Target Finite Burn to Raise Apogee

Audience	Intermediate level
Length	45 minutes
Prerequisite	Complete *Simulating an Orbit* and *Simple Orbit Transfer*
Script File	`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 **Finite Burn** resources
2. Create the **Differential Corrector** 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 fuel tank and then attach the newly created fuel tank 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 **Fuel Tank**. 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 1 below shows the default **FuelTank1** configuration that we will use and Figure 2 shows the finished **Thruster1** configuration.

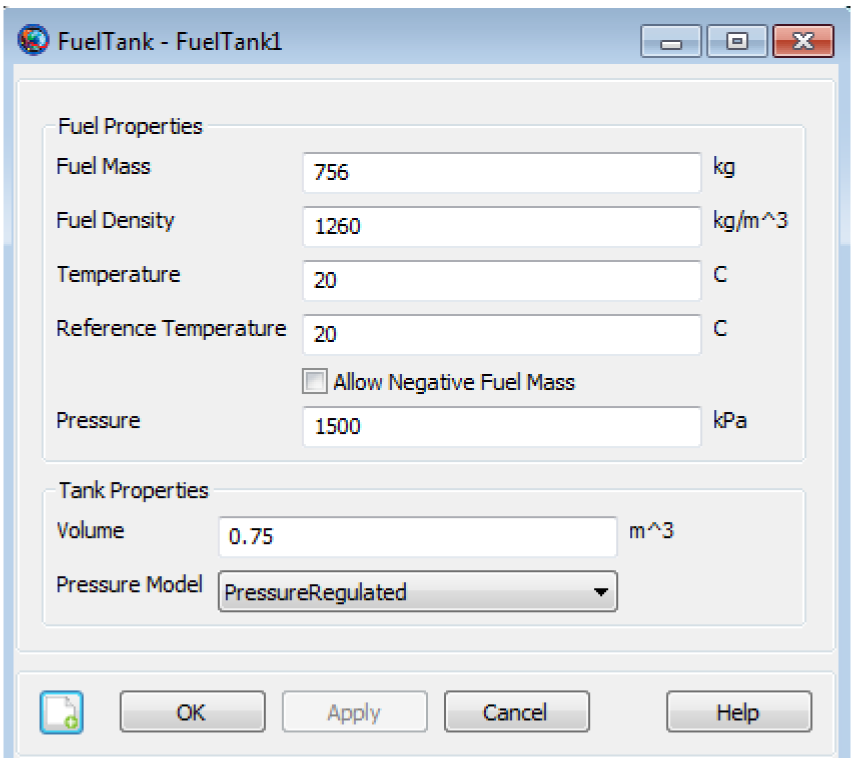


Figure 1. FuelTank1 Configuration

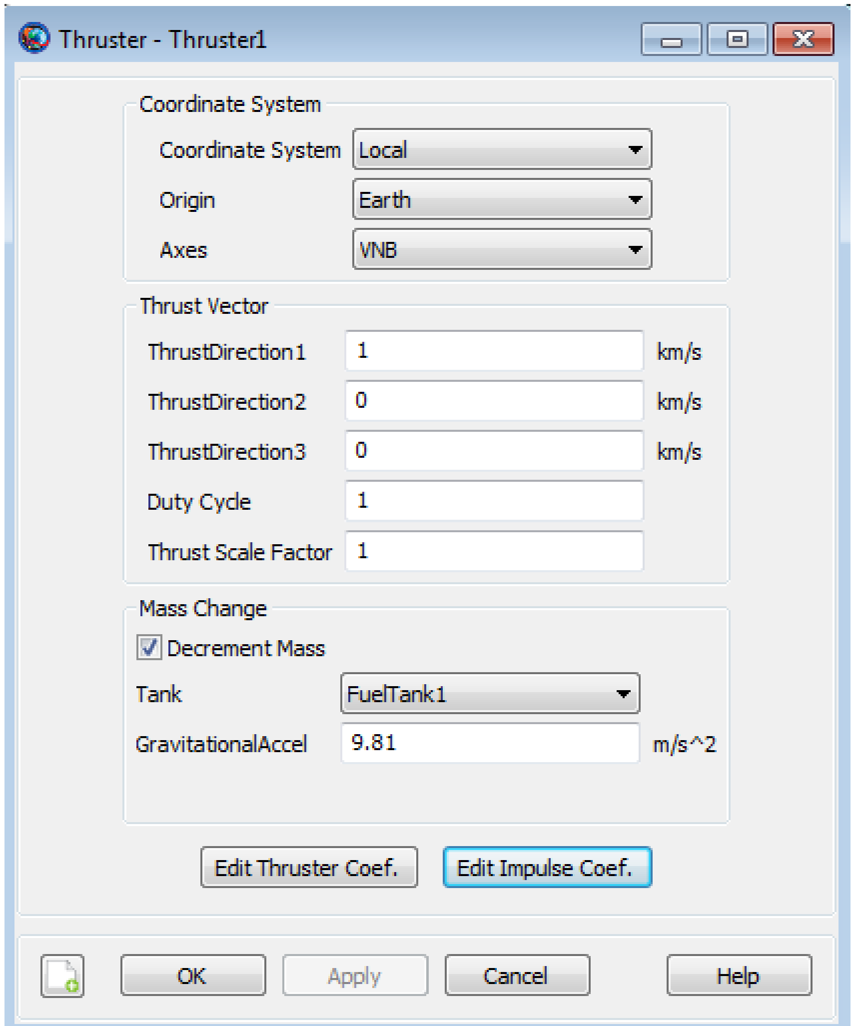


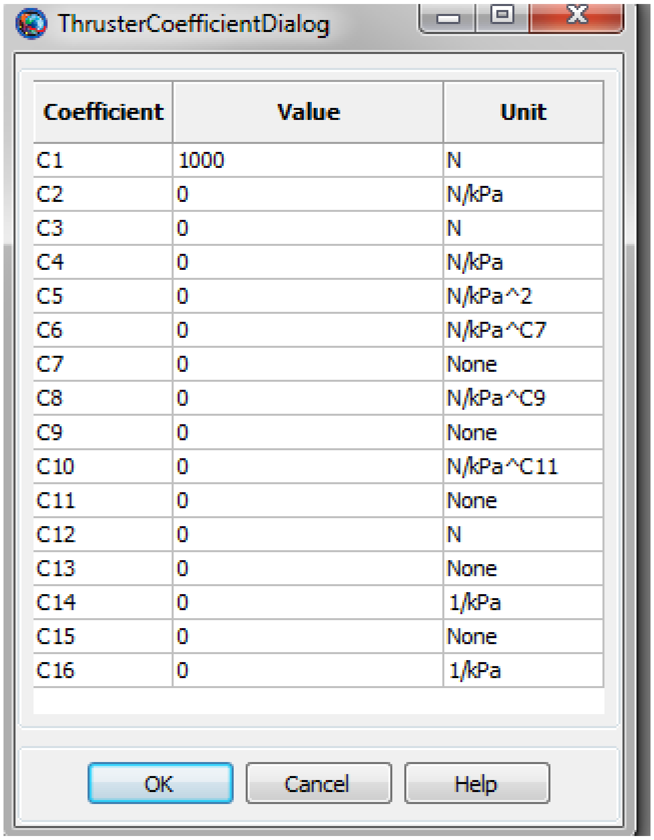
Figure 2. Thruster1 Configuration

Note that the default **Thruster1 Coordinate System**, as shown in Figure 2, 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 **Thruster** 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. Replace the default **C1** coefficient value of **10** with **1000**. Click **OK**.



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

Figure 3. 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 given 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**, select **FuelTank1**. Then click -> to add **FuelTank1** to the **SelectedTanks** list. Click **Apply**.
3. Select the **Actuators** tab. In the **Available Thrusters**, select **Thrurster1**. Then click -> to add **Thruster1** to the **SelectedThrusters** list. Click **OK**.

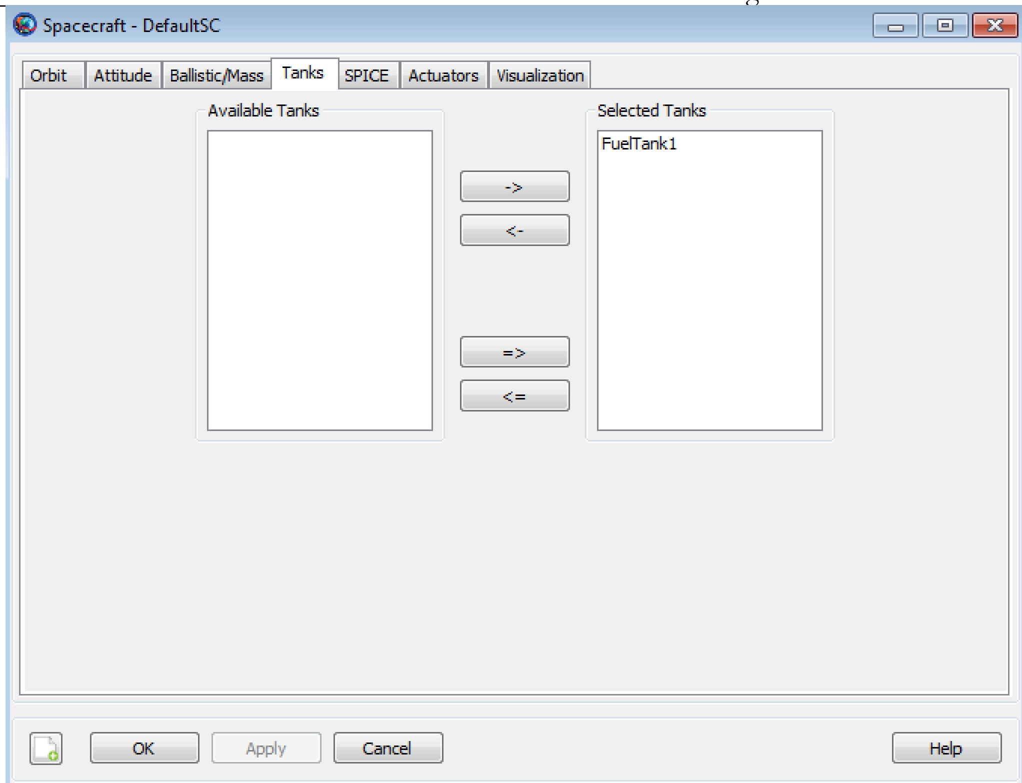


Figure 4. Attach FuelTank1 to DefaultSC

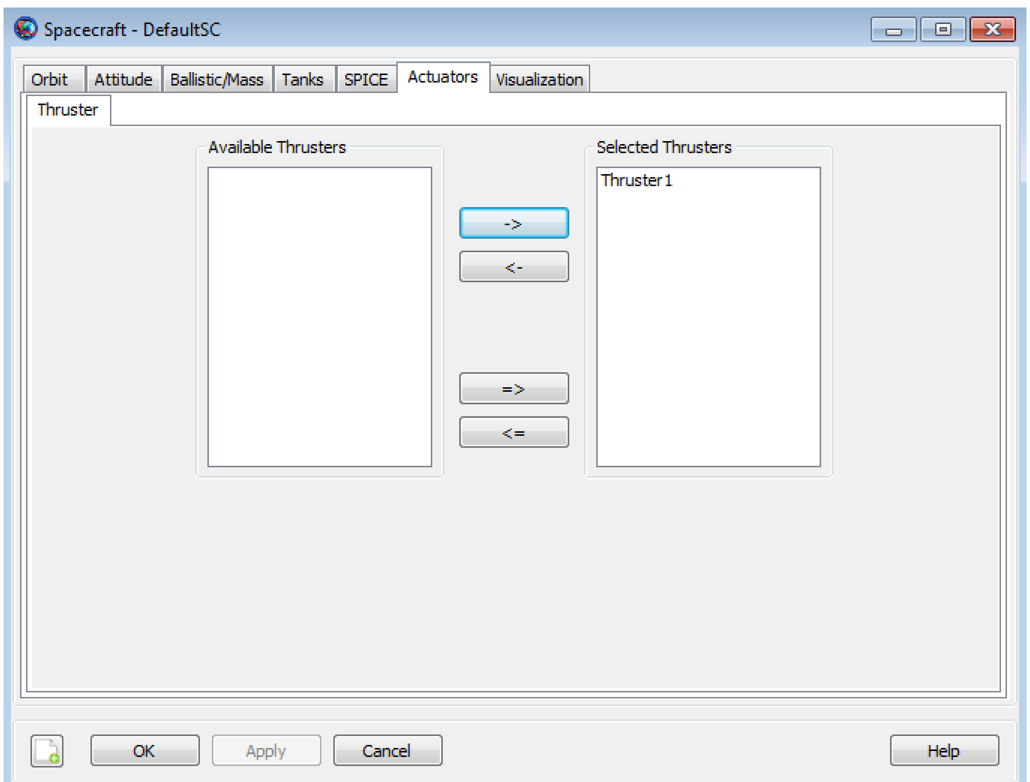


Figure 5. Attach Thruster1 to DefaultSC

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**.

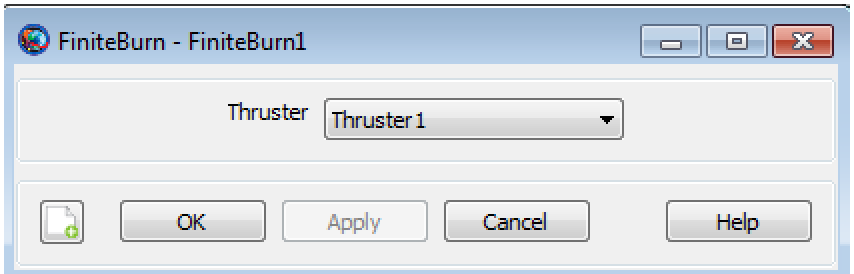


Figure 6. Creation of FiniteBurn Resource FiniteBurn1

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 **Create** (=>) button and then the **Close** button.
2. To verify that we have created this new variable correctly, double-click **BurnDuration** to view its properties.

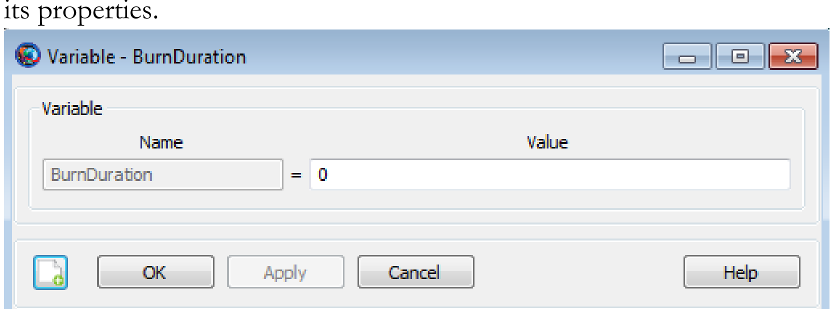


Figure 7. Creation of Variable Resource, BurnDuration

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`**.

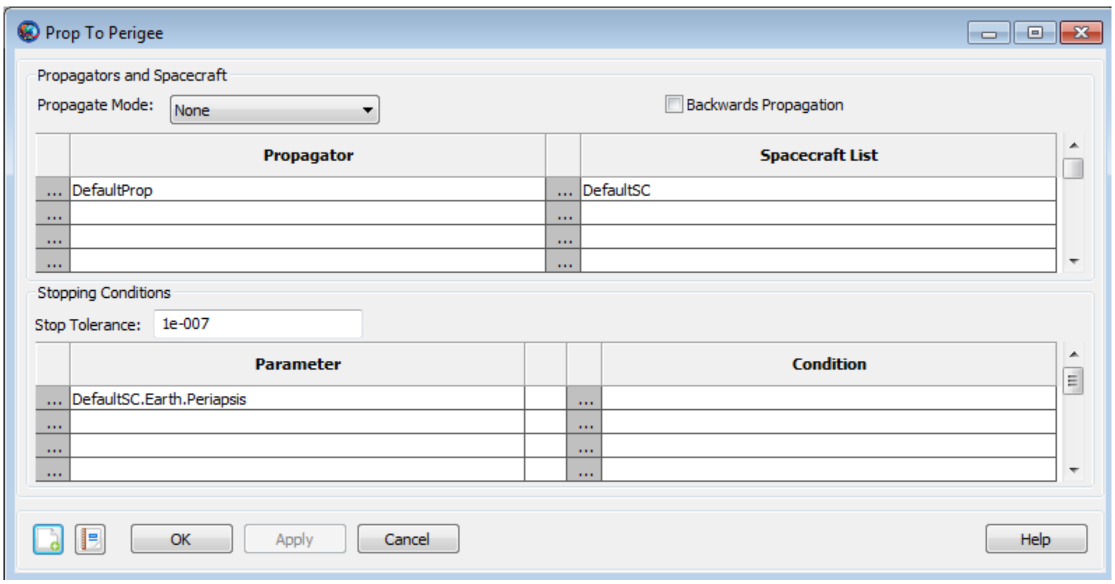


Figure 8. Prop To Perigee Command Configuration

Create the Target Sequence

Now create the commands necessary to perform the **Target** sequence. Figure 9 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.

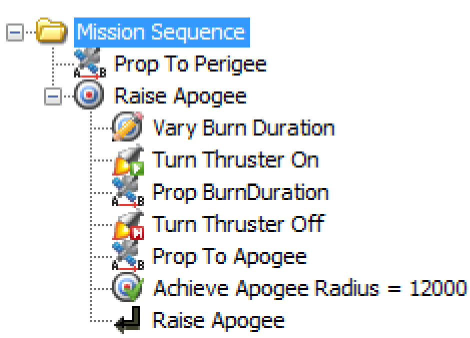


Figure 9. Final Mission Sequence

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 1.

Table 1. Additional Target Sequence Commands

Command	Name Maneuver
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.

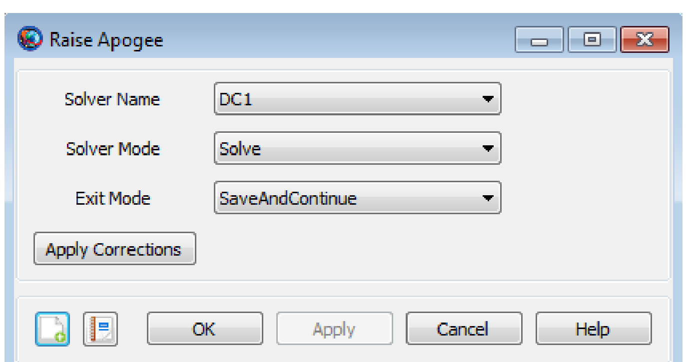


Figure 10. Raise Apogee Command Configuration

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.

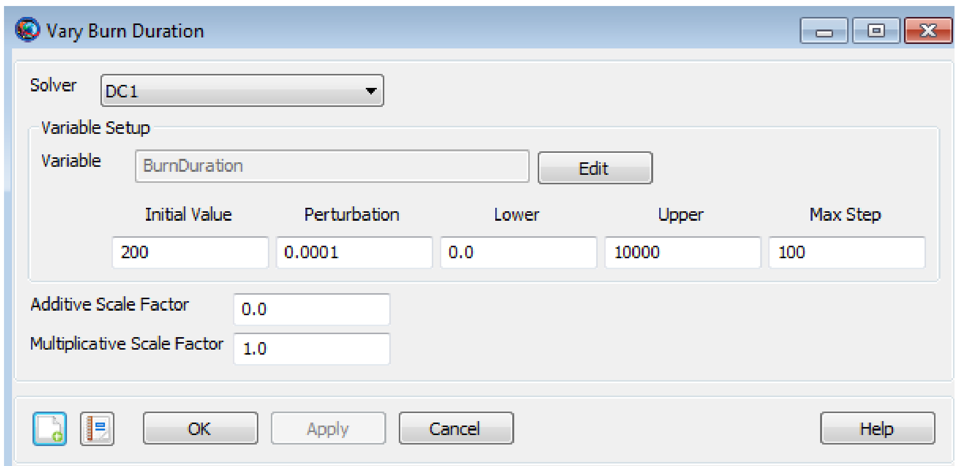


Figure 11. Vary Burn Duration Command Configuration

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 the **FiniteBurn1** to the **DefaultSC** spacecraft, so we don't need to change anything here.
2. Click **OK**.

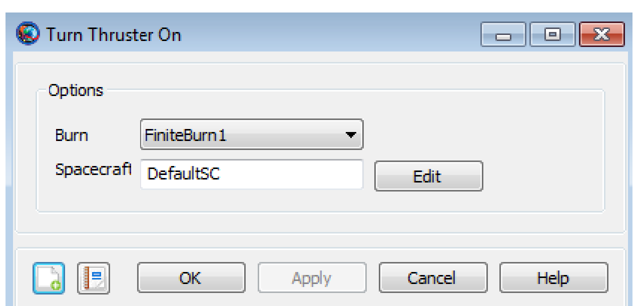


Figure 12. Turn Thruster On Command Configuration

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.

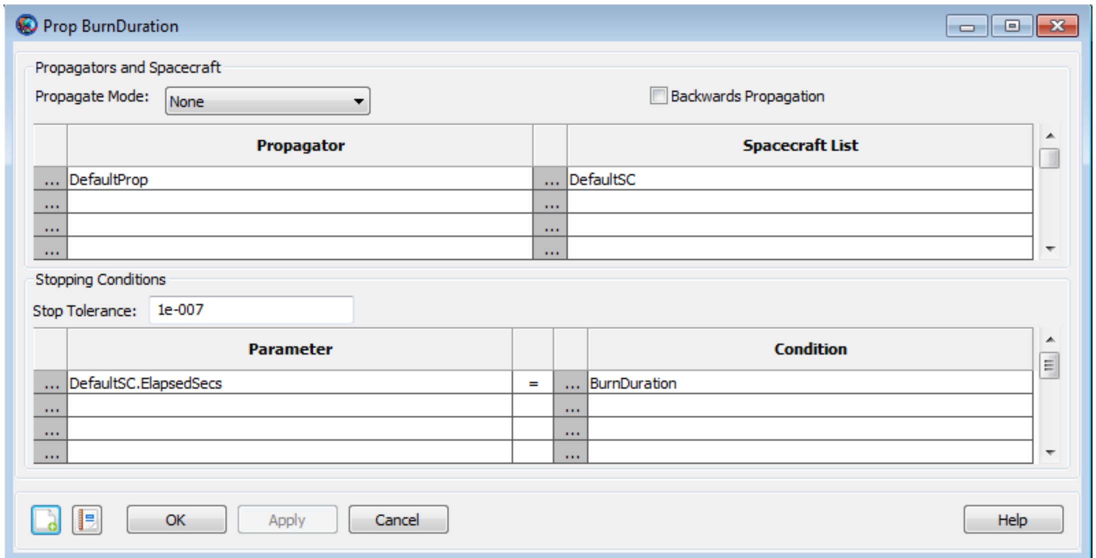


Figure 13. Prop BurnDuration Command Configuration

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**.

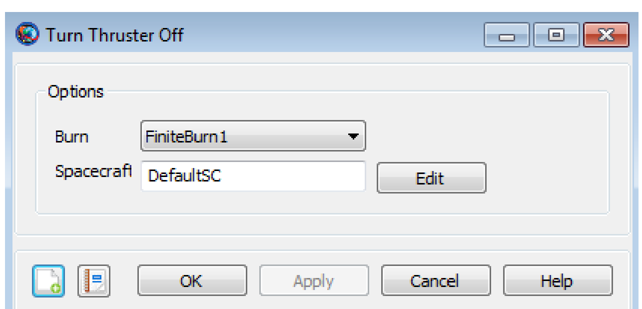


Figure 14. Turn Thruster Off Command Configuration

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.

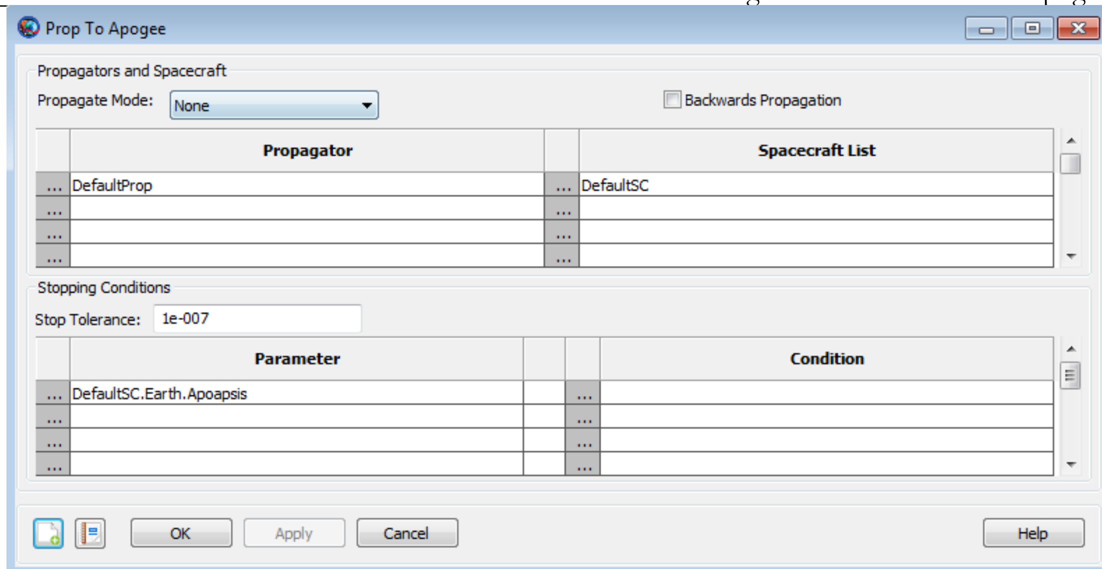


Figure 15. Prop To Apogee Command Configuration

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.

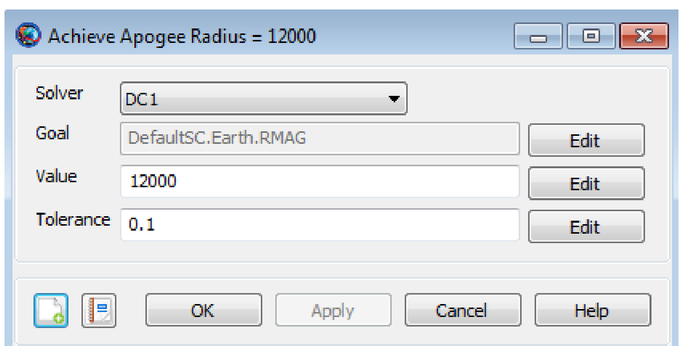


Figure 16. Achieve Apogee Radius = 12000 Command Configuration

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 shown in the image shown below. You may want to run the mission several times to see the targeting in progress.

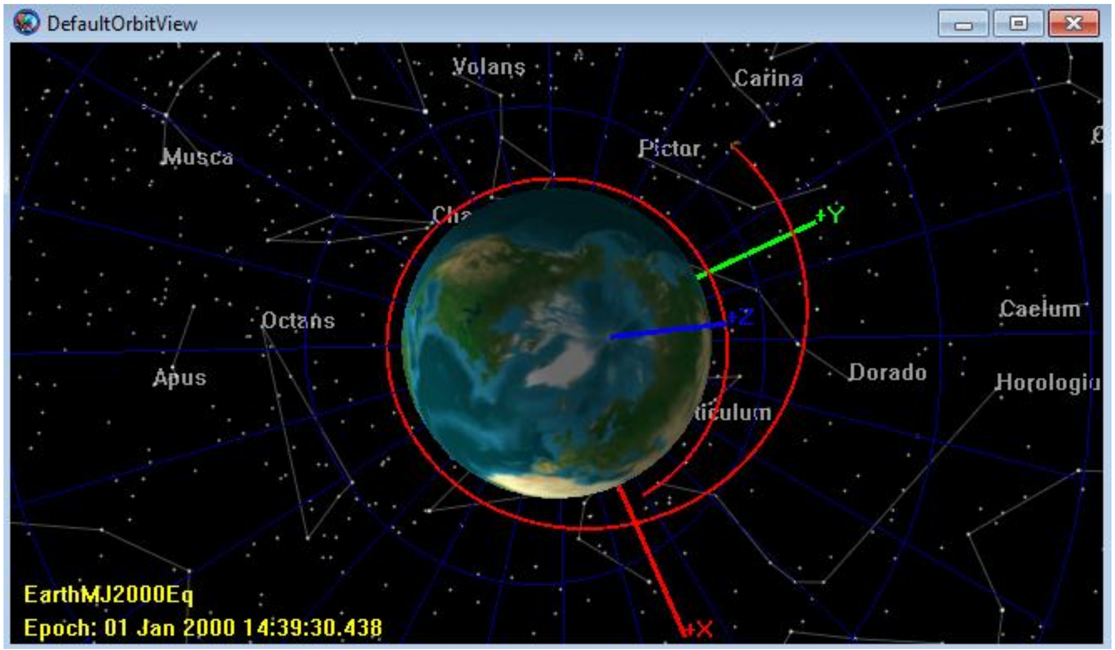


Figure 17. 3D View of Finite Burn to Raise Apogee

As shown below, we view the output message window to determine the number of iterations it took the differential corrector to converge and the final value of the control variable, **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.