

```
GMAT --minimize --exit MyScript.script
```

Keyboard Shortcuts

Keyboard shortcuts in the graphical user interface

Description

The GMAT graphical user interface (GUI) offers many keyboard shortcuts for easy access to common commands. See the tables below for details.

General shortcuts

These keyboard shortcuts are available any time when using GMAT.

Key	Meaning
Ctrl+Shift+<number>	Open recent script <number> (1–5).
Ctrl+N	Create a new mission.
Ctrl+Shift+N	Create a new empty script.
Ctrl+O	Open the **Open** dialog box.
Ctrl+S	Save the current mission.
F1	Open the Help documentation.
Ctrl+F1	Open the **Welcome Page**.
F5	Run the current mission.
F9	Animate the current graphics window.
F12	Open the **Save As** dialog box.

Tree view shortcuts

These keyboard shortcuts are available when navigating the Resources, Mission, and Output trees.

Key	Meaning
Enter	Open.
Space	Open.
Delete	Delete.
Ctrl+Shift+C	Clone (only available for resources).
F2	Rename.
Ctrl+Page Up	View the next tab.
Ctrl+Page Down	View the previous tab.

Dialog box shortcuts

These keyboard shortcuts are available when interacting with dialog boxes, such as the property windows for the **Spacecraft** resource or the **Propagate** command.

Key	Meaning
Tab	Move to the next item.
Shift+Tab	Move to the previous item.
Ctrl+C	Copy.
Ctrl+V	Paste.
Ctrl+W	Close.
F1	Open feature-specific help.
F7	Show script.

Script editor shortcuts

These keyboard shortcuts are available when using the script editor.

Tab	Insert a tab character.
Shift+Tab	Remove a tab character on the current line.
Ctrl+Tab	Move to the next editor button.
Ctrl+Shift+Tab	Move to the previous editor button.
Ctrl+A	Select all.
Ctrl+C	Copy.
Ctrl+F	Open the **Find and Replace** dialog box.
Ctrl+G	Open the **Go To** dialog box.
Ctrl+H	Open the **Find and Replace** dialog box.
Ctrl+I	Indent more.
Ctrl+Shift+I	Indent less.
Ctrl+R	Comment the current line.
Ctrl+Shift+S	Save,Sync.
Ctrl+T	Uncomment the current line.
Ctrl+V	Paste.
Ctrl+W	Close.
Ctrl+X	Cut.
Ctrl+Y	Redo.
Ctrl+Z	Undo.
F3	Find next (after using **Find and Replace**)..
Ctrl+Shift+F5	Save,Sync,Run.
Ctrl+Shift+F12	Save As.

Additionally, the following mouse controls are available:

- Hold down **Ctrl** while rotating the wheel button to increase or decrease the font size.

MATLAB Interface

Interface to MATLAB system

Description

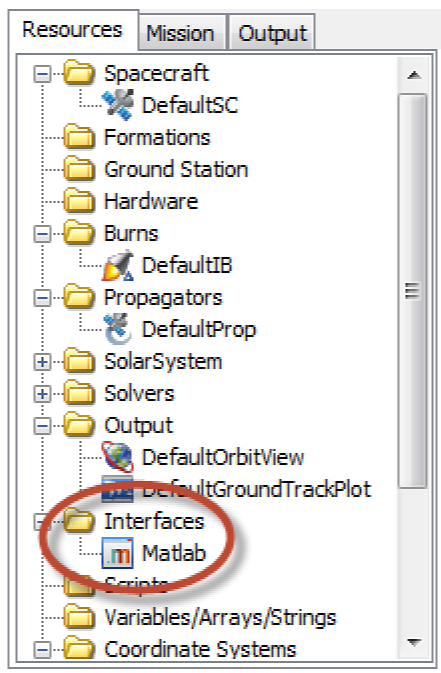
The MATLAB interface provides a link to the Mathworks MATLAB environment, allowing GMAT to run MATLAB functions as if they were native functions in the GMAT script language.

The interface cannot be controlled directly through the script language, though it can be in the GMAT GUI. Instead, GMAT starts the interface automatically when it calls a MATLAB function.

There are two GMAT components that provide user access to the interface. For details on declaring a MATLAB function, see the **MatlabFunction** reference. For details on calling a function and passing data, see the **CallMatlabFunction** reference.

See Also: CallMatlabFunction, MatlabFunction

GUI



The MATLAB interface provides an icon in the **Interfaces** folder in the Resources tree that can be used to control the interface. Right-clicking the icon shows two options: **Open** and **Close**.

The **Open** menu item causes GMAT to open a connection to the MATLAB Engine, which in turns displays a MATLAB command window in the background. This connection is then used for all communication between GMAT and MATLAB until the connection is closed. Only one connection can be open at a time.

The **Close** menu item causes GMAT to close any open connection to the MATLAB Engine. If no connection is open, it has no effect.

Remarks

Interface Setup

The following conditions must be true for GMAT to successfully initiate communication with MATLAB. All conditions must be true for the same instance of MATLAB.

- A compatible, licensed version of MATLAB must be installed on the same machine on which GMAT is running. GMAT is tested with the latest version of MATLAB at the time of release, though versions R2006b and newer have been known to work.
- The architecture (32-bit or 64-bit) of GMAT and the installed version of MATLAB must match. For example, the 32-bit version of GMAT is compatible only with the 32-bit version of MATLAB.
- On Windows:
  - The following path (where `MATLAB` is the path to the installed version of MATLAB) must be present in the `Path` environment variable. For some older versions of MATLAB, this path must be present before the default Windows paths.

    `MATLAB\bin\win32` (or `win64` for use with 64-bit versions of GMAT)

  - MATLAB must be registered as a COM server. This is done automatically by the MATLAB installer. To do it manually, open an elevated command window and run the command: **`matlab -regserver`**. Make sure the proper instance of MATLAB is being run by this command.
- On Mac OS X:
  - The MATLABFORGMAT environment variable must exist and contain the full path to the MATLAB application bundle (e.g. /Applications/MATLAB_R2010a/MATLAB_R2010a.app).

    Note that 64-bit GMAT must be used to interface with MATLAB after version R2010a.

> **Note**
>
> Common troubleshooting tips on Windows:
>
> - If you are using the officially-released 32-bit version of GMAT, make sure you have the 32-bit version of MATLAB installed.
> - If the path above exists in your system `Path` variable, try place it at the front.
> - Make sure the same instance of MATLAB is referenced both in the `Path` variable and when running **`matlab -regserver`**.

MATLAB Engine Connection

Warning

Caution: GMAT does not close the MATLAB Command Window it creates after a run has completed. This allows manual inspection of the MATLAB workspace, but it can lead to confusing behavior if MATLAB functions or paths are changed and rerun in the same window.

We recommend closing the MATLAB Command Window by right-clicking Matlab in the Resources tree and clicking Close between each run if you are actively editing the script.

When GMAT runs a mission that contains a MATLAB function call, it opens a connection to the MATLAB engine before it makes the function call. It then reuses this connection for the rest of the GMAT session.

The MATLAB Engine can be controlled manually through the **Open** and **Close** options available by right-clicking the **Matlab** item in the Resources tree.

Examples

See the MatlabFunction reference for common examples.

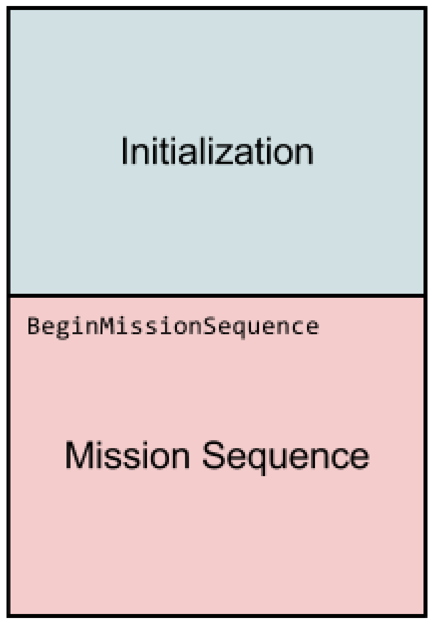
Script Language

The GMAT script language

Script Structure

A GMAT script is a text file consisting of valid script syntax elements, such as initialization statements, Mission Sequence commands, and comments. These syntax elements are described later in this specification.

At the highest level, a GMAT script is made up of two sections: Initialization and the Mission Sequence. These sections each contain statements, but they have different rules about which sorts of statements are valid. The **BeginMissionSequence** command defines the beginning of the Mission Sequence section.



Initialization

The first section in a script file, referred to as Initialization, is responsible for creating resources and setting their initial state. The Initialization section can contain the following types of statements:

- resource creation statements (the **Create** statement)
- initialization statements

Only literal assignments are allowed in this section; no execution of commands or evaluation of parameters is done. In the GUI, the Initialization section maps directly to the Resources tree. All resources created, and all fields set, in this section appear as resources in the GUI when the script is loaded.

Mission Sequence

The Mission Sequence section contains the Mission Sequence, or the list of GMAT commands that are executed sequentially when the mission is run. The Mission Sequence section can contain the following types of statements:

- command statements

The Mission Sequence begins at the first instance of the **BeginMissionSequence** command; therefore, this must be the first command statement in the script file. For backwards compatibility, if the **BeginMissionSequence** command is missing, the Mission Sequence begins with the first command encountered.

In the GUI, the Mission Sequence section maps directly to the Mission tree. Each statement in the script (with the exception of the **BeginScript**/**EndScript** compound command) is displayed as a single element in the tree.

Basic Syntax

Source Text

A GMAT script consists of a single file containing characters from the 7-bit US-ASCII character set. The script language is case-sensitive, so this line creates four different Variable resources:

```
Create Variable x X y Y
```

The script language is made up of lines. A line can be:

- empty
- a comment (see Comments, below)
- a statement (see Statements)

Statement lines can be split over multiple physical lines with the continuation marker ("`...`").

Line Termination

Script lines are terminated by any of the following ASCII character sequences:

- line feed (hex: 0A)
- carriage return (hex: 0D)
- carriage return followed by line feed (hex: 0D0A)

White Space

White space can appear above or below any line, before or after any statement within a line, and many other places in a script. The following characters are recognized as white space:

- space (hex: 20)
- horizontal tab (hex: 09)

Horizontal tab characters are preserved in string literals, but are replaced by spaces in some other contexts (e.g. equations, comments).

Comments

Comments begin with the percent symbol ("**%**", hex: 25) and extend to the end of the line. There is no multi-line or embedded comment in the script language.

File Paths

Several resource types have fields that accept file paths as input. The general syntax of such paths is common to the language, but some specific behavior is specified by each resource.

Forward slashes and backslashes can be used interchangeably within GMAT, and can be mixed in a single path. The following three paths are considered identical:

```
data/planetary_ephem/spk/de421.bsp
data\planetary_ephem\spk\de421.bsp
data\planetary_ephem/spk\de421.bsp
```

Absolute paths are passed to the underlying operating system as-is, aside from normalizing the slashes.

Relative paths are considered relative to a location defined by each resource type separately, and usually defined in the GMAT startup file. For details, see the reference documentation for each resource type.

File paths are written as string literals (see Strings under Data Types). Quotes are mandatory if the path contains spaces, but are optional otherwise.

Data Types

Literals

Integers

Integers are written as a sequence of literal digits, with no decimal. Preceding zeros and prepended signs (`+` or `-`) are allowed. Scientific notation is not permitted.

Real Numbers

Real numbers can be written in any of the following formats:

- `12` (whole number)
- `12.5` (decimal)
- `1.25e1` or `1.25e-1` (scientific notation)

In all formats, the base can contain preceding or trailing zeros. In scientific notation, the exponent can be prepended by a sign (`+` or `-`) and can contain preceding zeros, but cannot contain a decimal. The exponent delimiter is case-insensitive (e.g. `"e"` or `"E"`).

Strings

String literals are delimited by single-quote characters (“`'`”, hex: 27).

All language-supported characters are allowed in strings, with the exceptions below. There are no escape characters or character substitute sequences (such as “`\n`” for line feed).

In Initialization, the following characters are not allowed in string literals:

- some non-printable characters (NUL, SUB) (hex: 00, 1A)
- line termination characters (LF, CR) (hex: 0A, 0D)
- percent character ("%") (hex: 25)

In the Mission Sequence, the following characters are not allowed in string literals:

- some non-printable characters (NUL, SUB) (hex: 00, 1A)
- line termination characters (LF, CR) (hex: 0A, 0D)
- percent character ("%") (hex: 25)

Quotes are generally optional, but are mandatory in Initialization if the string contains whitespace, any script language symbols, or any GMAT-recognized elements (e.g. keywords, resource names). They are mandatory in the Mission Sequence in the same instances, and additionally if the string contains mathematical operators and certain non-printable characters. We recommend quoting all string literals.

Booleans

The following boolean values are supported:

- `true` (alias: `on`)
- `false` (alias: `off`)

Boolean literals are case-insensitive.

Enumerated Values

Many resource fields accept enumerated values. For example, **Spacecraft**.**DateFormat** accepts one of 10 values (**A1ModJulian**, **A1Gregorian**, etc.). Enumerated values are written as string literals. Quotes are always optional, as none contain spaces or special characters.

References

References to resources and resource parameters are indicated by the name of the resource or resource parameter. References are written as string literals. Quotes are always optional, as resource names and parameters cannot contain spaces or special characters.

Resources

Resource Types

Resources in GMAT are instances of a base resource type that are given user-defined names and store data independently of other resources of the same type. Resource types include **Spacecraft**, **GroundStation**, and **Variable**. They cannot be used directly; they must first be instantiated with the **Create** statement. For example:

```
Create Spacecraft aSat
```

In the example, `Spacecraft` is the resource type and `aSat` is the resource. This is similar to the concept of classes and objects in object-oriented programming, where GMAT's resource types are analogous to classes and its resources are analogous to objects.

Naming Rules

Resources must be named according to these rules:

- Name must be made up of ASCII letters, numbers, or the underscore character (“`_`”). This corresponds to hex values 30–39, 41–5A, 5F, and 61–7A.
- Name must begin with a letter (`A`–`Z` or `a`–`z`, hex: 41–5A or 61–7A)
- Name cannot be a reserved keyword or command name

Shadowing

When the same name is used for multiple purposes in a script, the shadowing rules apply to determine how a reference to the name is interpreted.

Resource names must be unique within a script. If a script attempts to create multiple resources that have the same case-sensitive name, the first **Create** statement in the script with that name is executed and all subsequent ones are ignored. The conflict is noted in a warning message.

Command names and keywords are reserved. They cannot be used as resource names. See the Keywords section for a list of keywords.

Built-in function names (like `sin` or `cos`) can be used as resource names with one exception: a reference to, for example, “`sin(1)`” on the right-hand side of an equal sign will be interpreted as a call to the `sin` built-in function, not element 1 of an **Array** resource named **sin**. The same is true for the other built-in functions.

Resource type names (like “**Spacecraft**”) can be used as resource names. In such an instance, the conflict is resolved by the context. For example:

```
Create Spacecraft Spacecraft
Create Spacecraft aSat
```

In the example, GMAT knows by context that in the second **Create** statement, the argument “`Spacecraft`” refers to the resource type, not the resource instance created in the first statement.

Compound Types

Array of Literals

Arrays of literals are accepted as input by some resources. Arrays of booleans, integers, and real numbers are surrounded by square brackets (“[“ and “]”, hex: 5B and 5D). Arrays of strings are surrounded by curly brackets (“{“ and “}”, hex: 7B and 7D). In all cases, the values are separated by whitespace or commas. Only one-dimensional arrays of literals are supported. See the following examples.

```
anOrbitView.DrawObject = [true true]           % boolean array
aSat.OrbitColor = [255 0 0]                    % integer array
anOrbitView.ViewPointVector = [3e4, 1.2, -14]  % real array
aSpacecraft.OrbitSpiceKernelName = ...
    {'file1.bsp', 'file2.bsp'}                 % string array
```

Arrays of References

Some resources accept arrays of references to other resources or resource fields. These reference arrays are surrounded by curly brackets ("{" and "}", hex: 7B and 7D) and the values are separated by whitespace or commas. Only one-dimensional arrays of references are supported. The values can optionally be surrounded by single quotes. See the following example.

```
aForceModel.PointMasses = {'Luna', Mars}  % array of resource references
aReport.Add = {Sat1.X, 'Sat1.Y', Sat1.Z}  % array of parameter references
```

Conversion

In contexts that accept a real number, integer literals (those with no fractional value) are automatically converted to the equivalent floating-point value upon execution.

There is no built-in conversion between string values and numeric values, though such a conversion may be implemented by individual commands.

Keywords

The script language recognized these reserved keywords:

- `Create`
- `GMAT`
- `function`

In addition, all command names are reserved, including commands created by active plugins.

Expressions

The only types of expressions common to multiple commands are logical expressions, which are used by the **If**/**Else** and **While** commands. They are documented here instead of in both command references.

Relational Operators

The following relational operators are supported in logical expressions:

`<`	less than
`<=`	less than or equal to
`>`	greater than
`>`	greater than or equal to
`==`	equal to
`~=`	not equal to

The relational operators are scalar operators; they do not operate on **Array** resources (only individual elements).

Each relational operator operates on the values of its arguments, not on their identity. Consider the example:

```
Create Variable x y
x = 5
y = 5

BeginMissionSequence

If x == y
    % body
EndIf
```

Logical Operators

The following logical operators are supported in logical expressions:

`&`	logical AND (short-circuit operator)
`|`	logical OR

The logical AND operator exhibits short-circuit behavior. That is, if the left-hand side of the operator evaluates to false, the right-hand side is not evaluated, though it is still parsed for syntactic validity.

Logical Expressions

Logical expressions are composed of relational expressions combined with logical operators.

Relational expressions must contain one relational operator and two valid arguments. Literal boolean values are not supported, and numeric values are not interpreted as truth or falsehood. See the following examples:

```
1 == 5          % false
1 ~= 5          % true
true            % error
1               % error
A               % where "A" is an Array resource; error
1 == 5 <= 3     % error
```

Logical expressions must contain at least one relational expression. Multiple relational expressions are combined using logical operators. All relational expressions are evaluated first, from left to right, then the full logical expression is evaluated from left to right, though the short-circuit AND operator (“**&**”) may terminate the full evaluation. Parentheses are not allowed. See the following examples:

```
1 == 1                   % true
2 ~= 4 | 3 == 3          % true
8 >= 3 & 3 < 4           % true
2 < 4 & 1 > 3 | 5 == 5   % true
2 < 4 & (1 > 3 | 5 == 5) % error
1 & 1                    % error
true | false             % error
```

Statements

Statement Structure

Script statements consist of (in order):

1. Optional "`GMAT `" prefix
2. Valid statement syntax (with optional line continuation)
3. Optional semicolon
4. Line termination sequence

Any statement in the script may be prefixed by the characters "`GMAT `". This prefix is optional and has no effect, but is supported for backward compatibility.

A statement can be split over multiple physical lines by using the line continuation marker, three sequential period characters ("`...`", hex: 2E2E2E), before each line break within the statement.

Any statement may be terminated with a semicolon character ("`;`", hex: 3B). The semicolon is optional and has no effect, but is supported for backward compatibility. Multiple statements cannot be combined on a line.

White space may occur before or after a statement, or between any of the components listed above. It is also generally allowed anywhere inside of a statement, and any exceptions are noted in the documentation specific to that statement.

The Create Statement

The **Create** statement is a special statement that creates resources and assigns them names. It is only valid in the Initialization section of the script. It has the following components:

1. `Create` keyword
2. Resource type
3. Resource name(s)

The `Create` keyword indicates the start of the statement. It is followed by the resource type, which indicates the type of resource to create. This is followed by a resource name, a user-defined name that is then used to refer to that particular resource. This name must follow the resource naming rules, listed previously.

The only exception to this syntax is when creating an **Array** resource, in which case the dimension of the resource must also be specified

Multiple resource names are allowed, in which case multiple resources of the same type will be created. Multiple names are separated by white space or by commas ("`,`", hex: 2C).

See the following examples:

```
Create Spacecraft aSat  % creates a resource "aSat" of type Spacecraft
Create ForceModel aFM
Create Propagator aProp
Create Variable x y     % creates two Variable resources: "x" and "y"
Create String s1, s2    % creates two String resources: "s1" and "s2"
Create Array A[2,2]     % creates a 2x2 Array resource named "A"
```

Initialization Statements

Initialization statements are special statements that assign initial values to resource fields. They are only valid in the Initialization section of the script, and generally take the following form:

```
resource.field = value
```

Some fields, like those on ForceModel resources, have a multiple-dotted form:

```
ForceModel.GravityField.PrimaryBody.Degree = value
```

All initialization statements are composed of the following elements:

1. Resource name
2. Period character ("`.`", hex: 2E)
3. Field name, potentially in multiple-dotted form
4. Equal character ("`=`", hex: 3D)
5. Initial field value

The resource name must refer to a resource created previously in same script.

The field name must refer to a valid field that exists for the associated resource type. Parameters cannot be set with an initialization statement, though it is valid to set a dual-mode field (one that can also be a parameter). Fields and parameters are listed in the documentation for each resource type.

All values are taken literally; no evaluation is performed. Therefore, numeric and string values must be specified as literals, and resource names and parameters are stored as references. See the following example:

```
Create Spacecraft aSat
Create XYPlot aPlot
Create Variable x y z

x = 7100                     % valid
aSat.X = 7100                % valid
aSat.X = 7100 + 2            % error (mathematical expression)

aSat.X = x                   % error (field accepts literal, and variable
                             % evaluation does not occur)
aPlot.XVariable = x          % valid (field accepts reference to Variable x)
aPlot.YVariables = {y, z}    % valid (field accepts array of references to
                             % Variables y and z)
```

For backwards compatibility, there is one exception to the literal-value rule: **Spacecraft** resources can copied with an initialization statement like:

```
Create Spacecraft aSat1 aSat2
aSat2 = aSat1                          % Valid only for Spacecraft resources
```

Fields that have no assigned value in the Initialization section of the script remain at their default values, as specified in the documentation for each resource type.

Command Statements

Command statements invoke GMAT commands. They must appear in the Mission Sequence section of the script. One special command, **BeginMissionSequence**, initiates the Mission Sequence.

Command statements are displayed by the GUI as individual line items in the Mission tree. The only exception is the **BeginScript/EndScript** compound command; this is displayed as a single **ScriptEvent** item by the GUI.

Command statements are composed of the following elements:

1. Command name (except assignment commands)
2. Optional label
3. Command arguments

The command name is the name of the command being invoked (e.g. **Propagate** or **BeginFiniteBurn**). The command name is mandatory with one exception: the assignment command is indicated by its structure ("*`LHS = RHS`*") instead of its name.

A command label is an optional string literal that can be added immediately after the command name. This label is used by the GUI to "name" the statement in the Mission tree, and is intended for a short text description to aid the user. It must be single-quoted, whether or not it contains spaces. The command label may contain any ASCII character except certain non-printable characters (NUL, SUB), line termination characters (LF, CR), the percent sign ("`%`"), and the single quote ("`'`"). If the command label is omitted, the Mission tree statement is given a default label made up of the command name and an ID number. For example, if the third **Propagate** command in the script is unlabeled, it will be given the default label "**Propagate3**".

The command arguments control the behavior of the command. The syntax of the arguments is specified by each command individually, and is documented separately. Some commands, such as **Stop**, have no arguments.

See the following example:

```
Propagate 'Prop to periapsis' aProp(aSat) {aSat.Periapsis}
```

In the example, "`Propagate`" is the command name, "`'Prop to periapsis'`" is the command label, and "`aProp(aSat) {aSat.Periapsis}`" is the argument string.

Compound Statements

Compound statements are command statements that control the execution of other command statements. Compound statements are composed of three elements:

1. Begin statement
2. Body
3. End statement

The begin statement carries the name of the command itself, while the end statement begins with the string "End". For example, the **While** command is a compound command composed of two statements:

```
While ['label'] arguments
    [body]
EndWhile
```

The **If/Else** compound command is composed of three statements:

```
If ['label'] arguments
    [body]
Else
    [body]
EndIf
```

The body of a compound command may consist of independent command statements, possibly including other compound statements. Certain compound commands may limit the commands that can be present in the body, while other commands may only be contained within certain compound commands. These limitations are documented separately for each command.

Processing

GMAT processes a script in two phases: interpretation and execution. This section gives an overview of the processing sequence; low-level details are documented in Chapter 17 of the GMAT Architectural Specification.

Interpretation

GMAT interprets a script in two stages: a parsing stage and a validation stage. In the parsing stage, GMAT reads and interprets each line of the script sequentially. As it interprets a line, it checks it for syntactic correctness and performs any initialization needed by the line. For example, if the line being interpreted is a **Create** statement, the related resource is created. If GMAT encounters an initialization line, it assigns the appropriate value to the indicated resource field. And if it encounters a command statement, it creates the command structure and interprets its arguments. All language, resource initialization, and command syntax errors are caught during this parsing stage.

In the validation stage, GMAT checks that all references between resources are valid. For example, if the script indicates that a **Spacecraft** resource should be defined in relation to a specific **CoordinateSystem** resource, the reference is validated during this stage. The validation checks that all referenced resources exist and are of the correct type.

The two-stage interpretation method affects the order of statements in the script. For example, **Create** statements must appear in the script above any initialization statements that reference the resource being created. But because validation is performed separately, the **Create** statement for a **CoordinateSystem** resource can appear in the script below an initialization line that references this resource. See the following examples:

```
Create Spacecraft aSat

% This is valid; the aSat resource has been created by the line above.
aSat.DateFormat = TAIGregorian

% This is invalid; the aReport resource has not yet been created.
aReport.Filename = 'report.txt'
Create ReportFile aReport
```

```
Create XYPlot aPlot

% This is valid; the reference to aSat is validated
% after all resources are created.
aPlot.XVariable = aSat.A1ModJulian
```

```
Create Spacecraft aSat
```

Once both stages have completed, the script has been loaded into GMAT. In the GUI, if any, the Resources tree is populated with the resources created in the Initialization section of the script, and the Mission tree is populated with the command statements in the Mission Sequence.

The interpretation phase is also sometimes called the “build” phase or the “load” phase.

Execution

When a mission is run, GMAT first builds interconnections between resources, then performs command execution. In this phase, all commands in the Mission Sequence are executed sequentially, in the order of definition in the script. When a command statement is executed, its arguments are fully processed by the command, and any remaining errors are reported. Examples of execution-phase errors include mismatched data types, out-of-bounds array references, and divide-by-zero errors.

Processing Errors

If GMAT encounters an error during the interpretation stage (parsing or validation), the mission is not loaded. Instead, GMAT reverts to a minimum mission consisting of:

- **SolarSystem**
- Default **CoordinateSystem** resources: **EarthMJ2000Eq**, **EarthMJ2000Ec**, **EarthFixed**, **EarthICRF**

If an error is encountered during the execution stage (linking or command execution), execution of the mission stops at the point of the error.

Startup File

The `gmat_startup_file.txt` configuration file

Description

The GMAT startup file (`gmat_startup_file.txt`) contains basic configuration settings for the GMAT application. This includes the locations of data files and plugins, search paths for user-defined functions, and various options that control execution.

The startup file must be located in the same location as the GMAT executable, and must be named `gmat_startup_file.txt`. GMAT loads the startup file once during program initialization.

File Format

Basic Syntax

The startup file is a text file containing characters from the 7-bit US-ASCII character set. The startup file is case-sensitive.

Lines are terminated by any of the following ASCII character sequences:

- line feed (hex: 0A)
- carriage return (hex: 0D)
- carriage return followed by line feed (hex: 0D0A)

White space can appear above or below any line and before or after any key or value. The following characters are recognized as white space:

- space (hex: 20)
- horizontal tab (hex: 09)

Comments begin with the number sign (“`#`”) and must appear on their own line. Inline comments are not allowed.

Setting Properties

Properties are specified via key-value pairs, with the following syntax:

```
PROPERTY = VALUE
```

Properties are one word, with no spaces. Values extend from the first non-whitespace character after the equal sign to the end of the line. At least one whitespace character is required on both sides of the equal sign.

Properties are named according to the following conventions:

- Properties that accept directory paths end with “`_PATH`”.
- Properties that accept file paths end with “`_FILE`”.

The behavior of duplicate property entries is dependent on the individual property. In general:

- Multiple `PLUGIN` entries cause GMAT to load each named plugin.
- Multiple identical `*_FUNCTION_PATH` entries add each path to the search path, starting with the first.
- Multiple identical `*_FILE` entries are ignored; the last value is used.

Accessing Property Values

The value of any property ending in "_PATH" (including custom ones) can be referenced by other values. To reference a value, include the property name as part of the value. Repeated slash characters are collapsed. For example:

```
ROOT_PATH = ../
OUTPUT_PATH = ROOT_PATH/output/
```

sets `OUTPUT_PATH` to a value of `"../output/"`.

File Paths

Forward slashes and backslashes can be used interchangeably, and can be mixed in a single path. The following three paths are considered identical:

```
data/planetary_ephem/spk/de421.bsp
data\planetary_ephem\spk\de421.bsp
data\planetary_ephem/spk\de421.bsp
```

Absolute paths are passed to the underlying operating system as-is, aside from normalizing the slashes.

Relative paths are relative to the location of the GMAT executable.

Properties

The available properties are shown here, with default values where appropriate.

System

`ROOT_PATH=../`
: Path to GMAT root directory.

Plugins

`PLUGIN`
: Path to plugin library, without extension. Multiple `PLUGIN` properties are allowed, one per plugin.

Output

`EPHEM_PATH=`*`OUTPUT_PATH/`*
: Default output directory path for **EphemerisFile** resources.

`LOG_FILE=`*`OUTPUT_PATH`*`/GmatLog.txt`
Path of application log file

`MEASUREMENT_PATH=`*`OUTPUT_PATH/`*
Path of simulated measurement data files. Only used with the `libGmatEstimation` plugin.

`OUTPUT_PATH=../output/`
Output directory path for **ReportFile** resources.

`SCREENSHOT_FILE=`*`OUTPUT_PATH`*`/OUTPUT_PATH`
Output path and base filename for screenshots. The base filename is appended with "`_###.png`", where "`###`" is a number sequence starting from `001`. If the base filename is missing, it defaults to "`SCREEN_SHOT`".

Data Files

`CELESTIALBODY`*`_POT_PATH=`*`DATA_PATH`*`/gravity/`*`celestialbody/`
Search path for gravity potential files for *`CELESTIALBODY`*. *`CELESTIALBODY`* is the name of any celestial body defined in a given GMAT mission. This property has no default for user-defined celestial bodies.

`DATA_PATH=`*`ROOT_PATH`*`/data/`
Path to directory containing data files.

`DE_PATH=`*`DATA_PATH`*`/planetary_ephem/de/`
Path to directory containing DE ephemeris files.

`DE405_FILE=`*`DE_PATH`*`/leDE1941.405`
Path to DE405 DE-file ephemeris file.

`DE421_FILE`
Path to DE421 DE-file ephemeris file.

`DE424_FILE`
Path to DE424 DE-file ephemeris file.

`EGM96_FILE=`*`EARTH_POT_PATH`*`/EGM96.cof`
Path to EGM-96 Earth gravity potential file.

`EOP_FILE`
Path to IERS "EOP 08 C04 (IAU1980)" Earth orientation parameters file.

`ICRF_FILE`
Path to data required for computing rotation matrix from FK5 to ICRF (`ICRF_Table.txt`).

`JGM2_FILE=`*`EARTH_POT_PATH`*`/JGM2.cof`
Path to JGM-2 Earth gravity potential file.

`JGM3_FILE=`*`EARTH_POT_PATH`*`/JGM3.cof`
Path to JGM-3 Earth gravity potential file.

`LEAP_SECS_FILE=`*`TIME_PATH`*`/tai-utc.dat`
Path to cumulative leap seconds file from `http://maia.usno.navy.mil`.

`LP165P_FILE=`*`LUNA_POT_PATH`*`/LP165P.cof`
Path to LP165P Moon gravity potential file.

`LSK_FILE=`*`TIME_PATH`*`/naif0010.tls`
Path to SPICE leap second kernel.

`MARS50C_FILE=`*`MARS_POT_PATH`*`/Mars50c.cof`
Path to Mars50c Mars gravity potential file.

`MGNP180U_FILE=`*`VENUS_POT_PATH`*`/MGNP180U.cof`
Path to MGNP180U Venus gravity potential file.

NUTATION_COEFF_FILE=*PLANETARY_COEFF_PATH*/NUTATION.DAT
: Path to nutation series data for FK5 reduction (`NUTATION.DAT`).

PLANETARY_COEFF_PATH=*DATA_PATH*/planetary_coeff/
: Path to directory containing planetary coefficient files.

PLANETARY_SPK_FILE
: Path to SPICE ephemeris kernel for default celestial bodies.

SPK_PATH
: Path to directory containing SPICE ephemeris kernels

TIME_PATH=*DATA_PATH*/time/
: Path to directory containing leap-second files.

Application Files

CELESTIALBODY_TEXTURE_FILE=*TEXTURE_PATH*/DefaultTextureFile.jpg
: Path to texture file for CELESTIALBODY. CELESTIALBODY is the name of any of the built-in celestial bodies in GMAT. DefaultTextureFile is the default texture file defined for that celestial body.

CONSTELLATION_FILE=*STAR_PATH*/inp_Constellation.txt
: Path to constellation catalog.

GUI_CONFIG_PATH=*DATA_PATH*/gui_config/
: Path to directory containing GUI configuration files.

HELP_FILE
: Path to help file.

ICON_PATH=*DATA_PATH*/graphics/icons/
: Path to directory containing application icons.

MAIN_ICON_FILE
: Path to GUI icon.

MODEL_PATH=*DATA_PATH*/vehicle/models/
: Path to directory containing 3D spacecraft models.

PERSONALIZATION_FILE=*DATA_PATH*/gui_config/MyGmat.ini
: Path to GUI configuration and history file.

SPACECRAFT_MODEL_FILE=*MODEL_PATH*/aura.3ds
: Path to default Spacecraft 3D model file.

SPLASH_FILE=*SPLASH_PATH*/GMATSplashScreen.tif
: Path to GUI splash image.

SPLASH_PATH=*DATA_PATH*/graphics/splash/
: Path to directory containing splash file.

STAR_FILE=*STAR_PATH*/inp_StarCatalog.txt
: Path to star catalog.

STAR_PATH=*DATA_PATH*/graphics/stars/
: Path to directory containing star and constellation catalogs.

TEXTURE_PATH=*DATA_PATH*/graphics/texture/
: Path to directory containing celestial body texture files.

Program Settings

MATLAB_MODE=SHARED
: MATLAB interface connection mode. The available options are:

NO_MATLAB

Disables the MATLAB interface.

SHARED

Each GMAT instance shares a single MATLAB connection. Default.

SINGLE

Each GMAT instance uses its own MATLAB connection.

WRITE_GMAT_KEYWORD=ON

Write "`GMAT `" prefix before assignment lines when saving a GMAT script file. Accepted values are `ON` and `OFF`.

Debug Settings

DEBUG_PARAMETERS=OFF

Write table of available parameters to log file on startup. Accepted values are `ON` and `OFF`.

HIDE_SAVEMISSION=TRUE

Hide the **SaveMission** command from the GUI. Accepted values are `TRUE` and `FALSE`.

PLOT_MODE

XYPlot window placement mode. The only accepted value is `TILE`, which will cause GMAT to ignore plot window placement fields and tile the windows.

RUN_MODE

GMAT execution mode. The available options are:

EXIT_AFTER_RUN

When GMAT is called with the `-r` or `--run` command-line argument, automatically exit after the run is finished.

TESTING

Shows testing options in the GUI.

TESTING_NO_PLOTS

Same as `TESTING`, but also disables all graphical output in the GUI.

Release Notes

GMAT R2014a Release Notes

The General Mission Analysis Tool (GMAT) version R2014a was released May 2014. This is the first public release since April 2013, and is the 8th release for the project.

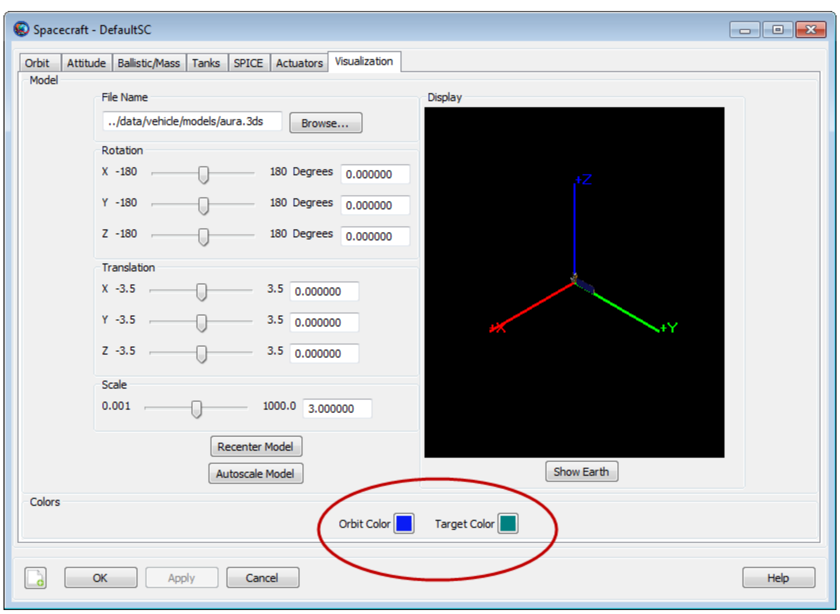
Below is a summary of key changes in this release. Please see the full R2014a Release Notes on JIRA for a complete list.

New Features

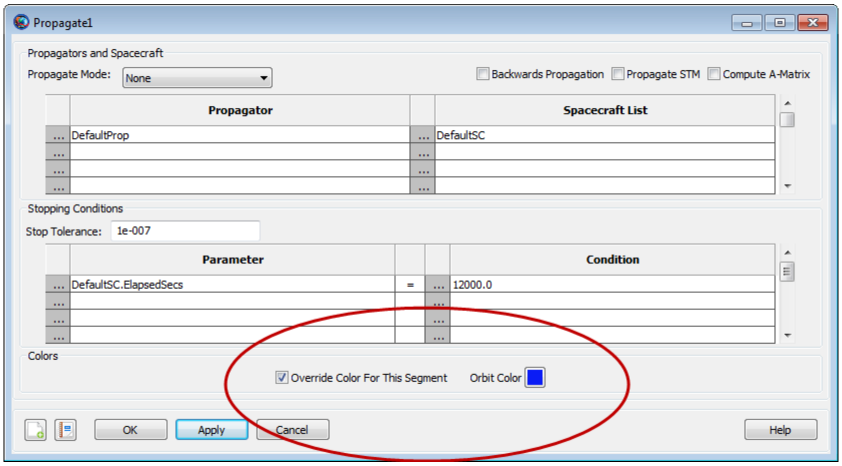
Trajectory Colors and Labels

In GMAT R2014a, you can now specify colors for each segment of your trajectory independently, so you can clearly see where a segment begins and ends. This can help define portions of a trajectory, such as before or after maneuvers. All color handling has also been moved from the graphics resources (**OrbitView** and **GroundTrackPlot**) to the resources and commands controlling the trajectory (e.g. **Spacecraft**, **Planet**, **Propagate**).

On Spacecraft, the color specification has moved to the Visualization tab. See the circled area in the screenshot below. Colors for celestial bodies (**Planet**, **Moon**, **Asteroid**, etc.) are specified similarly.



The trajectory color associated with a particular trajectory segment can be changed by changing the color for that particular **Propagate** command. It will override the color for the Spacecraft being propagated for that segment only, and it will return to the default color afterwards.



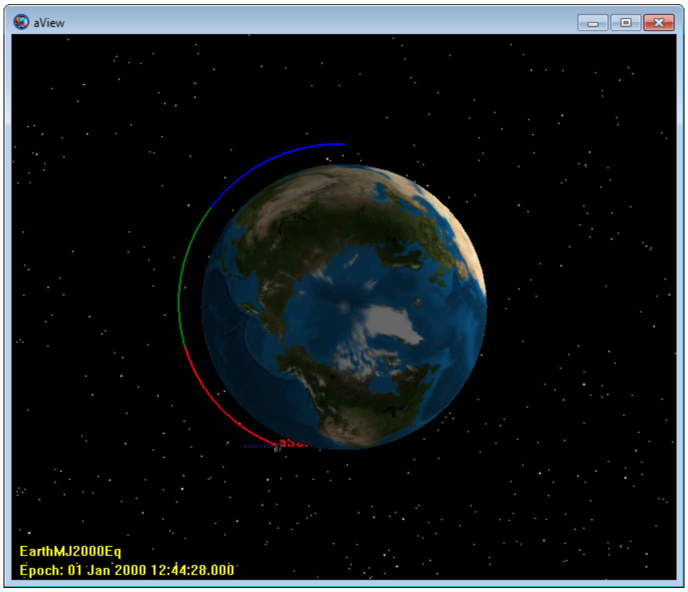
Additionally, colors can now be specified either by name (`'Blue'`) or by RGB value (`[0 0 255]`).

This release also adds participant labels in the graphics as well. As long as **OrbitView**.**ShowLabels** is enabled, each celestial body or **Spacecraft** in the plot will show its name next to it.

See the following example:

```
Create Spacecraft aSat
aSat.OrbitColor = 'Blue'

Create Propagator aProp

Create OrbitView aView
aView.Add = {aSat, Earth}
aView.XYPlane = off
aView.Axes = off
aView.EnableConstellations = off
aView.ShowLabels = on

BeginMissionSequence
% plots in blue
Propagate aProp(aSat) {aSat.ElapsedSecs = 900}
aSat.OrbitColor = 'Green'
% plots in green
Propagate aProp(aSat) {aSat.ElapsedSecs = 900}
 % plots in red
Propagate aProp(aSat) {aSat.ElapsedSecs = 900, OrbitColor = Red}
```

This example results in the following image:



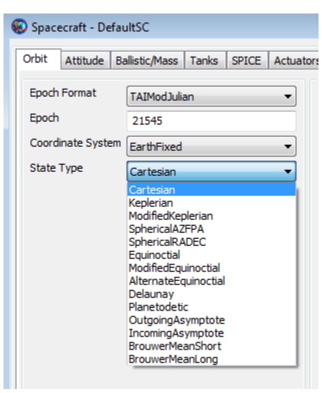
See the Color reference, as well as the individual Spacecraft, CelestialBody, Propagate, and OrbitView references, for more information.

New Orbit State Representations

GMAT now supports six new common orbit state representations, developed with support by the Korean Aerospace Research Institute (KARI). The new representations are:

- Long- and short-period Brouwer-Lyddane mean elements (**BrouwerMeanLong** and **BrouwerMeanShort**)
- Incoming and outgoing hyperbolic asymptote elements (**IncomingAsymptote** and **OutgoingAsymptote**)
- Modified equinoctial elements (**ModifiedEquinoctial**)
- Alternate equinoctial elements (**AlternateEquinoctial**)
- Delaunay elements (**Delaunay**)
- Planetodetic elements, when using a body-fixed coordinate system (**Planetodetic**)

The new representations are available as options in the **Spacecraft** "**State Type**" list, and as options to the **Spacecraft.DisplayStateType** field.



See the Spacecraft Orbit State reference for more information.

New Attitude Models

GMAT now supports three new kinematic attitude models, developed with support by the Korean Aerospace Research Institute (KARI). The new representations are:

- Precessing spinner
- Nadir pointing
- CCSDS Attitude Ephemeris Message (AEM)

The new representations are available as options in the **Spacecraft "Attitude"** list, and as options to the **Spacecraft.DisplayStateType** field.

See the Spacecraft Attitude reference for more information.

Dynamics and Model Improvements

GMAT now supports several new dynamics models and a new numerical integrator.

- Prince Dormand 853 integrator. See the Propagator reference for more information.
- Mars-GRAM density model. See the Propagator reference for more information.
- High-fidelity, attitude dependent SRP dynamics model. See the Propagator reference, and the Spacecraft Ballistic and Mass Properties reference for more information.

Targeting and Optimization Improvements

- There are new boundary value solver options on **DifferentialCorrector** (**Broyden**, and **ModifiedBroyden**). Brodyen's method and modified Broyden's method usually take more iterations but fewer function evaluations than **NewtonRaphson** and so are often faster. See the Differential Corrector reference for more information.
- There are new parameters that check for convergence of solvers. See the Calculation Parameters reference for more information.

Below is a script example that illustrates the new algorithm and parameter options.

```
Create Spacecraft aSat
Create Propagator aPropagator

Create ImpulsiveBurn aBurn
Create DifferentialCorrector aDC
%  This algorithm is often faster, as is ModifiedBroyden
aDC.Algorithm = Broyden

Create OrbitView EarthView
EarthView.Add = {Earth,aSat}
EarthView.ViewScaleFactor = 5

Create ReportFile aReport
```

```
BeginMissionSequence

%  Report targeter status here
Report aReport aDC.SolverStatus aDC.SolverState
Target aDC
    Vary aDC(aBurn.Element1 = 1.0, {Upper = 3, MaxStep = 0.4})
    Maneuver aBurn(aSat)
    Propagate aPropagator(aSat,{aSat.Apoapsis})
    Achieve aDC(aSat.RMAG = 42164)
EndTarget
%  Report targeter status here
Report aReport aDC.SolverStatus aDC.SolverState
```

Improvements

Dependencies in Assignment Command

You can now define settable parameters by using a dependency on the LHS of an assignment command:

```
Create Spacecraft aSat

BeginMissionSequence

aSat.EarthFixed.X = 7000
aSat.EarthMJ2000Eq.VZ = 1
```

Other Improvements

- You can now set true retrograde orbits when using the Keplerian representation.
- You can now use the quaternion Rvector parameter on the right hand side of an assignment command.
- You can now use a **Spacecraft** body fixed coordinate system as the coordinate system for an **OrbitView**.
- The number of **Spacecraft** that that can be displayed in **OrbitView** is no longer limited to 30.
- The documentation for **OrbitView** has been significantly expanded. See the Orbit View reference for details.
- You can now save an XY plot graphics window to an image file.
- The supported set of keyboard shortcuts has been greatly expanded. See the Keyboard Shortcuts reference for more information.
- You can now use many more common ASCII characters in GMAT strings.
- You can now generate orbit state command summary reports using coordinate systems that have any point type as the origin of the selected coordinate system. Previously the origin had to be a **Celestial Body**.

Compatibility Changes

- Color settings for **Resources** displayed in graphics are now configured on the **Resource** and via the **Propagate** command. **OrbitColor** and **TargetColor** fields on graphics resources are no longer used.. See the Spacecraft Visualization reference, and Propagate command reference for details.

- AtmosDensity is now reported in units of kg/km^3. See the Calculation Parameter reference for details.

Known & Fixed Issues

Over 123 bugs were closed in this release. See the "Critical Issues Fixed in R2014a" report for a list of critical bugs and resolutions in R2014a. See the "Minor Issues Fixed for R2014a" report for minor issues addressed in R2014a.

Known Issues

All known issues that affect this version of GMAT can be seen in the "Known Issues in R2014a" report in JIRA.

There are several known issues in this release that we consider to be significant:

ID	Description
GMT-2561	UTC Epoch Entry and Reporting During Leap Second is incorrect.
GMT-3043	Inconsistent validation when creating variables that shadow built-in math functions
GMT-3108	OrbitView with STM and Propagate Synchronized does not show spacecraft in correct locations
GMT-3289	First step algorithm fails for backwards propagation using SPK propagator
GMT-3350	Single-quote requirements are not consistent across objects and modes
GMT-3556	Unable to associate tank with thruster in command mode
GMT-3629	GUI starts in bad state when started with --minimize
GMT-3669	Planets not drawn during optimization in OrbitView
GMT-3738	Cannot set standalone FuelTank, Thruster fields in CallMatlabFunction
GMT-4520	Unrelated script line in Optimize changes results (causes crash)
GMT-4408	Failed to load icon file and to open DE file
GMT-4520	Coordinate System Fixed attitudes are held constant in SPAD SRP model during a propagation step

GMAT R2013b Release Notes

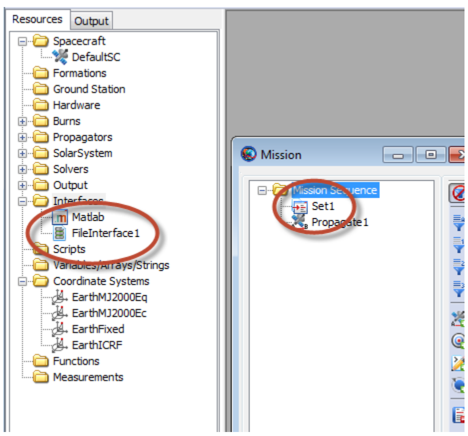
The General Mission Analysis Tool (GMAT) version R2013b was released in August 2013. This is the first public release since April, and is the 7th release for the project. This is an internal-only release, intended to support the ACE mission.

Below is a summary of key changes in this release. Please see the full R2013b Release Notes on JIRA for a complete list.

New Features

Data File Interface

GMAT now can load **Spacecraft** state and physical properties data directly from a data file. A new resource, **FileInterface**, controls the interface to the data file, and the new **Set** command lets you apply the data as a part of the Mission Sequence.



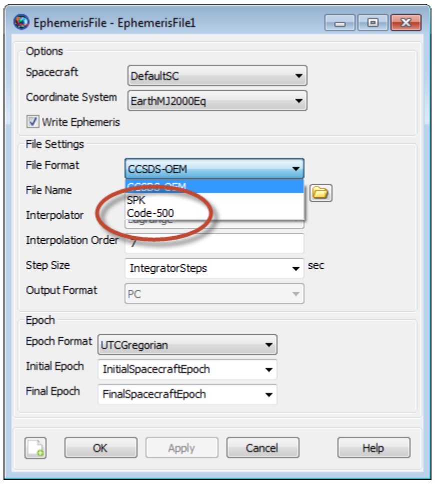
See the following example:

```
Create Spacecraft aSat
Create FileInterface tvhf
tvhf.Filename = 'statevec.txt'
tvhf.Format = 'TVHF_ASCII'

BeginMissionSequence

Set aSat tvhf
```

See the FileInterface and Set references for more information.

Code-500 Ephemeris Format

GMAT's **EphemerisFile** resource can now write a Code-500 format ephemeris file. The Code-500 format is a binary ephemeris format defined by the NASA Goddard Space Flight Center Flight Dynamics Facility.

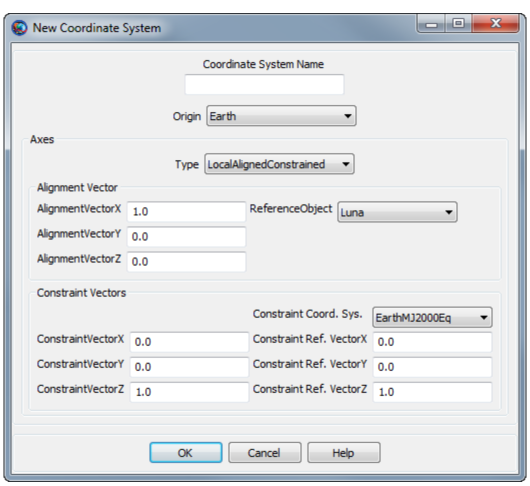



```
Create Spacecraft sc
Create Propagator prop
Create EphemerisFile ephem
ephem.Spacecraft = sc
ephem.Filename = 'ephem.eph'
ephem.FileFormat = 'Code-500'
ephem.StepSize = 60
ephem.OutputFormat = 'PC'

BeginMissionSequence

Propagate prop(sc) {sc.ElapsedDays = 1}
```

See the EphemerisFile reference for more information on this format.

New Local Aligned-Constrained Coordinate System

A local aligned-constrainted coordinate system is one defined by an alignment vector (defined based on the position of a reference object with respect to the origin) and two constraint vectors. This is a highly flexible coordinate system that can be defined in many ways, depending on mission needs. To use it, select the **LocalAlignedConstraned** axes type when creating a new **CoordinateSystem**.



```
Create CoordinateSystem ACECoordSys
ACECoordSys.Origin = Earth
ACECoordSys.Axes = LocalAlignedConstrained
ACECoordSys.ReferenceObject = ACE
ACECoordSys.AlignmentVectorX = 0
ACECoordSys.AlignmentVectorY = 0
ACECoordSys.AlignmentVectorZ = 1
ACECoordSys.ConstraintVectorX = 1
ACECoordSys.ConstraintVectorY = 0
ACECoordSys.ConstraintVectorY = 0
ACECoordSys.ConstraintCoordinateSystem = EarthMJ2000Ec
ACECoordSys.ConstraintReferenceVectorX = 0
ACECoordSys.ConstraintReferenceVectorY = 0
ACECoordSys.ConstraintReferenceVectorZ = 1
```

See the CoordinateSystem reference for more information.

Improvements

Force Model Parameters

You can now access **ForceModel**-dependent parameters, such as **Spacecraft** acceleration and atmospheric density. The new parameters are:

- `*Spacecraft*.*ForceModel*.Acceleration`
- `*Spacecraft*.*ForceModel*.AccelerationX`
- `*Spacecraft*.*ForceModel*.AccelerationY`
- `*Spacecraft*.*ForceModel*.AccelerationZ`
- `*Spacecraft*.*ForceModel*.AtmosDensity`

Space Point Parameters

All Resources that have coordinates in space now have Cartesian position and velocity parameters, so you can access ephemeris information. This includes all built-in solar system bodies and other Resources such as **CelestialBody**,**Planet**, **Moon**, **Asteroid**, **Comet**, **Barycenter**, **LibrationPoint**, and **GroundStation** :

- `*CelestialBody*.*CoordinateSystem*.X`
- `*CelestialBody*.*CoordinateSystem*.Y`
- `*CelestialBody*.*CoordinateSystem*.Z`
- `*CelestialBody*.*CoordinateSystem*.VX`
- `*CelestialBody*.*CoordinateSystem*.VY`
- `*CelestialBody*.*CoordinateSystem*.VZ`

Note that to use these parameters, you must first set the epoch of the Resource to the desired epoch at which you want the data. See the following example:

```
Create ReportFile rf

BeginMissionSequence

```

```
Luna.Epoch.A1ModJulian = 21545
Report rf Luna.EarthMJ2000Eq.X Luna.EarthMJ2000Eq.Y Luna.EarthMJ2000Eq.Z ...
      Luna.EarthMJ2000Eq.VX Luna.EarthMJ2000Eq.VY Luna.EarthMJ2000Eq.VZ
```

Compatibility Changes

- `EphemerisFile.InitialEpoch` now cannot be later than `EphemerisFile.FinalEpoch`. See the EphemerisFile reference for details.
- When `EphemerisFile.FileFormat` is set to `'SPK'`, `EphemerisFile.CoordinateSystem` must have `MJ2000Eq` as the axis system. Other axis systems are no longer allowed with this ephemeris format. See the EphemerisFile reference for details.
- The deprecated fields `Thruster.Element{1-3}` have been removed. Use `Thruster.ThrustDirection{1-3}` instead. See the Thruster reference for details.
- Tab characters in strings are now treated literally, instead of being changed to spaces. See GMT-3336 for details.

Known & Fixed Issues

Over 50 bugs were closed in this release. See the "Critical Issues Fixed in R2013b" report for a list of critical bugs and resolutions in R2013b. See the "Minor Issues Fixed for R2013b" report for minor issues addressed in R2013b.

Known Issues

All known issues that affect this version of GMAT can be seen in the "Known Issues in R2013b" report in JIRA.

There are several known issues in this release that we consider to be significant:

ID	Description
GMT-2561	UTC Epoch Entry and Reporting During Leap Second is incorrect.
GMT-3043	Inconsistent validation when creating variables that shadow built-in math functions
GMT-3108	OrbitView with STM and Propagate Synchronized does not show spacecraft in correct locations
GMT-3289	First step algorithm fails for backwards propagation using SPK propagator
GMT-4097	Ephemeris File is Not Chunking File At Some Discontinuty Types
GMT-3350	Single-quote requirements are not consistent across objects and modes
GMT-3556	Unable to associate tank with thruster in command mode
GMT-3629	GUI starts in bad state when started with --minimize
GMT-3669	Planets not drawn during optimization in OrbitView
GMT-3738	Cannot set standalone FuelTank, Thruster fields in CallMatlabFunction
GMT-3745	SPICE ephemeris stress tests are not writing out ephemeris for the entire mission sequence

GMAT R2013a Release Notes

The General Mission Analysis Tool (GMAT) version R2013a was released in April, 2013. This is the first public release since May 23, 2012, and is the 6th public release for the project. R2013a is a major release transitioning GMAT from beta to production status. In this release:

- End-user documentation was rewritten and greatly expanded.
- 11,000 script-based regression tests run nightly.
- 5,000 GUI-based regression tests run weekly.
- Code and documentation was contributed by 11 developers from 3 organizations.

Licensing

GMAT is now licensed under Apache License, Version 2.0. According to the Open Source Proliferation Report, the Apache License 2.0 is one of the most widely-used open source licenses, thereby making GMAT compatible with more existing software and projects.

Major Improvements

Production Status

Release R2013a is a major release of GMAT that transitions from beta to production status. Most of our efforts have been devoted to improving the quality of the software and its documentation. This year we made a complete sweep through the system, starting by updating engineering specifications for all features, identifying test gaps, writing new tests, addressing known and newly found bugs, and completing user documentation.

Tutorials

The GMAT User Guide now contains 5 in-depth tutorials that show how to use GMAT for end-to-end analysis. The tutorials are designed to teach you how to use GMAT in the context of performing real-world analysis and are intended to take between 30 minutes and several hours to complete. Each tutorial has a difficulty level and an approximate duration listed with any prerequisites in its introduction, and is arranged in a general order of difficulty. The simplest tutorial shows you how to enter orbital initial conditions and propagate to orbit perigee, while more advanced tutorials show how to perform finite-maneuver targeting, Mars B-plane targeting, and lunar flyby optimization.

Reference Guide

We have written a complete reference manual for GMAT for R2013a. The reference manual contains detailed information on all GMAT components. Whether you need detailed information on syntax or application-specific examples, go here. For each GMAT resource (e.g. **Spacecraft**, **Thruster**, **XYPlot**) and command (e.g. **Optimize**, **Propagate**), the following information is documented:

- Brief description of the feature
- List of related or coupled features
- Complete syntactical specification of the interface
- Tables with detailed options, variable ranges and data types, defaults, and expected behavior
- Copy-and-paste-ready examples

The guide also contains general reference material about the system, such as:

- Script language syntax
- External interfaces
- Parameter listings
- Configuration files
- Command line interface

Testing

We have spent much of our time preparing for R2013a on testing. Our script and GUI-based regression test systems doubled in size in the last year. They now contain:

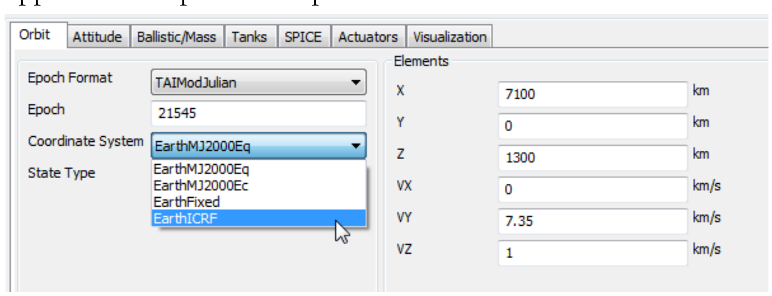
- Over 6,000 new system, validation, and end-to-end script-based tests
- 30 new end-to-end GUI tests
- 3,000 new GUI system tests

GUI test are performed using SmartBear's TestComplete software. Script tests are performed using a custom MATLAB-based automated test system. A complete execution of the regression test system now takes almost four days of computer time.

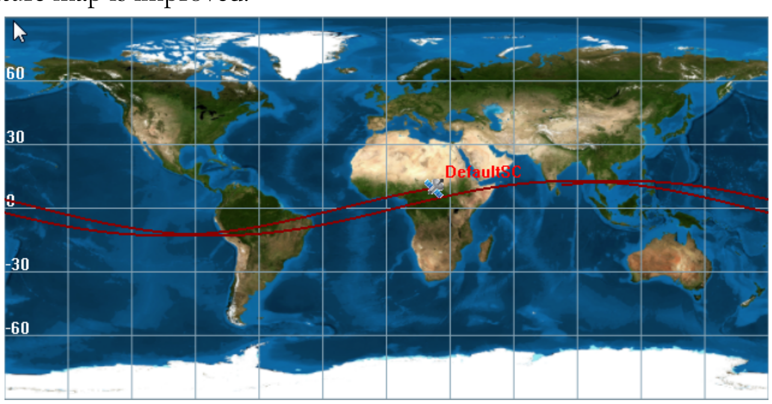
Minor Enhancements

While most of our effort has been focused on quality for this release, we have included some new features.

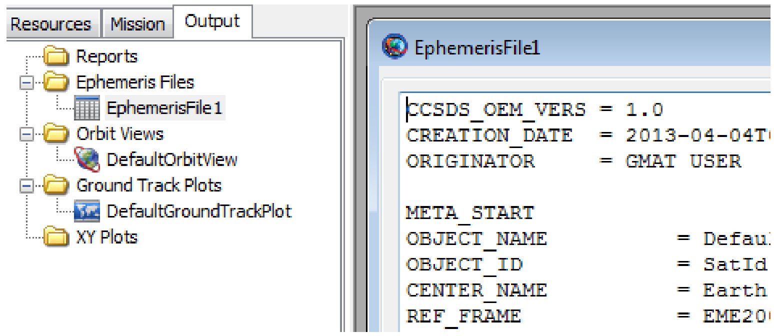
- ICRF is now supported for input and output of orbit state data:



- The Earth texture map is improved:



- CCSDS ephemeris files are now accessible in the output tab:



- Improved mouse controls for interactive 3-D graphics. See the OrbitView reference for details.
- Improved 3ds model support
- Improved error messages system-wide
- New **BodySpinSun** axis system for asteroid survey missions
- Improved system modularization by moving more features to plugins

Compatibility Changes

Our last release, R2012a, was beta software. R2013a is mature, production software. We made some changes that may cause backwards compatibility issues with scripts written in previous beta versions. Examples of changes in R2013a that affect backwards compatibility with previous beta versions include:

- Fixed many poorly-named fields and/or parameters (i.e. **OrbitView.CelestialPlane** → **OrbitView.EclipticPlane**)
- Corrected missed or invalid data validation checking
- Removed partially-implemented functionality from previous releases
- Removed improperly-exposed internal fields and functions
- Disabled configuration of some resources in the mission sequence

In all cases, we modified GMAT to work correctly as specified in the documentation, but did not always maintain backwards compatibility with previous versions. This was a one-time, "pull-of-the-Band-Aid" approach, and future releases will maintain backwards compatibility with R2013a or provide deprecation notifications of features that are no longer supported.

In addition, there were some features that did not meet quality expectations for this release and have been turned off in the release package. Most of these features can be turned on for analysis purposes, but they are not fully tested and should be used with caution.

- Orbit Designer (disabled)
- GMAT functions (`libGmatFunctions`)
- Save command (`libSaveCommand`)
- Bulirsh-Stoer integrator (`libExtraPropagators`)

To turn on these features, see the Startup File reference.

Known & Fixed Issues

Over 720 bugs and issues were closed in this release. See the "Critical Issues Fixed for R2013a" report for a list of critical bugs and resolutions for R2013a. See the "Minor Issues Fixed for R2013a" report" for minor issues addressed in R2013a.

Known Issues

All known issues that affect this version of GMAT can be seen in the "Known issues in R2013a" report in JIRA.

There are several known issues in this release that we consider to be significant:

ID	Description
GMT-2561	UTC Epoch Entry and Reporting During Leap Second is incorrect.
GMT-3043	Inconsistent validation when creating variables that shadow built-in math functions
GMT-3108	OrbitView with STM and Propagate Synchronized does not show spacecraft in correct locations
GMT-3289	First step algorithm fails for backwards propagation using SPK propagator
GMT-3321	MATLAB uses stale version of function if command window isn't restarted between runs
GMT-3350	Single-quote requirements are not consistent across objects and modes
GMT-3556	Unable to associate tank with thruster in command mode
GMT-3629	GUI starts in bad state when started with --minimize
GMT-3669	Planets not drawn during optimization in OrbitView
GMT-3738	Cannot set standalone FuelTank, Thruster fields in CallMatlabFunction
GMT-3745	SPICE ephemeris stress tests are not writing out ephemeris for the entire mission sequence

GMAT R2012a Release Notes

The General Mission Analysis Tool (GMAT) version R2012a was released May 23, 2012. This is the first public release in over a year, and is the 5th public release for the project. In this release:

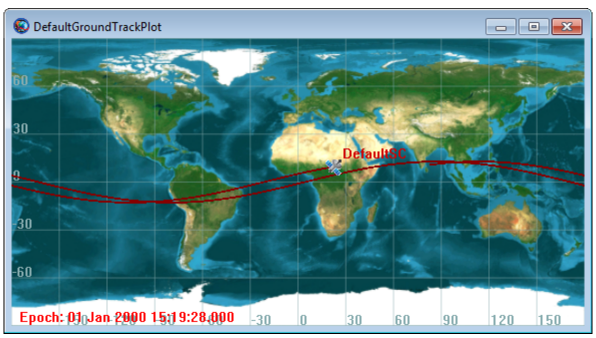
- 52,000 lines of code were added
- Code and documentation was contributed by 9 developers from 2 organizations
- 6847 system tests were run every weeknight

This is a beta release. It has undergone extensive testing in many areas, but is not considered ready for production use.

New Features

Ground Track Plot

GMAT can now show the ground track of a spacecraft using the new **GroundTrackPlot** resource. This view shows the orbital path of one or more spacecraft projected onto a two-dimensional map of a celestial body, and can use any celestial body that you have configured. Here's an example of the plot created as part of the default mission:



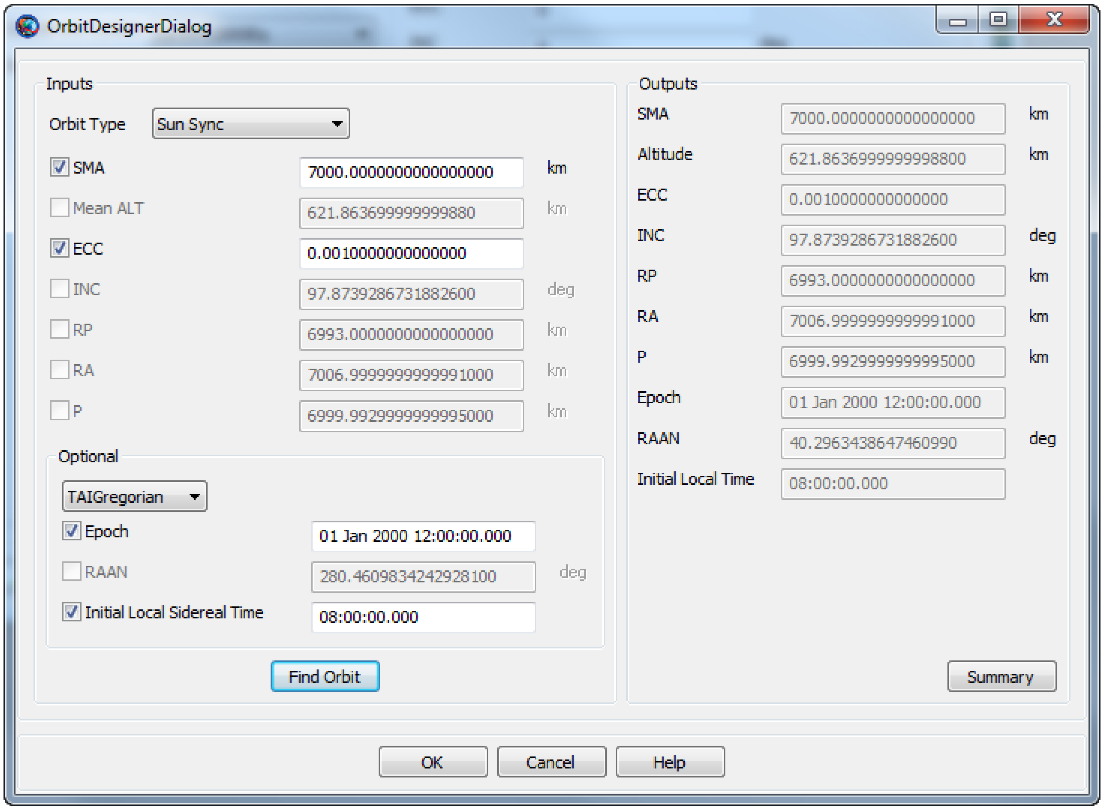
Orbit Designer

Sometimes you need to create a spacecraft in a particular orbit but don't exactly know the proper orbital element values. Before, you had to make a rough estimate, or go back to the math to figure it out. Now, GMAT R2012a comes with a new **Orbit Designer** that does this math for you.

The **Orbit Designer** helps you create one of six different Earth-centered orbit types, each with a flexible array of input options:

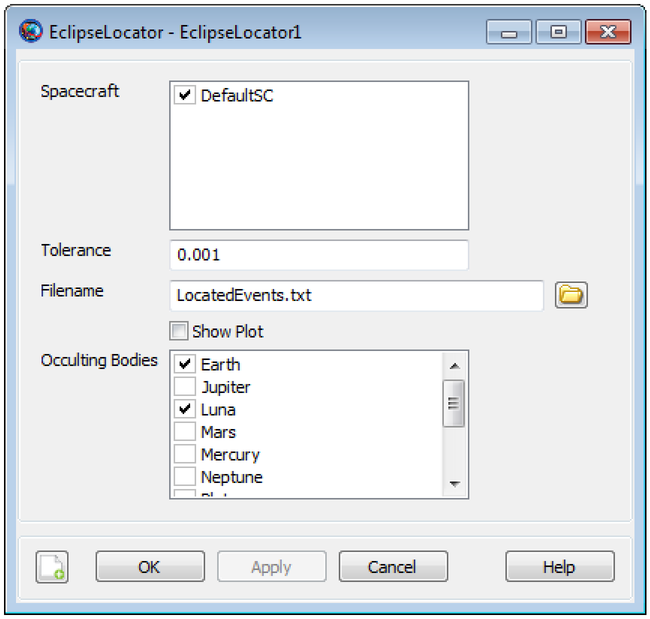
- sun-synchronous
- repeat sun-synchronous
- repeat ground track
- geostationary
- molniya
- frozen

Once you've created your desired orbit, it is automatically imported into the Spacecraft resource for later use. Here's an example of a sun-synchronous orbit using the Designer. To open the **Orbit Designer**, click the button on the **Spacecraft** properties window.



Eclipse Locator [alpha]

We've done significant work toward having a robust eclipse location tool in GMAT, but this work is not complete. This release comes with an alpha-stage plugin (disabled by default) called `libEventLocator`. When enabled, this plugin adds a new **EclipseLocator** resource that can be configured to calculate eclipse entry and exit times and durations with respect to any configured Spacecraft and celestial bodies. The eclipse data can be reported to a text file or plotted graphically. Some known limitations include an assumption of spherical celestial bodies and a lack of light-time correction. This feature has not been rigorously tested, and may be brittle. We've included it here as a preview of what's coming in future releases.



C Interface [alpha]

Likewise, we've included an experimental library and plugin that exposes a plain-C interface to GMAT's internal dynamics model functionality. This interface is intended to fill a very specific need: to expose force model derivates from GMAT to external software, especially MATLAB, for use with an external integrator (though GMAT can do the propagation also, if desired). The interface is documented by an API reference for now.

Improvements

Dynamics Models

We've made lots of improvements to GMAT's already capable force model suite. Here's some highlights:

- GMAT now models Earth ocean and pole tides. This is a script-only option that can be turned on alongside an Earth harmonic gravity model; turn it on with a line like this:

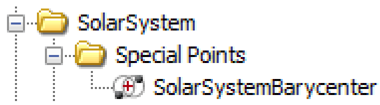
  ```
  ForceModel.GravityField.Earth.EarthTideModel = 'SolidAndPole'
  ```
- You can now apply relativistic corrections using the checkbox on the properties for **Propagator**.

Solar System

GMAT can now use the DE421 and DE424 ephemerides for the solar system. These files are included in the installer, but are not activated by default. To use either of these ephemerides, double-click the **SolarSystem** folder and select it from the **Ephemeris Source** list. Or include the following script line:

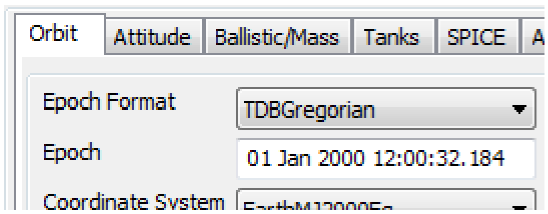
```
SolarSystem.EphemerisSource = 'DE421'
```

There's also a new **SolarSystem** resource called **SolarSystemBarycenter** that represents the barycenter as given by the chosen ephemeris source (DE405, DE421, SPICE, etc.). This resource can be used directly in reports or as the origin of a user-defined coordinate system.



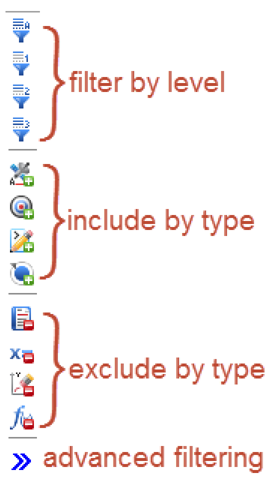
TDB Input

You can now input the epoch of a **Spacecraft** orbit in the TDB time system (in both Modified Julian and Gregorian formats).

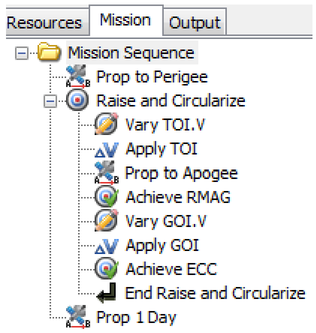


Mission Tree

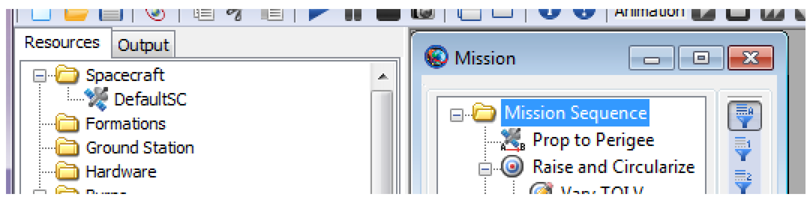
We've made significant improvements to the mission tree to make it more user-friendly to heavy users. The biggest improvement is that you can now filter the mission sequence in different ways to make complex missions easier to understand, for example by hiding non-physical events or collapsing the tree to only its top-level elements.



GMAT also now lets you name your mission sequence commands. Thus, instead of a sequence made up of commands like "Optimize1" and "Propagate3", you can label them "Optimize LOI" and "Prop to Periapsis". This example shows the `Ex_HohmannTransfer.script` sample with labeled commands.



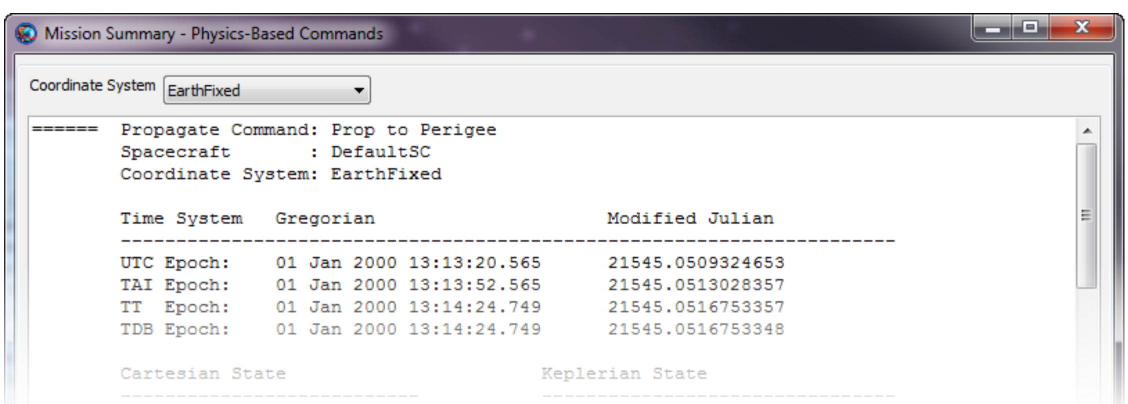
Finally, we added the ability to undock the mission tree so you can place it and the resources tree side by side and see both at the same time. To undock the tree, right-click the **Mission** tab and drag it from its docked position. To dock it again, just close the new **Mission** window.



Mission Summary

You can now change the coordinate system shown in the **Mission Summary** on the fly: just change the **Coordinate System** list at the top of the window and the numbers will update. This feature can use any coordinate system currently defined in GMAT, including user-defined ones.

There's also a new **Mission Summary - Physics-Based Commands** that shows only physical events (**Propagate** commands, burns, etc.), and further data was added to both **Mission Summary** types.



Window Persistency

The locations of output windows are now saved with the mission in the script file. This means that when running a mission, all the output windows that were open when the mission was last saved will reappear in their old positions.

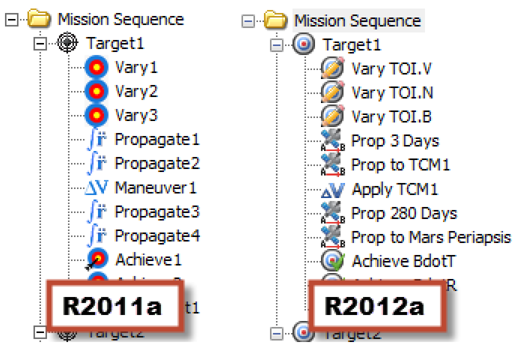
In addition, the locations of certain GMAT windows, like the mission tree, the script editor, and the application window itself are saved to the user preferences file (`MyGMAT.ini`).

Switch to Visual Studio on Windows

With this release, the official GMAT binaries for Windows are now compiled with Microsoft Visual Studio 2010 instead of GCC. The biggest benefit of this is in performance; we've seen up to a 50% performance improvement in certain cases in unofficial testing. It also leads to more a industry-standard development process on Windows, as the MinGW suite is no longer needed.

New Icons

The last release saw a major overhaul of GMAT's GUI icons. This time we've revised some and added more, especially in the mission tree.



Training Manual

The non-reference material in the GMAT User Guide has been overhauled, partially rewritten, and reformatted to form a new GMAT Training Manual. This includes the "Getting Started" material, some short how-to articles, and some longer tutorials. All of this information is included in the GMAT User Guide as well, in addition to reference material that is undergoing a similar rewrite later this year.

Infrastructure

The GMAT project has implemented several infrastructure improvements in the last year. The biggest of these was switching from our old Bugzilla system to JIRA for issue tracking.

This year also saw the creation of the GMAT Blog and the GMAT Plugins and Extensions Blog with a fair number of posts each, plus reorganizations for the wiki and the forums. We reactivated our two mailing lists, gmat-developers and gmat-users, but haven't seen much usage of each yet. And finally, we created a new mailing list, gmat-buildtest, for automated daily build and test updates.

Compatibility Changes

Application Control Changes

The command-line arguments for the GMAT executable have changed. See the following table for replacements.

Old	New	Description
`-help`	`--help`, `-h`	Shows available options
`-date`	`--version`, `-v`	Shows GMAT build date
`-ms`	`--start-server`	Starts GMAT server on startup
`-br` *`filename`*	`--run`, `-r` *`scriptname`*	Builds and runs the script
`-minimize`	`--minimize`, `-m`	Minimizes GMAT window
`-exit`	`--exit`, `-x`	Exits GMAT after a script is run

Script Syntax Changes

Resource	Field	Replacement
`ForceModel`	`Drag`	`Drag.AtmosphereModel`
`Propagator`	`MinimumTolerance (BulirschStoer)`	(none)

Known & Fixed Issues

Many bugs were closed in this release, but a comprehensive list is difficult to create because of the move from Bugzilla to JIRA. See the "Bugs closed in R2012a" report in for a partial list.

All known issues that affect this version of GMAT can be seen in the "Known issues in R2012a" report in JIRA.

GMAT R2011a Release Notes

The General Mission Analysis Tool (GMAT) version R2011a was released April 29, 2011 on the following platforms:

Windows (XP, Vista, 7)	Beta
Mac OS X (10.6)	Alpha
Linux	Alpha

This is the first release since September 2008, and is the 4th public release for the project. In this release:

- 100,000 lines of code were added
- 798 bugs were opened and 733 were closed
- Code was contributed by 9 developers from 4 organizations
- 6216 system tests were written and run nightly

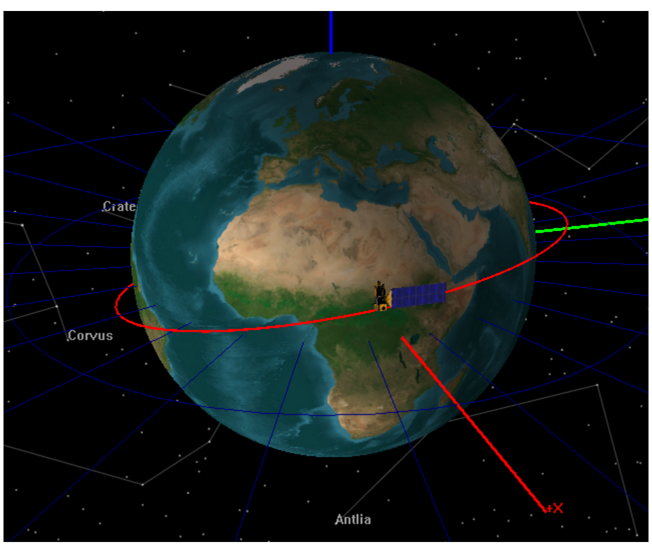
New Features

OrbitView

GMAT's old OpenGLPlot 3D graphics view was completely revamped and renamed OrbitView. The new OrbitView plot supports all of the features of OpenGLPlot, but adds several new ones:

- Perspective view instead of orthogonal
- Stars and constellations (with names)
- A new default Earth texture
- Accurate lighting
- Support for user-supplied spacecraft models in 3ds and POV formats.

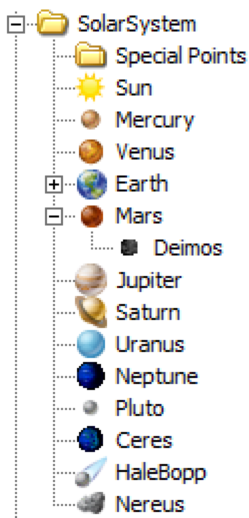
All existing scripts will use the new OrbitView object automatically, with no script changes needed. Here's a sample of what can be done with the new graphics:



User-Defined Celestial Bodies

Users can now define their own celestial bodies (Planets, Moons, Asteroids, and Comets) through the GMAT interface, by right-clicking on the Sun resource (for Planets, Asteroids, and Comets) or any other Solar System resource (for Moons). User-defined celestial bodies can be customized in many ways:

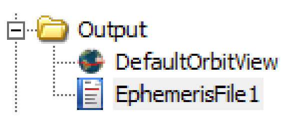
- Mu (for propagation), radius and flattening (for calculating altitude)
- User-supplied texture file, for use with OrbitView
- Ephemeris from two-body propagation of an initial Keplerian state or from a SPICE kernel
- Orientation and spin state



Ephemeris Output

GMAT can now output spacecraft ephemeris files in CCSDS-OEM and SPK formats by using the EphemerisFile resource. For each ephemeris, you can customize:

- Coordinate system
- Interpolation order
- Step size
- Epoch range



SPICE Integration for Spacecraft

Spacecraft in GMAT can now be propagated using data from a SPICE kernel rather than by numerical integration. This can be activated on the SPICE tab of the Spacecraft resource, or through the script. The following SPICE kernels are supported:

- SPK/BSP (orbit)
- CK (attitude)
- FK (frame)

- SCLK (spacecraft clock)

Plugins

New features can now be added to GMAT through plugins, rather than being compiled into the GMAT executable itself. The following plugins are included in this release, with their release status indicated:

libMatlabPlugin	Beta
libFminconOptimizer (Windows only)	Beta
libGmatEstimation	Alpha (preview)

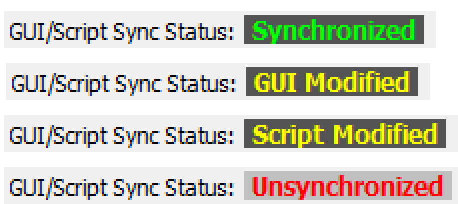
Plugins can be enabled or disabled through the startup file (`gmat_startup_file.txt`), located in the GMAT bin directory. All plugins are disabled by default.

GUI/Script Synchronization

For those that work with both the script and the graphical interface, GMAT now makes it explicitly clear if the two are synchronized, and which script is active (if you have several loaded). The possible states are:

- Synchronized (the interface and the script have the same data)
- GUI or Script Modified (one of them has been modified with respect to the other)
- Unsynchronized (different changes exist in each place)

The only state in which manual intervention is necessary is Unsynchronized, which must be merged manually (or one set of changes must be discarded). The following status indicators are available on Windows and Linux (on Mac, they appear as single characters on the GMAT toolbar).



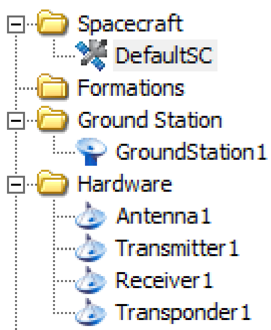
Estimation [Alpha]

GMAT R2011a includes significant new state estimation capabilities in the libGmatEstimation plugin. The included features are:

- Measurement models
  - Geometric
  - TDRSS range
  - USN two-way range
- Estimators
  - Batch
  - Extended Kalman
- Resources
  - GroundStation
  - Antenna

- Transmitter
- Receiver
- Transponder

> **Note**
>
> This functionality is alpha status, and is included with this release as a preview only. It has not been rigorously tested.



User Documentation

GMAT's user documentation has been completely revamped. In place of the old wiki, our formal documentation is now implemented in DocBook, with HTML, PDF, and Windows Help formats shipped with GMAT. Our documentation resources for this release are:

- Help (shipped with GMAT, accessed through the Help > Contents menu item)
- Online Help (updated frequently, http://gmat.sourceforge.net/docs/)
- Video Tutorials (http://gmat.sourceforge.net/docs/videos.html)
- Help Forum (http://gmat.ed-pages.com/forum/)
- Wiki (for informal and user-contributed documentation, samples, and tips: http://gmat.ed-pages.com/wiki/tiki-index.php)

Screenshot ( )

GMAT can now export a screenshot of the OrbitView panel to the output folder in PNG format.

Improvements

Automatic MATLAB Detection

MATLAB connectivity is now automatically established through the libMatlabInterface plugin, if enabled in your gmat_startup_file.txt. We are no longer shipping separate executables with and without MATLAB integration. Most recent MATLAB versions are supported, though configuration is necessary.

Dynamics Model Numerics

All included dynamics models have been thoroughly tested against truth software (AGI STK, and A.I. Solutions FreeFlyer, primarily), and all known numeric issues have been corrected.

Script Editor [Windows]

GMAT's integrated script editor on Windows is much improved in this release, and now features:

- Syntax highlighting for GMAT keywords
- Line numbering
- Find & Replace
- Active script indicator and GUI synchronization buttons

```

Create Spacecraft DefaultSC;
GMAT DefaultSC.DateFormat = TAIModJulian;
GMAT DefaultSC.Epoch = 21545;
GMAT DefaultSC.CoordinateSystem = EarthMJ2000Eq;
GMAT DefaultSC.DisplayStateType = Cartesian;
GMAT DefaultSC.X = 7100;
GMAT DefaultSC.Y = 0;
GMAT DefaultSC.Z = 1300;
GMAT DefaultSC.VX = 0;
GMAT DefaultSC.VY = 7.3499999999999996;
GMAT DefaultSC.VZ = 1;
GMAT DefaultSC.DryMass = 850;
GMAT DefaultSC.Cd = 2.2;
GMAT DefaultSC.Cr = 1.8;
GMAT DefaultSC.DragArea = 15;
GMAT DefaultSC.SRPArea = 1;
```

Regression Testing

The GMAT project developed a completely new testing system that allows us to do nightly, automated tests across the entire system, and on multiple platforms. The new system has the following features:

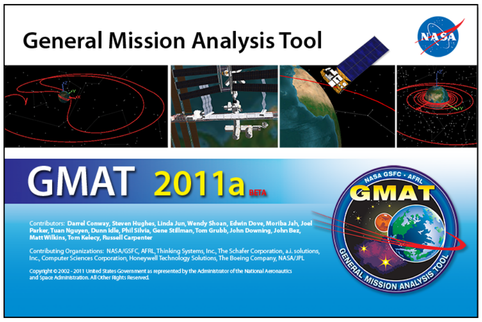
- Focused on GMAT script testing
- Written in MATLAB language
- Includes 6216 tests with coverage of most of GMAT's functional requirements
- Allows automatic regression testing on nightly builds
- Compatible with all supported platforms

The project is also regularly testing the GMAT graphical interface on Windows using the SmartBear TestComplete tool. This testing occurs approximately twice a week, and is focused on entering and running complete missions through the interface and checking that the results match those generated in script mode.

Visual Improvements

This release features numerous visual improvements, including:

- A new application icon and splash screen (shown below)
- Many new, professionally-created icons
- A welcome page for new users



Compatibility Changes

Platform Support

GMAT supports the following platforms:

- Windows XP
- Windows Vista
- Windows 7
- Mac OS X Snow Leopard (10.6)
- Linux (Intel 64-bit)

With the exception of the Linux version, GMAT is a 32-bit application, but will run on 64-bit platforms in 32-bit mode. The MATLAB interface was tested with 32-bit MATLAB 2010b on Windows, and is expected to support 32-bit MATLAB versions from R2006b through R2011a.

Mac: MATLAB 2010a was tested, but version coverage is expected to be identical to Windows.

Linux: MATLAB 2009b 64-bit was tested, and 64-bit MATLAB is required. Otherwise, version coverage is expected to be identical to Windows.

Script Syntax Changes

The `BeginMissionSequence` command will soon be required for all scripts. In this release a warning is generated if this statement is missing.

The following syntax elements are deprecated, and will be removed in a future release:

Resource	Field	Replacement
`DifferentialCorrector`	`TargeterTextFile`	`ReportFile`
`DifferentialCorrector`	`UseCentralDifferences`	`DerivativeMethod = "CentralDifference"`
`EphemerisFile`	`FileName`	`Filename`
`FiniteBurn`	`Axes`	
`FiniteBurn`	`BurnScaleFactor`	
`FiniteBurn`	`CoordinateSystem`	
`FiniteBurn`	`Origin`	
`FiniteBurn`	`Tanks`	

Resource	Field	Replacement
FiniteBurn ImpulsiveBurn	CoordinateSystem = "Inertial"	CoordinateSystem = "MJ2000Eq"
FiniteBurn ImpulsiveBurn	VectorFormat	
FiniteBurn ImpulsiveBurn	V N B	Element1 Element2 Element3
FuelTank	PressureRegulated	PressureModel = PressureRegulated
OpenGLPlot		OrbitView
OrbitView	EarthSunLines	SunLine
OrbitView	ViewDirection = Vector ViewDirection = [0 0 1]	ViewDirection = [0 0 1]
OrbitView	ViewPointRef	ViewPointReference
OrbitView	ViewPointRef = Vector ViewPointRefVector = [0 0 1]	ViewPointReference = [0 0 1]
OrbitView	ViewPointVector = Vector ViewPointVectorVector = [0 0 1]	ViewPointVector = [0 0 1]
SolarSystem	Ephemeris	EphemerisSource
Spacecraft	StateType	DisplayStateType
Thruster	X_Direction Y_Direction Z_Direction Element1 Element2 Element3	ThrustDirection1 ThrustDirection2 ThrustDirection3
XYPlot	Add	YVariable

Resource	Field	Replacement
XYPlot	Grid	ShowGrid
XYPlot	IndVar	XVariable

Command	Old Syntax	New Syntax
Propagate	Propagate - DefaultProp(sc)	Propagate BackProp DefaultProp(sc)

Fixed Issues

733 bugs were closed in this release, including 368 marked "major" or "critical". See the full report for details.

Known Issues

There remain 268 open bugs in the project's Bugzilla database, 42 of which are marked "major" or "critical". These are tabulated below.

Table 15. Multiple platforms

407	Multi-Matlab run bug
636	MATLAB Callbacks on Linux and Mac
648	DOCUMENT BEHAVIOR - Final orbital state does not match for the two report methods
776	Batch vs Individual Runs different
1604	Keplerian Conversion Errors for Hyperbolic Orbits
1668	Decimal marker not flexible enough for international builds
1684	MMS script in GMAT takes 300 times longer than similar run in FreeFlyer
1731	Major Performance issue in GMAT Functions
1734	Spacecraft allows conversion for singular conic section.
1992	Determinant of "large" disallowed due to poor algorithm performance
2058	Can't set SRP Flux and Nominal Sun via GUI
2088	EOP file reader uses Julian Day
2147	Empty parentheses "( )" are not caught in math validation
2313	Finite Burn/Thruster Tests Have errors > 1000 km but may be due to script differences
2322	DOCUMENT: MATLAB interface requires manual configuration by user
2344	when a propagator object is deleted, its associated force model is not deleted
2349	Performance Issue in Force Modelling
2410	Ephemeris propagator has large numeric error
2416	STM Parameters are wrong when using Coordinate System other than EarthMJ2000Eq

Table 16. Windows

970	Matlab connection issue
1012	Quirky Numerical Issues 2 in Batch mode
1128	GMAT incompatible with MATLAB R14 and earlier
1417	Some lines prefixed by "function" are ingored
1436	Potential performance issue using many propagate commands
1528	GMAT Function scripts unusable depending on file ownership/permissions
1580	Spacecraft Attitude Coordinate System Conversion not implemented
1592	Atmosphere Model Setup File Features Not Implemented
2056	Reproducibility of script run not guaranteed
2065	Difficult to read low number in Spacecraft Attitude GUI
2066	SC Attitude GUI won't accept 0.0:90.0:0.0 as a 3-2-1 Euler Angle input
2067	Apply Button Sometimes Not Functional in SC Attitude GUI
2374	Crash when GMAT tries to write to a folder without write permissions
2381	TestComplete does not match user inputs to DefaultSC
2382	Point Mass Issue when using Script vs. User Input

Table 17. Mac OS X

1216	MATLAB->GMAT not working
2081	Texture Maps not showing on Mac for OrbitView
2092	GMAT crashes when MATLAB engine does not open
2291	LSK file text ctrl remains visible when source set to DE405 or 2Body
2311	Resource Tree - text messed up for objects in folders
2383	Crash running RoutineTests with plots ON

Table 18. Linux

1851	On Linux, STC Editor crashes GMAT on Close
1877	On Linux, Ctrl-C crashes GMAT if no MDIChildren are open

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