

Mars Mission with B-Plane Targeting

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

Objective and Overview



Note

One of the most challenging problems in space mission design is to design an interplanetary transfer trajectory that takes the spacecraft within a very close vicinity of the target planet. One possible approach that puts the spacecraft close to a target planet is by targeting the B-Plane of that planet. The B-Plane is a planar coordinate system that allows targeting during a gravity assist. It can be thought of as a target attached to the assisting body. In addition, it must be perpendicular to the incoming asymptote of the approach hyperbola. See figures 1 and 2 that 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.

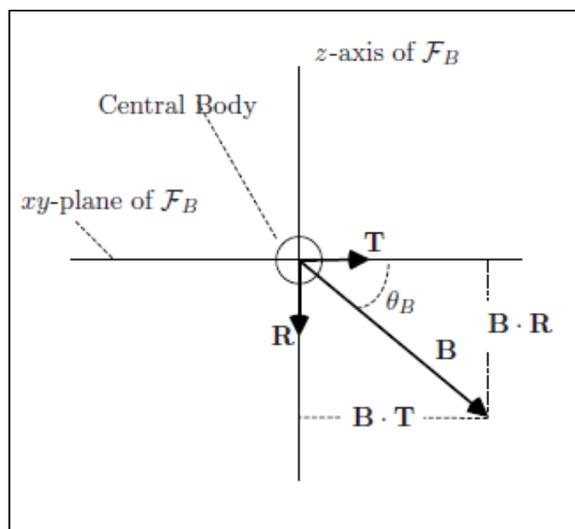


Figure 1: Geometry of the B-Plane as seen from a viewpoint perpendicular to the B-Plane

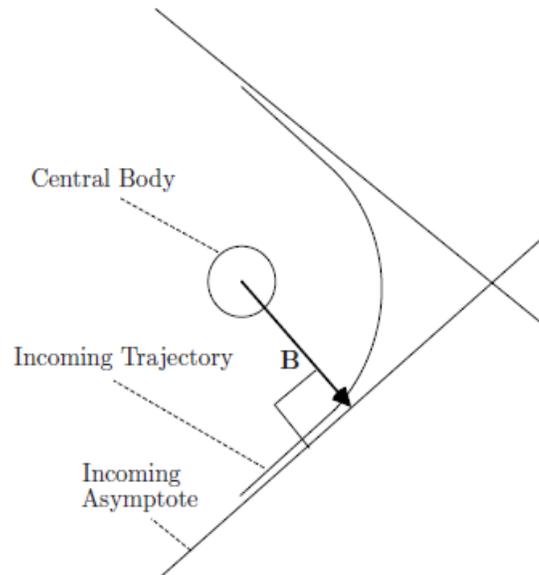


Figure 2: The B-vector as seen from a viewpoint perpendicular to orbit plane

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

The first target sequence employs maneuvers in the Earth-based Velocity (V), Normal (N) and Bi-normal (B) directions and includes four propagation sequences. The purpose of the maneuvers in VNB directions is to target B_{dotT} and B_{dotR} components of the B-vector. B_{dotT} is targeted to 0 km and B_{dotR} is targeted to a non-zero value to generate a polar orbit that has inclination of 90 degrees. B_{dotR} 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 B_{dotT} and B_{dotR} 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 1. 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 2. 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 will 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 **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**.
3. Double-click **TCM** to edit its properties.
4. Check **Decrement Mass** under **Mass Change**.
5. For **Tank** field under **Mass Change**, select **MainTank** from the 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 3. 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 **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 4. 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 5. 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 these changes.

Create the Differential Corrector

Two **Target** sequences 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 6. 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 7. 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 8. 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 these changes.

Configure the Mission Sequence

Now we will configure first **Target** sequence to solve for the maneuver values required to achieve B_{dotT} and B_{dotR} components of the B-vector. B_{dotT} will be targeted to 0 km and B_{dotR} 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 to a desired condition by working through the *Simulating an Orbit* and *Simple Orbit Transfer* 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 3 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.

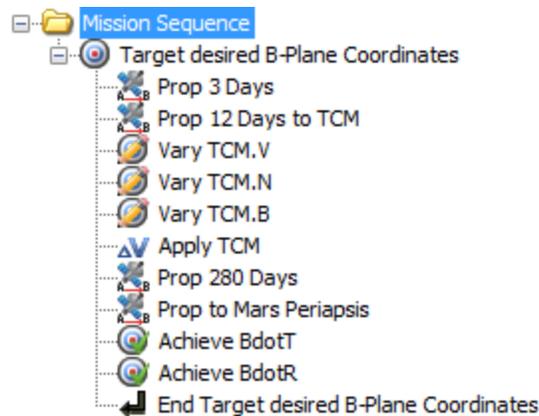


Figure 3. Mission Sequence for the first Target sequence

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 9.

Table 9. 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 $B_{dot{T}}$ and $B_{dot{R}}$ 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, $B_{dot{T}}$ and $B_{dot{R}}$ 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, $B_{dot{T}}$ and $B_{dot{R}}$ values that result in a 90 degree inclination.

Configure the first Target Sequence

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

Configure the Target desired B-plane Coordinates Command

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

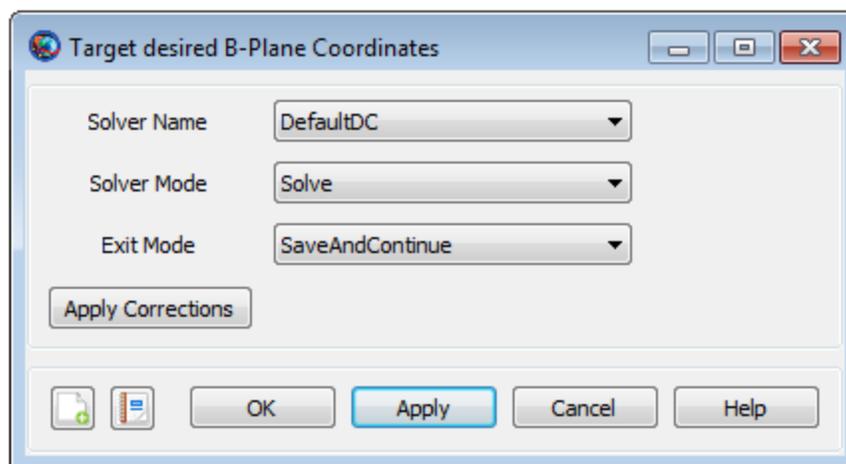


Figure 4. Target desired B-plane Coordinates Command Configuration

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.

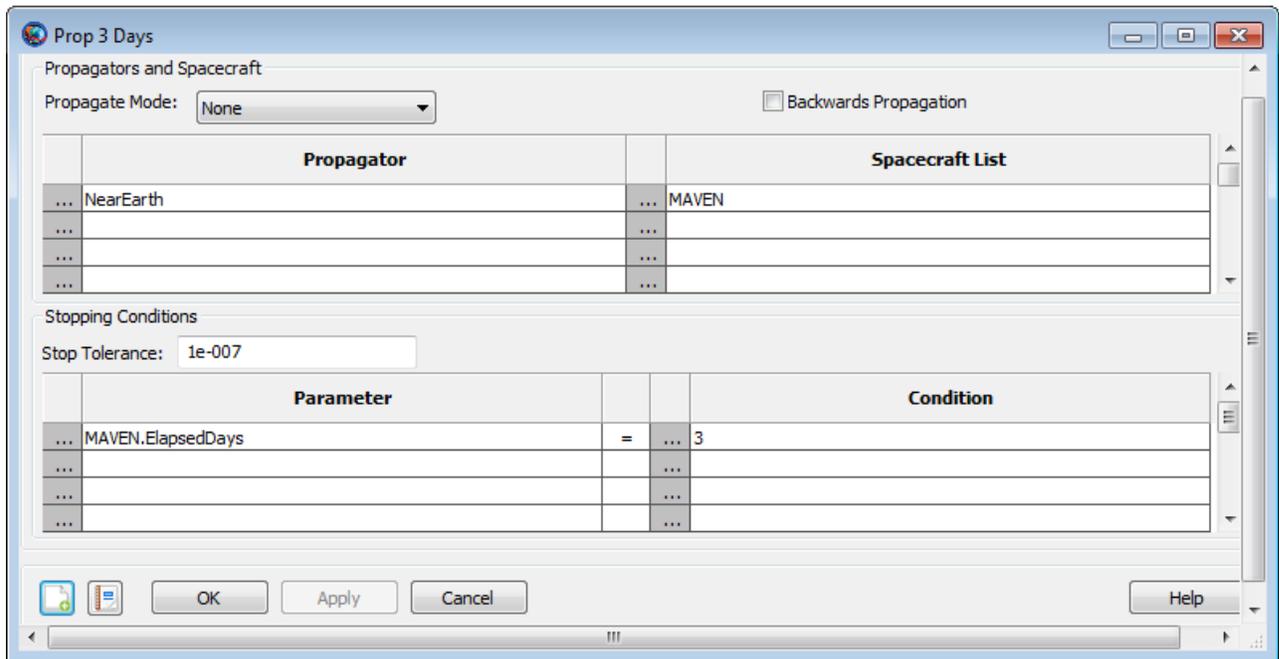


Figure 5. Prop 3 Days Command Configuration

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.

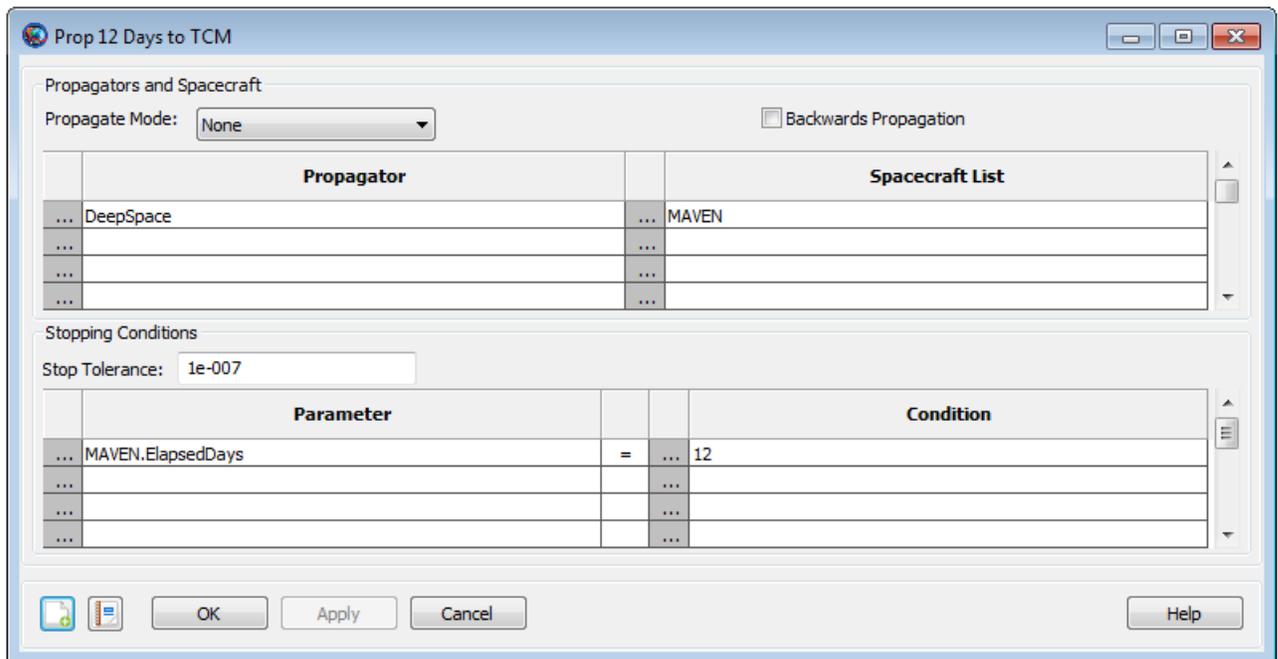


Figure 6. Prop 12 Days to TCM Command Configuration

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.

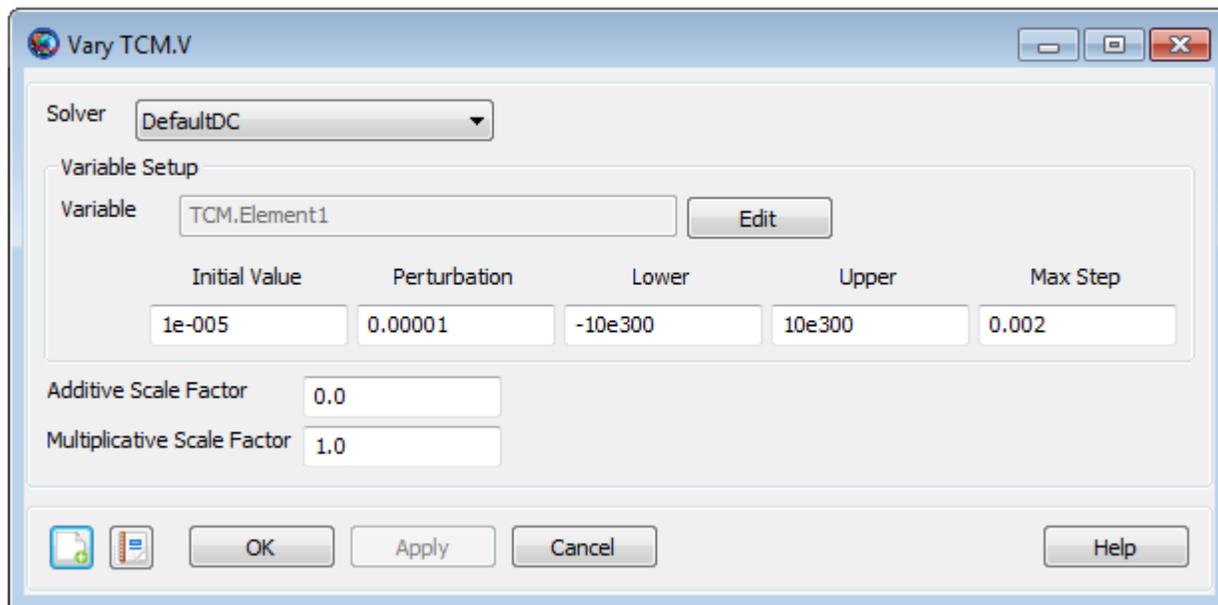


Figure 7. Vary TCM.V Command Configuration

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.

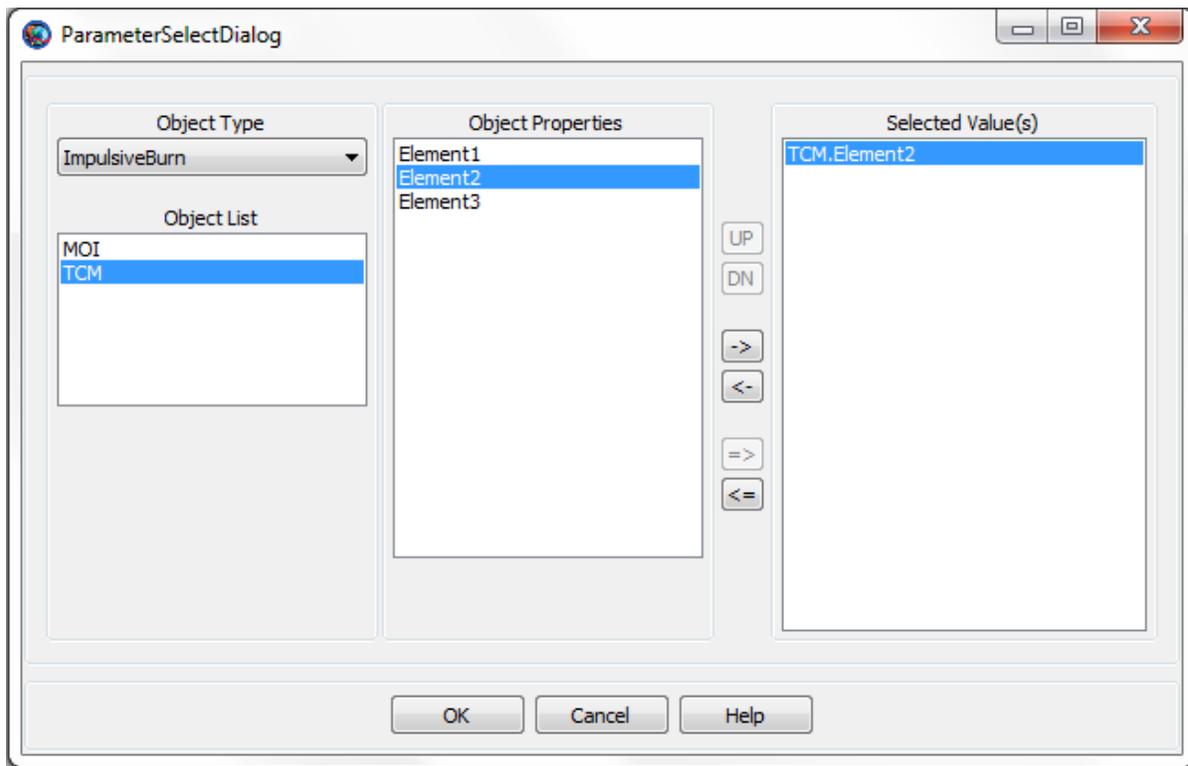


Figure 8. Vary TCM.N Parameter Selection

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.

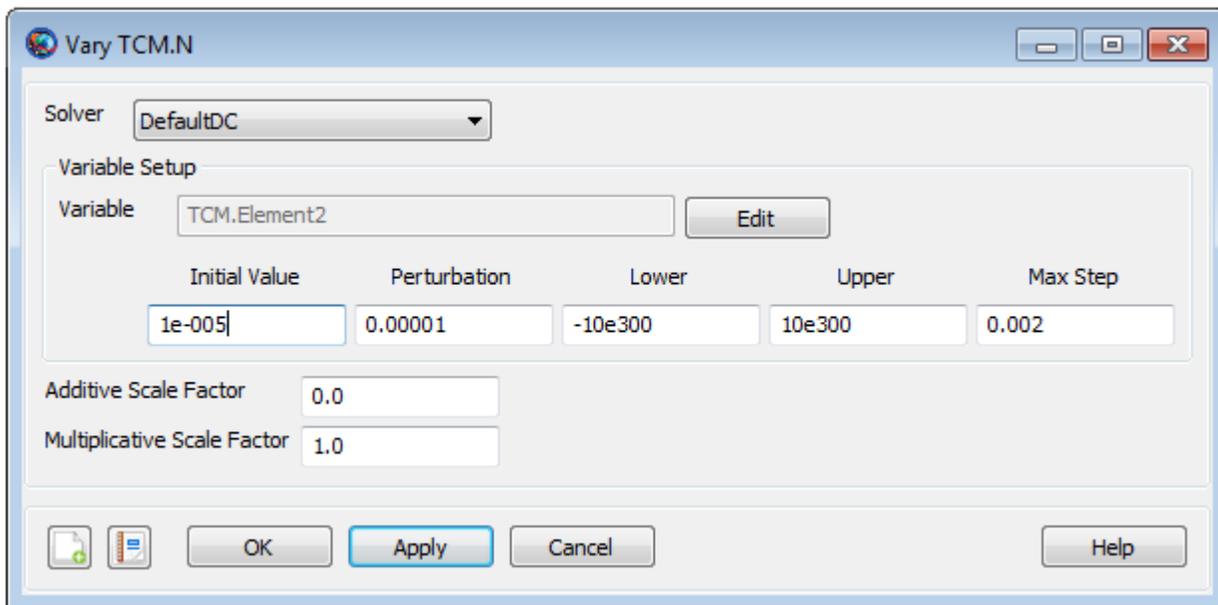


Figure 9. Vary TCM.N Command Configuration

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.

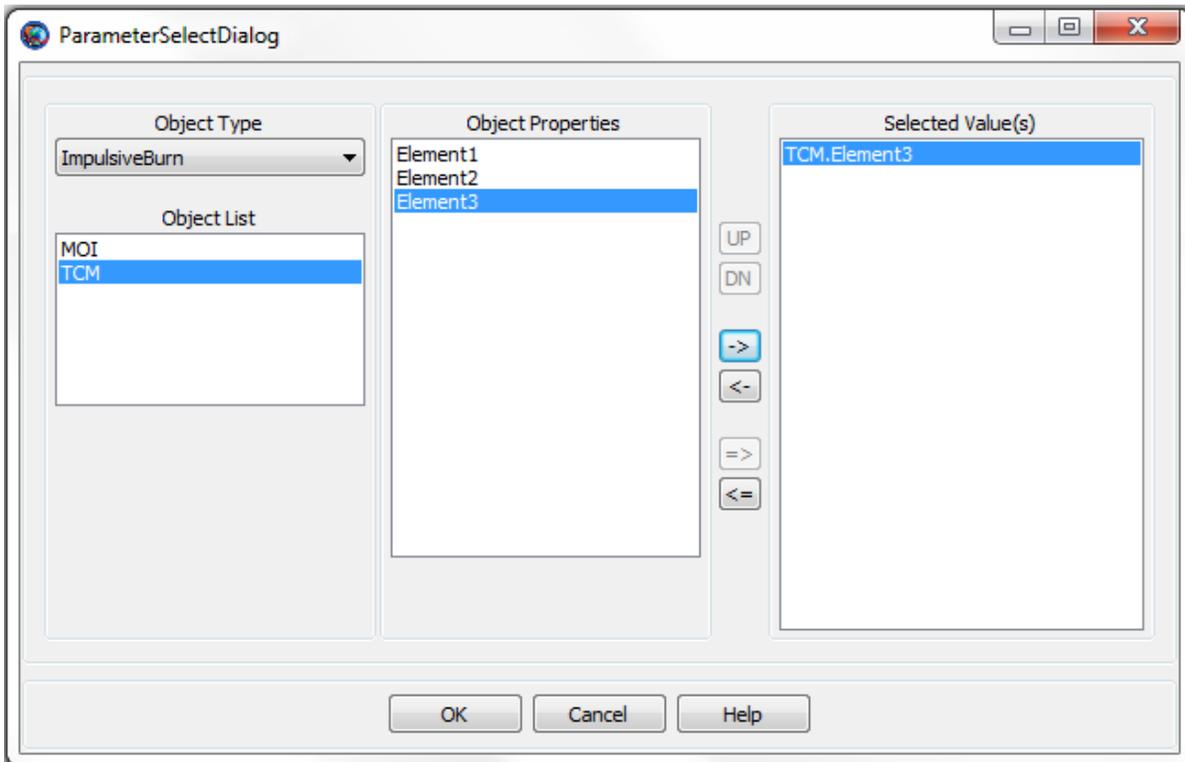


Figure 10. Vary TCM.B Parameter Selection

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.

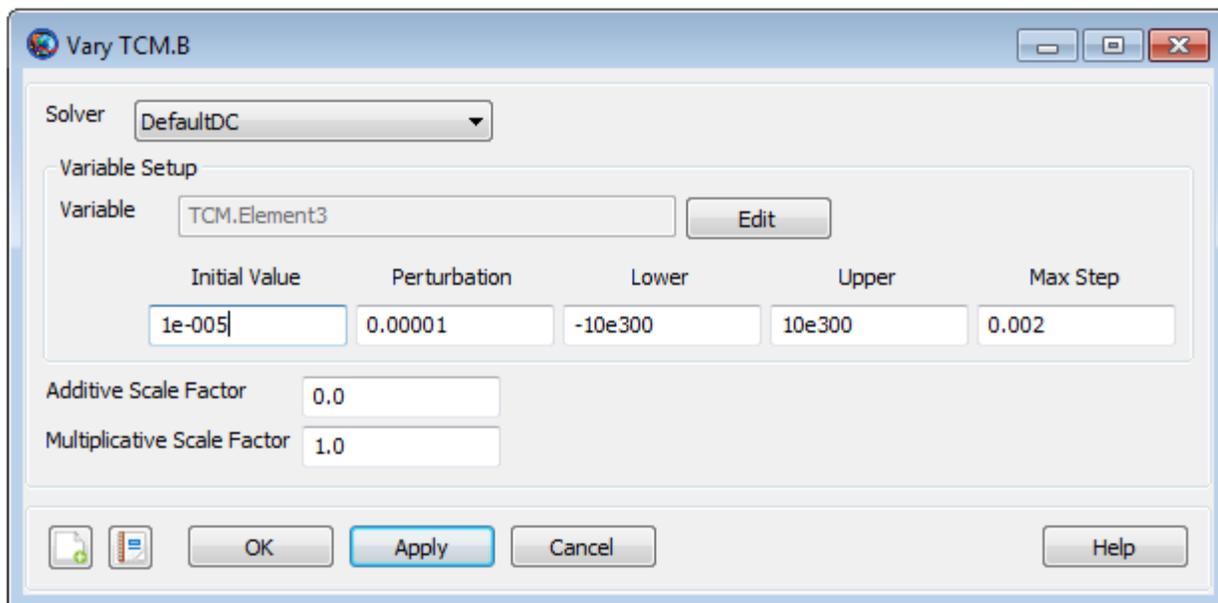


Figure 11. Vary TCM.B Command Configuration

Configure the Apply TCM Command

1. 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.

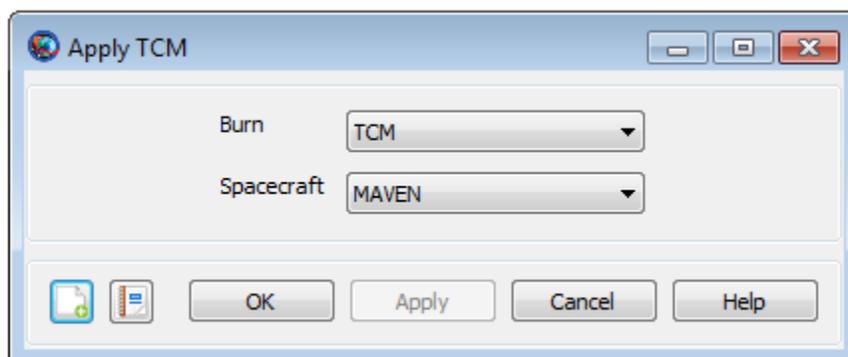


Figure 12. Apply TCM Command Configuration

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.

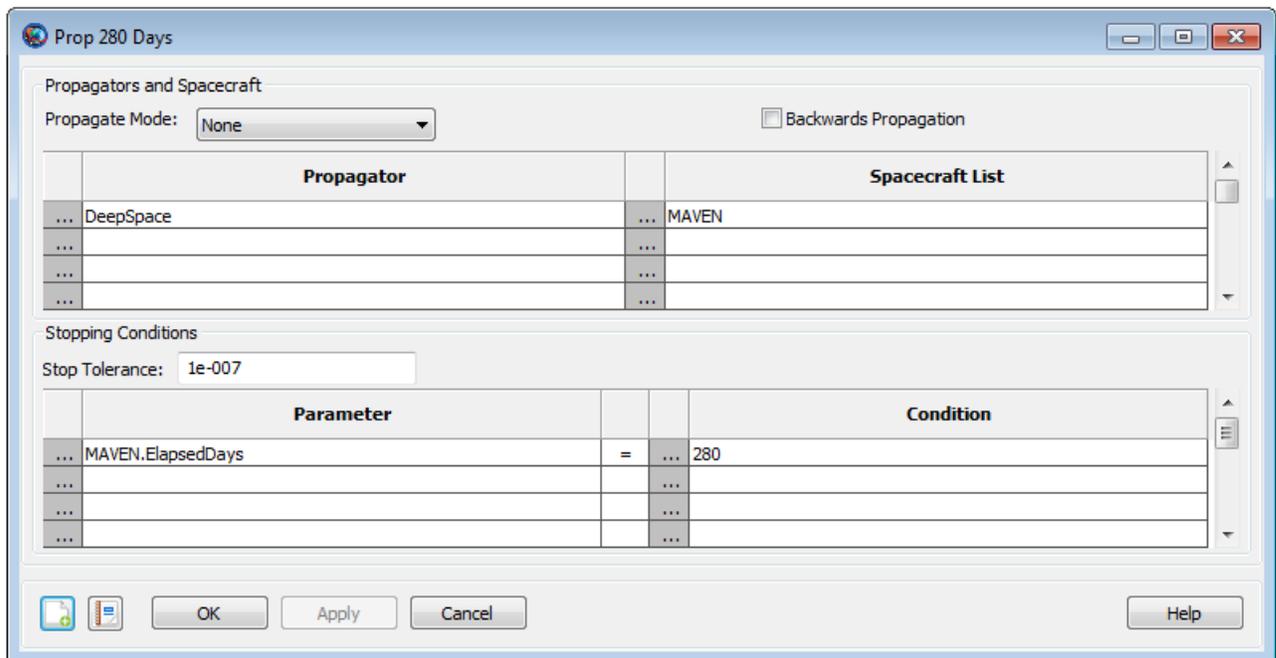


Figure 13. Prop 280 Days Command Configuration

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.

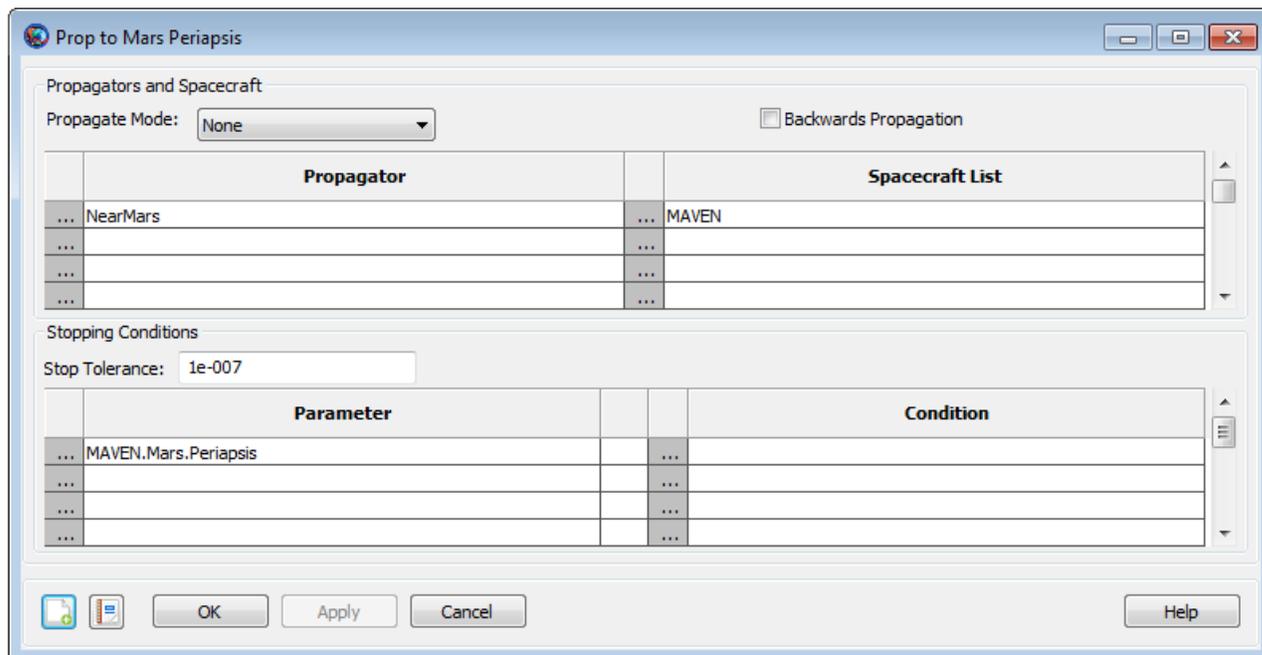


Figure 14. Prop to Mars Periapsis Command Configuration

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.

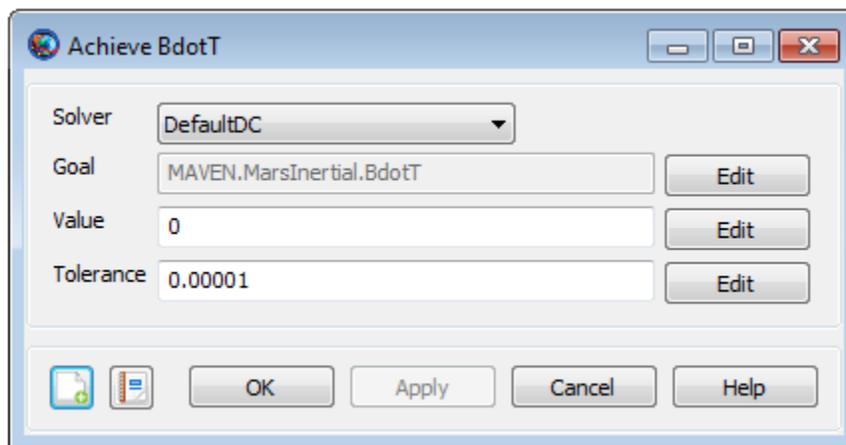


Figure 15. Achieve BdotT Command Configuration

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.

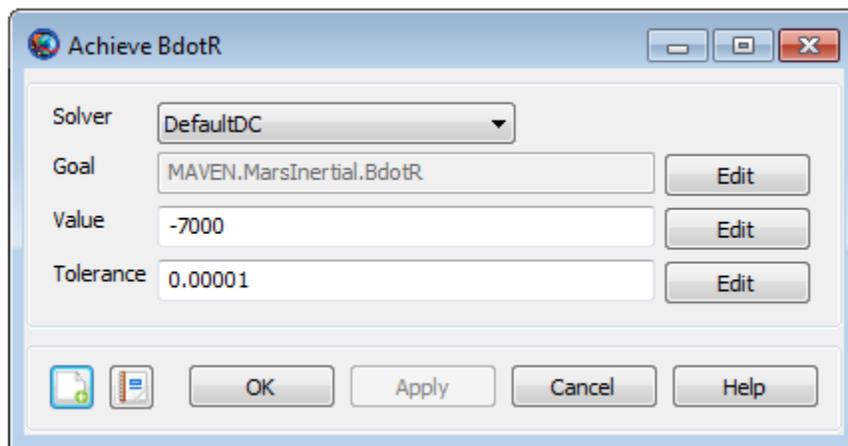


Figure 16. Achieve BdotR Command Configuration

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.

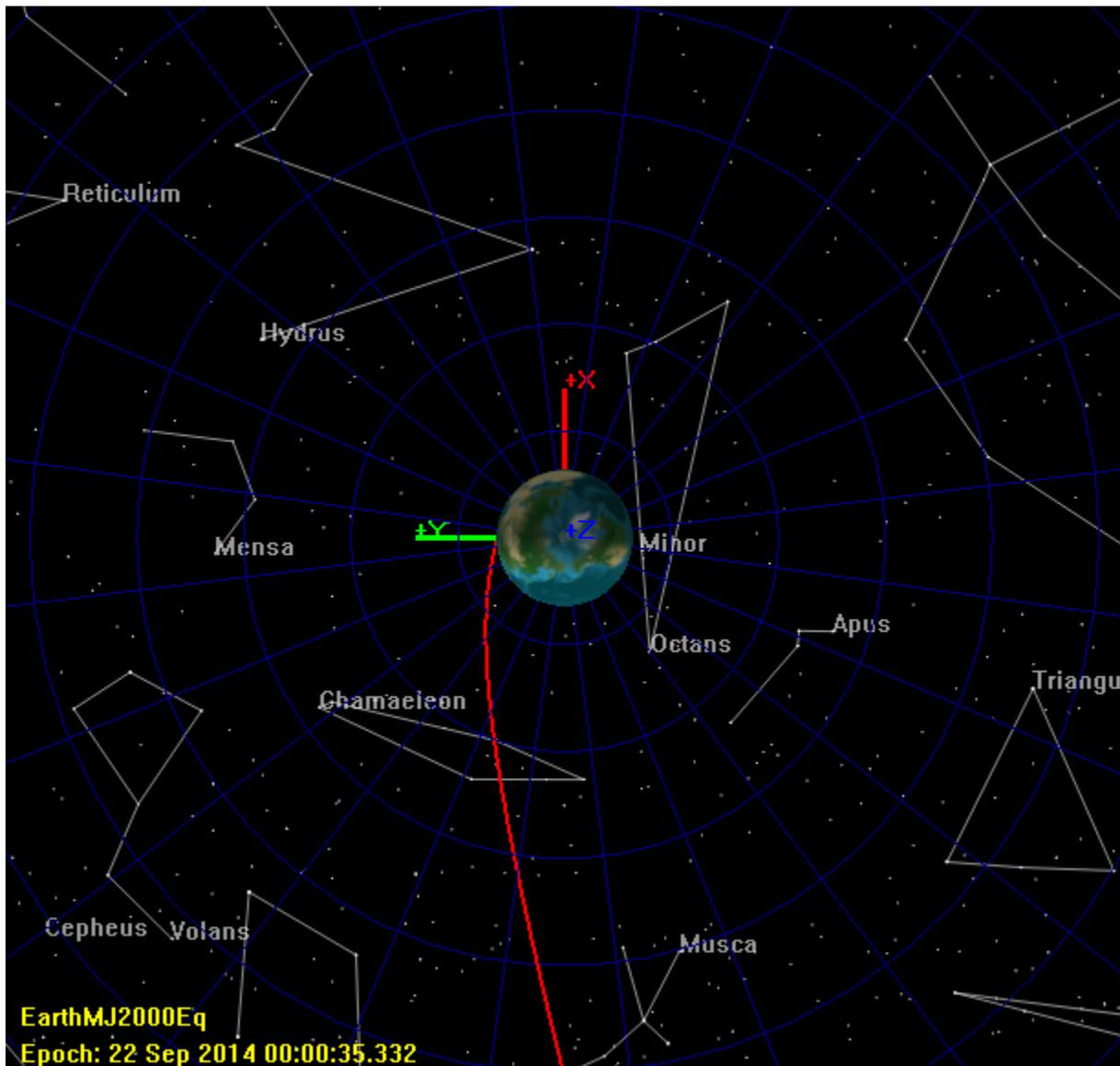


Figure 17. 3D View of departure hyperbolic trajectory (EarthView)

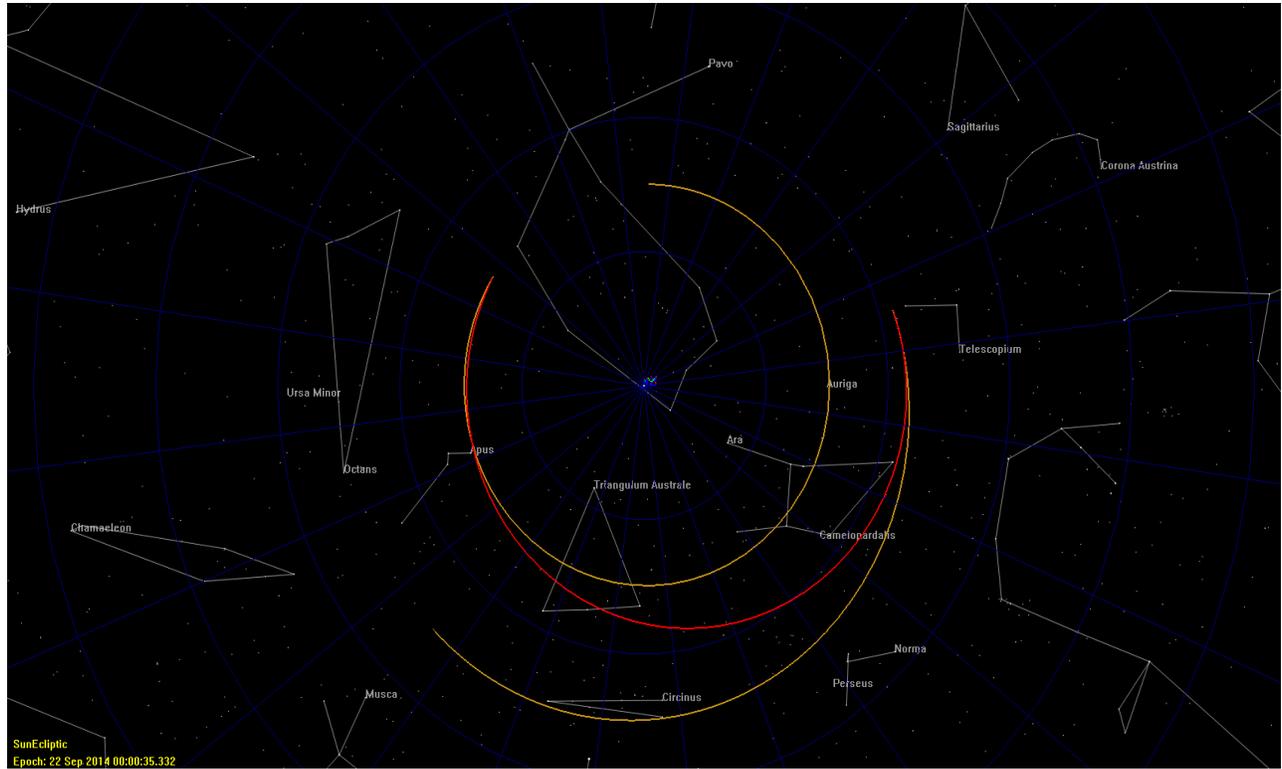


Figure 18. 3D View of heliocentric transfer trajectory (SolarSystemView)

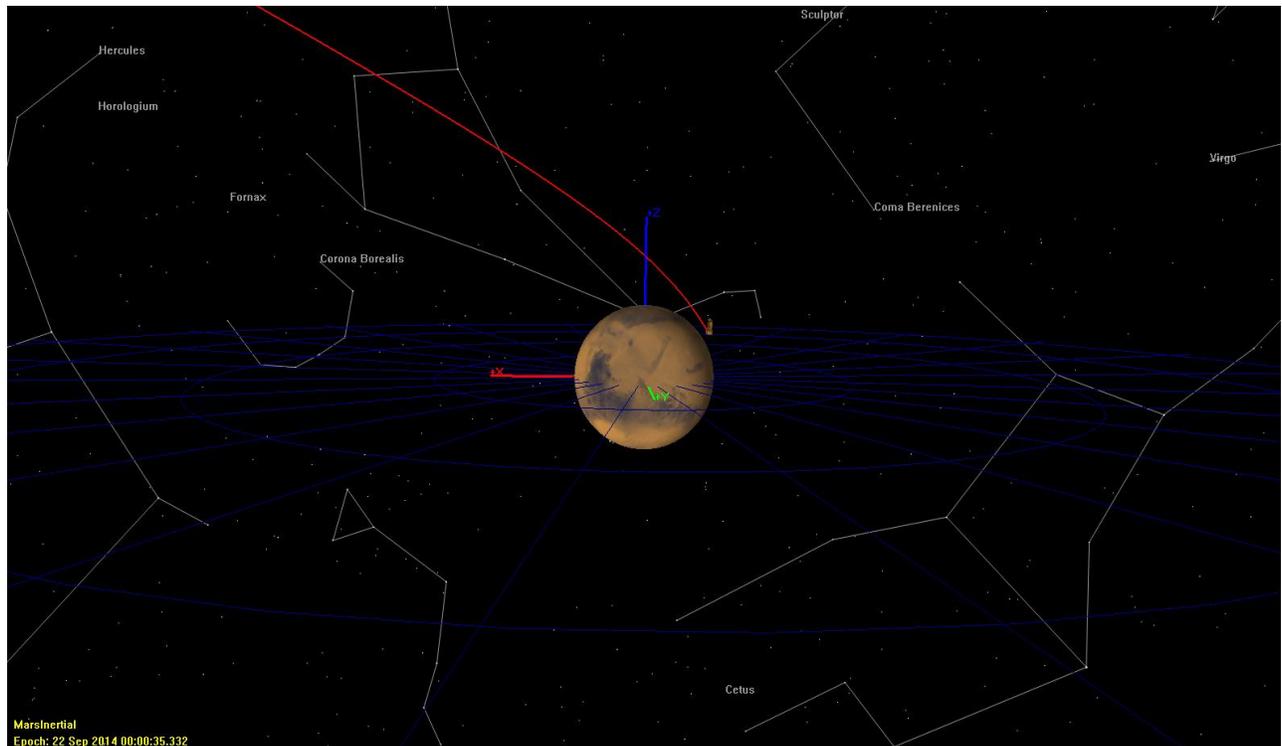


Figure 19. 3D View of approach hyperbolic trajectory. MAVEN stopped at periapsis (MarsView)

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 20 illustrates the configuration of the **Mission** tree after you have completed the steps in this section. Notice that in Figure 20, the second **Target** sequence is created after the first **Target** sequence. We'll discuss the second **Target** sequence after it has been created.

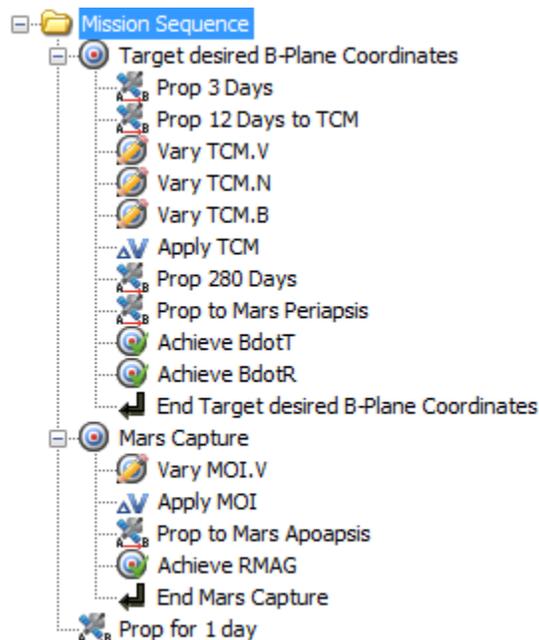


Figure 20. Mission Sequence showing first and second Target sequences

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 10.

Table 10. 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.

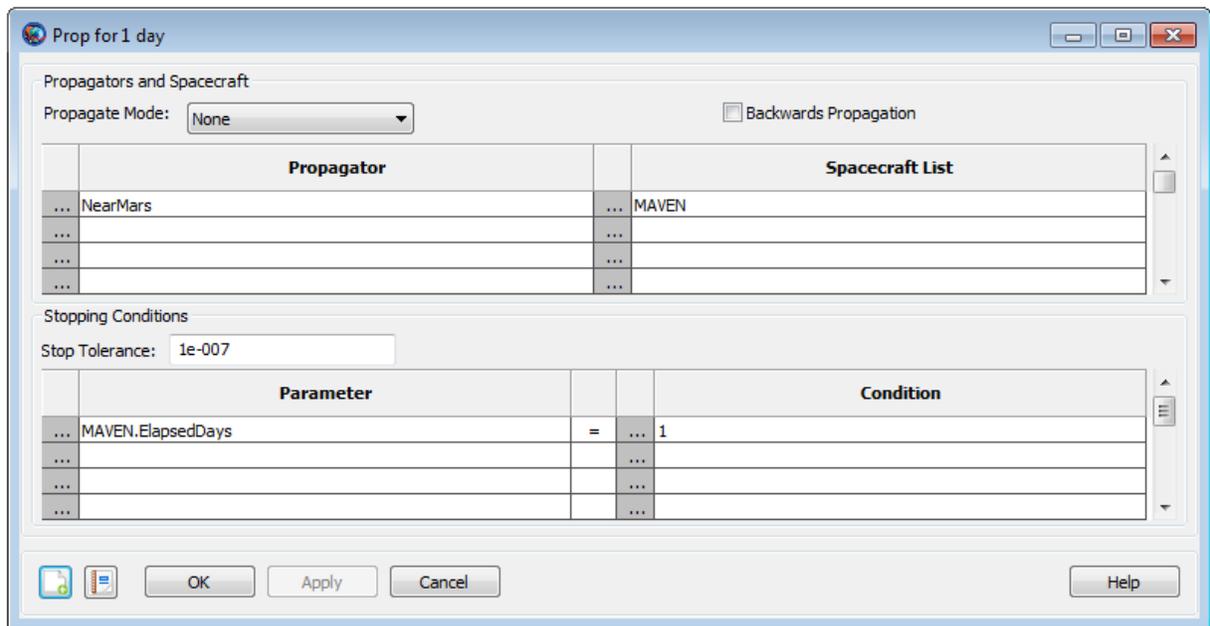


Figure 21. Prop for 1 day Command Configuration

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.

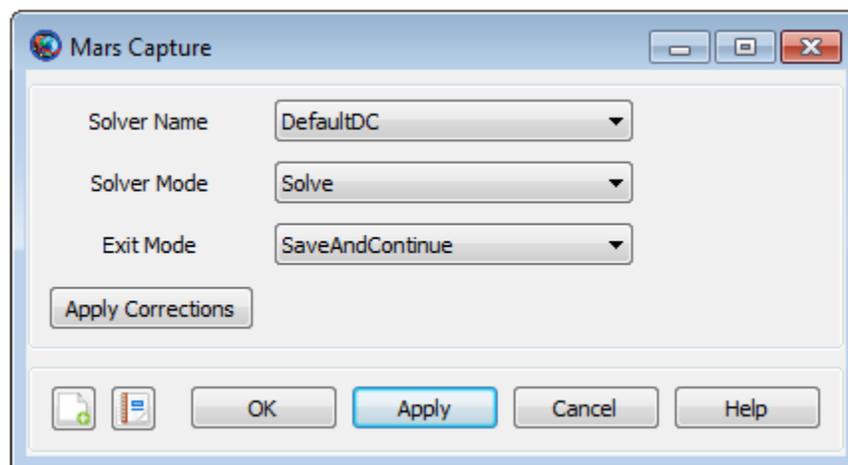


Figure 22. Mars Capture Command Configuration

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.

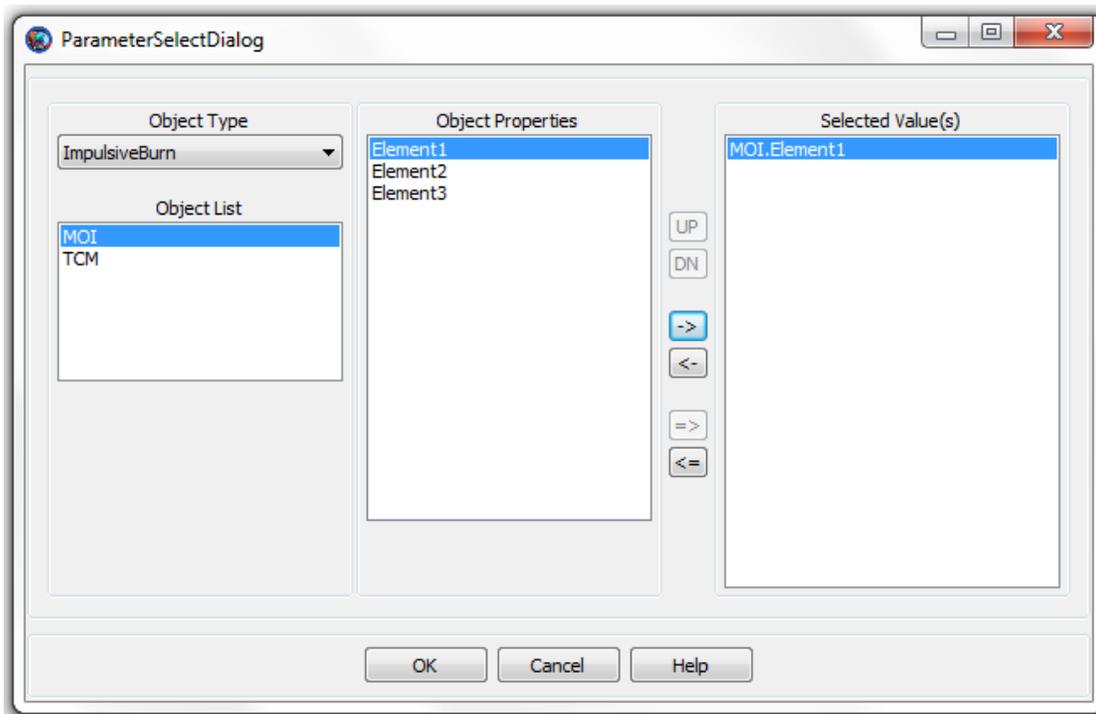


Figure 23. Vary MOI Parameter Selection

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.

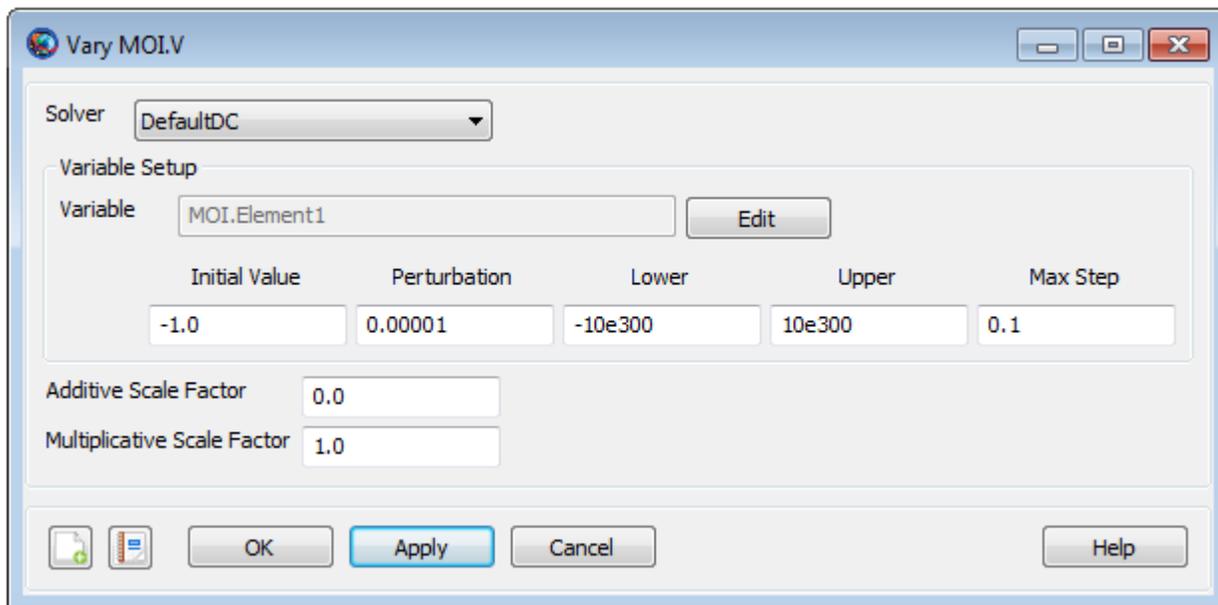


Figure 24. Vary MOI Command Configuration

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.

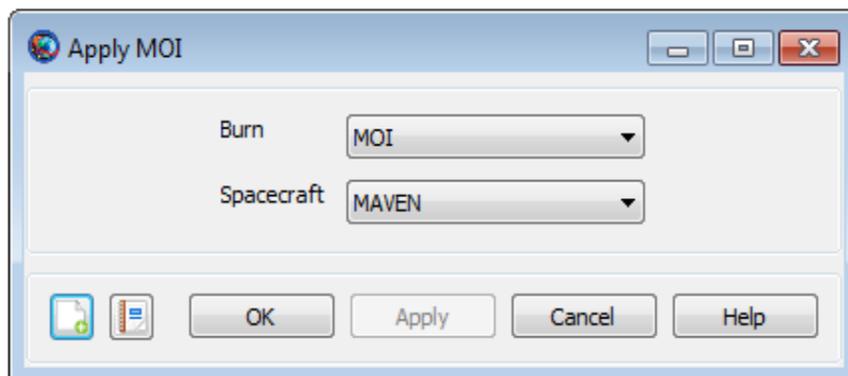


Figure 25. Apply MOI Command Configuration

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.

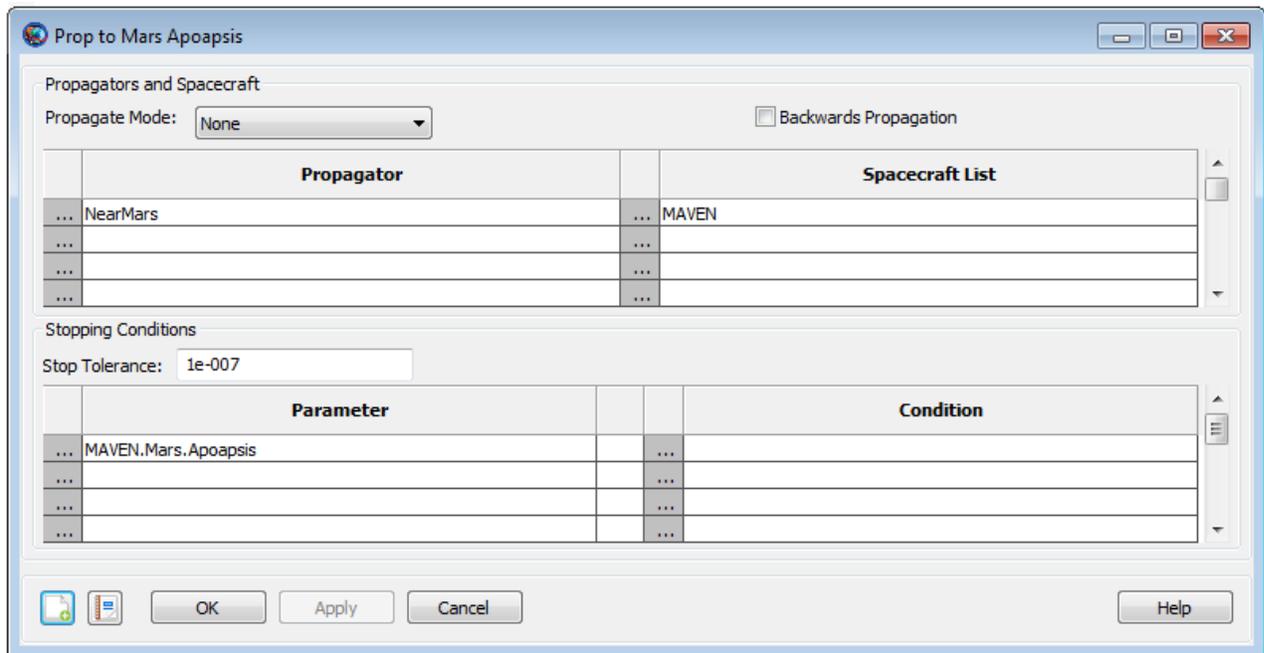


Figure 26. Prop to Mars Apoapsis Command Configuration

Configure the Achieve RMAG Command

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

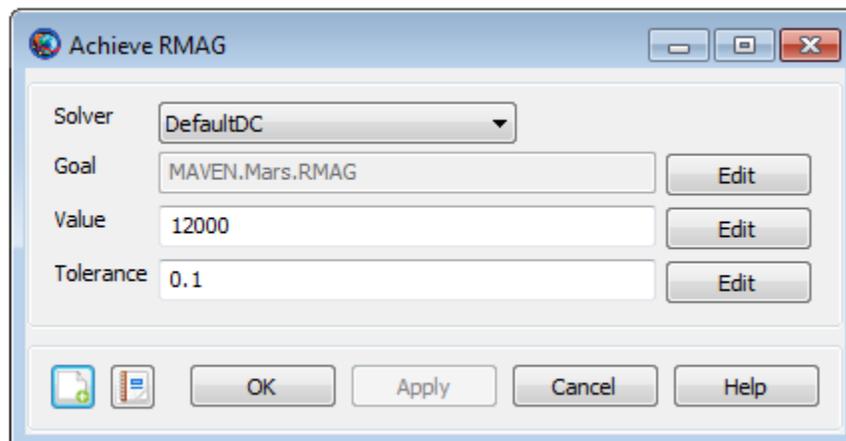


Figure 27. Achieve RMAG Command Configuration

Run the Mission with first and second Target Sequences

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

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

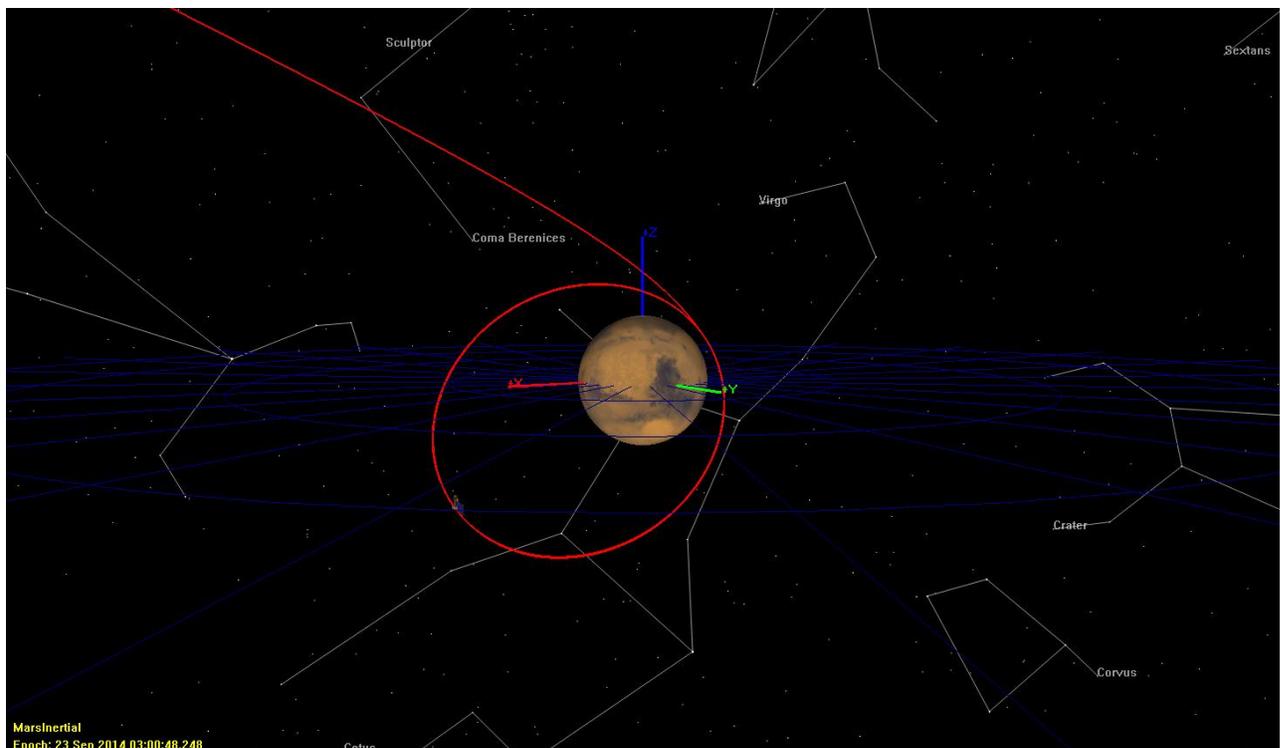


Figure 28. 3D view of Mars Capture orbit after MOI maneuver (MarsView)

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 has 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 **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
```