

Draft: Work in Progress

**DRAFT**  
**General Mission Analysis Tool (GMAT)**  
**Acceptance Test Plan**

GMAT PC Build Date: December 10, 2007

GMAT Mac Build Date: December 10, 2007

GMAT Linux Build Date: December 10, 2007



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December 14, 2007

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## Chapter 1

# Acceptance Test Plan Overview

### 1.1 GMAT Introduction

The information presented in this Acceptance Test Plan document shows the current status of the General Mission Analysis Tool (GMAT). GMAT is a software system developed by NASA Goddard Space Flight Center (GSFC) in collaboration with the private sector. The GMAT development team continuously performs acceptance tests in order to verify that the software continues to operate properly after updates are made. The GMAT Development team consists of NASA/GSFC Code 583 software developers, NASA/GSFC Code 595 analysts, and contractors of varying professions.

GMAT was developed to provide a development approach that maintains involvement from the private sector and academia, encourages collaborative funding from multiple government agencies and the private sector, and promotes the transfer of technology from government funded research to the private sector.

GMAT contains many capabilities, such as integrated formation flying modeling and MATLAB compatibility. The propagation capabilities in GMAT allow for fully coupled dynamics modeling of multiple spacecraft, in any flight regime. Other capabilities in GMAT include: user definable coordinate systems, 3-D graphics in any coordinate system GMAT can calculate, 2-D plots, branch commands, solvers, optimizers, GMAT functions, planetary ephemeris sources including DE405, DE200, SLP and analytic models, script events, impulsive and finite maneuver models, and many more.

GMAT runs on Windows, Mac, and Linux platforms. Both the Graphical User Interface (GUI) and the GMAT engine were built and tested on all of the mentioned platforms. GMAT was designed for intuitive use from both the GUI and with an importable script language similar to that of MATLAB.

### 1.2 Testing Methodology

#### **Purpose**

GMAT needs to undergo a series of rigorous tests to validate the numerical implementations of its models and establish a set of acceptable performance times. The 595 analysts created the acceptance test plan to achieve this goal by comparing GMAT with flight-operational reference software packages and documenting the results. Results can be reproduced with the initial conditions and software setups presented in this document.

## Reference software

For this comparative study to have merit, GMAT was tested against reliable, trustworthy, and flight operational programs, such as STK-HPOP, STK-Astrogator, Free-Flyer, Swingby, and previous GMAT Builds that were comparable to the aforementioned programs. To achieve accurate comparison results, each program was compared with equivalent, or close to equivalent, test case setups.

## Testing Categories

The Acceptance Test Plan divides into the following testing categories: Propagation, Calculation Parameters [Central body(Cb) and Coordinate System(CS) dependent], Integrators, Libration Points, Stopping Conditions, Delta V, and Performance.

## Scripts Used

MATLAB scripts were created to make comparisons between GMAT Builds and the reference software. The majority of the comparisons involved taking the difference of the data and extracting the maximum absolute difference observed over the propagation duration. Scripts were also created to compare performance times for individual GMAT test cases to the reference software. The scripts created are as followed: Comparison\_Tool1\_Tool2\_PV.m, Comparison\_Tool1\_Tool2\_CS.m, Comparison\_Tool1\_Tool2\_Cb.m, Comparison\_Integ.m, TimeComparo.m, BuildRun\_Script\_GMAT.m, Comparison\_Tool1\_Tool2\_Libr.m, Comparison\_StopCond, and STK\_Repropagate.m.

The user of the semi-automated scripts provides input when requested, in order to perform the script's core functions. For example, a user that wants to see the position and velocity differences between STK and GMAT would select a few choices from a menu. Next, the script would generate the comparisons based on the report data available. The semi-automation scripts adhere to the naming conventions outlined in their relevant testing category chapter.

Most of the scripts generate output in at least one of the following formats: ASCII, LaTeX, MATLAB .mat, or Excel .xls files. The report files are in an ASCII space delimited format and contain the different test case parameters outputted after propagation. The LaTeX files contain the comparison data between two programs and provide an easy way to include that data into a PDF document. The .mat and .xls file are two other methods used to save the comparison data that proved useful from the software development team.

The details of each script and how to use them are outlined in the relevant Testing Category section and/or the Comparison Scripts Guide section, located in Appendix C.

### 1.2.1 Propagation

The propagation test cases account for various orbits about Earth, as well as other celestial bodies. The main propagation parameters to monitor for differences are the position and velocity vectors. The following script was generated to perform the comparisons for this category:

```
Comparison_Tool1_Tool2_CS.m
```

See the Propagators section (Chapter 2) for more detail and comparison results.

### 1.2.2 Calculation Parameters

The calculation parameter test cases verify the internal calculations used to output the various parameters presented in the list below. This section consists of two subsections: Coordinate System(CS) and Central Body(Cb) dependent parameters. The following scripts were generated to perform the comparisons for this testing category: Comparison\_Tool1\_Tool2\_CS.m & Comparison\_Tool1\_Tool2\_Cb.m

- Coordinate Systems
  - Earth Fixed
  - Earth Mean J2000 Equator (MJ2000Eq)
  - Earth Mean J2000 Ecliptic (MJ2000Ec)
  - Earth Mean of Date Equator (MODEq)
  - Earth Mean of Date Ecliptic (MODEc)
  - Earth True of Date Equator (TODEq)
  - Earth True of Date Ecliptic (TODEc)
  - Earth Geocentric Solar Ecliptic (GSE)
  - Earth Geocentric Solar Magnetic (GSM)
  - Mars Fixed
  - Mars MJ2000Eq
  - Mars MJ2000Ec
  - Mercury Fixed
  - Mercury MJ2000Eq
  - Mercury MJ2000Ec
  - Moon Fixed
  - Moon MJ2000Eq
  - Moon MJ2000Ec
  - Neptune Fixed
  - Neptune MJ2000Eq
  - Neptune MJ2000Ec
  - Pluto Fixed
  - Pluto MJ2000Eq
  - Pluto MJ2000Ec
  - Saturn Fixed
  - Saturn MJ2000Eq
  - Saturn MJ2000Ec
  - Uranus Fixed
  - Uranus MJ2000Eq
  - Uranus MJ2000Ec
  - Venus Fixed
  - Venus MJ2000Eq
  - Venus MJ2000Ec
- Coordinate System Parameters
  - Position (X,Y,Z)

- Velocity(X,Y,Z)
- Magnitude of Velocity
- Right Ascension of Velocity
- Specific Angular Momentum
- Argument of Periapsis
- Declination
- Declination of Velocity
- Inclination
- Right Ascension
- Right Ascension of Ascending Node
- Central Body Parameters
  - Altitude
  - Beta Angle
  - C3 Energy
  - Eccentricity
  - Latitude
  - Longitude
  - Specific Angular Momentum
  - Mean Anomaly
  - Mean Motion
  - Period
  - Apoapsis Radius
  - Perigee Radius
  - Position Magnitude
  - Semi-major Axis
  - True Anomaly
  - Semilatus Rectum
  - Apoapsis Velocity
  - Periapsis Velocity
  - Greenwich Hour Angle
  - Local Sidereal Time

See the Calculation Parameters Section (Chapter 3) for more detail and comparison results.

### 1.2.3 Integrators

The integrator test cases isolate the differences that would occur when changing the integrators for the same orbit. The following script was generated to perform the test case comparisons for this category:  
Comparison\_Integ.m

- RungaKutta(RKV) 8(9)
- DormandElMikkawyPrince(RKN) 6(8)



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- RungeKuttaFehlberg(RKF) 5(6)
- PrinceDormand(PD) 4(5)
- PrinceDormand(PD) 7(8)
- BulirschStoer(BS)
- AdamsBashforthMoulton(ABM)

See the Integrators Section (Chapter 4) for more detail and comparison results.

### 1.2.4 Stopping Conditions

The stopping condition test cases determine how effective GMAT is at stopping satellite propagation on certain conditions. The following script was created to perform the test case comparisons for this category: Comparison\_StopCond.m

The stopping conditions tested are as followed:

- Epoch (A1 Modified Julian Date)
- Apoapsis
- Elapsed Days
- Mean Anomaly
- Periapsis
- Elapsed Seconds
- True Anomaly
- XY Plane Intersection
- XZ Plane Intersection
- YZ Plane Intersection

See the Stopping Conditions Section (Chapter 5) for more detail and comparison results.

### 1.2.5 Libration Point

The libration point test cases create data about the location of several libration points. Current and future satellite missions use libration points as part of their mission architecture. It is important to have accurate data for these libration points. The following script was created to perform the test case comparisons for this category:

Comparison\_Tool1\_Tool2\_Libr.m

See the Libration Point Section (Chapter 6) for more detail and comparison results.

## 1.2.6 Delta V

The delta v test cases determine the effectiveness of the delta v capabilities built into GMAT. When thruster burns are added to the mission sequence it is important that they are added correctly. The following script was created to perform the test case comparisons for this category:

Comparison\_DeltaV.m

See the Delta V Section (Chapter 7) for more detail and comparison results.

## 1.2.7 Performance

The performance test cases generate performance time data for later comparison between GMAT and the reference software packages. Numerical calculation accuracy is important, but the amount of computing time it takes for the software to run is equally as important. We extracted several test cases from previous sections and ran them on the reference software packages, in order to check to make sure GMAT can perform just as good or better.

See the Performance Section (Chapter 8) for more detail and comparison results.

## 1.2.8 Control Flow

The control flow tests generate report data that easily allows a Matlab script to produce a table of Pass and Fail cases. The following script was created to generate the Pass/Fail table for this category:

LoopTestSummary.m

See the Control Flow Section (Chapter 9) for more detail and results.

## Chapter 2

# Propagation

In order to validate the accuracy of GMAT's propagation, the fundamental unit-level components need to be combined and propagated on a system level. From a software development point of view, if the program under development is tested in a wide range of core applications, it is more likely that problems would be found before each new version is released to the public. This Acceptance Test Plan tests GMAT by comparing many possible scenarios users of GMAT would encounter to reference software packages. Although it is impossible to create all the possible scenarios each user would encounter in GMAT, this is a start to eliminate possible frustrations a user could experience if a component did not work correctly.

Propagation is one of the most important aspects of GMAT. Everything from outputting parameters to performing a thruster burns at the correct stopping condition depend on whether or not GMAT is able to propagate the satellite/object for a defined time period with acceptable accuracy.

Parts of the Initial Orbit State Conditions section are referenced from Emergent Space Technologies' Orbit Determination Toolbox (ODTBX) Spiral 1 DEMO document,<sup>1</sup> due to a similar objective of testing the numerical implementation of the programs base functions.

## 2.1 Initial Orbit State Conditions

### 2.1.1 Earth Based Test Cases

The initial orbit states for the Sun-Synchronous (SunSync), Geostationary (GEO), Molniya, International Space Station (ISS) and the Global Positioning Satellite (GPS) orbits were obtained from Emergent Space Technologies' ODTBX Spiral 1 Demo .<sup>1</sup> Emergent used STK-High Precision Orbit Propagator (STK-HPOP) models and two-Line Element (TLE) sets with an initial UTC orbit epoch of June 1st 2004, 12:00:00:00. The initial orbit states that were used for the test case orbits can be seen in Table 2.1, on Page 28. The perigee and apogee altitudes of the test case orbits can be seen in Table 2.2, on Page 28.

The propagation duration, report output step size, and integrator step sizes were varied for the different test cases. For the ISS, SunSync, GPS, Molynia, and GEO cases, the propagation length and report output step size were chosen based on a study performed by The Aerospace Corporation to validate STK-HPOP's.<sup>2</sup> The integrator time steps were chosen to allow for the most accurate comparison of the test case results. These time steps were based on Vallado's analysis of state vector propagation.<sup>3</sup>

Table 2.1: Satellite Initial Conditions

Category	Orbit Type	X(km)	Y(km)	Z(km)	V <sub>x</sub> (km/s)	V <sub>y</sub> (km/s)	V <sub>z</sub> (km/s)
LEO	ISS	-4453.783586	-5038.203756	-426.384456	3.831888	-2.887221	-6.018232
LEO	Sun-Sync	-2290.301063	-6379.471940	0	-0.883923	0.317338	7.610832
MEO	GPS	5525.33668	-15871.18494	-20998.992446	2.750341	2.434198	-1.068884
HEO	Molniya	-1529.894287	-2672.877357	-6150.115340	8.717518	-4.989709	0
GEO	GEO	36607.358256	-20921.723703	0	1.525636	2.669451	0

Table 2.2: Apogee and Perigee Altitudes for Test Satellites

Orbit Type	Perigee Altitude(km)	Apogee Altitude(km)
ISS	358.168	380.387
Sun-Sync	400	400
GPS	19757.6	20603.8
Molniya	500	39850.5
GEO	35786	35786

The chosen parameters can be seen in Table 2.3, on Page 28.

Table 2.3: Integrator, Propagator, and Output Frequency

Orbit Type	Integrator Step Size(s)	Propagator Length(days)	Output Frequency(mins)
ISS	5	1	1
Sun-Sync	5	1	1
GPS	60	2	2
Molniya	5	3	5
GEO	60	7	10

Several test cases were created for each satellite orbit to verify GMAT's ability to perform accurately, while applying various forces. The forces used for Earth-based test cases were two-body, JGM2, EGM96, and JGM3 gravity models, third-body perturbation effects from other planets, the Jacchia-Roberts (JR) and the Mass Spectrometer and Incoherent Scatter Radar Exosphere (MSISE 1990 & 2000) Atmospheric Drag Model, and Solar Radiation Pressure (SRP). Each of the force models were run independently within GMAT to verify their individual accuracy, as well as a test case that includes an atmospheric drag model, the SRP model, a non-spherical gravity model, and third-body perturbations. These last test cases were performed to validate the capability of the GMAT to accurately propagate satellite orbits while multiple force models were applied.

The Degree and Order for Earth-based non-spherical gravity cases was set at a constant 20 by 20.

Refer to Appendix B.1 for an alternate listing of all Propagator initial orbit state conditions.

## 2.1.2 Non-Earth Based Test Cases

GMAT is designed for accuracy in non-Earth mission scenarios. Test cases for Mars, Mercury, the Moon, Neptune, Pluto, Saturn, Uranus, Venus, L2 orbits, and deep space orbits were created to test various forces, individually and jointly, affecting a spacecraft in an orbit. Many satellite parameters, such as Cd, Cr, satellite area, and satellite mass, were kept the same as the Earth test cases for simplicity and consistency. The initial Keplerian satellite state only varied in Semi-Major Axis and gravity field degree & order for the non-Earth test cases.

Refer to Table 2.4 for the initial Keplerian orbital elements and the Degree & Order used for the non-spherical gravity force cases. The integrator step size, propagation length, and output frequency for all the non-Earth cases are 5 seconds, 3 days, and 5 minutes, respectively. Table 2.4 excludes the deep space and L2 orbit test cases.

Table 2.4: Non-Earth Keplerian Orbital Elements

Orbit Type	SMA (km)	Ecc.	Inc. (deg)	AOP (deg)	RAAN (deg)	TA (deg)	Deg. x Ord. used
Mars	4603	0.2	45	45	90	45	20x20
Mercury	3640	0.2	45	45	90	45	4x0
Moon	2500	0.2	45	45	90	45	20x20
Neptune	34999	0.2	45	45	90	45	4x0
Pluto	1795	0.2	45	45	90	45	4x0
Saturn	80000	0.2	45	45	90	45	4x0
Uranus	45000	0.2	45	45	90	45	4x0
Venus	8125	0.2	45	45	90	45	20x20

SMA: Semi-Major Axis | Ecc.: Eccentricity | Inc.: Inclination | AOP: Argument of Perigee  
 RAAN: Right Ascension of Ascending Node | TA: True Anomaly

The DeepSpace, Earth Moon L2 (EML2), and Earth Sun L2 (ESL2) cases involve propagating about libration points and propagating deep space orbits. Table B.14, B.15, and B.16, in Appendix B, provide the initial states for the DeepSpace, EML2, and ESL2 test cases, respectively.

Refer to Appendix B.1 for a listing of all Propagator initial orbit state conditions.

## 2.2 Other Initial State Conditions

In order to reduce the complications of the comparisons, certain initial orbit parameters were kept constant throughout all of the cases. These parameters are Cd, Cr, Spacecraft Area, each programs integrator, and software settings affecting the results of various force models.

The GMAT integrator used for all the test cases was Runga Kutta 8(9), except for the STK-HPOP test cases, to avoid any additional differences that could occur from changing integrators. The Integrators Section compares the differences between the various integrators GMAT can use.

The parameters in Table 2.5 shows the differences between GMAT and the reference programs. The ideal situation would be for all the programs to match perfectly, but that is not realistic due to the different approaches each program takes to solve each problem.

Table 2.5: Universal Test Case Parameters

Parameter	GMAT	STK-HPOP	FF	STK-Astro
Cd	2.2	2.2	2.2	2.2
Cr	1.2	1.2	1.2	1.2
Area( $m^2$ )	20	20	20	20
Satellite Mass(kg)	1000	1000	1000	1000
Integrator (excluding integrator test cases)	RK8(9)	RK7(8)	RK8(9)	RK8(9)
Integrator error tolerance	1e-013	1e-013	1e-013	1e-013
Integrator error control. Relative to	Step	Step?	?	Step
Drag: Altitude Calculation	Approximate	Approximate	Exact	?
Drag: Sun Position	True	True	True	True
SRP: Sun Position	True	True	True?	True
Solar Flux ( $W/m^2$ ) at 1 AU	1359.38857	1359.38857	1358	1359.38857
Solid Tides	N/A	Disabled	N/A	N/A
Ocean Tides	N/A	Disabled	N/A	N/A
Daily F10.7: JR and MSISE models	150	150	N/A	150
Average F10.7	150	150	150	150
Geomagnetic Index(Kp): JR and MSISE only	3	3	N/A	3
Drag: Geomagnetic Flux Update	Constant	Constant	N/A	Constant
Boundary Mitigation	N/A	Disabled	N/A	N/A
Relativistic Accelerations	N/A	Disabled	N/A	N/A
Shadow Modeling	Dual Cone	Dual Cone	Dual Cone	?
IERS EOP format used:	Long term C04	Bulletin A	Bulletin A	Bulletin A
Polar Motion calculation:	Enabled	Enabled	Enabled	Enabled?
Nutation update interval: Earth (sec)	60	60	60	60
Planetary Ephemeris update interval (sec)	0	0?	0	0?

Exceptions to Table 2.5 are as followed:

- STK has trouble propagating the EML2 test case at an error tolerance of 1e-013 with a relative to step error control. The GMAT and STK cases were changed to both use relative to state error control

### 2.2.1 Earth Orientation Parameters(EOP) data

*"International Earth Rotation Service (IERS) Bulletins A and B provide current information on the Earth's orientation in the IERS Reference System. This includes Universal Time, coordinates of the terrestrial pole, and celestial pole offsets. Bulletin A gives an advanced solution updated weekly by e-mail subscription or daily by anonymous ftp; the standard solution is given monthly in Bulletin B and updated every week in the (IERS) C04 solution."*<sup>6</sup>

*"Bulletin A is issued by the IERS Rapid Service/Prediction Centre at the U.S. Naval Observatory(USNO), Washington, DC and Bulletin B", as well as the C04 data, "is issued by the IERS Earth Orientation Centre at the Paris Observatory."*<sup>4</sup>

*"Bulletin A is intended for users who need accurate information before the Bulletin B finals series is available, i.e., those who reduce data in the very recent past (require rapid service) or those who operate in real-time (require predictions). Bulletin B is intended for standard use. For scientific and long-term analyses of the Earth's orientation, the long-term continuous series",<sup>4</sup> C04 (1962- present), can be used.*

*"EOP (IERS) C04 is regularly recomputed to take advantage on one hand of the improvement of the various individual contributions and in the other hand of the refinement of the analysis procedures. To date, it is twice-weekly updated."*<sup>5</sup>

*"The EOP (IERS) C04 is given at one-day intervals, it is free from the diurnal/subdiurnal terms due to the oceanic effects and can be interpolated linearly. The oscillations in UT and duration of the days due to zonal tides for periods under 35 days are present in full size in the series."*<sup>5</sup>

GMAT retrieves long term earth orientation IERS EOP CO4 data, which includes UTC-UT1 data, from a file. This file includes smoothed values at 1-day intervals and data from 1962-present.

STK and FF retrieves its EOP data from the USNO series 7 / IERS Bulletin A.

The differences between the EOP data sets are displayed in Table 2.6. The Terrestrial Pole column refers to the accuracy of the pole position [x,y] and the UT1 column refers to the accuracy of the rotation angle about the pole UT1.

As shown in Table 2.6, there are differences between STK and GMAT, but the Terrestrial Pole data agrees to within the thousandth place of a milli-arcseconds and the UT1 data agrees to within the hundredth place of second.

Table 2.6: EOP Format Accuracy

EOP Format	Pole Position (mas)	UT1 (ms)
Bulletin A obs. 1-d (1)	0.10	0.02
Bulletin A pred. 1-d (2)	0.50	0.14
Bulletin A pred. 4-d (2)	1.60	0.52
Bulletin A pred. 10-d (2)	3.9	1.60
Bulletin A pred. 40-d (2)	11.2	7.70
Bulletin B obs. smooth 5-d (3)	0.15	0.02
Bulletin B obs. raw 5-d (3)	0.15	0.02
Bulletin B pred. 5-d (3)	1.6	0.60
Bulletin B pred. 10-d (3)	3.0	1.60
Bulletin B pred. 30-d (3)	10.0	4.0
Long-Term C04 '62-'67	30.0	2.0
Long-Term C04 '68-'71	20.0	1.5
Long-Term C04 '72-'79	15.0	1.0
Long-Term C04 '80-'83	2.0	0.4
Long-Term C04 '84-'95	0.7	0.04
Long-Term C04 '96-present	0.2	0.02

NOTES: (1) Based on data after 1997; applies only to latest epochs in each update.

(2) Based on data since 1995.

(3) Based on data since 1996.

The Terrestrial Pole and UT1 data is free from the diurnal/subdiurnal terms due to the oceanic effects and can be interpolated linearly.

These terms can be added after interpolation.



### 2.2.2 Other Planetary Parameters

#### Gravitational Constant

All programs used for comparisons utilize the DE405 Planetary Gravitational Constants listed in Table 2.7, except when non-spherical gravity was used. When non-spherical gravity files are used they typically call the gravitational constants located in the file, unless the program creates an exception.

Table 2.7: Planetary Gravitational Constants(mu values)

Planet	mu ( $km^3/s^2$ )
Sun	132712440017.99
Mercury	22032.080486418
Venus	324858.59882646
Earth	398600.44150000
Moon	4902.8005821478
Mars	42828.314258067
Jupiter	126712767.85780
Saturn	37940626.061137
Uranus	5794549.0070719
Neptune	6836534.0638793
Pluto	981.60088770700

#### Flattening Coefficient

Whenever possible the flattening coefficients listed in Table 2.8 were used. Without the use of these values the planetary bodies could have wildly different shapes, which would result in large differences in parameters such as longitude, latitude, and altitude.

Table 2.8: Flattening Coefficient

Planet	Flattening Coefficient
Sun	0.00000000
Mercury	0.00000000
Venus	0.00000000
Earth	0.00335270
Moon	0.00000000
Mars	0.00647630
Jupiter	0.06487439
Saturn	0.09796243
Uranus	0.02292734
Neptune	0.01856029
Pluto	0.00000000

### Equatorial Radius

The several celestial body equatorial radii used are listed in Table 2.9. Similar differences as the flattening coefficient occur when GMAT and the reference programs don't use the same values.

Table 2.9: Equatorial Radius

Planet	Radius (km)
Sun	695990.0
Mercury	2439.7
Venus	6051.90
Earth	6378.1363
Moon	1738.2
Mars	3397.0
Jupiter	71492.0
Saturn	60268.0
Uranus	25559.0
Neptune	25269.0
Pluto	1162.0

### Leap Seconds

The amount of leap seconds, or  $\Delta AT$ , has been used since 1972 in order to keep  $-\text{UTC}-\text{UT1} \leq 0.9\text{sec}$ . GMAT and the reference software packages use all the leap seconds up until 2004. In 2004 the amount of leap seconds in use were 32 seconds.

## 2.3 Naming Convention

This section describes the naming convention for propagator scripts and output reports. The naming convention consists of an ordered series of option strings, separated by underscores (`_`). Currently, options are allowed for the following fields, and will be present in the file name in order:

1. *tool* - The tool used to generate the test case
2. *traj* - The trajectory to use. This includes initial conditions, physical parameters, and time step
3. *pmg* - The point-mass gravity model to use
4. *nsg* - The non-spherical gravity model to use
5. *drag* - The atmospheric drag model to use
6. *other* - Any other forces to include, such as SRP, secondary body gravity, etc

The *tool* field should always be the first field. Future additional fields should be added to the end of the list of fields. If multiple *other* options are required, they should be added to the end of the file as required. For example, the file name will be *tool\_traj\_pmg\_nsg\_drag\_other1\_other2.report* (file extensions are described later.) Each field has a finite list of options, as follows (future options should be added to this list):

1. *tool*
  - STK - Satellite Toolkit HPOP or Astrogator
  - FF - FreeFlyer
  - GMAT - General Mission Analysis Tool
2. *traj*
  - ISS - LEO orbit
  - SunSync - LEO orbit
  - GPS - MEO orbit
  - GEO - GEO orbit
  - Molniya - HEO orbit
  - Mars1 - eccentric low orbit
  - Mercury1 - eccentric low orbit
  - Moon - eccentric low orbit
  - Neptune1 - eccentric low orbit
  - Pluto1 - eccentric low orbit
  - Saturn1 - eccentric low orbit
  - Uranus1 - eccentric low orbit
  - Venus1 - eccentric low orbit
  - DeepSpace - deep space orbit
  - EML2 - Earth Moon L2 orbit
  - ESL2 - Earth Sun L2 orbit

NOTE: Some test cases contain *traj* variations. In these cases, *traj* precedes the modification. For example, if ISS trajectory is needed with no output, then *traj* can be ISSnoOut. The lack of a report file is shortened to noOut.

3. *pmg*
  - Earth - Earth point mass gravity
  - Sun - Sun point mass gravity
  - Luna - Lunar point mass gravity
  - AllPlanets - Sun, Mercury, Venus, Earth, Moon, Mars, Mercury, Jupiter, and Pluto point mass gravity included.

NOTE: When dealing with a combination of *pmg*'s the first point mass is the primary body and the following are third body point masses. For example, LunaSunEarth would be a Lunar primary body with

the Earth and Sun as third body point masses. The *pmg*'s after the primary body are arranged based on the order from the sun, in order to reduce repeat filenames.

4. *nsg*

- 0 - no non-spherical gravity included
- JGM2 - Earth JGM2 20x20 gravity
- JGM3 - Earth JGM3 20x20 gravity
- EGM96 - Earth EGM96 20x20 gravity
- MARS50C - Mars Mars50c 20x20 gravity
- LP165P - Moon LP165P 20x20 gravity

5. *drag*

- 0 - drag not included
- HP - Harris Priester
- JRXX - Jacchia-Roberts
- MSISEXX - NRL MSISE

NOTE: XX in the *drag* field refers to the year. For example, JR77 would be the Jacchia-Roberts 1977 model, and MSISE00 would be NRL MSISE 2000. Refer to Table 2.5 for the drag settings used.

6. *other*

- 0 - no other forces included
- SRP - Solar Radiation Pressure

NOTE: Any of the above options may be included as an *other* field. Refer to Table 2.5 for the SRP settings used.

### 2.3.1 Comparison Script Information

The script used to perform the position and velocity comparisons needed for the Propagator section is Comparison\_Tool1.Tool2\_PV.m. This script takes the normalized position and velocity vector difference between two programs.

Refer to Appendix C for more details about this script and others used in the Acceptance Test Plan document.

## 2.4 Test Case Results

The following results are for the Propagator section. The current GMAT Build is compared to STK and FreeFlyer for this section, with the maximum normalized position and velocity difference displayed in table format.

To determine if a propagator test case comparison value was acceptable, an acceptance matrix, presented in Table 2.10, was created. The values in Table 2.10 were obtained from the lower position difference bounds of David Vallados An Analysis of State Vector Propagation Using Differing Flight Dynamics Programs, presented at the 2005 American Astronomical Society (AAS)/AIAA Astrodynamics Specialist Conference. These lower bounds are difficult to meet in some orbits due to the wide range of orbits that are possible but they give a order of magnitude number to strive for. If a case has a combination of either Drag, Non-Spherical Gravity, Solar Radiation Pressure(SRP), or Point Mass gravity, the largest acceptable position difference is used.

The next step beyond this acceptance matrix is to compare GMAT's comparison data to differences seen in FF and STK comparisons, and peer reviews.

Table 2.10: Acceptance Matrix

Difference in	Acceptable Position Difference (m)
Non-Spherical Gravity	< 0.001
Point Mass Gravity	< 0.001
Solar Radiation Pressure	< 0.6
Drag	< 20

Table 2.11: WinGMAT/STK GEO Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.000213182651	1.464452825e-008
EarthLuna-0-0-0	0.000275769545	1.920121823e-008
EarthSunLuna-EGM96-JR-SRP	0.0001234937747	8.588604644e-009
EarthSunLuna-EGM96-MSISE90-SRP	0.0001234937846	8.588604669e-009
EarthSunLuna-JGM2-JR-SRP	9.579905961e-005	6.566145012e-009
EarthSunLuna-JGM2-MSISE90-SRP	9.579906571e-005	6.566144915e-009
EarthSunLuna-JGM3-JR-SRP	0.0003550036603	2.534142929e-008
EarthSunLuna-JGM3-MSISE90-SRP	0.0003550036587	2.53414294e-008
EarthSun-0-0-0	5.960012396e-005	4.310763669e-009
Earth-0-0-0	0.0001197102853	8.719081232e-009
Earth-0-0-SRP	5.601896844e-005	3.475200934e-009
Earth-0-JR-0	0.0001197102853	8.719081232e-009
Earth-0-MSISE90-0	0.0001197102853	8.719081232e-009
Earth-EGM96-0-0	2.255903168e-005	1.594926888e-009
Earth-EGM96full-0-0	2.255903168e-005	1.594926888e-009
Earth-JGM2-0-0	3.171564774e-005	2.262226167e-009
Earth-JGM2full-0-0	3.171564774e-005	2.262226167e-009
Earth-JGM3-0-0	7.915085073e-006	4.803359596e-010
Earth-JGM3full-0-0	7.915085062e-006	4.803359596e-010

Table 2.12: WinGMAT/STK GPS Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.662740721e-005	2.426869795e-009
EarthLuna-0-0-0	2.169469985e-005	3.149240969e-009
EarthSunLuna-EGM96-JR-SRP	0.195905184	2.485430203e-005
EarthSunLuna-EGM96-MSISE90-SRP	0.1959401287	2.48595588e-005
EarthSunLuna-JGM2-JR-SRP	0.1959114558	2.485518206e-005
EarthSunLuna-JGM2-MSISE90-SRP	0.1959370522	2.485908528e-005
EarthSunLuna-JGM3-JR-SRP	0.195912776	2.485544606e-005
EarthSunLuna-JGM3-MSISE90-SRP	0.1959037092	2.485406879e-005
EarthSun-0-0-0	2.126558099e-006	2.635314542e-010
Earth-0-0-0	2.339552039e-006	3.55591523e-010
Earth-0-0-SRP	0.08781441205	9.617352649e-006
Earth-0-JR-0	2.339552039e-006	3.55591523e-010
Earth-0-MSISE90-0	1.286060527e-005	1.871867604e-009
Earth-EGM96-0-0	3.820040266e-005	5.07887288e-009
Earth-EGM96full-0-0	3.820040266e-005	5.07887288e-009
Earth-JGM2-0-0	3.053563286e-005	4.048314034e-009
Earth-JGM2full-0-0	3.053563286e-005	4.048314034e-009
Earth-JGM3-0-0	2.911826529e-005	3.860659381e-009
Earth-JGM3full-0-0	2.911826529e-005	3.860659381e-009

Table 2.13: WinGMAT/STK ISS Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	4.925492414e-006	5.377666748e-009
EarthLuna-0-0-0	1.358158208e-005	1.517858521e-008
EarthSunLuna-EGM96-JR-SRP	278.7490121	0.3182017225
EarthSunLuna-EGM96-MSISE90-SRP	56.19364565	0.06443180958
EarthSunLuna-JGM2-JR-SRP	265.0437723	0.3028869261
EarthSunLuna-JGM2-MSISE90-SRP	56.19391989	0.06443210378
EarthSunLuna-JGM3-JR-SRP	278.7488721	0.3182015919
EarthSunLuna-JGM3-MSISE90-SRP	56.19329612	0.06443141798
EarthSun-0-0-0	2.038964805e-005	2.299027331e-008
Earth-0-0-0	1.228551517e-005	1.369393916e-008
Earth-0-0-SRP	0.2448384487	0.0002550460104
Earth-0-JR-0	251.7652015	0.2867219027
Earth-0-MSISE90-0	54.12966818	0.06180122646
Earth-EGM96-0-0	0.0003644150208	4.148262569e-007
Earth-EGM96full-0-0	0.0003581331287	4.090838088e-007
Earth-JGM2-0-0	0.0002170842842	2.484711427e-007
Earth-JGM2full-0-0	0.0002311364039	2.630113885e-007
Earth-JGM3-0-0	0.0002105116091	2.411358849e-007
Earth-JGM3full-0-0	0.0002096614486	2.393860442e-007

Table 2.14: WinGMAT/STK Molniya Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.0003314487264	2.730602986e-007
EarthLuna-0-0-0	0.0003210729838	2.590749514e-007
EarthSunLuna-EGM96-JR-SRP	13.53104131	0.009730536577
EarthSunLuna-EGM96-MSISE90-SRP	7.258014332	0.004949493739
EarthSunLuna-JGM2-JR-SRP	13.53359776	0.009731939777
EarthSunLuna-JGM2-MSISE90-SRP	7.261154113	0.004951225468
EarthSunLuna-JGM3-JR-SRP	13.53264889	0.009731430743
EarthSunLuna-JGM3-MSISE90-SRP	7.260596361	0.004951067604
EarthSun-0-0-0	0.0003809309497	3.180452068e-007
Earth-0-0-0	0.000279053648	2.328471744e-007
Earth-0-0-SRP	0.5715055849	0.0004792621788
Earth-0-JR-0	15.701198	0.01312861082
Earth-0-MSISE90-0	7.010176917	0.005861586148
Earth-EGM96-0-0	0.001875376476	1.572660098e-006
Earth-EGM96full-0-0	0.001685211881	1.406295112e-006
Earth-JGM2-0-0	0.00175910342	1.459627919e-006
Earth-JGM2full-0-0	0.00144502936	1.213360093e-006
Earth-JGM3-0-0	0.001324236096	1.112597884e-006
Earth-JGM3full-0-0	0.001614529441	1.354914031e-006

Table 2.15: WinGMAT/STK SunSync Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	2.358971554e-005	2.681211454e-008
EarthLuna-0-0-0	3.724362647e-005	4.203343824e-008
EarthSunLuna-EGM96-JR-SRP	185.5519142	0.2108883648
EarthSunLuna-EGM96-MSISE90-SRP	45.12791477	0.05132426321
EarthSunLuna-JGM2-JR-SRP	185.5518973	0.2108882696
EarthSunLuna-JGM2-MSISE90-SRP	45.12682131	0.0513230801
EarthSunLuna-JGM3-JR-SRP	185.5516858	0.2108881201
EarthSunLuna-JGM3-MSISE90-SRP	45.12760886	0.05132392543
EarthSun-0-0-0	3.443868462e-006	3.874965572e-009
Earth-0-0-0	5.571604256e-005	6.318329659e-008
Earth-0-0-SRP	0.1578630287	0.0001369434068
Earth-0-JR-0	172.0259211	0.1950745552
Earth-0-MSISE90-0	42.66517645	0.04839010638
Earth-EGM96-0-0	7.209659837e-005	8.344664839e-008
Earth-EGM96full-0-0	7.044664547e-005	8.112441794e-008
Earth-JGM2-0-0	9.113915069e-005	9.862877795e-008
Earth-JGM2full-0-0	7.614138933e-005	8.067195018e-008
Earth-JGM3-0-0	7.04560142e-005	8.157554621e-008
Earth-JGM3full-0-0	0.0001045870308	1.115116441e-007

Table 2.16: WinGMAT/STK Mars1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.3263591838	0.0002753937339
Mars-0-0-0	0.05976581646	5.050620937e-005
Mars-0-0-SRP	0.3036535239	0.0002490264815
Mars-MARS50C-0-0	0.2778239479	0.000235230768
Mars-MARS50C-0-SRP	1.151830065	0.0009688088308

Table 2.17: WinGMAT/STK Mercury1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.08082045191	6.902235176e-005
Mercury-0-0-0	0.02035225238	1.757707099e-005
Mercury-0-0-SRP	58.81841734	0.05047123529

Table 2.18: WinGMAT/STK Moon Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.0001788613456	1.076366643e-007
Luna-0-0-0	5.509298741e-005	3.956541351e-008
Luna-0-0-SRP	0.01743136945	1.252125413e-005
Luna-LP165P-0-0	8.151617246e-005	5.328061379e-008
Luna-LP165P-0-SRP	0.1352303773	9.612735277e-005

Table 2.19: WinGMAT/STK Neptune1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.9992944513	0.0005089272419
Neptune-0-0-0	1.654238681	0.0008394180641
Neptune-0-0-SRP	0.6217617836	0.0003128743726

Table 2.20: WinGMAT/STK Pluto1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.8883195792	0.0004683900409
Pluto-0-0-0	0.2632397208	0.0001382385272
Pluto-0-0-SRP	0.7924549248	0.000412930356



Table 2.21: WinGMAT/STK Saturn1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.1414864331	4.873113155e-005
Saturn-0-0-0	0.4275798897	0.0001483054614
Saturn-0-0-SRP	0.3125074647	0.0001026084411

Table 2.22: WinGMAT/STK Uranus1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.2826432569	9.08640035e-005
Uranus-0-0-0	0.5181308012	0.0001672502964
Uranus-0-0-SRP	1.083706536	0.0002672686565

Table 2.23: WinGMAT/STK Venus1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.04745630345	4.710021014e-005
Venus-0-0-0	0.007229278127	7.099075839e-006
Venus-0-0-SRP	0.3951875089	0.0003923662219
Venus-MGNP180U-0-0	0.03235827735	3.211565583e-005
Venus-MGNP180U-0-SRP	0.3856665851	0.0003824631351

Table 2.24: WinGMAT/STK DeepSpace Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.007940981789	1.605854348e-009

Table 2.25: WinGMAT/STK EML2 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	379958.6978	2.07681039
AllPlanets-0-0-SRP	301791.4051	1.634141485
EarthSunLuna-0-0-0	190756.5042	1.042335372
EarthSunLuna-JGM2-0-0	246282.4376	1.342146751

Table 2.26: WinGMAT/STK ESL2 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	161033.3719	0.08787739748
AllPlanets-0-0-SRP	70015.99553	0.05565329132

Table 2.27: FF/WinGMAT GEO Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.02462022161	2.34556955e-006
EarthLuna-0-0-0	0.02461856937	2.26101172e-006
EarthSun-0-0-0	7.736664473e-005	8.493951389e-007
Earth-0-0-0	5.165299947e-005	6.914602569e-007
Earth-0-0-SRP	2.899304383	0.0001245207705
Earth-JGM2-0-0	0.02512308636	2.311277555e-006

Table 2.28: FF/WinGMAT GPS Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.001888065605	1.052273653e-006
EarthLuna-0-0-0	0.001875214557	9.432466481e-007
EarthSun-0-0-0	2.961701873e-006	8.317803892e-007
Earth-0-0-0	5.89820441e-006	7.983233622e-007
Earth-0-0-SRP	0.5814644005	6.084153284e-005
Earth-JGM2-0-0	0.01103887303	2.139507827e-006

Table 2.29: FF/WinGMAT ISS Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.040838507e-005	8.250414612e-007
EarthLuna-0-0-0	3.213533909e-005	8.438391078e-007
EarthSun-0-0-0	5.785143022e-006	8.130790146e-007
Earth-0-0-0	3.532391024e-005	8.185863284e-007
Earth-0-0-SRP	0.1095514283	0.0001183410894
Earth-JGM2-0-0	0.207617684	0.0002404563627

Table 2.30: FF/WinGMAT Molniya Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.01426816524	1.188656079e-005
EarthLuna-0-0-0	0.01441439853	1.209920704e-005
EarthSun-0-0-0	0.0002989249764	8.230318908e-007
Earth-0-0-0	0.0001282379623	8.075748526e-007
Earth-0-0-SRP	2.735289122	0.002258411874
Earth-JGM2-0-0	3.064868806	0.002563083367

Table 2.31: FF/WinGMAT SunSync Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.290367452e-005	8.52125062e-007
EarthLuna-0-0-0	5.607687083e-005	8.182561764e-007
EarthSun-0-0-0	1.813206632e-005	8.471813729e-007
Earth-0-0-0	1.980913919e-005	8.215203234e-007
Earth-0-0-SRP	0.04777161483	4.874211014e-005
Earth-JGM2-0-0	0.09458037292	0.0001055177926

Table 2.32: FF/WinGMAT EML2 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	589627.1159	3.220817503
AllPlanets-0-0-SRP	509623.79	2.760208334
EarthSunLuna-0-0-0	400024.5526	2.184157603
EarthSunLuna-JGM2-0-0	455562.7987	2.484088688

Table 2.33: FF/WinGMAT ESL2 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	5500773.426	3.026168807
AllPlanets-0-0-SRP	6951247.218	5.415905104

## 2.5 Win/Mac GMAT Comparison

Table 2.34: WinGMAT/MacGMAT GEO Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	7.889320184e-006	4.981092583e-010
EarthLuna-0-0-0	3.862310091e-005	2.829034403e-009
EarthSunLuna-EGM96-JR-SRP	0.0001255674449	9.1445459e-009
EarthSunLuna-EGM96-MSISE90-SRP	0.0001255674449	9.144545899e-009
EarthSunLuna-JGM2-JR-SRP	7.353496438e-005	5.462181017e-009
EarthSunLuna-JGM2-MSISE90-SRP	7.353496437e-005	5.462181016e-009
EarthSunLuna-JGM3-JR-SRP	0.0001352482846	9.775905712e-009
EarthSunLuna-JGM3-MSISE90-SRP	0.0001352482846	9.775905715e-009
EarthSun-0-0-0	9.928130768e-005	7.154327853e-009
Earth-0-0-0	4.990522323e-005	3.634067315e-009
Earth-0-0-SRP	4.520549659e-005	3.269987835e-009
Earth-0-JR-0	4.990522323e-005	3.634067315e-009
Earth-0-MSISE90-0	4.990522323e-005	3.634067315e-009
Earth-EGM96-0-0	6.81671185e-005	4.950072943e-009
Earth-EGM96full-0-0	6.81671185e-005	4.950072943e-009
Earth-JGM2-0-0	1.538671514e-005	1.112479746e-009
Earth-JGM2full-0-0	1.538671514e-005	1.112479746e-009
Earth-JGM3-0-0	5.489787175e-006	4.047244602e-010
Earth-JGM3full-0-0	5.489787175e-006	4.047244602e-010

Table 2.35: WinGMAT/MacGMAT GPS Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.524285564e-005	2.13023419e-009
EarthLuna-0-0-0	7.689731018e-006	1.062224728e-009
EarthSunLuna-EGM96-JR-SRP	1.627453194e-005	2.270918492e-009
EarthSunLuna-EGM96-MSISE90-SRP	9.265605105e-006	1.328441506e-009
EarthSunLuna-JGM2-JR-SRP	2.80275826e-006	3.762387107e-010
EarthSunLuna-JGM2-MSISE90-SRP	7.908282521e-006	1.128542622e-009
EarthSunLuna-JGM3-JR-SRP	6.035842385e-006	7.962769859e-010
EarthSunLuna-JGM3-MSISE90-SRP	6.490395836e-006	9.21768e-010
EarthSun-0-0-0	3.222076727e-006	4.833482138e-010
Earth-0-0-0	5.234750509e-006	7.706152625e-010
Earth-0-0-SRP	1.171446476e-006	1.822703558e-010
Earth-0-JR-0	5.234750509e-006	7.706152625e-010
Earth-0-MSISE90-0	2.782120359e-006	3.443304045e-010
Earth-EGM96-0-0	1.050744267e-005	1.447584802e-009
Earth-EGM96full-0-0	1.050744267e-005	1.447584802e-009
Earth-JGM2-0-0	2.283784887e-006	3.435638023e-010
Earth-JGM2full-0-0	2.283784887e-006	3.435638023e-010
Earth-JGM3-0-0	7.101270799e-006	1.060395602e-009
Earth-JGM3full-0-0	7.101270799e-006	1.060395602e-009

Table 2.36: WinGMAT/MacGMAT ISS Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.767688707e-005	1.987826967e-008
EarthLuna-0-0-0	4.058801998e-005	4.617387375e-008
EarthSunLuna-EGM96-JR-SRP	2.350033054e-005	2.662367385e-008
EarthSunLuna-EGM96-MSISE90-SRP	0.0006669672891	7.368745763e-007
EarthSunLuna-JGM2-JR-SRP	1.840611847e-005	2.086797767e-008
EarthSunLuna-JGM2-MSISE90-SRP	0.0006391410111	7.093227198e-007
EarthSunLuna-JGM3-JR-SRP	4.906955953e-005	5.585723624e-008
EarthSunLuna-JGM3-MSISE90-SRP	0.0001694547514	1.723059642e-007
EarthSun-0-0-0	3.963497881e-006	4.502622513e-009
Earth-0-0-0	3.476512236e-005	3.980331596e-008
Earth-0-0-SRP	1.709387551e-005	1.961412784e-008
Earth-0-JR-0	1.516771704e-006	1.633830233e-009
Earth-0-MSISE90-0	0.0006871347746	7.902102731e-007
Earth-EGM96-0-0	1.608009486e-005	1.792593523e-008
Earth-EGM96full-0-0	1.796350308e-005	2.023666e-008
Earth-JGM2-0-0	8.522888644e-006	9.778070887e-009
Earth-JGM2full-0-0	7.900862621e-006	8.784310979e-009
Earth-JGM3-0-0	6.904868565e-006	7.605149901e-009
Earth-JGM3full-0-0	8.703769381e-006	9.962336035e-009

Table 2.37: WinGMAT/MacGMAT Molniya Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.0001161355335	9.734627028e-008
EarthLuna-0-0-0	0.0001765185068	1.474675389e-007
EarthSunLuna-EGM96-JR-SRP	9.149240024e-005	7.550332195e-008
EarthSunLuna-EGM96-MSISE90-SRP	0.000337018456	2.517462331e-007
EarthSunLuna-JGM2-JR-SRP	0.0001687015187	1.180293741e-007
EarthSunLuna-JGM2-MSISE90-SRP	0.0003458685231	2.567145268e-007
EarthSunLuna-JGM3-JR-SRP	2.89102084e-005	1.439959413e-008
EarthSunLuna-JGM3-MSISE90-SRP	0.0004306462955	3.433138109e-007
EarthSun-0-0-0	0.0004166915691	3.484312793e-007
Earth-0-0-0	0.0004592790738	3.839183118e-007
Earth-0-0-SRP	3.343036684e-005	2.780900576e-008
Earth-0-JR-0	0.0002482930089	2.078309993e-007
Earth-0-MSISE90-0	9.929293779e-005	8.265330135e-008
Earth-EGM96-0-0	4.303627343e-005	2.617173925e-008
Earth-EGM96full-0-0	0.0001105407449	9.218740603e-008
Earth-JGM2-0-0	0.0002507869521	1.785682667e-007
Earth-JGM2full-0-0	0.0002346500837	1.623140036e-007
Earth-JGM3-0-0	5.099576082e-005	4.255038887e-008
Earth-JGM3full-0-0	0.0001446553101	8.368203852e-008

Table 2.38: WinGMAT/MacGMAT SunSync Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	6.500418074e-006	6.999302677e-009
EarthLuna-0-0-0	4.322773976e-005	4.846536744e-008
EarthSunLuna-EGM96-JR-SRP	1.07874072e-005	1.222942998e-008
EarthSunLuna-EGM96-MSISE90-SRP	0.0002907736973	3.198710152e-007
EarthSunLuna-JGM2-JR-SRP	5.336201438e-006	5.644390406e-009
EarthSunLuna-JGM2-MSISE90-SRP	8.135754448e-005	8.017598457e-008
EarthSunLuna-JGM3-JR-SRP	4.666661247e-005	5.293796337e-008
EarthSunLuna-JGM3-MSISE90-SRP	0.0003578443346	3.980896788e-007
EarthSun-0-0-0	1.500943262e-005	1.689722434e-008
Earth-0-0-0	2.653939383e-005	2.998036763e-008
Earth-0-0-SRP	3.969621364e-005	4.465304759e-008
Earth-0-JR-0	3.885692582e-005	4.338304594e-008
Earth-0-MSISE90-0	0.0001846260209	2.024641677e-007
Earth-EGM96-0-0	2.749076581e-006	2.902225971e-009
Earth-EGM96full-0-0	3.242311524e-006	3.49137102e-009
Earth-JGM2-0-0	1.047153324e-005	1.171331382e-008
Earth-JGM2full-0-0	1.439187158e-005	1.599554939e-008
Earth-JGM3-0-0	1.416756213e-005	1.591877652e-008
Earth-JGM3full-0-0	1.85849559e-005	2.086516383e-008



Table 2.39: WinGMAT/MacGMAT Mars1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.03972223921	3.343331462e-005
Mars-0-0-0	0.005311861757	4.268418571e-006
Mars-0-0-SRP	0.05222305978	4.393980991e-005
Mars-MARS50C-0-0	0.01297658486	1.093110803e-005
Mars-MARS50C-0-SRP	0.1117967472	9.414441698e-005

Table 2.40: WinGMAT/MacGMAT Mercury1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.004516330784	3.600005592e-006
Mercury-0-0-0	0.03778257814	3.190578299e-005
Mercury-0-0-SRP	0.02607980485	2.236210801e-005

Table 2.41: WinGMAT/MacGMAT Moon Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.0003918908681	2.810115186e-007
Luna-0-0-0	8.768096011e-005	6.221838761e-008
Luna-0-0-SRP	0.000593804859	4.250992344e-007
Luna-LP165P-0-0	0.0004664933125	3.338481962e-007
Luna-LP165P-0-SRP	0.0001597775244	1.143221729e-007

Table 2.42: WinGMAT/MacGMAT Neptune1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.455191523e-008	6.20685014e-010
Neptune-0-0-0	1.543463691e-008	1.126411949e-010
Neptune-0-0-SRP	1.458030924e-008	1.741877302e-010

Table 2.43: WinGMAT/MacGMAT Pluto1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.286219742e-009	3.384705673e-011
Pluto-0-0-0	1.286219742e-009	9.024959195e-012
Pluto-0-0-SRP	1.023181539e-009	1.649647961e-010

Table 2.44: WinGMAT/MacGMAT Saturn1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.626953583e-008	1.628929876e-010
Saturn-0-0-0	2.057951587e-008	1.669113889e-010
Saturn-0-0-SRP	2.057951587e-008	1.124589615e-010

Table 2.45: WinGMAT/MacGMAT Uranus1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.458030924e-008	2.642610672e-011
Uranus-0-0-0	1.455191523e-008	8.413351831e-011
Uranus-0-0-SRP	2.057951587e-008	6.76066571e-011

Table 2.46: WinGMAT/MacGMAT Venus1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.001945532067	1.947340584e-006
Venus-0-0-0	0.01882594263	1.859722326e-005
Venus-0-0-SRP	0.02322953755	2.299817313e-005
Venus-MGNP180U-0-0	0.03289233273	3.254048475e-005
Venus-MGNP180U-0-SRP	0.03086632412	3.063642165e-005

Table 2.47: WinGMAT/MacGMAT DeepSpace Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.004474133849	9.33402511e-010

Table 2.48: WinGMAT/MacGMAT EML2 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	55804.23343	0.3054834604
AllPlanets-0-0-SRP	124016.2439	0.6662855702
EarthSunLuna-0-0-0	33336.13696	0.1885640618
EarthSunLuna-JGM2-0-0	214046.0535	1.167672328

Table 2.49: WinGMAT/MacGMAT ESL2 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	380849.9527	0.2067925122
AllPlanets-0-0-SRP	234119.7653	0.1824594525

## 2.6 Win/Linux GMAT Comparison

Table 2.50: WinGMAT/LinuxGMAT GEO Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.818989404e-008	1.256073967e-012
EarthLuna-0-0-0	1.818989404e-008	1.256073967e-012
EarthSunLuna-EGM96-JR-SRP	1.818989404e-008	1.256073967e-012
EarthSunLuna-EGM96-MSISE90-SRP	1.818989404e-008	1.256073967e-012
EarthSunLuna-JGM2-JR-SRP	1.818989404e-008	1.256073967e-012
EarthSunLuna-JGM2-MSISE90-SRP	1.818989404e-008	1.256073967e-012
EarthSunLuna-JGM3-JR-SRP	1.818989404e-008	1.256073967e-012
EarthSunLuna-JGM3-MSISE90-SRP	1.818989404e-008	1.256073967e-012
EarthSun-0-0-0	1.818989404e-008	1.256073967e-012
Earth-0-0-0	1.818989404e-008	1.256073967e-012
Earth-0-0-SRP	1.626953583e-008	1.256073967e-012
Earth-0-JR-0	1.818989404e-008	1.256073967e-012
Earth-0-MSISE90-0	1.818989404e-008	1.256073967e-012
Earth-EGM96-0-0	1.818989404e-008	1.256073967e-012
Earth-EGM96full-0-0	1.818989404e-008	1.256073967e-012
Earth-JGM2-0-0	1.818989404e-008	8.950904183e-013
Earth-JGM2full-0-0	1.818989404e-008	8.950904183e-013
Earth-JGM3-0-0	1.466516141e-008	1.256073967e-012
Earth-JGM3full-0-0	1.466516141e-008	1.256073967e-012

Table 2.51: WinGMAT/LinuxGMAT GPS Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.543463691e-008	1.256073967e-012
EarthLuna-0-0-0	1.164721514e-008	1.256073967e-012
EarthSunLuna-EGM96-JR-SRP	1.543463691e-008	1.256073967e-012
EarthSunLuna-EGM96-MSISE90-SRP	1.286219742e-008	1.25611709e-012
EarthSunLuna-JGM2-JR-SRP	1.311691913e-008	1.256073967e-012
EarthSunLuna-JGM2-MSISE90-SRP	1.311691913e-008	1.256073967e-012
EarthSunLuna-JGM3-JR-SRP	1.314841238e-008	1.538370149e-012
EarthSunLuna-JGM3-MSISE90-SRP	1.311691913e-008	1.256073967e-012
EarthSun-0-0-0	1.42067614e-008	1.256073967e-012
Earth-0-0-0	1.311691913e-008	1.256073967e-012
Earth-0-0-SRP	1.311691913e-008	1.256073967e-012
Earth-0-JR-0	1.311691913e-008	1.256073967e-012
Earth-0-MSISE90-0	1.42067614e-008	1.256073967e-012
Earth-EGM96-0-0	1.311691913e-008	1.256073967e-012
Earth-EGM96full-0-0	1.311691913e-008	1.256073967e-012
Earth-JGM2-0-0	1.311691913e-008	1.256073967e-012
Earth-JGM2full-0-0	1.311691913e-008	1.256073967e-012
Earth-JGM3-0-0	1.311691913e-008	1.256073967e-012
Earth-JGM3full-0-0	1.311691913e-008	1.256073967e-012

Table 2.52: WinGMAT/LinuxGMAT ISS Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	2.087012916e-009	2.512147934e-012
EarthLuna-0-0-0	2.033691978e-009	2.512147934e-012
EarthSunLuna-EGM96-JR-SRP	2.033691978e-009	2.512147934e-012
EarthSunLuna-EGM96-MSISE90-SRP	0.0008470424638	9.587548246e-007
EarthSunLuna-JGM2-JR-SRP	2.572439484e-009	2.512147934e-012
EarthSunLuna-JGM2-MSISE90-SRP	0.0007669211768	8.667589808e-007
EarthSunLuna-JGM3-JR-SRP	2.572439484e-009	1.986027323e-012
EarthSunLuna-JGM3-MSISE90-SRP	0.0008251276656	9.357517454e-007
EarthSun-0-0-0	2.572439484e-009	2.512147934e-012
Earth-0-0-0	2.572439484e-009	1.986027323e-012
Earth-0-0-SRP	2.033691978e-009	2.512147934e-012
Earth-0-JR-0	2.033691978e-009	2.512147934e-012
Earth-0-MSISE90-0	0.0005086050402	5.7095113e-007
Earth-EGM96-0-0	2.033691978e-009	2.512147934e-012
Earth-EGM96full-0-0	2.033691978e-009	2.664535259e-012
Earth-JGM2-0-0	2.572439484e-009	2.512147934e-012
Earth-JGM2full-0-0	2.572439484e-009	2.512147934e-012
Earth-JGM3-0-0	2.033691978e-009	1.986027323e-012
Earth-JGM3full-0-0	2.033691978e-009	2.512147934e-012

Table 2.53: WinGMAT/LinuxGMAT Molniya Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.543463691e-008	1.776356839e-012
EarthLuna-0-0-0	1.818989404e-008	1.776356839e-012
EarthSunLuna-EGM96-JR-SRP	1.818989404e-008	1.986027323e-012
EarthSunLuna-EGM96-MSISE90-SRP	0.0002835450278	1.639475709e-007
EarthSunLuna-JGM2-JR-SRP	1.818989404e-008	1.776356839e-012
EarthSunLuna-JGM2-MSISE90-SRP	0.0003637177938	2.536251812e-007
EarthSunLuna-JGM3-JR-SRP	1.818989404e-008	1.986027323e-012
EarthSunLuna-JGM3-MSISE90-SRP	0.0001377244321	6.842684735e-008
EarthSun-0-0-0	1.455191523e-008	2.512147934e-012
Earth-0-0-0	1.818989404e-008	1.986027323e-012
Earth-0-0-SRP	1.455191523e-008	1.776356839e-012
Earth-0-JR-0	1.818989404e-008	2.512147934e-012
Earth-0-MSISE90-0	0.0005204508808	4.351107742e-007
Earth-EGM96-0-0	1.543463691e-008	1.986027323e-012
Earth-EGM96full-0-0	1.818989404e-008	2.512147934e-012
Earth-JGM2-0-0	1.626953583e-008	1.779822905e-012
Earth-JGM2full-0-0	1.818989404e-008	1.776356839e-012
Earth-JGM3-0-0	1.626953583e-008	2.512147934e-012
Earth-JGM3full-0-0	1.626953583e-008	1.986027323e-012

Table 2.54: WinGMAT/LinuxGMAT SunSync Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	2.033691978e-009	1.986027323e-012
EarthLuna-0-0-0	2.033691978e-009	2.512147934e-012
EarthSunLuna-EGM96-JR-SRP	2.033691978e-009	2.664535259e-012
EarthSunLuna-EGM96-MSISE90-SRP	0.0004937360699	5.662979365e-007
EarthSunLuna-JGM2-JR-SRP	2.033691978e-009	2.512147934e-012
EarthSunLuna-JGM2-MSISE90-SRP	0.0006551562744	7.5461681e-007
EarthSunLuna-JGM3-JR-SRP	2.033691978e-009	1.986027323e-012
EarthSunLuna-JGM3-MSISE90-SRP	0.0005964945835	6.857578925e-007
EarthSun-0-0-0	2.033691978e-009	1.986027323e-012
Earth-0-0-0	2.572439484e-009	1.986027323e-012
Earth-0-0-SRP	2.572439484e-009	2.512147934e-012
Earth-0-JR-0	2.033691978e-009	1.986027323e-012
Earth-0-MSISE90-0	0.0006288991645	7.221314608e-007
Earth-EGM96-0-0	2.033691978e-009	1.986027323e-012
Earth-EGM96full-0-0	2.036867143e-009	2.512147934e-012
Earth-JGM2-0-0	2.033691978e-009	1.986027323e-012
Earth-JGM2full-0-0	2.572439484e-009	1.986027323e-012
Earth-JGM3-0-0	2.033691978e-009	2.512147934e-012
Earth-JGM3full-0-0	2.572439484e-009	2.512147934e-012

Table 2.55: WinGMAT/LinuxGMAT Mars1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	2.033691978e-009	1.256073967e-012
Mars-0-0-0	1.818989404e-009	1.256073967e-012
Mars-0-0-SRP	1.818989404e-009	1.256073967e-012
Mars-MARS50C-0-0	1.818989404e-009	1.256073967e-012
Mars-MARS50C-0-SRP	1.822538655e-009	1.256073967e-012

Table 2.56: WinGMAT/LinuxGMAT Mercury1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.818989404e-009	1.256073967e-012
Mercury-0-0-0	1.286219742e-009	1.256073967e-012
Mercury-0-0-SRP	1.822538655e-009	1.26097096e-012

Table 2.57: WinGMAT/LinuxGMAT Moon Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.286219742e-009	8.950904183e-013
Luna-0-0-0	1.575291033e-009	8.950904183e-013
Luna-0-0-SRP	1.286219742e-009	8.881784197e-013
Luna-LP165P-0-0	0.0001310647334	9.401096987e-008
Luna-LP165P-0-SRP	0.0001872108595	1.337602461e-007

Table 2.58: WinGMAT/LinuxGMAT Neptune1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.455191523e-008	1.50728876e-011
Neptune-0-0-0	1.543463691e-008	1.080515682e-011
Neptune-0-0-SRP	1.458030924e-008	1.080515682e-011

Table 2.59: WinGMAT/LinuxGMAT Pluto1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.286219742e-009	1.570092459e-013
Pluto-0-0-0	1.286219742e-009	1.570092459e-013
Pluto-0-0-SRP	1.023181539e-009	1.570092459e-013

Table 2.60: WinGMAT/LinuxGMAT Saturn1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.626953583e-008	1.50728876e-011
Saturn-0-0-0	2.057951587e-008	1.280949134e-011
Saturn-0-0-SRP	2.057951587e-008	1.280949134e-011

Table 2.61: WinGMAT/LinuxGMAT Uranus1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.458030924e-008	1.065814104e-011
Uranus-0-0-0	1.455191523e-008	1.065814104e-011
Uranus-0-0-SRP	2.057951587e-008	1.065814104e-011

Table 2.62: WinGMAT/LinuxGMAT Venus1 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	2.572439484e-009	1.986027323e-012
Venus-0-0-0	2.572439484e-009	1.986027323e-012
Venus-0-0-SRP	2.033691978e-009	2.514600007e-012
Venus-MGNP180U-0-0	2.572439484e-009	2.512147934e-012
Venus-MGNP180U-0-SRP	2.572439484e-009	2.512147934e-012



Table 2.63: WinGMAT/LinuxGMAT DeepSpace Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.009386010342	1.886732646e-009

Table 2.64: WinGMAT/LinuxGMAT EML2 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	135364.0795	0.7390519353
AllPlanets-0-0-SRP	269258.1081	1.459047458
EarthSunLuna-0-0-0	13791.8204	0.07140281919
EarthSunLuna-JGM2-0-0	104302.9029	0.5713126463

Table 2.65: WinGMAT/LinuxGMAT ESL2 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	161033.6102	0.0878775284
AllPlanets-0-0-SRP	70022.39058	0.05565825527

## 2.7 FF/STK Comparison

Table 2.66: FF/STK GEO Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.02441863704	2.331183059e-006
EarthLuna-0-0-0	0.02435631273	2.242953735e-006
EarthSunLuna-JGM2-HP-SRP	2.852626845	0.0001210061727
EarthSun-0-0-0	4.231055926e-005	8.493736892e-007
Earth-0-0-0	6.836800608e-005	6.889863428e-007
Earth-0-0-SRP	2.899330477	0.0001245233005
Earth-0-HP-0	6.836800608e-005	6.889863428e-007
Earth-JGM2-0-0	0.02513336324	2.312005083e-006

Table 2.67: FF/STK GPS Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.001903432726	1.053971199e-006
EarthLuna-0-0-0	0.001896072444	9.455916149e-007
EarthSunLuna-JGM2-HP-SRP	0.6785588953	6.968633698e-005
EarthSun-0-0-0	3.872950958e-006	8.316397374e-007
Earth-0-0-0	8.164858288e-006	7.983006024e-007
Earth-0-0-SRP	0.6692784196	6.82998214e-005
Earth-0-HP-0	8.164858288e-006	7.983006024e-007
Earth-JGM2-0-0	0.01104063243	2.139211093e-006

Table 2.68: FF/STK ISS Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.17832665e-005	8.274218823e-007
EarthLuna-0-0-0	2.023778135e-005	8.422726373e-007
EarthSunLuna-JGM2-HP-SRP	3.468138188	0.003970584682
EarthSun-0-0-0	2.067991746e-005	8.1799381e-007
Earth-0-0-0	4.404163183e-005	8.186528591e-007
Earth-0-0-SRP	0.1637932094	0.0001561216566
Earth-0-HP-0	3.213782043	0.003648358681
Earth-JGM2-0-0	0.2076446785	0.0002404801574

Table 2.69: FF/STK Molniya Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.01457313187	1.215436806e-005
EarthLuna-0-0-0	0.01409431455	1.184376446e-005
EarthSunLuna-JGM2-HP-SRP	7.784661066	0.004770671087
EarthSun-0-0-0	0.0006798546862	1.003660696e-006
Earth-0-0-0	0.0003365057467	8.083469211e-007
Earth-0-0-SRP	2.16384821	0.001779529358
Earth-0-HP-0	15.27354394	0.01277094127
Earth-JGM2-0-0	3.063128789	0.002561623783

Table 2.70: FF/STK SunSync Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	3.408772257e-005	8.692082437e-007
EarthLuna-0-0-0	1.971678896e-005	8.200621923e-007
EarthSunLuna-JGM2-HP-SRP	0.7800584002	0.0008377097699
EarthSun-0-0-0	1.533280696e-005	8.472050762e-007
Earth-0-0-0	3.656123033e-005	8.215198955e-007
Earth-0-0-SRP	0.2052485046	0.0001828464597
Earth-0-HP-0	0.6524853805	0.0007361489035
Earth-JGM2-0-0	0.09463135069	0.0001055896904

Table 2.71: FF/STK EML2 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	209675.0986	1.14402647
AllPlanets-0-0-SRP	207842.3945	1.126072479
EarthSunLuna-0-0-0	209277.3047	1.141861418
EarthSunLuna-JGM2-0-0	209283.0825	1.141942183

Table 2.72: FF/STK ESL2 Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	5661795.485	3.114044517
AllPlanets-0-0-SRP	6881239.331	5.360316234

## Chapter 3

# Calculation Parameters

GMAT's Central Body (Cb) and Coordinate System (CS) dependent parameters were tested to verify that the internal calculations were correct. In order to minimize the effects of other forces/elements, the two-body cases from the Propagators section were used, with some modification, to test both the central body and coordinate system parameters. The only changes to the two body cases were in the report output intervals and report output parameters. Data was outputted in ten minute intervals. The ISS two-body case was used for the Earth case and each planets respective two-body case was used for the non-Earth cases.

### 3.1 Initial Orbit State Conditions

The ISS, GEO, Mars1, Mercury1, Moon, Neptune1, Pluto1, Saturn1, Uranus1 and Venus1 two-body case's initial orbit parameters were used from the Propagation section (Chapter 2) for the test cases in this section.

Refer to Appendix B.1 Tables B.1- B.13 for a listing of all Propagator initial orbit states used for the Calculation Parameter test cases.

### 3.2 Central Body Dependent Parameters

#### 3.2.1 Naming Convention

This section describes the naming convention for central body dependent parameter scripts and output reports. The naming convention consists of a case sensitive ordered series of option strings, separated by underscores (`_`). Currently, options are allowed for the following fields, and will be present in the file name:

1. *tool* - The tool used to generate the test case.
2. *traj* - The trajectory to use. This includes initial conditions, physical parameters, and time step.

CbParams precedes the *tool* field and 2Body follows the *traj* field. The central body used can be determined based on the *traj* field. The final Cb file format is as followed:

CbParams\_*tool*\_*traj*\_2Body.report

The *tool* field should always be the first option field. Each field has a finite list of options, as follows (future options should be added to this list):

1. *tool*
  - STK - Satellite Toolkit HPOP or Astrogator
  - FF - FreeFlyer
  - GMAT - General Mission Analysis Tool
2. *traj*
  - ISS - leo orbit
  - Mars1 - eccentric low orbit
  - Mercury1 - eccentric low orbit
  - Moon - eccentric low orbit
  - Pluto1 - eccentric low orbit
  - Venus1 - eccentric low orbit

NOTE: Some test cases contain *traj* variations. In this case *traj* precedes the modification. For example, if an ISS trajectory is needed with a different Cd, *traj* could be ISSdiffCd1.

### 3.2.2 Comparison Script Information

Comparison\_Tool1\_Tool2\_Cb.m is the script used to perform the coordinate system comparisons needed for the Acceptance Test Plan. Many elements of this script were extracted from the Comparison\_Tool1\_Tool2\_CS.m script.

Comparison\_Tool1\_Tool2\_Cb.m was designed to allow the user to select two programs to compare to one another. The comparison involves taking the difference of the variables listed in the Acceptance Test Plan Overview Chapter->Testing Methodology->Calculation Parameters section.

Refer to Appendix C for more details on this script and others used in the Acceptance Test Plan document.

### 3.2.3 Test Case Results

The following results are for the Central Body-Calculation Parameter section. The current GMAT Build is compared to STK and FreeFlyer for this section.

FF-STK comparison results presented in Tables 3.11- 3.15 are used as a way to determine if the GMAT comparison values are acceptable. If GMAT comparison data is within the same order of magnitude as the FF-STK comparison data, that is acceptable. A more detailed acceptance metric/matrix will be developed at a later date.

Table 3.1: WinGMAT/STK Central Body Dependent Parameter Differences (1)

Test Case	Altitude (m)	Eccentricity	M. Anomaly (deg)	M. Motion (rad/sec)	Period (sec)
GEO-2Body	5.07862e-006	2.58444e-014	8.45405e-006	3.02098e-015	1.35187e-008
Hyperbolic-2Body	0.00422986	1.96065e-013	351.401	0.000223215	N/A
ISS-2Body	0.00543371	5.35459e-014	5.36033e-010	4.98408e-015	2.78305e-010
Mars1-2Body	0.00854993	6.36153e-011	4.14335e-007	1.4374e-013	2.02357e-006
Mercury1-2Body	0.00816747	3.32993e-011	6.26235e-007	8.4331e-014	1.16344e-006
Moon-2Body	1.25125e-005	1.19516e-013	1.40113e-009	4.29452e-016	5.97902e-009
Neptune1-2Body	0.129938	1.31688e-010	6.04917e-007	1.00478e-013	4.02808e-006
Pluto1-2Body	0.0408938	1.40508e-009	6.46394e-006	1.92829e-012	7.1273e-005
Saturn1-2Body	0.752271	1.05365e-011	1.08424e-007	1.75659e-014	1.58638e-006
Uranus1-2Body	0.214503	7.3413e-011	6.90012e-007	1.03813e-013	1.01941e-005
Venus1-2Body	0.000586204	1.1888e-011	1.99647e-008	9.29324e-015	1.03911e-007

Table 3.2: WinGMAT/STK Central Body Dependent Parameter Differences (2)

Test Case	Semi-major Axis (m)	True Anomaly (deg)	Semilatus Rectum(m)
GEO-2Body	4.40923e-006	8.45405e-006	4.3874e-006
Hyperbolic-2Body	1.68075e-006	7.3328e-012	1.30385e-005
ISS-2Body	2.26464e-007	5.31941e-010	2.23736e-007
Mars1-2Body	0.000654924	6.07863e-007	0.000695219
Mercury1-2Body	0.000303703	9.41577e-007	0.000302225
Moon-2Body	8.87667e-007	2.13311e-009	7.6443e-007
Neptune1-2Body	0.00597326	9.20473e-007	0.00497034
Pluto1-2Body	0.00559228	9.78524e-006	0.00483516
Saturn1-2Body	0.0036656	1.55097e-007	0.00339607
Uranus1-2Body	0.0122739	9.53123e-007	0.0105231
Venus1-2Body	6.97164e-005	3.0111e-008	4.77958e-005

Table 3.3: WinGMAT/STK Central Body Dependent Parameter Differences (3)

Test Case	Apoapsis Rad. (m)	Periapsis Rad. (m)	Apo. Vel. (m/sec)	Per. Vel. (m/sec)
GEO-2Body	4.81668e-006	3.9945e-006	2.39808e-010	9.59233e-011
Hyperbolic-2Body	N/A	4.5311e-006	N/A	1.87228e-009
ISS-2Body	4.91127e-007	2.3465e-007	3.77476e-010	2.78e-010
Mars1-2Body	0.000649562	0.00072951	1.97211e-007	4.69038e-007
Mercury1-2Body	0.000364466	0.000281601	1.00335e-007	1.73215e-007
Moon-2Body	1.11686e-006	6.68706e-007	2.18936e-010	2.48246e-010
Neptune1-2Body	0.0107942	0.00537949	2.28612e-006	2.18738e-006
Pluto1-2Body	0.00835419	0.00390449	1.66437e-006	1.27662e-006
Saturn1-2Body	0.00470792	0.00273832	4.79137e-007	6.01371e-007
Uranus1-2Body	0.0178846	0.00794457	1.94054e-006	1.37437e-006
Venus1-2Body	0.000159391	9.49995e-005	7.57927e-008	8.94333e-008

Table 3.4: WinGMAT/STK Central Body Dependent Parameter Differences (4)

Test Case	C3-Energy ( $m^2/sec^2$ )	Latitude (deg)	Longitude (deg)	MHA (deg)	LST (deg)
GEO-2Body	9.78773e-007	3.24499e-008	3.14428e-007	0.00196862	0.00196872
Hyperbolic-2Body	1.68043e-006	5.65537e-008	1.34994e-007	0.00196857	0.00196865
ISS-2Body	2.01084e-006	1.07156e-007	1.32738e-007	0.00196857	0.00196866
Mars1-2Body	0.00132386	3.17321e-007	5.33392e-007	N/A	N/A
Mercury1-2Body	0.00050501	6.8337e-007	9.88629e-007	N/A	N/A
Moon-2Body	6.96998e-007	1.54426e-009	1.41478e-007	N/A	N/A
Neptune1-2Body	0.0333358	7.39515e-007	1.2737e-006	N/A	N/A
Pluto1-2Body	0.00170371	6.40226e-006	1.49814e-005	N/A	N/A
Saturn1-2Body	0.0217304	1.27002e-006	5.73475e-007	N/A	N/A
Uranus1-2Body	0.0351218	9.94292e-007	2.37107e-006	N/A	N/A
Venus1-2Body	0.000343071	2.12925e-008	3.28642e-008	N/A	N/A

Table 3.5: WinGMAT/STK Central Body Dependent Parameter Differences (5)

Test Case	Beta Angle (deg)	(RxV)-Mag ( $m^2/sec$ )	R-Mag (m)
GEO-2Body	45.7421	0.00673754	5.02769e-006
Hyperbolic-2Body	130.969	0.0252476	1.43191e-005
ISS-2Body	98.3615	0.000887667	4.71118e-007
Mars1-2Body	70.1724	1.08224	0.00663077
Mercury1-2Body	173.794	0.379399	0.00816747
Moon-2Body	34.7765	0.000597993	1.25128e-005
Neptune1-2Body	122.85	35.4493	0.0763421
Pluto1-2Body	56.4158	1.82465	0.0408938
Saturn1-2Body	99.1135	37.7335	0.0303186
Uranus1-2Body	150.273	60.9356	0.106239
Venus1-2Body	31.881	0.15433	0.000586208



Table 3.6: FF/WinGMAT Central Body Dependent Parameter Differences (1)

Test Case	Altitude (m)	Eccentricity	M. Anomaly (deg)	M. Motion (rad/sec)	Period (sec)
GEO-2Body	9.88075e-006	1.93961e-010	1.5778e-005	5.74193e-016	7.39237e-009
ISS-2Body	0.433346	6.38449e-012	1.92313e-009	4.25961e-015	7.24867e-010

Table 3.7: FF/WinGMAT Central Body Dependent Parameter Differences (2)

Test Case	Semi-major Axis (m)	True Anomaly (deg)	Semilatus Rectum(m)
GEO-2Body	2.70666e-006	1.5778e-005	2.62662e-006
ISS-2Body	3.84716e-007	1.84814e-009	1.55524e-007

Table 3.8: FF/WinGMAT Central Body Dependent Parameter Differences (3)

Test Case	Apoapsis Rad. (m)	Periapsis Rad. (m)	Apo. Vel. ( $m/sec$ )	Per. Vel. ( $m/sec$ )
GEO-2Body	3.0559e-006	3.18687e-006	2.4134e-008	2.39755e-008
ISS-2Body	3.98359e-007	6.07542e-007	2.91207e-008	2.88614e-008

Table 3.9: FF/WinGMAT Central Body Dependent Parameter Differences (4)

Test Case	C3-Energy ( $m^2/sec^2$ )	Latitude (deg)	Longitude (deg)	MHA (deg)	LST (deg)
GEO-2Body	0.000148109	5.40781e-008	0	0.003009	0.00300921
ISS-2Body	0.000444686	6.02543e-006	5.81807e-007	0.003009	0.00300921

Table 3.10: FF/WinGMAT Central Body Dependent Parameter Differences (5)

Test Case	Beta Angle (deg)	(RxV)-Mag ( $m^2/sec$ )	R-Mag (m)
GEO-2Body	45.7413	0.0042055	3.32511e-006
ISS-2Body	98.3649	0.00147702	9.46784e-007

Table 3.11: FF/STK Central Body Dependent Parameter Differences (1)

Test Case	Altitude (m)	Eccentricity	M. Anomaly (deg)	M. Motion (rad/sec)	Period (sec)
GEO-2Body	8.04721e-006	1.9396e-010	1.76421e-005	2.44679e-015	6.4756e-009
ISS-2Body	0.427915	6.34e-012	1.73014e-009	9.18666e-015	8.14907e-010

Table 3.12: FF/STK Central Body Dependent Parameter Differences (2)

Test Case	Semi-major Axis (m)	True Anomaly (deg)	Semilatus Rectum(m)
GEO-2Body	2.08092e-006	1.76414e-005	1.92085e-006
ISS-2Body	4.47471e-007	1.67717e-009	1.56433e-007

Table 3.13: FF/STK Central Body Dependent Parameter Differences (3)

Test Case	Apoapsis Rad. (m)	Periapsis Rad. (m)	Apo. Vel. (m/sec)	Per. Vel. (m/sec)
GEO-2Body	2.72848e-006	2.03727e-006	2.38942e-008	2.38796e-008
ISS-2Body	5.23869e-007	6.23913e-007	2.87432e-008	2.88605e-008

Table 3.14: FF/STK Central Body Dependent Parameter Differences (4)

Test Case	C3-Energy ( $m^2/sec^2$ )	Latitude (deg)	Longitude (deg)	MHA (deg)	LST (deg)
GEO-2Body	0.000147141	3.06691e-008	0	0.00497708	0.00497715
ISS-2Body	0.000442895	5.92635e-006	6.1431e-007	0.00497708	0.00497716

Table 3.15: FF/STK Central Body Dependent Parameter Differences (5)

Test Case	Beta Angle (deg)	(RxV)-Mag ( $m^2/sec$ )	R-Mag (m)
GEO-2Body	0.000773444	0.00355067	4.05998e-006
ISS-2Body	0.00344889	0.00178261	1.01772e-006

### 3.2.4 Win/Mac GMAT Comparison

Table 3.16: WinGMAT/MacGMAT Central Body Dependent Parameter Differences (1)

Test Case	Altitude (m)	Eccentricity	M. Anomaly (deg)	M. Motion (rad/sec)	Period (sec)
GEO-2Body	2.452e-006	1.74542e-014	8.52452e-006	6.93889e-018	8.22183e-009
Hyperbolic-2Body	5.23869e-007	9.99201e-015	0	1.0842e-018	N/A
ISS-2Body	4.58385e-007	3.9682e-014	1.38419e-009	8.39172e-017	4.02906e-010
Mars1-2Body	0.00342313	1.47847e-010	2.00985e-007	1.34903e-013	1.93017e-006
Mercury1-2Body	0.00505079	4.83717e-011	3.89952e-007	1.08871e-013	1.49741e-006
Moon-2Body	2.24818e-005	1.43691e-013	2.53274e-009	4.53522e-016	9.08949e-009
Neptune1-2Body	2.00089e-008	4.93383e-013	4.70095e-011	2.99186e-016	1.17889e-008
Pluto1-2Body	0.0110934	9.63307e-010	1.50655e-006	1.2462e-012	4.61344e-005
Saturn1-2Body	5.09317e-008	5.10703e-015	1.19371e-012	2.81893e-018	2.40107e-010
Uranus1-2Body	3.09228e-008	1.8624e-014	7.95808e-012	1.24141e-017	1.22236e-009
Venus1-2Body	0.00131446	1.40132e-011	4.55151e-008	2.2602e-014	2.34479e-007

Table 3.17: WinGMAT/MacGMAT Central Body Dependent Parameter Differences (2)

Test Case	Semi-major Axis (m)	True Anomaly (deg)	Semilatus Rectum(m)
GEO-2Body	2.67755e-006	8.52451e-006	2.67755e-006
Hyperbolic-2Body	6.91216e-008	5.11591e-013	3.27418e-007
ISS-2Body	3.29237e-007	1.38273e-009	3.28328e-007
Mars1-2Body	0.000624696	3.06826e-007	0.000545762
Mercury1-2Body	0.000390883	5.87062e-007	0.000336432
Moon-2Body	1.35014e-006	3.8051e-009	1.19917e-006
Neptune1-2Body	1.74914e-005	3.54987e-011	2.07729e-005
Pluto1-2Body	0.00361984	2.21937e-006	0.00371269
Saturn1-2Body	5.38421e-007	1.3074e-012	4.80213e-007
Uranus1-2Body	1.46974e-006	7.53175e-012	1.36788e-006
Venus1-2Body	0.000157314	6.88501e-008	0.000105473

Table 3.18: WinGMAT/MacGMAT Central Body Dependent Parameter Differences (3)

Test Case	Apoapsis Rad. (m)	Periapsis Rad. (m)	Apo. Vel. (m/sec)	Per. Vel. (m/sec)
GEO-2Body	2.78669e-006	2.91766e-006	1.22125e-010	1.15019e-010
Hyperbolic-2Body	N/A	1.89175e-007	N/A	7.81597e-011
ISS-2Body	3.21052e-007	5.7571e-007	2.98428e-010	4.69846e-010
Mars1-2Body	0.00139151	0.000626785	5.33045e-007	5.19715e-007
Mercury1-2Body	0.000578938	0.00021615	1.72014e-007	1.50894e-007
Moon-2Body	1.92404e-006	8.39918e-007	4.62075e-010	3.57048e-010
Neptune1-2Body	3.5041e-005	2.87691e-005	7.62945e-009	1.22924e-008
Pluto1-2Body	0.00374967	0.00349214	4.00636e-007	1.2944e-006
Saturn1-2Body	1.06229e-006	7.05768e-007	1.59872e-010	2.02505e-010
Uranus1-2Body	2.55386e-006	1.56433e-006	3.23297e-010	3.8014e-010
Venus1-2Body	0.000302634	6.57656e-005	1.25344e-007	5.78817e-008

Table 3.19: WinGMAT/MacGMAT Central Body Dependent Parameter Differences (4)

Test Case	C3-Energy ( $m^2/sec^2$ )	Latitude (deg)	Longitude (deg)	MHA (deg)	LST (deg)
GEO-2Body	6.00409e-007	5.68504e-014	3.10763e-010	1.16529e-010	3.10706e-010
Hyperbolic-2Body	7.10543e-008	6.03961e-014	2.24389e-010	1.16529e-010	2.24304e-010
ISS-2Body	2.8848e-006	5.10916e-011	2.10321e-010	1.16529e-010	2.10321e-010
Mars1-2Body	0.00126275	1.58843e-007	3.08052e-007	N/A	N/A
Mercury1-2Body	0.00064998	4.31925e-007	6.27266e-007	N/A	N/A
Moon-2Body	1.05893e-006	2.93206e-009	4.7355e-009	N/A	N/A
Neptune1-2Body	9.75149e-005	6.39488e-014	2.08502e-010	N/A	N/A
Pluto1-2Body	0.0011028	1.59299e-006	3.42747e-006	N/A	N/A
Saturn1-2Body	3.18323e-006	6.39488e-014	4.16918e-010	N/A	N/A
Uranus1-2Body	4.20641e-006	6.03961e-014	2.08502e-010	N/A	N/A
Venus1-2Body	0.000774136	5.2415e-008	8.42126e-008	N/A	N/A

Table 3.20: WinGMAT/MacGMAT Central Body Dependent Parameter Differences (5)

Test Case	Beta Angle (deg)	(RxV)-Mag ( $m^2/sec$ )	R-Mag (m)
GEO-2Body	1.42109e-014	0.00410364	2.43745e-006
Hyperbolic-2Body	7.10543e-014	0.000640284	4.07454e-007
ISS-2Body	5.96856e-013	0.00125874	4.65661e-007
Mars1-2Body	2.6164e-009	0.849539	0.0034188
Mercury1-2Body	1.88567e-009	0.422386	0.00505079
Moon-2Body	6.94911e-012	0.000856744	2.24832e-005
Neptune1-2Body	1.7053e-013	0.14808	1.45519e-008
Pluto1-2Body	2.51034e-008	1.40107	0.0110934
Saturn1-2Body	4.26326e-014	0.0060536	1.45519e-008
Uranus1-2Body	1.84741e-013	0.00791624	1.45519e-008
Venus1-2Body	1.98796e-010	0.34034	0.00131445

### 3.2.5 Win/Linux GMAT Comparison

Table 3.21: WinGMAT/LinuxGMAT Central Body Dependent Parameter Differences (1)

Test Case	Altitude (m)	Eccentricity	M. Anomaly (deg)	M. Motion (rad/sec)	Period (sec)
GEO-2Body	1.45519e-008	1.05879e-022	1.02318e-012	0	0
Hyperbolic-2Body	1.16415e-007	8.88178e-016	0	1.0842e-019	N/A
ISS-2Body	1.13687e-010	1.0842e-018	1.13687e-013	1.0842e-018	1.81899e-012
Mars1-2Body	9.09495e-010	1.11022e-016	1.50635e-012	1.0842e-019	0
Mercury1-2Body	9.09495e-010	1.11022e-016	1.13687e-013	1.0842e-019	0
Moon-2Body	1.13687e-009	1.11022e-016	4.83169e-013	1.0842e-019	1.09139e-011
Neptune1-2Body	1.09139e-008	1.11022e-016	3.41061e-013	1.0842e-019	1.09139e-011
Pluto1-2Body	1.13687e-010	1.11022e-016	1.3074e-012	1.0842e-019	1.09139e-011
Saturn1-2Body	1.45519e-008	1.11022e-016	1.98952e-013	1.0842e-019	1.09139e-011
Uranus1-2Body	1.09139e-008	1.11022e-016	1.10845e-012	1.0842e-019	1.09139e-011
Venus1-2Body	1.02318e-009	1.11022e-016	5.55099e-013	1.0842e-019	1.81899e-012

Table 3.22: WinGMAT/LinuxGMAT Central Body Dependent Parameter Differences (2)

Test Case	Semi-major Axis (m)	True Anomaly (deg)	Semilatus Rectum(m)
GEO-2Body	1.45519e-008	9.09495e-013	1.45519e-008
Hyperbolic-2Body	1.09139e-008	1.13687e-013	7.27596e-009
ISS-2Body	1.81899e-009	1.13687e-013	1.81899e-009
Mars1-2Body	1.81899e-009	9.9476e-013	1.81899e-009
Mercury1-2Body	9.09495e-010	1.13687e-013	9.09495e-010
Moon-2Body	9.09495e-010	3.97904e-013	9.09495e-010
Neptune1-2Body	1.45519e-008	3.97904e-013	1.45519e-008
Pluto1-2Body	9.09495e-010	7.95808e-013	9.09495e-010
Saturn1-2Body	0	1.98952e-013	0
Uranus1-2Body	1.45519e-008	7.10543e-013	1.45519e-008
Venus1-2Body	1.81899e-009	8.4982e-013	1.81899e-009

Table 3.23: WinGMAT/LinuxGMAT Central Body Dependent Parameter Differences (3)

Test Case	Apoapsis Rad. (m)	Periapsis Rad. (m)	Apo. Vel. (m/sec)	Per. Vel. (m/sec)
GEO-2Body	1.45519e-008	1.45519e-008	8.88178e-013	8.88178e-013
Hyperbolic-2Body	N/A	1.09139e-008	N/A	0
ISS-2Body	1.81899e-009	1.81899e-009	1.77636e-012	1.77636e-012
Mars1-2Body	1.81899e-009	9.09495e-010	8.88178e-013	8.88178e-013
Mercury1-2Body	1.81899e-009	9.09495e-010	8.88178e-013	8.88178e-013
Moon-2Body	9.09495e-010	9.09495e-010	8.88178e-013	8.88178e-013
Neptune1-2Body	1.45519e-008	1.09139e-008	1.06581e-011	1.06581e-011
Pluto1-2Body	9.09495e-010	9.09495e-010	0	0
Saturn1-2Body	0	1.45519e-008	1.06581e-011	1.06581e-011
Uranus1-2Body	1.45519e-008	1.45519e-008	0	1.06581e-011
Venus1-2Body	0	1.81899e-009	1.77636e-012	1.77636e-012

Table 3.24: WinGMAT/LinuxGMAT Central Body Dependent Parameter Differences (4)

Test Case	C3-Energy ( $m^2/sec^2$ )	Latitude (deg)	Longitude (deg)	MHA (deg)	LST (deg)
GEO-2Body	0	1.04083e-017	0	1.13687e-013	1.13687e-013
Hyperbolic-2Body	1.06581e-008	1.06581e-014	1.13687e-013	1.13687e-013	1.13687e-013
ISS-2Body	1.42109e-008	1.42109e-014	1.13687e-013	1.13687e-013	1.13687e-013
Mars1-2Body	0	1.06581e-014	1.13687e-013	N/A	N/A
Mercury1-2Body	1.77636e-009	1.42109e-014	1.13687e-013	N/A	N/A
Moon-2Body	8.88178e-010	6.03961e-014	1.13687e-013	N/A	N/A
Neptune1-2Body	1.13687e-007	1.42109e-014	1.13687e-013	N/A	N/A
Pluto1-2Body	0	1.42109e-014	1.13687e-013	N/A	N/A
Saturn1-2Body	1.13687e-007	1.42109e-014	1.13687e-013	N/A	N/A
Uranus1-2Body	1.13687e-007	1.42109e-014	1.13687e-013	N/A	N/A
Venus1-2Body	1.42109e-008	1.42109e-014	1.13687e-013	N/A	N/A

Table 3.25: WinGMAT/LinuxGMAT Central Body Dependent Parameter Differences (5)

Test Case	Beta Angle (deg)	(RxV)-Mag ( $m^2/sec$ )	R-Mag (m)
GEO-2Body	1.42109e-014	0.000101863	1.45519e-008
Hyperbolic-2Body	1.42109e-014	0	1.16415e-007
ISS-2Body	1.42109e-014	0	1.81899e-009
Mars1-2Body	1.42109e-014	1.09139e-005	1.81899e-009
Mercury1-2Body	2.84217e-014	0	1.81899e-009
Moon-2Body	1.42109e-014	9.09495e-007	9.09495e-010
Neptune1-2Body	1.42109e-014	0.000116415	1.45519e-008
Pluto1-2Body	1.42109e-014	9.09495e-007	9.09495e-010
Saturn1-2Body	1.42109e-014	0.000931323	1.45519e-008
Uranus1-2Body	1.42109e-014	0.000116415	1.45519e-008
Venus1-2Body	1.42109e-014	1.45519e-005	1.81899e-009

### 3.3 Coordinate System Dependent Parameters

#### 3.3.1 Naming Convention

This section describes the naming convention for coordinate system dependent parameter scripts and output reports. The naming convention consists of a case sensitive ordered series of option strings, separated by underscores (-). Currently, options are allowed for the following fields, and will be present in the file name:

1. *tool* - The tool used to generate the test case
2. *traj* - The trajectory to use. This includes initial conditions, physical parameters, and time step
3. *CS* - The coordinate system to use. The celestial body to use is followed by the CS in the name

CSPParams precedes the *tool* field and 2Body precedes the *CS* field. The final CS file format is as followed:  
 CSPParams\_*tool*\_*traj*\_2Body\_*CS*.report

The *tool* field should always be the first option field. Each field has a finite list of options, as follows (future options should be added to this list):

1. *tool*
  - STK - Satellite Toolkit HPOP or Astrogator
  - FF - FreeFlyer
  - GMAT - General Mission Analysis Tool
2. *traj*
  - ISS - leo orbit
  - SunSync - leo orbit
  - GPS - meo orbit
  - GEO - geo orbit
  - Molniya - heo orbit
  - Mars1 - eccentric low orbit
  - Mercury1 - eccentric low orbit
  - Moon - eccentric low orbit
  - Pluto1 - eccentric low orbit
  - Venus1 - eccentric low orbit

NOTE: Some test cases contain *traj* variations. In this case *traj* precedes the modification. For example, if ISS trajectory is needed with no output, then *traj* can be ISSnoOut. The lack of a report file is shortened to noOut.

3. *CS*

EarthFixed	EarthMJ2000Eq	EarthMJ2000Ec
EarthTODEq	EarthTODEc	EarthMODEq
EarthMODEc	EarthGSM	EarthGSE
MarsFixed	MarsMJ2000Eq	MarsMJ2000Ec
MercuryFixed	MercuryMJ2000Eq	MercuryMJ2000Ec
MoonFixed	MoonMJ2000Eq	MoonMJ2000Ec
NeptuneFixed	NeptuneMJ2000Eq	NeptuneMJ2000Ec
PlutoFixed	PlutoMJ2000Eq	PlutoMJ2000Ec
SaturnFixed	SaturnMJ2000Eq	SaturnMJ2000Ec
UranusFixed	UranusMJ2000Eq	UranusMJ2000Ec
VenusFixed	VenusMJ2000Eq	VenusMJ2000Ec

## 3.3.2 Comparison Script Information

The script used to perform the Coordinate System comparisons needed for the Acceptance Test Plan is `Comparison_Tool1_Tool2_CS.m`. Many elements of this script were extracted from the `Comparison_Tool1_Tool2_PV.m` script.

`Comparison_Tool1_Tool2_CS.m` was designed to allow the user to select two programs to compare to one another. The comparison involves taking the difference of the variables listed in the Acceptance Test Plan Overview Chapter->Testing Methodology->Calculation Parameters section.

Refer to Appendix C for more details of this script and others used in the Acceptance Test Plan document.

## 3.3.3 Test Case Results

The following results are for the Coordinate System-Calculation Parameter section. The current GMAT Build is compared to STK and FreeFlyer for this section.

FF-STK comparison results presented in Tables 3.36- 3.40 are used as a way to determine if the GMAT comparison values are acceptable. If GMAT comparison data is within the same order of magnitude as the FF-STK comparison data that is acceptable. A more detailed acceptance metric/matrix will be developed at a later date.



Table 3.26: WinGMAT/STK Coordinate System Dependent Parameter Differences (Position)

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)
GEO-2Body-EarthFixed	0.2279480941	0.04019724292	0.02037045826
GEO-2Body-EarthMJ2000Ec	4.121250186e-005	0.0003267923603	0.0007510352589
GEO-2Body-EarthMJ2000Eq	4.12125587e-005	4.111393537e-005	4.46e-009
GEO-2Body-EarthMODEc	0.001291301203	0.00140066436	1.522624871e-005
GEO-2Body-EarthMODEq	0.00129130143	0.001291143235	0.0005432075092
GEO-2Body-EarthMOEEc	4.122210839e-005	3.773459412e-005	1.635578428e-005
GEO-2Body-EarthMOEEq	4.122210839e-005	4.112530405e-005	4.162467864e-009
GEO-2Body-EarthTODEc	0.006358783594	0.006834873602	0.0006267036952
GEO-2Body-EarthTODEq	0.006358782912	0.006272416158	0.003423116819
GEO-2Body-EarthTOEEc	0.005506250034	0.005993989021	1.635578428e-005
GEO-2Body-EarthTOEEq	0.005506249977	0.005505937452	0.002404046677
Hyperbolic-2Body-EarthFixed	0.3489023948	0.5435725325	0.1095402695
Hyperbolic-2Body-EarthMJ2000Ec	1.781154424e-005	0.001917796908	0.004851521226
Hyperbolic-2Body-EarthMJ2000Eq	1.781154424e-005	2.066371962e-006	2.153683454e-006
Hyperbolic-2Body-EarthMODEc	0.008122064173	0.01077653724	7.34871719e-006
Hyperbolic-2Body-EarthMODEq	0.008122064173	0.009883398889	0.004294211976
Hyperbolic-2Body-EarthMOEEc	1.781154424e-005	2.299202606e-006	2.197339199e-006
Hyperbolic-2Body-EarthMOEEq	1.781154424e-005	2.008164302e-006	2.095475793e-006
Hyperbolic-2Body-EarthTODEc	0.01367524965	0.01960271038	0.003635170287
Hyperbolic-2Body-EarthTODEq	0.01367519144	0.02924868022	0.0053634285
Hyperbolic-2Body-EarthTOEEc	0.03537029261	0.04713775706	2.197339199e-006
Hyperbolic-2Body-EarthTOEEq	0.03537029261	0.0450850057	0.01691188663
ISS-2Body-EarthFixed	0.01006701359	0.01444669078	0.002769957518
ISS-2Body-EarthGSE	6.088487225e-005	3.998593456e-005	1.257905069e-005
ISS-2Body-EarthGSM	3.893592293e-005	0.003798986654	0.002931082236
ISS-2Body-EarthMJ2000Ec	1.702539976e-005	8.047027222e-005	0.0001261626039
ISS-2Body-EarthMJ2000Eq	1.702539976e-005	1.612960432e-005	1.522789717e-005
ISS-2Body-EarthMODEc	0.0002104263785	0.000179437734	1.252678317e-005
ISS-2Body-EarthMODEq	0.0002104270607	0.0001648027137	7.129392543e-005
ISS-2Body-EarthMOEEc	1.702380814e-005	1.850162334e-005	1.260940508e-005
ISS-2Body-EarthMOEEq	1.702380814e-005	1.61289222e-005	1.522698767e-005
ISS-2Body-EarthTODEc	0.0003541449587	0.0002454873993	0.0001090174919
ISS-2Body-EarthTODEq	0.0003541447313	0.0003261193342	0.0003840964382
ISS-2Body-EarthTOEEc	0.0009192901871	0.000788845341	1.260963245e-005
ISS-2Body-EarthTOEEq	0.0009192899597	0.0006982813829	0.0002932483767
Mars1-2Body-MarsFixed	0.03183730485	0.02844549941	0.01768979689
Mars1-2Body-MarsMJ2000Ec	0.02507192036	0.03287313962	0.02860135534
Mars1-2Body-MarsMJ2000Eq	0.02507192059	0.03542635011	0.02514645194
Mercury1-2Body-MercuryFixed	0.03539446271	0.04040023134	0.03499280479
Mercury1-2Body-MercuryMJ2000Ec	0.03272952299	0.04177094868	0.03718656083
Mercury1-2Body-MercuryMJ2000Eq	0.03272952299	0.04458368369	0.03275185406
Moon-2Body-MoonFixed	0.006440126754	0.006418489193	5.380302071e-005
Moon-2Body-MoonMJ2000Ec	4.841280088e-005	3.755191358e-005	5.448401907e-005
Moon-2Body-MoonMJ2000Eq	4.841277246e-005	6.922813256e-005	4.867032999e-005
Neptune1-2Body-NeptuneFixed	0.4563472403	0.4741459925	0.2913599045
Neptune1-2Body-NeptuneMJ2000Ec	0.2946186363	0.379445414	0.3350099978
Neptune1-2Body-NeptuneMJ2000Eq	0.2946186363	0.4144292316	0.30129434
Pluto1-2Body-PlutoFixed	0.2198316816	0.1716734655	0.1610651478
Pluto1-2Body-PlutoMJ2000Ec	0.1530930988	0.1978928284	0.1709355889
Pluto1-2Body-PlutoMJ2000Eq	0.1530930986	0.2164849678	0.1519010141
Saturn1-2Body-SaturnFixed	0.6589240984	0.6401781839	0.1048206248
Saturn1-2Body-SaturnMJ2000Ec	0.1163767133	0.1554946466	0.1315841849
Saturn1-2Body-SaturnMJ2000Eq	0.1163767133	0.1697155017	0.1164363707
Uranus1-2Body-UranusFixed	0.4351761957	0.5796910355	0.5379000236
Uranus1-2Body-UranusMJ2000Ec	0.4004211498	0.5312628291	0.4515566279
Uranus1-2Body-UranusMJ2000Eq	0.4004211489	0.5761433076	0.3958314512
Venus1-2Body-VenusFixed	0.002884314654	0.002322745331	0.002460205451
Venus1-2Body-VenusMJ2000Ec	0.00222088147	0.002962369763	0.002628566563

Table 3.27: WinGMAT/STK Coordinate System Dependent Parameter Differences (Velocity)

Test Case	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
GEO-2Body-EarthFixed	1.014407668e-005	1.788716977e-006	2.603041852e-007
GEO-2Body-EarthMJ2000Ec	2.941868971e-009	2.388311771e-008	5.47080159e-008
GEO-2Body-EarthMJ2000Eq	2.941868971e-009	3.061495502e-009	0
GEO-2Body-EarthMODEc	9.408329671e-008	1.021924212e-007	1.137256955e-009
GEO-2Body-EarthMODEq	9.408329671e-008	9.420833905e-008	3.961584294e-008
GEO-2Body-EarthMOEEc	2.941868971e-009	2.803399873e-009	1.221238388e-009
GEO-2Body-EarthMOEEq	2.941868971e-009	3.062203269e-009	3.03533858e-013
GEO-2Body-EarthTODEc	4.572995038e-007	5.05203962e-007	4.601985459e-008
GEO-2Body-EarthTODEq	4.572995038e-007	4.63679109e-007	2.603101875e-007
GEO-2Body-EarthTOEEc	4.014216529e-007	4.371652484e-007	1.221238388e-009
GEO-2Body-EarthTOEEq	4.014216529e-007	4.015777433e-007	1.753077669e-007
Hyperbolic-2Body-EarthFixed	3.95709101e-005	4.822739186e-005	7.705180938e-006
Hyperbolic-2Body-EarthMJ2000Ec	1.900701818e-010	2.841193947e-008	7.195000151e-008
Hyperbolic-2Body-EarthMJ2000Eq	1.949551631e-010	7.283063042e-011	7.416289804e-011
Hyperbolic-2Body-EarthMODEc	1.2022916e-007	3.212755617e-007	2.731981308e-010
Hyperbolic-2Body-EarthMODEq	1.2022916e-007	2.946586863e-007	1.280421325e-007
Hyperbolic-2Body-EarthMOEEc	1.900701818e-010	8.393286066e-011	5.306866058e-011
Hyperbolic-2Body-EarthMOEEq	1.900701818e-010	7.1942452e-011	7.283063042e-011
Hyperbolic-2Body-EarthTODEc	1.646798253e-007	2.454370041e-007	6.046096956e-008
Hyperbolic-2Body-EarthTODEq	1.646798253e-007	3.61354946e-007	2.506728158e-007
Hyperbolic-2Body-EarthTOEEc	5.242419832e-007	1.403957839e-006	5.306866058e-011
Hyperbolic-2Body-EarthTOEEq	5.242419832e-007	1.28404759e-006	5.625160338e-007
ISS-2Body-EarthFixed	1.121940096e-005	1.427406016e-005	3.056304987e-006
ISS-2Body-EarthGSE	4.276756727e-008	7.704865196e-008	1.358013701e-008
ISS-2Body-EarthGSM	2.529176868e-008	4.264810727e-006	3.338569421e-006
ISS-2Body-EarthMJ2000Ec	1.820199547e-008	9.097611553e-008	1.441760045e-007
ISS-2Body-EarthMJ2000Eq	1.820199547e-008	1.898980972e-008	1.720845688e-008
ISS-2Body-EarthMODEc	2.404580979e-007	2.053310855e-007	1.355116019e-008
ISS-2Body-EarthMODEq	2.404580979e-007	1.883573297e-007	8.17870216e-008
ISS-2Body-EarthMOEEc	1.820019135e-008	2.154498802e-008	1.361255553e-008
ISS-2Body-EarthMOEEq	1.820019135e-008	1.898858848e-008	1.720790177e-008
ISS-2Body-EarthTODEc	4.015190402e-007	2.811573196e-007	1.237678848e-007
ISS-2Body-EarthTODEq	4.015190402e-007	3.76443765e-007	4.359881345e-007
ISS-2Body-EarthTOEEc	1.051024157e-006	8.982621313e-007	1.362254753e-008
ISS-2Body-EarthTOEEq	1.051024157e-006	7.945453184e-007	3.338707089e-007
Mars1-2Body-MarsFixed	2.518835929e-005	2.756774142e-005	1.157631901e-005
Mars1-2Body-MarsMJ2000Ec	2.020604195e-005	2.897913998e-005	1.950214013e-005
Mars1-2Body-MarsMJ2000Eq	2.020604195e-005	2.838055202e-005	2.027164991e-005
Mercury1-2Body-MercuryFixed	2.903238738e-005	3.879752281e-005	2.295677293e-005
Mercury1-2Body-MercuryMJ2000Ec	2.684522205e-005	3.954380223e-005	2.507491992e-005
Mercury1-2Body-MercuryMJ2000Eq	2.684522205e-005	3.767025258e-005	2.683619238e-005
Moon-2Body-MoonFixed	3.1286021e-006	3.408238386e-006	3.078204358e-008
Moon-2Body-MoonMJ2000Ec	3.333122667e-008	2.416866707e-008	2.883249195e-008
Moon-2Body-MoonMJ2000Eq	3.333122667e-008	4.759437289e-008	3.355971057e-008
Neptune1-2Body-NeptuneFixed	0.002311722852	0.002324633282	0.0001281027
Neptune1-2Body-NeptuneMJ2000Ec	0.000142514911	0.0002082202331	0.0001364492794
Neptune1-2Body-NeptuneMJ2000Eq	0.000142514911	0.0002067146241	0.0001464608408
Pluto1-2Body-PlutoFixed	0.0001007571934	7.402795582e-005	9.38525348e-005
Pluto1-2Body-PlutoMJ2000Ec	7.740999469e-005	0.0001101941279	7.234059568e-005
Pluto1-2Body-PlutoMJ2000Eq	7.740999469e-005	0.000108224251	7.64393229e-005
Saturn1-2Body-SaturnFixed	0.0001216362282	0.000117247799	3.764139045e-005
Saturn1-2Body-SaturnMJ2000Ec	4.019146882e-005	5.57857609e-005	3.751250155e-005
Saturn1-2Body-SaturnMJ2000Eq	4.019146882e-005	5.582207052e-005	4.014094834e-005
Uranus1-2Body-UranusFixed	0.0001010712944	0.000154047445	0.0001669326699
Uranus1-2Body-UranusMJ2000Ec	0.0001277347388	0.0001777035219	0.0001192743007
Uranus1-2Body-UranusMJ2000Eq	0.0001277347388	0.000176861541	0.0001256739708
Venus1-2Body-VenusFixed	3.255281822e-006	1.905678726e-006	1.968240237e-006
Venus1-2Body-VenusMJ2000Ec	2.047197967e-006	3.222437317e-006	2.132475085e-006

Table 3.28: WinGMAT/STK Coordinate System Dependent Parameter Differences (Specific Angular Momentum)

Test Case	X-(H) ( $m^2/sec$ )	Y-(H) ( $m^2/sec$ )	Z-(H) ( $m^2/sec$ )
GEO-2Body-EarthFixed	10.77395412	2.103753774	434.3112279
GEO-2Body-EarthMJ2000Ec	1.108595761e-005	2.307067916	1.00035686
GEO-2Body-EarthMJ2000Eq	0	0	0.002633896656
GEO-2Body-EarthMODEc	1.670212519	0.002313754521	0.002764863893
GEO-2Body-EarthMODEq	1.670202522	0.001656588439	0.00350701157
GEO-2Body-EarthMOEEc	2.199989404e-005	0.0008803908713	0.002721208148
GEO-2Body-EarthMOEEq	1.279825357e-005	3.231174268e-021	0.002633896656
GEO-2Body-EarthTODEc	8.532207623	1.939195499	0.8412171155
GEO-2Body-EarthTODEq	8.532204788	9.575559793	0.004525645636
GEO-2Body-EarthTOEEc	7.285381645	0.001346052159	0.002750311978
GEO-2Body-EarthTOEEq	7.285369894	1.252008813	0.002488377504
Hyperbolic-2Body-EarthFixed	12991.66493	5060.377996	11584.88356
Hyperbolic-2Body-EarthMJ2000Ec	0.0001497576609	1.809261448	0.7237395039
Hyperbolic-2Body-EarthMJ2000Eq	5.820766091e-005	0.01791340765	0.01791340765
Hyperbolic-2Body-EarthMODEc	1.183644109	0.007596099749	0.02366141416
Hyperbolic-2Body-EarthMODEq	1.183615538	0.01674925443	0.01837906893
Hyperbolic-2Body-EarthMOEEc	0.0001774553218	0.00878208084	0.02361775842
Hyperbolic-2Body-EarthMOEEq	0.0001164153218	0.01791340765	0.01791340765
Hyperbolic-2Body-EarthTODEc	2.066537292	1.515734766	0.6020418368
Hyperbolic-2Body-EarthTODEq	2.066543715	5.08769881	5.08732046
Hyperbolic-2Body-EarthTOEEc	5.182837213	0.009189534467	0.02386514097
Hyperbolic-2Body-EarthTOEEq	5.182834381	0.6909831427	0.6995251169
ISS-2Body-EarthFixed	89.90005517	67.11701735	31.77822509
ISS-2Body-EarthGSE	0.247576736	0.02882006811	0.0004947651178
ISS-2Body-EarthGSM	3.261546226	22.63859642	29.3813282
ISS-2Body-EarthMJ2000Ec	0.0009204086382	0.7920116332	0.2577944542
ISS-2Body-EarthMJ2000Eq	0.000924046617	0.0006657501217	0.0003674358595
ISS-2Body-EarthMODEc	0.4286630428	0.9410505299	0.001316948328
ISS-2Body-EarthMODEq	0.4286703188	0.8628958312	0.3753048077
ISS-2Body-EarthMOEEc	0.0009204086382	0.0003510649549	0.0005311449058
ISS-2Body-EarthMOEEq	0.000924046617	0.0006548361853	0.0003783497959
ISS-2Body-EarthTODEc	0.7478811312	2.259925168	0.2176457201
ISS-2Body-EarthTODEq	0.7478811312	3.630510037	2.533735824
ISS-2Body-EarthTOEEc	1.879710908	4.109835572	0.0005384208634
ISS-2Body-EarthTOEEq	1.879718184	4.081070074	1.90953142
Mars1-2Body-MarsFixed	19.78945875	21.41383516	5.543548468
Mars1-2Body-MarsMJ2000Ec	0.9250215953	0.5880056051	0.6370537449
Mars1-2Body-MarsMJ2000Eq	0.9250197763	0.3278661847	0.6568207027
Mercury1-2Body-MercuryFixed	0.2396564014	0.527476459	0.3840395948
Mercury1-2Body-MercuryMJ2000Ec	0.233366336	0.2684596438	0.2551932994
Mercury1-2Body-MercuryMJ2000Eq	0.233366336	0.07785584718	0.317305421
Moon-2Body-MoonFixed	5.574742886	5.283694918	0.002643446351
Moon-2Body-MoonMJ2000Ec	0.0006161826605	0.04315063507	0.01897387847
Moon-2Body-MoonMJ2000Eq	0.0006157279131	0.0003656784858	0.0003005879989
Neptune1-2Body-NeptuneFixed	42912.25303	43242.34228	96195.52561
Neptune1-2Body-NeptuneMJ2000Ec	29.59131962	77.10748469	79.35875328
Neptune1-2Body-NeptuneMJ2000Eq	29.59131962	84.00219825	57.4325677
Pluto1-2Body-PlutoFixed	3.507136626	3.811760621	4.255305385
Pluto1-2Body-PlutoMJ2000Ec	1.962340434	1.310305606	1.578711021
Pluto1-2Body-PlutoMJ2000Eq	1.962340889	1.41555836	1.536549917
Saturn1-2Body-SaturnFixed	7838.359044	8267.108118	1377.034001
Saturn1-2Body-SaturnMJ2000Ec	26.04536712	25.11049388	40.41916691
Saturn1-2Body-SaturnMJ2000Eq	26.04513429	16.25671616	33.01072866
Uranus1-2Body-UranusFixed	3205.604833	3803.228377	2429.486194
Uranus1-2Body-UranusMJ2000Ec	4.425237421	26.53393312	93.69524196
Uranus1-2Body-UranusMJ2000Eq	4.42500459	44.32307736	85.10262705
Venus1-2Body-VenusFixed	0.7005425573	0.1408989192	0.1297958079

Table 3.29: WinGMAT/STK Coordinate System Dependent Parameter Differences (Velocity Vector-based)

Test Case	Mag-Vel (m/s)	Right Asc. of Vel. (deg)	Dec. of Vel. (deg)
GEO-2Body-EarthFixed	3.27856174e-006	1.162785482	0.1785304183
GEO-2Body-EarthMJ2000Ec	1.239008895e-010	2.998703508e-010	1.110930015e-009
GEO-2Body-EarthMJ2000Eq	1.230127111e-010	6.014033715e-011	0
GEO-2Body-EarthMODEc	1.239008895e-010	1.915338999e-009	2.114108888e-011
GEO-2Body-EarthMODEq	1.239008895e-010	1.759033808e-009	7.38156529e-010
GEO-2Body-EarthMOEEc	1.239008895e-010	6.370726169e-011	2.268207844e-011
GEO-2Body-EarthMOEEq	1.239008895e-010	6.014033715e-011	5.656303434e-015
GEO-2Body-EarthTODEc	1.199040867e-010	9.473467344e-009	9.346905472e-010
GEO-2Body-EarthTODEq	1.230127111e-010	8.70409167e-009	4.850754132e-009
GEO-2Body-EarthTOEEc	1.199040867e-010	8.158295373e-009	2.268096821e-011
GEO-2Body-EarthTOEEq	1.239008895e-010	7.486747222e-009	3.266776477e-009
Hyperbolic-2Body-EarthFixed	4.7147239e-005	2.061213209e-007	5.501370381e-008
Hyperbolic-2Body-EarthMJ2000Ec	1.669775429e-010	2.154649792e-010	7.097700205e-010
Hyperbolic-2Body-EarthMJ2000Eq	1.669775429e-010	1.449507181e-012	9.485745522e-013
Hyperbolic-2Body-EarthMODEc	1.669775429e-010	1.854090215e-009	1.580957587e-012
Hyperbolic-2Body-EarthMODEq	1.669775429e-010	1.910819947e-009	7.375580147e-010
Hyperbolic-2Body-EarthMOEEc	1.652011861e-010	1.705302566e-012	2.504663144e-013
Hyperbolic-2Body-EarthMOEEq	1.652011861e-010	1.449507181e-012	9.379164112e-013
Hyperbolic-2Body-EarthTODEc	1.669775429e-010	3.401112281e-009	5.877502929e-010
Hyperbolic-2Body-EarthTODEq	1.669775429e-010	5.039368034e-009	1.71946013e-009
Hyperbolic-2Body-EarthTOEEc	1.652011861e-010	8.09623657e-009	2.504663144e-013
Hyperbolic-2Body-EarthTOEEq	1.652011861e-010	8.594184919e-009	3.265990145e-009
ISS-2Body-EarthFixed	1.000267424e-006	1.289114504e-007	3.871035403e-008
ISS-2Body-EarthGSE	4.245492846e-010	5.887130783e-010	1.01566755e-010
ISS-2Body-EarthGSM	3.118838521e-008	3.000519655e-008	3.98758786e-008
ISS-2Body-EarthMJ2000Ec	4.25437463e-010	8.288090214e-010	1.104098146e-009
ISS-2Body-EarthMJ2000Eq	4.25437463e-010	2.533688814e-010	1.295425989e-010
ISS-2Body-EarthMODEc	4.25437463e-010	1.852910714e-009	1.013642503e-010
ISS-2Body-EarthMODEq	4.25437463e-010	2.479652039e-009	7.340688057e-010
ISS-2Body-EarthMOEEc	4.25437463e-010	2.173123903e-010	1.018332085e-010
ISS-2Body-EarthMOEEq	4.25437463e-010	2.533475651e-010	1.295319407e-010
ISS-2Body-EarthTODEc	4.25437463e-010	3.142545779e-009	9.539711243e-010
ISS-2Body-EarthTODEq	4.263256415e-010	4.20565982e-009	4.169244505e-009
ISS-2Body-EarthTOEEc	4.245492846e-010	8.094446002e-009	1.018332085e-010
ISS-2Body-EarthTOEEq	4.25437463e-010	1.066275956e-008	3.258890047e-009
Mars1-2Body-MarsFixed	5.023911065e-006	5.441387074e-007	2.033612345e-007
Mars1-2Body-MarsMJ2000Ec	4.663051278e-006	7.395171053e-007	3.167181291e-007
Mars1-2Body-MarsMJ2000Eq	4.663041064e-006	6.266018318e-007	3.200667393e-007
Mercury1-2Body-MercuryFixed	5.903864952e-006	1.125874249e-006	4.680184595e-007
Mercury1-2Body-MercuryMJ2000Ec	5.897458077e-006	1.230217492e-006	5.09582609e-007
Mercury1-2Body-MercuryMJ2000Eq	5.897458077e-006	1.045274644e-006	5.196149395e-007
Moon-2Body-MoonFixed	7.400080548e-009	1.412720962e-007	1.086499779e-009
Moon-2Body-MoonMJ2000Ec	7.382983114e-009	1.54608415e-009	1.105380676e-009
Moon-2Body-MoonMJ2000Eq	7.382983114e-009	2.225874596e-009	1.145114226e-009
Neptune1-2Body-NeptuneFixed	0.001546170703	1.313484218e-005	1.351642408e-005
Neptune1-2Body-NeptuneMJ2000Ec	3.205436094e-005	1.140866033e-006	4.847767592e-007
Neptune1-2Body-NeptuneMJ2000Eq	3.205436983e-005	9.779470531e-007	4.998893708e-007
Pluto1-2Body-PlutoFixed	1.77587437e-005	1.01980179e-005	5.919212011e-006
Pluto1-2Body-PlutoMJ2000Ec	1.8004647e-005	1.129954273e-005	4.821600147e-006
Pluto1-2Body-PlutoMJ2000Eq	1.800464688e-005	9.713120306e-006	4.93951859e-006
Saturn1-2Body-SaturnFixed	1.385954995e-005	7.695682029e-007	1.408171393e-007
Saturn1-2Body-SaturnMJ2000Ec	8.489390524e-006	1.990535736e-007	8.619320901e-008
Saturn1-2Body-SaturnMJ2000Eq	8.489390524e-006	1.683731909e-007	8.82835538e-008
Uranus1-2Body-UranusFixed	3.547928884e-005	7.311058212e-006	7.890196088e-007
Uranus1-2Body-UranusMJ2000Ec	2.723635006e-005	1.205474632e-006	5.251472182e-007
Uranus1-2Body-UranusMJ2000Eq	2.723635006e-005	1.023190492e-006	5.309789515e-007
Venus1-2Body-VenusFixed	4.773834661e-007	3.641271462e-008	1.529566873e-008
Venus1-2Body-VenusMJ2000Ec	4.774838303e-007	3.774394486e-008	1.673504002e-008

Table 3.30: WinGMAT/STK Coordinate System Dependent Parameter Differences (Angle-based)

Test Case	Arg. of Per. (deg)	Decl. (deg)	Inc. (deg)	RA (deg)	RAAN (deg)
GEO-2Body-EarthFixed	3.357e-005	2.768e-008	0.2044	3.145e-007	9.529e-005
GEO-2Body-EarthMJ2000Ec	1.172e-005	1.111e-009	1.111e-009	2.969e-010	0
GEO-2Body-EarthMJ2000Eq	1.179e-005	0	1e-014	5.866e-011	0
GEO-2Body-EarthMODEc	1.189e-005	2.071e-011	3.233e-013	1.913e-009	1.865e-009
GEO-2Body-EarthMODEq	1.188e-005	7.381e-010	7.586e-010	1.757e-009	8.657e-010
GEO-2Body-EarthMOEEc	1.17e-005	2.224e-011	3.126e-013	6.111e-011	0
GEO-2Body-EarthMOEEq	1.172e-005	5.656e-015	0	5.866e-011	0
GEO-2Body-EarthTODEc	1.189e-005	9.281e-010	9.348e-010	9.501e-009	9.482e-009
GEO-2Body-EarthTODEq	1.072e-005	4.652e-009	3.537e-009	8.707e-009	1.046e-005
GEO-2Body-EarthTOEEc	1.179e-005	2.224e-011	3.126e-013	8.156e-009	8.107e-009
GEO-2Body-EarthTOEEq	8.147e-005	3.267e-009	1.764e-009	7.485e-009	6.978e-005
Hyperbolic-2Body-EarthFixed	3.504e-007	1.754e-008	2.357e-007	1.35e-007	1.528e-007
Hyperbolic-2Body-EarthMJ2000Ec	7.816e-012	1.096e-009	1.111e-009	2.172e-010	1.4e-013
Hyperbolic-2Body-EarthMJ2000Eq	7.944e-012	8.598e-013	2.913e-013	1.251e-012	2.5e-013
Hyperbolic-2Body-EarthMODEc	1.198e-011	1.563e-012	4.512e-013	1.854e-009	1.858e-009
Hyperbolic-2Body-EarthMODEq	1.052e-009	7.379e-010	7.887e-013	2.405e-009	9.809e-010
Hyperbolic-2Body-EarthMOEEc	7.83e-012	3.091e-013	4.192e-013	1.506e-012	1.4e-013
Hyperbolic-2Body-EarthMOEEq	7.944e-012	8.704e-013	9.948e-014	1.251e-012	0
Hyperbolic-2Body-EarthTODEc	9.635e-012	9.216e-010	9.348e-010	3.396e-009	3.235e-009
Hyperbolic-2Body-EarthTODEq	1.824e-009	3.924e-009	4.129e-009	4.887e-009	1.689e-009
Hyperbolic-2Body-EarthTOEEc	8.001e-012	3.091e-013	4.405e-013	8.096e-009	8.107e-009
Hyperbolic-2Body-EarthTOEEq	4.561e-009	3.265e-009	5.532e-010	1.062e-008	4.29e-009
ISS-2Body-EarthFixed	3.204e-008	3.275e-008	3.965e-008	1.327e-007	1.379e-007
ISS-2Body-EarthGSE	8.605e-010	1.067e-010	7.39e-013	6.522e-010	4.463e-010
ISS-2Body-EarthGSM	2.428e-006	3.918e-008	4.041e-008	2.864e-008	7.131e-009
ISS-2Body-EarthMJ2000Ec	1.718e-009	1.109e-009	4.625e-010	8.196e-010	1.29e-009
ISS-2Body-EarthMJ2000Eq	6.289e-010	1.311e-010	6.963e-013	2.591e-010	5.187e-013
ISS-2Body-EarthMODEc	6.385e-010	1.062e-010	1.606e-012	1.853e-009	1.852e-009
ISS-2Body-EarthMODEq	7.367e-010	7.378e-010	5.283e-010	2.489e-009	1.291e-009
ISS-2Body-EarthMOEEc	6.337e-010	1.069e-010	6.324e-013	2.089e-010	6.963e-013
ISS-2Body-EarthMOEEq	6.308e-010	1.311e-010	6.963e-013	2.591e-010	5.116e-013
ISS-2Body-EarthTODEc	1.954e-009	9.521e-010	3.892e-010	3.141e-009	4.239e-009
ISS-2Body-EarthTODEq	3.383e-009	4.165e-009	3.569e-009	4.208e-009	4.395e-009
ISS-2Body-EarthTOEEc	6.428e-010	1.069e-010	6.182e-013	8.095e-009	8.095e-009
ISS-2Body-EarthTOEEq	2.444e-009	3.264e-009	2.689e-009	1.063e-008	5.96e-009
Mars1-2Body-MarsFixed	1.088e-006	2.695e-007	2.7e-008	5.334e-007	2.095e-007
Mars1-2Body-MarsMJ2000Ec	3.437e-008	4.443e-007	2.346e-009	6.624e-007	2.039e-009
Mars1-2Body-MarsMJ2000Eq	3.496e-008	3.733e-007	2.412e-009	7.103e-007	1.931e-009
Mercury1-2Body-MercuryFixed	2.408e-008	6.834e-007	1.199e-009	9.886e-007	4.503e-009
Mercury1-2Body-MercuryMJ2000Ec	2.118e-008	7.237e-007	5.978e-010	1.126e-006	1.716e-009
Mercury1-2Body-MercuryMJ2000Eq	1.977e-008	6.331e-007	7.595e-010	1.206e-006	7.189e-010
Moon-2Body-MoonFixed	1.664e-010	1.544e-009	5.615e-011	1.415e-007	1.412e-007
Moon-2Body-MoonMJ2000Ec	1.419e-009	1.106e-009	4.115e-010	1.446e-009	8.817e-010
Moon-2Body-MoonMJ2000Eq	5.987e-011	1.373e-009	7.574e-012	2.671e-009	8.654e-012
Neptune1-2Body-NeptuneFixed	4.002e-005	5.911e-007	1.341e-005	1.274e-006	7.637e-006
Neptune1-2Body-NeptuneMJ2000Ec	2.002e-008	6.812e-007	1.011e-008	1.058e-006	1.042e-008
Neptune1-2Body-NeptuneMJ2000Eq	2.142e-008	6.033e-007	6.69e-009	1.147e-006	1.42e-008
Pluto1-2Body-PlutoFixed	1.838e-006	6.402e-006	1.836e-007	1.498e-005	2.213e-007
Pluto1-2Body-PlutoMJ2000Ec	7.36e-007	6.868e-006	6.629e-008	1.077e-005	4.681e-008
Pluto1-2Body-PlutoMJ2000Eq	7.689e-007	6.006e-006	4.481e-008	1.178e-005	8.819e-008
Saturn1-2Body-SaturnFixed	2.426e-007	9.2e-008	8.857e-008	5.735e-007	4.444e-007
Saturn1-2Body-SaturnMJ2000Ec	3.185e-009	1.174e-007	8.835e-010	1.922e-007	9.333e-010
Saturn1-2Body-SaturnMJ2000Eq	4.438e-009	1.038e-007	5.041e-010	2.059e-007	7.717e-010
Uranus1-2Body-UranusFixed	4.393e-006	8.722e-007	3.127e-007	2.371e-006	4.83e-007
Uranus1-2Body-UranusMJ2000Ec	9.063e-009	7.191e-007	8.27e-009	1.155e-006	3.675e-009
Uranus1-2Body-UranusMJ2000Eq	8.861e-009	6.271e-007	6.81e-009	1.247e-006	7.178e-009
Venus1-2Body-VenusFixed	1.612e-009	2.129e-008	8.714e-011	3.286e-008	1.065e-009
Venus1-2Body-VenusMJ2000Ec	2.432e-009	2.278e-008	4.334e-010	3.396e-008	8.709e-010

Table 3.31: FF/WinGMAT Coordinate System Dependent Parameter Differences (Position)

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)
ISS-2Body-EarthMJ2000Eq	1.879209321e-005	1.857853249e-005	1.720309228e-005

Table 3.32: FF/WinGMAT Coordinate System Dependent Parameter Differences (Velocity)

Test Case	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
ISS-2Body-EarthMJ2000Eq	4.989892943e-007	4.941756726e-007	4.960516442e-007

Table 3.33: FF/WinGMAT Coordinate System Dependent Parameter Differences (Specific Angular Momentum)

Test Case	X-(H) ( $m^2/sec$ )	Y-(H) ( $m^2/sec$ )	Z-(H) ( $m^2/sec$ )
ISS-2Body-EarthMJ2000Eq	0.0006730260793	0.0010986696	0.001509761205

Table 3.34: FF/WinGMAT Coordinate System Dependent Parameter Differences (Velocity Vector-based)

Test Case	Mag-Vel (m/s)	Right Asc. of Vel. (deg)	Dec. of Vel. (deg)
ISS-2Body-EarthMJ2000Eq	4.85915308e-007	296.2928006	67.36750845

Table 3.35: FF/WinGMAT Coordinate System Dependent Parameter Differences (Angle-based)

Test Case	Arg. of Per. (deg)	Decl. (deg)	Inc. (deg)	RA (deg)	RAAN (deg)
ISS-2Body-EarthMJ2000Eq	1.699e-009	5.633e-010	4.684e-010	6.932e-010	2.416e-010

Table 3.36: FF/STK Coordinate System Dependent Parameter Differences (Position)

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)
ISS-2Body-EarthMJ2000Eq	3.580873909e-005	3.470813681e-005	3.243098945e-005

Table 3.37: FF/STK Coordinate System Dependent Parameter Differences (Velocity)

Test Case	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
ISS-2Body-EarthMJ2000Eq	5.092002375e-007	5.105600387e-007	5.025699856e-007

Table 3.38: FF/STK Coordinate System Dependent Parameter Differences (Specific Angular Momentum)

Test Case	X-(H) ( $m^2/sec$ )	Y-(H) ( $m^2/sec$ )	Z-(H) ( $m^2/sec$ )
ISS-2Body-EarthMJ2000Eq	0.0005711626727	0.001346052159	0.00146246748

Table 3.39: FF/STK Coordinate System Dependent Parameter Differences (Velocity Vector-based)

Test Case	Mag-Vel (m/s)	Right Asc. of Vel. (deg)	Dec. of Vel. (deg)
ISS-2Body-EarthMJ2000Eq	4.857803049e-007	296.2928006	67.36750845

Table 3.40: FF/STK Coordinate System Dependent Parameter Differences (Angle-based)

Test Case	Arg. of Per. (deg)	Decl. (deg)	Inc. (deg)	RA (deg)	RAAN (deg)
ISS-2Body-EarthMJ2000Eq	1.347e-009	6.518e-010	4.685e-010	8.637e-010	2.414e-010

## 3.3.4 Win/Mac GMAT Comparison



Table 3.41: WinGMAT/MacGMAT Coordinate System Dependent Parameter Differences (Position)

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)
GEO-2Body-EarthFixed	0.0001842481652	3.285822459e-005	8.177306055e-009
GEO-2Body-EarthMJ2000Ec	1.167290975e-005	1.199748567e-005	5.201599151e-006
GEO-2Body-EarthMJ2000Eq	1.167290975e-005	1.307660114e-005	0
GEO-2Body-EarthMODEc	1.167200026e-005	1.199771305e-005	5.201400199e-006
GEO-2Body-EarthMODEq	1.167200026e-005	1.30769422e-005	5.027978034e-009
GEO-2Body-EarthMOEEc	1.167381924e-005	1.199748567e-005	5.201599151e-006
GEO-2Body-EarthMOEEq	1.167381924e-005	1.307660114e-005	1.15236801e-021
GEO-2Body-EarthTODEc	1.167200026e-005	1.199788358e-005	5.201400199e-006
GEO-2Body-EarthTODEq	1.167200026e-005	1.307682851e-005	8.173711707e-009
GEO-2Body-EarthTOEEc	1.167427399e-005	1.199748567e-005	5.201599151e-006
GEO-2Body-EarthTOEEq	1.167427399e-005	1.307671482e-005	2.659095166e-009
Hyperbolic-2Body-EarthFixed	0.0008837669156	0.001192296622	1.164153218e-007
Hyperbolic-2Body-EarthMJ2000Ec	3.492459655e-007	1.164153218e-007	8.731149137e-008
Hyperbolic-2Body-EarthMJ2000Eq	3.492459655e-007	1.164153218e-007	1.164153218e-007
Hyperbolic-2Body-EarthMODEc	3.492459655e-007	1.164153218e-007	1.018634066e-007
Hyperbolic-2Body-EarthMODEq	3.492459655e-007	1.164153218e-007	1.164153218e-007
Hyperbolic-2Body-EarthMOEEc	3.492459655e-007	1.164153218e-007	7.275957614e-008
Hyperbolic-2Body-EarthMOEEq	3.492459655e-007	1.164153218e-007	1.164153218e-007
Hyperbolic-2Body-EarthTODEc	4.074536264e-007	1.164153218e-007	1.018634066e-007
Hyperbolic-2Body-EarthTODEq	4.074536264e-007	1.164153218e-007	1.164153218e-007
Hyperbolic-2Body-EarthTOEEc	3.492459655e-007	1.164153218e-007	7.275957614e-008
Hyperbolic-2Body-EarthTOEEq	3.492459655e-007	1.164153218e-007	1.164153218e-007
ISS-2Body-EarthFixed	2.39901965e-005	3.032710083e-005	1.251714821e-005
ISS-2Body-EarthGSE	7.217067832e-006	5.829974725e-006	4.693333722e-006
ISS-2Body-EarthGSM	1.589199883e-005	1.367493496e-005	9.297707493e-006
ISS-2Body-EarthMJ2000Ec	6.370953543e-006	7.136122804e-006	4.692878974e-006
ISS-2Body-EarthMJ2000Eq	6.370953543e-006	6.066102287e-006	5.955598681e-006
ISS-2Body-EarthMODEc	6.370100891e-006	7.13589543e-006	4.693220035e-006
ISS-2Body-EarthMODEq	6.370100891e-006	6.06996764e-006	5.953893378e-006
ISS-2Body-EarthMOEEc	6.371124073e-006	7.136122804e-006	4.692537914e-006
ISS-2Body-EarthMOEEq	6.371124073e-006	6.065874913e-006	5.955598681e-006
ISS-2Body-EarthTODEc	6.370214578e-006	7.13589543e-006	4.693220035e-006
ISS-2Body-EarthTODEq	6.370214578e-006	6.069058145e-006	5.954348126e-006
ISS-2Body-EarthTOEEc	6.371124073e-006	7.136122804e-006	4.692537914e-006
ISS-2Body-EarthTOEEq	6.371124073e-006	6.065192792e-006	5.955371307e-006
Mars1-2Body-MarsFixed	0.01889046771	0.0188483892	0.0101035551
Mars1-2Body-MarsMJ2000Ec	0.01384317869	0.01948085998	0.01588558911
Mars1-2Body-MarsMJ2000Eq	0.01384317869	0.020802021	0.01400709147
Mercury1-2Body-MercuryFixed	0.02247740872	0.02563626177	0.02199024959
Mercury1-2Body-MercuryMJ2000Ec	0.020712614	0.0263996169	0.02335545349
Mercury1-2Body-MercuryMJ2000Eq	0.020712614	0.02828240395	0.02072751528
Moon-2Body-MoonFixed	0.0001181998073	8.823919018e-005	0.0001023369123
Moon-2Body-MoonMJ2000Ec	8.999450074e-005	0.0001172169846	0.0001019149067
Moon-2Body-MoonMJ2000Eq	8.999450074e-005	0.0001284061	9.025099246e-005
Neptune1-2Body-NeptuneFixed	0.000139336862	0.0001421121851	1.818989404e-008
Neptune1-2Body-NeptuneMJ2000Ec	1.091393642e-008	1.455191523e-008	1.091393642e-008
Neptune1-2Body-NeptuneMJ2000Eq	1.091393642e-008	1.455191523e-008	1.091393642e-008
Pluto1-2Body-PlutoFixed	0.02447438351	0.05146786219	0.03691279483
Pluto1-2Body-PlutoMJ2000Ec	0.0331401825	0.0482615705	0.03949610559
Pluto1-2Body-PlutoMJ2000Eq	0.0331401825	0.05435943603	0.03361701965
Saturn1-2Body-SaturnFixed	0.0006473801477	0.0005969686754	1.455191523e-008
Saturn1-2Body-SaturnMJ2000Ec	1.455191523e-008	1.455191523e-008	1.455191523e-008
Saturn1-2Body-SaturnMJ2000Eq	1.455191523e-008	1.455191523e-008	1.455191523e-008
Uranus1-2Body-UranusFixed	0.0001626394805	0.0001651487764	2.182787284e-008
Uranus1-2Body-UranusMJ2000Ec	1.455191523e-008	1.455191523e-008	1.455191523e-008
Uranus1-2Body-UranusMJ2000Eq	1.455191523e-008	1.455191523e-008	1.455191523e-008
Venus1-2Body-VenusFixed	0.00709690994	0.005248550565	0.005916503937
Venus1-2Body-VenusMJ2000Ec	0.005392357707	0.007055124229	0.006031767612

Table 3.42: WinGMAT/MacGMAT Coordinate System Dependent Parameter Differences (Velocity)

Test Case	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
GEO-2Body-EarthFixed	1.909583602e-010	1.048050535e-010	6.29813042e-013
GEO-2Body-EarthMJ2000Ec	8.857428679e-010	8.001099783e-010	3.468336729e-010
GEO-2Body-EarthMJ2000Eq	8.857428679e-010	8.719136524e-010	0
GEO-2Body-EarthMODEc	8.85735929e-010	7.99998956e-010	3.468336729e-010
GEO-2Body-EarthMODEq	8.85735929e-010	8.719136524e-010	3.816391647e-013
GEO-2Body-EarthMOEEc	8.857428679e-010	7.99998956e-010	3.468197951e-010
GEO-2Body-EarthMOEEq	8.857428679e-010	8.718858968e-010	8.744261208e-026
GEO-2Body-EarthTODEc	8.857498068e-010	7.99998956e-010	3.468336729e-010
GEO-2Body-EarthTODEq	8.857498068e-010	8.719136524e-010	6.299214622e-013
GEO-2Body-EarthTOEEc	8.857428679e-010	7.99998956e-010	3.468197951e-010
GEO-2Body-EarthTOEEq	8.857428679e-010	8.719136524e-010	1.940721889e-013
Hyperbolic-2Body-EarthFixed	9.596945461e-008	5.1627147e-008	2.220446049e-012
Hyperbolic-2Body-EarthMJ2000Ec	5.329070518e-012	1.33226763e-012	1.110223025e-012
Hyperbolic-2Body-EarthMJ2000Eq	5.329070518e-012	1.33226763e-012	1.33226763e-012
Hyperbolic-2Body-EarthMODEc	5.329070518e-012	1.33226763e-012	1.998401444e-012
Hyperbolic-2Body-EarthMODEq	5.329070518e-012	1.33226763e-012	2.220446049e-012
Hyperbolic-2Body-EarthMOEEc	4.440892099e-012	2.220446049e-012	1.110223025e-012
Hyperbolic-2Body-EarthMOEEq	4.440892099e-012	1.33226763e-012	1.33226763e-012
Hyperbolic-2Body-EarthTODEc	4.440892099e-012	2.220446049e-012	1.998401444e-012
Hyperbolic-2Body-EarthTODEq	4.440892099e-012	2.220446049e-012	2.220446049e-012
Hyperbolic-2Body-EarthTOEEc	5.329070518e-012	1.33226763e-012	1.110223025e-012
Hyperbolic-2Body-EarthTOEEq	5.329070518e-012	1.33226763e-012	1.33226763e-012
ISS-2Body-EarthFixed	2.755173867e-008	2.405187161e-008	1.391098348e-008
ISS-2Body-EarthGSE	8.265110818e-009	6.57274235e-009	5.144329407e-009
ISS-2Body-EarthGSM	1.852806797e-008	1.512762138e-008	9.931833134e-009
ISS-2Body-EarthMJ2000Ec	6.995792834e-009	8.162914789e-009	5.144218385e-009
ISS-2Body-EarthMJ2000Eq	6.995792834e-009	6.909979533e-009	6.708356093e-009
ISS-2Body-EarthMODEc	6.994210766e-009	8.163247855e-009	5.144329407e-009
ISS-2Body-EarthMODEq	6.994210766e-009	6.913029177e-009	6.706690758e-009
ISS-2Body-EarthMOEEc	6.995792834e-009	8.162692744e-009	5.143885318e-009
ISS-2Body-EarthMOEEq	6.995792834e-009	6.909979533e-009	6.708356093e-009
ISS-2Body-EarthTODEc	6.994294033e-009	8.162803766e-009	5.144329407e-009
ISS-2Body-EarthTODEq	6.994294033e-009	6.912781111e-009	6.706801781e-009
ISS-2Body-EarthTOEEc	6.995889978e-009	8.162248655e-009	5.143885318e-009
ISS-2Body-EarthTOEEq	6.995889978e-009	6.909500749e-009	6.708245071e-009
Mars1-2Body-MarsFixed	1.65924548e-005	1.533683858e-005	6.959634646e-006
Mars1-2Body-MarsMJ2000Ec	1.200730537e-005	1.675083128e-005	1.136635897e-005
Mars1-2Body-MarsMJ2000Eq	1.200730537e-005	1.665495386e-005	1.200201838e-005
Mercury1-2Body-MercuryFixed	1.854803089e-005	2.453733106e-005	1.46014203e-005
Mercury1-2Body-MercuryMJ2000Ec	1.714795417e-005	2.490750972e-005	1.591344523e-005
Mercury1-2Body-MercuryMJ2000Eq	1.714795417e-005	2.425520762e-005	1.714533227e-005
Moon-2Body-MoonFixed	8.846923194e-008	5.997391472e-008	5.85231863e-008
Moon-2Body-MoonMJ2000Ec	6.150671639e-008	8.812783836e-008	5.794542624e-008
Moon-2Body-MoonMJ2000Eq	6.150671639e-008	8.844119881e-008	6.176040235e-008
Neptune1-2Body-NeptuneFixed	4.272804333e-008	4.349276495e-008	2.337685601e-009
Neptune1-2Body-NeptuneMJ2000Ec	1.761257806e-009	2.033040403e-009	2.637001728e-009
Neptune1-2Body-NeptuneMJ2000Eq	1.761257806e-009	2.881250794e-009	1.721289777e-009
Pluto1-2Body-PlutoFixed	1.731889131e-005	2.236791574e-005	2.158779519e-005
Pluto1-2Body-PlutoMJ2000Ec	1.866654031e-005	2.554708012e-005	1.668872029e-005
Pluto1-2Body-PlutoMJ2000Eq	1.866654031e-005	2.480730821e-005	1.907892511e-005
Saturn1-2Body-SaturnFixed	1.174538244e-007	1.154329965e-007	2.131628207e-011
Saturn1-2Body-SaturnMJ2000Ec	3.552713679e-011	6.039613254e-011	4.97379915e-011
Saturn1-2Body-SaturnMJ2000Eq	3.552713679e-011	7.105427358e-011	2.842170943e-011
Uranus1-2Body-UranusFixed	3.869882192e-008	3.740296961e-008	1.643130076e-010
Uranus1-2Body-UranusMJ2000Ec	6.75015599e-011	1.740829703e-010	5.151434834e-011
Uranus1-2Body-UranusMJ2000Eq	6.75015599e-011	1.767475055e-010	3.286954042e-011
Venus1-2Body-VenusFixed	7.910974986e-006	4.326484948e-006	4.740029036e-006
Venus1-2Body-VenusMJ2000Ec	5.252162039e-006	7.2970468e-006	4.826740119e-006

Table 3.43: WinGMAT/MacGMAT Coordinate System Dependent Parameter Differences (Specific Angular Momentum)

Test Case	X-(H) ( $m^2/sec$ )	Y-(H) ( $m^2/sec$ )	Z-(H) ( $m^2/sec$ )
GEO-2Body-EarthFixed	3.896616363e-005	0.0002159961099	0.00803578162
GEO-2Body-EarthMJ2000Ec	1.003716411e-005	0.0005893525667	0.001411535777
GEO-2Body-EarthMJ2000Eq	0	0	0.001411535777
GEO-2Body-EarthMODEc	1.380584536e-005	0.0006111804396	0.001396983862
GEO-2Body-EarthMODEq	6.323830348e-007	1.447106324e-008	0.001498847269
GEO-2Body-EarthMOEEc	1.02179897e-005	0.0005966285244	0.001396983862
GEO-2Body-EarthMOEEq	1.486340163e-019	2.762164459e-021	0.001411535777
GEO-2Body-EarthTODEc	1.321609489e-005	0.0005966285244	0.001396983862
GEO-2Body-EarthTODEq	6.394884622e-007	2.097522156e-005	0.001498847269
GEO-2Body-EarthTOEEc	1.725020127e-005	0.0005893525667	0.001396983862
GEO-2Body-EarthTOEEq	4.218847494e-008	7.14317494e-006	0.001498847269
Hyperbolic-2Body-EarthFixed	12.21429557	16.07602462	0.01862645149
Hyperbolic-2Body-EarthMJ2000Ec	0.0001451052704	0.0002546585165	0.0003929017112
Hyperbolic-2Body-EarthMJ2000Eq	8.698973375e-005	0.0003346940503	0.0002182787284
Hyperbolic-2Body-EarthMODEc	0.000164668279	0.0002983142622	0.0004802132025
Hyperbolic-2Body-EarthMODEq	0.0001312869813	0.0004074536264	0.0003055902198
Hyperbolic-2Body-EarthMOEEc	0.0001579081028	0.0002546585165	0.0003929017112
Hyperbolic-2Body-EarthMOEEq	9.90183124e-005	0.0003055902198	0.0002328306437
Hyperbolic-2Body-EarthTODEc	0.0001351310175	0.0003055902198	0.0004365574569
Hyperbolic-2Body-EarthTODEq	0.0001949373996	0.0004365574569	0.0004220055416
Hyperbolic-2Body-EarthTOEEc	0.0001569260277	0.0002401066013	0.0005675246939
Hyperbolic-2Body-EarthTOEEq	0.0002851092695	0.0004802132025	0.0004511093721
ISS-2Body-EarthFixed	0.1522203092	0.1153202902	0.005118636182
ISS-2Body-EarthGSE	0.0006320988177	0.0007676135283	0.001055013854
ISS-2Body-EarthGSM	0.002212800609	0.01764419721	0.02349042916
ISS-2Body-EarthMJ2000Ec	0.0007821654435	0.0007894414011	0.001033185981
ISS-2Body-EarthMJ2000Eq	0.0007821654435	0.001149601303	0.0006511982065
ISS-2Body-EarthMODEc	0.0007785274647	0.0007894414011	0.001055013854
ISS-2Body-EarthMODEq	0.0007785274647	0.001142325345	0.00064028427
ISS-2Body-EarthMOEEc	0.0007821654435	0.0008003553376	0.001047737896
ISS-2Body-EarthMOEEq	0.0007821654435	0.001142325345	0.0006511982065
ISS-2Body-EarthTODEc	0.0007821654435	0.0007894414011	0.001055013854
ISS-2Body-EarthTODEq	0.0007821654435	0.001138687367	0.0006511982065
ISS-2Body-EarthTOEEc	0.0007894414011	0.0007894414011	0.001047737896
ISS-2Body-EarthTOEEq	0.0007785274647	0.001149601303	0.0006693881005
Mars1-2Body-MarsFixed	3.465424925	3.332335609	3.114930223
Mars1-2Body-MarsMJ2000Ec	0.3840796126	0.6094032869	0.784824806
Mars1-2Body-MarsMJ2000Eq	0.3840814315	0.5609703017	0.9097748261
Mercury1-2Body-MercuryFixed	0.3643126547	0.2606343514	0.3183149602
Mercury1-2Body-MercuryMJ2000Ec	0.3474442565	0.2259671419	0.2800552465
Mercury1-2Body-MercuryMJ2000Eq	0.3474442565	0.1747036688	0.3285458661
Moon-2Body-MoonFixed	0.000881982487	0.0009599716577	0.0007757989806
Moon-2Body-MoonMJ2000Ec	0.0008471943147	0.0005061338015	0.0002769411367
Moon-2Body-MoonMJ2000Eq	0.0008471943147	0.0004473084551	0.0004151843314
Neptune1-2Body-NeptuneFixed	1.165190042	1.052001608	0.1091102604
Neptune1-2Body-NeptuneMJ2000Ec	0.1045991667	0.04150206223	0.09627547115
Neptune1-2Body-NeptuneMJ2000Eq	0.1045991667	0.0009723253477	0.1047737896
Pluto1-2Body-PlutoFixed	1.363703973	1.145837388	1.336115361
Pluto1-2Body-PlutoMJ2000Ec	1.259122314	0.8433575545	0.5252992423
Pluto1-2Body-PlutoMJ2000Eq	1.2591222	0.5801695134	0.7820016208
Saturn1-2Body-SaturnFixed	7.802096661	7.727998309	0.004423782229
Saturn1-2Body-SaturnMJ2000Ec	0.004190951586	0.001455191523	0.004190951586
Saturn1-2Body-SaturnMJ2000Eq	0.004190951586	0.001082360576	0.004190951586
Uranus1-2Body-UranusFixed	1.692169462	1.658292604	0.003681634553
Uranus1-2Body-UranusMJ2000Ec	0.005529727787	0.00320142135	0.004714820534
Uranus1-2Body-UranusMJ2000Eq	0.005587935448	0.001361763341	0.00570435077
Venus1-2Body-VenusFixed	0.1877981504	0.235006155	0.2762390068

Table 3.44: WinGMAT/MacGMAT Coordinate System Dependent Parameter Differences (Velocity Vector-based)

Test Case	Mag-Vel (m/s)	Right Asc. of Vel. (deg)	Dec. of Vel. (deg)
GEO-2Body-EarthFixed	2.259566986e-011	1.8981672e-005	1.296584657e-006
GEO-2Body-EarthMJ2000Ec	9.90318938e-011	1.799094207e-011	6.445399769e-012
GEO-2Body-EarthMJ2000Eq	9.90318938e-011	1.661248916e-011	0
GEO-2Body-EarthMODEc	9.90318938e-011	1.799094207e-011	6.445177725e-012
GEO-2Body-EarthMODEq	9.90318938e-011	1.659827831e-011	7.11149889e-015
GEO-2Body-EarthMOEEc	9.90318938e-011	1.799094207e-011	6.445510792e-012
GEO-2Body-EarthMOEEq	9.90318938e-011	1.661248916e-011	1.6293922e-027
GEO-2Body-EarthTODEc	9.992007222e-011	1.799094207e-011	6.445399769e-012
GEO-2Body-EarthTODEq	9.90318938e-011	1.661248916e-011	1.174581266e-014
GEO-2Body-EarthTOEEc	9.858780459e-011	1.799094207e-011	6.445510792e-012
GEO-2Body-EarthTOEEq	9.90318938e-011	1.651301318e-011	3.609959554e-015
Hyperbolic-2Body-EarthFixed	3.197442311e-011	2.243467634e-010	2.131628207e-014
Hyperbolic-2Body-EarthMJ2000Ec	3.552713679e-012	1.136868377e-013	1.065814104e-014
Hyperbolic-2Body-EarthMJ2000Eq	3.552713679e-012	1.136868377e-013	3.197442311e-014
Hyperbolic-2Body-EarthMODEc	4.440892099e-012	1.136868377e-013	1.953992523e-014
Hyperbolic-2Body-EarthMODEq	4.440892099e-012	1.136868377e-013	3.197442311e-014
Hyperbolic-2Body-EarthMOEEc	4.440892099e-012	1.136868377e-013	1.065814104e-014
Hyperbolic-2Body-EarthMOEEq	4.440892099e-012	1.136868377e-013	2.842170943e-014
Hyperbolic-2Body-EarthTODEc	4.440892099e-012	1.136868377e-013	1.065814104e-014
Hyperbolic-2Body-EarthTODEq	4.440892099e-012	1.136868377e-013	2.842170943e-014
Hyperbolic-2Body-EarthTOEEc	4.440892099e-012	1.136868377e-013	1.953992523e-014
Hyperbolic-2Body-EarthTOEEq	4.440892099e-012	1.136868377e-013	2.842170943e-014
ISS-2Body-EarthFixed	3.392841563e-010	4.350155791e-010	1.116795545e-010
ISS-2Body-EarthGSE	4.076738946e-010	7.855760487e-011	3.865352483e-011
ISS-2Body-EarthGSM	2.98427949e-010	1.684554718e-010	7.426859128e-011
ISS-2Body-EarthMJ2000Ec	4.085620731e-010	7.858602658e-011	3.864730758e-011
ISS-2Body-EarthMJ2000Eq	4.067857162e-010	9.879386198e-011	5.010614146e-011
ISS-2Body-EarthMODEc	4.067857162e-010	7.850076145e-011	3.864730758e-011
ISS-2Body-EarthMODEq	4.076738946e-010	9.879386198e-011	5.009281878e-011
ISS-2Body-EarthMOEEc	4.067857162e-010	7.861444828e-011	3.864464304e-011
ISS-2Body-EarthMOEEq	4.067857162e-010	9.879386198e-011	5.010614146e-011
ISS-2Body-EarthTODEc	4.058975378e-010	7.861444828e-011	3.864730758e-011
ISS-2Body-EarthTODEq	4.067857162e-010	9.879386198e-011	5.009415105e-011
ISS-2Body-EarthTOEEc	4.085620731e-010	7.861444828e-011	3.864553122e-011
ISS-2Body-EarthTOEEq	4.067857162e-010	9.882228369e-011	5.010303283e-011
Mars1-2Body-MarsFixed	2.56695909e-006	3.176321002e-007	1.198383277e-007
Mars1-2Body-MarsMJ2000Ec	2.3802742e-006	4.106476013e-007	1.879441101e-007
Mars1-2Body-MarsMJ2000Eq	2.3802742e-006	3.544875824e-007	1.887221774e-007
Mercury1-2Body-MercuryFixed	3.661154935e-006	7.217152387e-007	2.972837123e-007
Mercury1-2Body-MercuryMJ2000Ec	3.65724917e-006	7.752641977e-007	3.230690897e-007
Mercury1-2Body-MercuryMJ2000Eq	3.65724917e-006	6.616439805e-007	3.315035197e-007
Moon-2Body-MoonFixed	1.3161916e-008	4.923492725e-009	2.117699793e-009
Moon-2Body-MoonMJ2000Ec	1.312683295e-008	4.903711215e-009	2.089478812e-009
Moon-2Body-MoonMJ2000Eq	1.312683295e-008	4.149796951e-009	2.132098054e-009
Neptune1-2Body-NeptuneFixed	3.32711636e-009	2.27714736e-010	1.292577156e-011
Neptune1-2Body-NeptuneMJ2000Ec	3.531397397e-009	1.518785098e-011	1.053734877e-011
Neptune1-2Body-NeptuneMJ2000Eq	3.531397397e-009	1.961986129e-011	7.87991894e-012
Pluto1-2Body-PlutoFixed	4.408564513e-006	1.837341372e-006	1.37896188e-006
Pluto1-2Body-PlutoMJ2000Ec	4.473986848e-006	2.589462298e-006	1.17972953e-006
Pluto1-2Body-PlutoMJ2000Eq	4.473986848e-006	2.159538809e-006	1.245299624e-006
Saturn1-2Body-SaturnFixed	6.039613254e-011	4.178986046e-010	3.339550858e-013
Saturn1-2Body-SaturnMJ2000Ec	6.039613254e-011	2.611244554e-013	1.136868377e-013
Saturn1-2Body-SaturnMJ2000Eq	7.105427358e-011	2.486899575e-013	8.881784197e-014
Uranus1-2Body-UranusFixed	1.509903313e-010	2.093898388e-010	1.229238933e-012
Uranus1-2Body-UranusMJ2000Ec	1.705302566e-010	1.687538997e-012	5.897504707e-013
Uranus1-2Body-UranusMJ2000Eq	1.705302566e-010	1.440625397e-012	4.831690603e-013
Venus1-2Body-VenusFixed	1.088321433e-006	8.689147535e-008	3.770613866e-008

Table 3.45: WinGMAT/MacGMAT Coordinate System Dependent Parameter Differences (Angle-based)

Test Case	Arg. of Per. (deg)	Decl. (deg)	Inc. (deg)	RA (deg)	RAAN (deg)
GEO-2Body-EarthFixed	5.547e-009	1.111e-014	1.578e-006	2.543e-010	7.04e-010
GEO-2Body-EarthMJ2000Ec	8.149e-006	7.069e-012	3.908e-014	1.751e-011	0
GEO-2Body-EarthMJ2000Eq	8.149e-006	0	0	1.788e-011	0
GEO-2Body-EarthMODEc	8.39e-006	7.069e-012	3.908e-014	1.751e-011	1.188e-011
GEO-2Body-EarthMODEq	8.354e-006	6.855e-015	2.963e-011	1.782e-011	1.137e-013
GEO-2Body-EarthMOEEc	8.151e-006	7.069e-012	3.197e-014	1.751e-011	0
GEO-2Body-EarthMOEEq	8.151e-006	1.571e-027	0	1.782e-011	0
GEO-2Body-EarthTODEc	8.15e-006	7.069e-012	3.908e-014	1.751e-011	1.251e-011
GEO-2Body-EarthTODEq	8.029e-006	1.11e-014	3.12e-011	1.791e-011	2.268e-011
GEO-2Body-EarthTOEEc	8.309e-006	7.069e-012	3.197e-014	1.751e-011	9.419e-011
GEO-2Body-EarthTOEEq	8.029e-006	3.597e-015	0	1.782e-011	5.599e-011
Hyperbolic-2Body-EarthFixed	1.99e-013	3.197e-014	1.137e-013	2.243e-010	2.244e-010
Hyperbolic-2Body-EarthMJ2000Ec	4.263e-013	1.954e-014	1.599e-013	1.137e-013	0
Hyperbolic-2Body-EarthMJ2000Eq	3.553e-013	3.197e-014	8.527e-014	1.137e-013	0
Hyperbolic-2Body-EarthMODEc	3.979e-013	1.954e-014	1.315e-013	1.137e-013	1.184e-011
Hyperbolic-2Body-EarthMODEq	3.695e-013	3.908e-014	1.208e-013	1.137e-013	2.278e-011
Hyperbolic-2Body-EarthMOEEc	4.263e-013	1.954e-014	1.208e-013	1.137e-013	0
Hyperbolic-2Body-EarthMOEEq	3.553e-013	3.197e-014	1.066e-013	1.137e-013	0
Hyperbolic-2Body-EarthTODEc	4.405e-013	1.954e-014	1.208e-013	1.137e-013	1.251e-011
Hyperbolic-2Body-EarthTODEq	3.979e-013	3.197e-014	1.279e-013	1.137e-013	2.407e-011
Hyperbolic-2Body-EarthTOEEc	4.405e-013	1.954e-014	1.386e-013	1.137e-013	0
Hyperbolic-2Body-EarthTOEEq	4.263e-013	3.197e-014	1.705e-013	1.137e-013	0
ISS-2Body-EarthFixed	1.567e-010	1.078e-010	6.999e-012	3.318e-010	2.318e-010
ISS-2Body-EarthGSE	1.648e-009	4.005e-011	7.105e-013	7.881e-011	9.663e-013
ISS-2Body-EarthGSM	6.747e-009	7.885e-011	3.228e-011	1.605e-010	5.969e-012
ISS-2Body-EarthMJ2000Ec	1.418e-009	4.004e-011	6.892e-013	7.884e-011	9.805e-013
ISS-2Body-EarthMJ2000Eq	1.419e-009	5.081e-011	5.613e-013	1.026e-010	7.461e-013
ISS-2Body-EarthMODEc	1.419e-009	4.005e-011	6.892e-013	7.878e-011	9.663e-013
ISS-2Body-EarthMODEq	1.422e-009	5.079e-011	5.684e-013	1.026e-010	7.603e-013
ISS-2Body-EarthMOEEc	1.419e-009	4.004e-011	7.034e-013	7.878e-011	9.805e-013
ISS-2Body-EarthMOEEq	1.418e-009	5.081e-011	5.755e-013	1.026e-010	7.603e-013
ISS-2Body-EarthTODEc	1.428e-009	4.005e-011	7.105e-013	7.878e-011	9.805e-013
ISS-2Body-EarthTODEq	1.428e-009	5.079e-011	5.898e-013	1.026e-010	7.674e-013
ISS-2Body-EarthTOEEc	1.419e-009	4.004e-011	7.105e-013	7.884e-011	9.948e-013
ISS-2Body-EarthTOEEq	1.424e-009	5.08e-011	5.684e-013	1.027e-010	7.603e-013
Mars1-2Body-MarsFixed	6.651e-007	1.57e-007	1.706e-008	3.081e-007	3.345e-008
Mars1-2Body-MarsMJ2000Ec	4.123e-008	2.503e-007	1.833e-009	4.191e-007	3.198e-009
Mars1-2Body-MarsMJ2000Eq	4.11e-008	2.15e-007	2.508e-009	4.378e-007	3.304e-009
Mercury1-2Body-MercuryFixed	2.398e-008	4.319e-007	1.82e-009	6.273e-007	2.7e-009
Mercury1-2Body-MercuryMJ2000Ec	2.128e-008	4.547e-007	1.452e-009	7.112e-007	1.856e-009
Mercury1-2Body-MercuryMJ2000Eq	2.162e-008	3.982e-007	1.935e-009	7.662e-007	1.613e-009
Moon-2Body-MoonFixed	8.67e-011	2.932e-009	1.787e-011	4.735e-009	1.469e-011
Moon-2Body-MoonMJ2000Ec	4.79e-011	2.914e-009	9.791e-012	4.655e-009	4.306e-012
Moon-2Body-MoonMJ2000Eq	5.156e-011	2.513e-009	8.278e-012	4.934e-009	1.057e-011
Neptune1-2Body-NeptuneFixed	1.117e-010	2.132e-014	7.788e-012	2.085e-010	2.09e-010
Neptune1-2Body-NeptuneMJ2000Ec	3.546e-011	1.421e-014	1.208e-013	1.137e-013	1.99e-013
Neptune1-2Body-NeptuneMJ2000Eq	3.543e-011	1.421e-014	1.421e-013	1.137e-013	1.705e-013
Pluto1-2Body-PlutoFixed	3.573e-007	1.593e-006	4.45e-008	3.427e-006	5.587e-008
Pluto1-2Body-PlutoMJ2000Ec	2.584e-007	1.608e-006	2.63e-008	2.252e-006	2.507e-008
Pluto1-2Body-PlutoMJ2000Eq	2.522e-007	1.372e-006	1.672e-008	2.939e-006	3.615e-008
Saturn1-2Body-SaturnFixed	1.823e-011	2.132e-014	2.7e-013	4.169e-010	4.17e-010
Saturn1-2Body-SaturnMJ2000Ec	1.339e-012	1.421e-014	4.974e-014	1.137e-013	9.948e-014
Saturn1-2Body-SaturnMJ2000Eq	1.251e-012	1.421e-014	4.974e-014	1.137e-013	5.684e-014
Uranus1-2Body-UranusFixed	2.359e-011	2.132e-014	5.826e-013	2.085e-010	2.086e-010
Uranus1-2Body-UranusMJ2000Ec	7.58e-012	1.421e-014	1.563e-013	1.137e-013	2.984e-013
Uranus1-2Body-UranusMJ2000Eq	7.461e-012	1.421e-014	1.705e-013	1.137e-013	2.274e-013
Venus1-2Body-VenusFixed	2.72e-009	5.242e-008	1.107e-010	8.421e-008	3.777e-010
Venus1-2Body-VenusMJ2000Ec	2.669e-009	5.342e-008	1.041e-010	8.603e-008	2.702e-010

## 3.3.5 Win/Linux GMAT Comparison

Table 3.46: WinGMAT/LinuxGMAT Coordinate System Dependent Parameter Differences (Position)

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)
GEO-2Body-EarthFixed	1.818989404e-009	1.455191523e-008	1.065814104e-011
GEO-2Body-EarthMJ2000Ec	1.455191523e-008	1.455191523e-008	1.091393642e-008
GEO-2Body-EarthMJ2000Eq	1.455191523e-008	1.455191523e-008	0
GEO-2Body-EarthMODEc	1.455191523e-008	1.455191523e-008	1.091393642e-008
GEO-2Body-EarthMODEq	1.455191523e-008	1.455191523e-008	1.065814104e-011
GEO-2Body-EarthMOEEc	1.455191523e-008	1.455191523e-008	1.091393642e-008
GEO-2Body-EarthMOEEq	1.455191523e-008	1.455191523e-008	1.615587134e-024
GEO-2Body-EarthTODEc	1.455191523e-008	1.455191523e-008	1.091393642e-008
GEO-2Body-EarthTODEq	1.455191523e-008	1.455191523e-008	1.065814104e-011
GEO-2Body-EarthTOEEc	1.455191523e-008	1.455191523e-008	1.091393642e-008
GEO-2Body-EarthTOEEq	1.455191523e-008	1.455191523e-008	8.881784197e-013
Hyperbolic-2Body-EarthFixed	1.164153218e-007	1.164153218e-007	1.018634066e-007
Hyperbolic-2Body-EarthMJ2000Ec	1.164153218e-007	1.164153218e-007	1.455191523e-008
Hyperbolic-2Body-EarthMJ2000Eq	1.164153218e-007	1.164153218e-007	1.164153218e-007
Hyperbolic-2Body-EarthMODEc	1.164153218e-007	1.164153218e-007	1.455191523e-008
Hyperbolic-2Body-EarthMODEq	1.164153218e-007	1.164153218e-007	1.164153218e-007
Hyperbolic-2Body-EarthMOEEc	1.164153218e-007	1.164153218e-007	1.455191523e-008
Hyperbolic-2Body-EarthMOEEq	1.164153218e-007	1.164153218e-007	1.164153218e-007
Hyperbolic-2Body-EarthTODEc	1.164153218e-007	1.164153218e-007	1.455191523e-008
Hyperbolic-2Body-EarthTODEq	1.164153218e-007	1.455191523e-008	1.164153218e-007
Hyperbolic-2Body-EarthTOEEc	1.164153218e-007	1.164153218e-007	1.455191523e-008
Hyperbolic-2Body-EarthTOEEq	1.164153218e-007	1.164153218e-007	1.164153218e-007
ISS-2Body-EarthFixed	1.818989404e-009	1.818989404e-009	1.818989404e-009
ISS-2Body-EarthGSE	1.818989404e-009	1.818989404e-009	1.818989404e-009
ISS-2Body-EarthGSM	1.818989404e-009	9.094947018e-010	1.818989404e-009
ISS-2Body-EarthMJ2000Ec	1.818989404e-009	1.818989404e-009	1.818989404e-009
ISS-2Body-EarthMJ2000Eq	1.818989404e-009	1.818989404e-009	1.818989404e-009
ISS-2Body-EarthMODEc	1.818989404e-009	1.818989404e-009	1.818989404e-009
ISS-2Body-EarthMODEq	1.818989404e-009	1.818989404e-009	1.818989404e-009
ISS-2Body-EarthMOEEc	1.818989404e-009	1.818989404e-009	9.094947018e-010
ISS-2Body-EarthMOEEq	1.818989404e-009	1.818989404e-009	1.818989404e-009
ISS-2Body-EarthTODEc	1.818989404e-009	1.818989404e-009	1.818989404e-009
ISS-2Body-EarthTODEq	1.818989404e-009	1.818989404e-009	1.818989404e-009
ISS-2Body-EarthTOEEc	1.818989404e-009	1.818989404e-009	9.094947018e-010
ISS-2Body-EarthTOEEq	1.818989404e-009	1.818989404e-009	1.818989404e-009
Mars1-2Body-MarsFixed	1.818989404e-009	1.818989404e-009	9.094947018e-010
Mars1-2Body-MarsMJ2000Ec	9.094947018e-010	1.818989404e-009	9.094947018e-010
Mars1-2Body-MarsMJ2000Eq	9.094947018e-010	1.818989404e-009	9.094947018e-010
Mercury1-2Body-MercuryFixed	9.094947018e-010	9.094947018e-010	9.094947018e-010
Mercury1-2Body-MercuryMJ2000Ec	9.094947018e-010	9.094947018e-010	9.094947018e-010
Mercury1-2Body-MercuryMJ2000Eq	9.094947018e-010	1.818989404e-009	9.094947018e-010
Moon-2Body-MoonFixed	1.136868377e-009	1.364242053e-009	1.023181539e-009
Moon-2Body-MoonMJ2000Ec	9.094947018e-010	1.023181539e-009	9.094947018e-010
Moon-2Body-MoonMJ2000Eq	9.094947018e-010	9.094947018e-010	9.094947018e-010
Neptune1-2Body-NeptuneFixed	1.455191523e-008	1.455191523e-008	1.091393642e-008
Neptune1-2Body-NeptuneMJ2000Ec	1.091393642e-008	1.455191523e-008	1.091393642e-008
Neptune1-2Body-NeptuneMJ2000Eq	1.091393642e-008	1.455191523e-008	1.091393642e-008
Pluto1-2Body-PlutoFixed	9.094947018e-010	9.094947018e-010	1.023181539e-009
Pluto1-2Body-PlutoMJ2000Ec	1.023181539e-009	9.094947018e-010	1.023181539e-009
Pluto1-2Body-PlutoMJ2000Eq	1.023181539e-009	9.094947018e-010	1.023181539e-009
Saturn1-2Body-SaturnFixed	1.455191523e-008	1.455191523e-008	1.455191523e-008
Saturn1-2Body-SaturnMJ2000Ec	1.455191523e-008	1.455191523e-008	1.455191523e-008
Saturn1-2Body-SaturnMJ2000Eq	1.455191523e-008	1.455191523e-008	1.455191523e-008
Uranus1-2Body-UranusFixed	1.455191523e-008	1.455191523e-008	1.455191523e-008
Uranus1-2Body-UranusMJ2000Ec	1.455191523e-008	1.455191523e-008	1.455191523e-008
Uranus1-2Body-UranusMJ2000Eq	1.455191523e-008	1.455191523e-008	1.455191523e-008
Venus1-2Body-VenusFixed	1.818989404e-009	1.818989404e-009	1.818989404e-009
Venus1-2Body-VenusMJ2000Ec	1.818989404e-009	1.818989404e-009	1.818989404e-009

Table 3.47: WinGMAT/LinuxGMAT Coordinate System Dependent Parameter Differences (Velocity)

Test Case	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
GEO-2Body-EarthFixed	1.058791184e-018	1.058791184e-019	1.084202172e-015
GEO-2Body-EarthMJ2000Ec	8.881784197e-013	8.881784197e-013	8.881784197e-013
GEO-2Body-EarthMJ2000Eq	8.881784197e-013	8.881784197e-013	0
GEO-2Body-EarthMODEc	8.881784197e-013	8.881784197e-013	8.881784197e-013
GEO-2Body-EarthMODEq	8.881784197e-013	8.881784197e-013	1.084202172e-015
GEO-2Body-EarthMOEEc	8.881784197e-013	8.881784197e-013	8.881784197e-013
GEO-2Body-EarthMOEEq	8.881784197e-013	8.881784197e-013	9.860761315e-029
GEO-2Body-EarthTODEc	8.881784197e-013	8.881784197e-013	8.881784197e-013
GEO-2Body-EarthTODEq	8.881784197e-013	8.881784197e-013	1.084202172e-015
GEO-2Body-EarthTOEEc	8.881784197e-013	8.881784197e-013	8.881784197e-013
GEO-2Body-EarthTOEEq	8.881784197e-013	8.881784197e-013	1.084202172e-016
Hyperbolic-2Body-EarthFixed	1.776356839e-012	7.105427358e-012	8.881784197e-013
Hyperbolic-2Body-EarthMJ2000Ec	1.776356839e-012	8.881784197e-013	8.881784197e-013
Hyperbolic-2Body-EarthMJ2000Eq	1.776356839e-012	8.881784197e-013	8.881784197e-013
Hyperbolic-2Body-EarthMODEc	1.776356839e-012	8.881784197e-013	8.881784197e-013
Hyperbolic-2Body-EarthMODEq	1.776356839e-012	8.881784197e-013	8.881784197e-013
Hyperbolic-2Body-EarthMOEEc	1.776356839e-012	8.881784197e-013	8.881784197e-013
Hyperbolic-2Body-EarthMOEEq	1.776356839e-012	8.881784197e-013	8.881784197e-013
Hyperbolic-2Body-EarthTODEc	1.776356839e-012	8.881784197e-013	8.881784197e-013
Hyperbolic-2Body-EarthTODEq	1.776356839e-012	8.881784197e-013	8.881784197e-013
Hyperbolic-2Body-EarthTOEEc	8.881784197e-013	8.881784197e-013	8.881784197e-013
Hyperbolic-2Body-EarthTOEEq	8.881784197e-013	8.881784197e-013	8.881784197e-013
ISS-2Body-EarthFixed	1.776356839e-012	1.776356839e-012	1.776356839e-012
ISS-2Body-EarthGSE	1.776356839e-012	1.776356839e-012	1.776356839e-012
ISS-2Body-EarthGSM	1.776356839e-012	1.776356839e-012	1.776356839e-012
ISS-2Body-EarthMJ2000Ec	1.776356839e-012	1.776356839e-012	1.776356839e-012
ISS-2Body-EarthMJ2000Eq	1.776356839e-012	1.776356839e-012	1.776356839e-012
ISS-2Body-EarthMODEc	1.776356839e-012	1.776356839e-012	1.776356839e-012
ISS-2Body-EarthMODEq	1.776356839e-012	1.776356839e-012	1.776356839e-012
ISS-2Body-EarthMOEEc	1.776356839e-012	1.776356839e-012	8.881784197e-013
ISS-2Body-EarthMOEEq	1.776356839e-012	1.776356839e-012	1.776356839e-012
ISS-2Body-EarthTODEc	1.776356839e-012	1.776356839e-012	1.776356839e-012
ISS-2Body-EarthTODEq	1.776356839e-012	1.776356839e-012	1.776356839e-012
ISS-2Body-EarthTOEEc	1.776356839e-012	1.776356839e-012	8.881784197e-013
ISS-2Body-EarthTOEEq	1.776356839e-012	1.776356839e-012	1.776356839e-012
Mars1-2Body-MarsFixed	1.110223025e-012	1.33226763e-012	8.881784197e-013
Mars1-2Body-MarsMJ2000Ec	8.881784197e-013	8.881784197e-013	8.881784197e-013
Mars1-2Body-MarsMJ2000Eq	8.881784197e-013	8.881784197e-013	8.881784197e-013
Mercury1-2Body-MercuryFixed	8.881784197e-013	8.881784197e-013	8.881784197e-013
Mercury1-2Body-MercuryMJ2000Ec	8.881784197e-013	8.881784197e-013	8.881784197e-013
Mercury1-2Body-MercuryMJ2000Eq	8.881784197e-013	8.881784197e-013	8.881784197e-013
Moon-2Body-MoonFixed	8.881784197e-013	1.110223025e-012	8.881784197e-013
Moon-2Body-MoonMJ2000Ec	8.881784197e-013	8.881784197e-013	8.881784197e-013
Moon-2Body-MoonMJ2000Eq	8.881784197e-013	8.881784197e-013	8.881784197e-013
Neptune1-2Body-NeptuneFixed	1.065814104e-011	1.065814104e-011	1.065814104e-011
Neptune1-2Body-NeptuneMJ2000Ec	1.065814104e-011	1.065814104e-011	1.065814104e-011
Neptune1-2Body-NeptuneMJ2000Eq	1.065814104e-011	1.065814104e-011	1.065814104e-011
Pluto1-2Body-PlutoFixed	1.110223025e-013	1.110223025e-013	1.110223025e-013
Pluto1-2Body-PlutoMJ2000Ec	1.110223025e-013	1.110223025e-013	1.110223025e-013
Pluto1-2Body-PlutoMJ2000Eq	1.110223025e-013	1.110223025e-013	1.110223025e-013
Saturn1-2Body-SaturnFixed	1.065814104e-011	1.065814104e-011	1.065814104e-011
Saturn1-2Body-SaturnMJ2000Ec	1.065814104e-011	1.065814104e-011	1.065814104e-011
Saturn1-2Body-SaturnMJ2000Eq	1.065814104e-011	1.065814104e-011	1.065814104e-011
Uranus1-2Body-UranusFixed	1.065814104e-011	1.065814104e-011	1.065814104e-011
Uranus1-2Body-UranusMJ2000Ec	1.776356839e-012	1.065814104e-011	1.065814104e-011
Uranus1-2Body-UranusMJ2000Eq	1.776356839e-012	1.065814104e-011	1.776356839e-012
Venus1-2Body-VenusFixed	1.776356839e-012	1.776356839e-012	1.776356839e-012
Venus1-2Body-VenusMJ2000Ec	1.776356839e-012	1.776356839e-012	1.776356839e-012



Table 3.48: WinGMAT/LinuxGMAT Coordinate System Dependent Parameter Differences (Specific Angular Momentum)

Test Case	X-(H) ( $m^2/sec$ )	Y-(H) ( $m^2/sec$ )	Z-(H) ( $m^2/sec$ )
GEO-2Body-EarthFixed	1.421085472e-008	1.776356839e-009	1.387778781e-011
GEO-2Body-EarthMJ2000Ec	8.077935669e-022	1.455191523e-005	0.0001018634066
GEO-2Body-EarthMJ2000Eq	0	0	0.0001018634066
GEO-2Body-EarthMODEc	1.421085472e-008	1.455191523e-005	0.0001018634066
GEO-2Body-EarthMODEq	1.421085472e-008	1.040834086e-011	0.0001018634066
GEO-2Body-EarthMOEEc	9.693522803e-021	1.455191523e-005	0.0001018634066
GEO-2Body-EarthMOEEq	9.693522803e-021	0	0.0001018634066
GEO-2Body-EarthTODEc	1.421085472e-008	1.455191523e-005	0.0001018634066
GEO-2Body-EarthTODEq	1.421085472e-008	1.776356839e-009	0.0001018634066
GEO-2Body-EarthTOEEc	0	1.455191523e-005	0.0001018634066
GEO-2Body-EarthTOEEq	8.881784197e-010	8.881784197e-010	0.0001018634066
Hyperbolic-2Body-EarthFixed	0.001862645149	0.0009313225746	0.0111758709
Hyperbolic-2Body-EarthMJ2000Ec	9.693522803e-021	1.455191523e-005	0
Hyperbolic-2Body-EarthMJ2000Eq	8.077935669e-022	0	0
Hyperbolic-2Body-EarthMODEc	1.421085472e-008	1.455191523e-005	0
Hyperbolic-2Body-EarthMODEq	1.421085472e-008	0	0
Hyperbolic-2Body-EarthMOEEc	8.077935669e-022	1.455191523e-005	0
Hyperbolic-2Body-EarthMOEEq	8.077935669e-022	0	0
Hyperbolic-2Body-EarthTODEc	1.421085472e-008	1.455191523e-005	0
Hyperbolic-2Body-EarthTODEq	1.421085472e-008	0	0
Hyperbolic-2Body-EarthTOEEc	0	1.455191523e-005	0
Hyperbolic-2Body-EarthTOEEq	0	0	0
ISS-2Body-EarthFixed	1.455191523e-005	1.455191523e-005	7.275957614e-006
ISS-2Body-EarthGSE	9.094947018e-007	7.275957614e-006	1.455191523e-005
ISS-2Body-EarthGSM	9.094947018e-007	1.455191523e-005	1.455191523e-005
ISS-2Body-EarthMJ2000Ec	1.091393642e-005	0	1.455191523e-005
ISS-2Body-EarthMJ2000Eq	1.091393642e-005	0	0
ISS-2Body-EarthMODEc	1.091393642e-005	1.091393642e-005	1.455191523e-005
ISS-2Body-EarthMODEq	1.091393642e-005	1.091393642e-005	1.091393642e-005
ISS-2Body-EarthMOEEc	1.091393642e-005	1.091393642e-005	0
ISS-2Body-EarthMOEEq	1.091393642e-005	0	0
ISS-2Body-EarthTODEc	1.091393642e-005	1.091393642e-005	1.455191523e-005
ISS-2Body-EarthTODEq	7.275957614e-006	1.091393642e-005	7.275957614e-006
ISS-2Body-EarthTOEEc	7.275957614e-006	1.091393642e-005	0
ISS-2Body-EarthTOEEq	7.275957614e-006	1.091393642e-005	7.275957614e-006
Mars1-2Body-MarsFixed	1.818989404e-006	2.728484105e-006	1.091393642e-005
Mars1-2Body-MarsMJ2000Ec	0	9.094947018e-007	0
Mars1-2Body-MarsMJ2000Eq	0	1.058791184e-016	0
Mercury1-2Body-MercuryFixed	1.818989404e-006	1.818989404e-006	1.818989404e-006
Mercury1-2Body-MercuryMJ2000Ec	1.818989404e-006	9.094947018e-007	1.818989404e-006
Mercury1-2Body-MercuryMJ2000Eq	1.818989404e-006	1.32348898e-017	1.818989404e-006
Moon-2Body-MoonFixed	1.364242053e-006	1.136868377e-006	1.364242053e-006
Moon-2Body-MoonMJ2000Ec	9.094947018e-007	0	9.094947018e-007
Moon-2Body-MoonMJ2000Eq	9.094947018e-007	1.033975766e-019	9.094947018e-007
Neptune1-2Body-NeptuneFixed	0.0001164153218	0.0001164153218	0.0001164153218
Neptune1-2Body-NeptuneMJ2000Ec	0.0001164153218	0.0001164153218	0.0001164153218
Neptune1-2Body-NeptuneMJ2000Eq	0.0001164153218	1.355252716e-014	0.0001164153218
Pluto1-2Body-PlutoFixed	1.023181539e-006	1.023181539e-006	1.136868377e-007
Pluto1-2Body-PlutoMJ2000Ec	0	1.136868377e-007	0
Pluto1-2Body-PlutoMJ2000Eq	0	8.470329473e-016	0
Saturn1-2Body-SaturnFixed	0.0002328306437	0.0009313225746	0.0005384208634
Saturn1-2Body-SaturnMJ2000Ec	0.0009313225746	0.0001164153218	0.0009313225746
Saturn1-2Body-SaturnMJ2000Eq	0.0009313225746	1.016439537e-014	0.0009313225746
Uranus1-2Body-UranusFixed	0.0001164153218	0.0001164153218	0.0001164153218
Uranus1-2Body-UranusMJ2000Ec	0.0001164153218	0.0001164153218	0.0001164153218
Uranus1-2Body-UranusMJ2000Eq	0.0001164153218	1.355252716e-014	0.0001164153218
Venus1-2Body-VenusFixed	9.094947018e-007	1.455191523e-005	1.455191523e-005

Table 3.49: WinGMAT/LinuxGMAT Coordinate System Dependent Parameter Differences (Velocity Vector-based)

Test Case	Mag-Vel (m/s)	Right Asc. of Vel. (deg)	Dec. of Vel. (deg)
GEO-2Body-EarthFixed	1.084202172e-015	1.136868377e-013	0
GEO-2Body-EarthMJ2000Ec	8.881784197e-013	1.136868377e-013	1.065814104e-014
GEO-2Body-EarthMJ2000Eq	8.881784197e-013	1.136868377e-013	0
GEO-2Body-EarthMODEc	8.881784197e-013	1.136868377e-013	1.065814104e-014
GEO-2Body-EarthMODEq	8.881784197e-013	1.136868377e-013	1.040834086e-017
GEO-2Body-EarthMOEEc	8.881784197e-013	1.136868377e-013	1.065814104e-014
GEO-2Body-EarthMOEEq	8.881784197e-013	1.136868377e-013	1.57772181e-030
GEO-2Body-EarthTODEc	8.881784197e-013	1.136868377e-013	1.065814104e-014
GEO-2Body-EarthTODEq	8.881784197e-013	1.136868377e-013	1.040834086e-017
GEO-2Body-EarthTOEEc	8.881784197e-013	1.136868377e-013	1.065814104e-014
GEO-2Body-EarthTOEEq	8.881784197e-013	1.136868377e-013	1.084202172e-018
Hyperbolic-2Body-EarthFixed	1.065814104e-011	1.136868377e-013	1.065814104e-014
Hyperbolic-2Body-EarthMJ2000Ec	1.776356839e-012	1.136868377e-013	1.065814104e-014
Hyperbolic-2Body-EarthMJ2000Eq	1.776356839e-012	1.136868377e-013	1.065814104e-014
Hyperbolic-2Body-EarthMODEc	1.776356839e-012	1.136868377e-013	1.065814104e-014
Hyperbolic-2Body-EarthMODEq	1.776356839e-012	1.136868377e-013	1.065814104e-014
Hyperbolic-2Body-EarthMOEEc	1.776356839e-012	1.136868377e-013	1.065814104e-014
Hyperbolic-2Body-EarthMOEEq	1.776356839e-012	1.136868377e-013	1.065814104e-014
Hyperbolic-2Body-EarthTODEc	1.776356839e-012	1.136868377e-013	1.065814104e-014
Hyperbolic-2Body-EarthTODEq	1.776356839e-012	1.136868377e-013	1.065814104e-014
Hyperbolic-2Body-EarthTOEEc	1.776356839e-012	1.136868377e-013	1.065814104e-014
Hyperbolic-2Body-EarthTOEEq	1.776356839e-012	1.136868377e-013	1.065814104e-014
ISS-2Body-EarthFixed	1.776356839e-012	1.136868377e-013	1.421085472e-014
ISS-2Body-EarthGSE	1.776356839e-012	1.065814104e-014	1.421085472e-014
ISS-2Body-EarthGSM	1.776356839e-012	1.136868377e-013	1.421085472e-014
ISS-2Body-EarthMJ2000Ec	1.776356839e-012	1.136868377e-013	1.421085472e-014
ISS-2Body-EarthMJ2000Eq	1.776356839e-012	1.136868377e-013	1.421085472e-014
ISS-2Body-EarthMODEc	1.776356839e-012	1.136868377e-013	1.421085472e-014
ISS-2Body-EarthMODEq	1.776356839e-012	1.136868377e-013	1.421085472e-014
ISS-2Body-EarthMOEEc	1.776356839e-012	1.136868377e-013	1.421085472e-014
ISS-2Body-EarthMOEEq	1.776356839e-012	1.136868377e-013	1.421085472e-014
ISS-2Body-EarthTODEc	1.776356839e-012	1.136868377e-013	1.421085472e-014
ISS-2Body-EarthTODEq	1.776356839e-012	1.136868377e-013	1.421085472e-014
ISS-2Body-EarthTOEEc	1.776356839e-012	1.136868377e-013	1.421085472e-014
ISS-2Body-EarthTOEEq	1.776356839e-012	1.136868377e-013	1.421085472e-014
Mars1-2Body-MarsFixed	1.33226763e-012	1.136868377e-013	1.065814104e-014
Mars1-2Body-MarsMJ2000Ec	8.881784197e-013	1.136868377e-013	1.421085472e-014
Mars1-2Body-MarsMJ2000Eq	8.881784197e-013	1.136868377e-013	1.421085472e-014
Mercury1-2Body-MercuryFixed	8.881784197e-013	1.136868377e-013	1.421085472e-014
Mercury1-2Body-MercuryMJ2000Ec	8.881784197e-013	1.136868377e-013	1.421085472e-014
Mercury1-2Body-MercuryMJ2000Eq	8.881784197e-013	1.136868377e-013	1.421085472e-014
Moon-2Body-MoonFixed	1.110223025e-012	1.136868377e-013	1.421085472e-014
Moon-2Body-MoonMJ2000Ec	8.881784197e-013	1.136868377e-013	1.421085472e-014
Moon-2Body-MoonMJ2000Eq	8.881784197e-013	1.136868377e-013	1.421085472e-014
Neptune1-2Body-NeptuneFixed	1.065814104e-011	1.136868377e-013	2.131628207e-014
Neptune1-2Body-NeptuneMJ2000Ec	1.065814104e-011	1.136868377e-013	1.421085472e-014
Neptune1-2Body-NeptuneMJ2000Eq	1.065814104e-011	1.136868377e-013	1.421085472e-014
Pluto1-2Body-PlutoFixed	1.110223025e-013	1.136868377e-013	1.421085472e-014
Pluto1-2Body-PlutoMJ2000Ec	0	1.136868377e-013	1.421085472e-014
Pluto1-2Body-PlutoMJ2000Eq	0	1.136868377e-013	1.421085472e-014
Saturn1-2Body-SaturnFixed	1.065814104e-011	3.552713679e-013	2.131628207e-014
Saturn1-2Body-SaturnMJ2000Ec	1.065814104e-011	1.136868377e-013	1.421085472e-014
Saturn1-2Body-SaturnMJ2000Eq	1.065814104e-011	1.136868377e-013	1.421085472e-014
Uranus1-2Body-UranusFixed	1.065814104e-011	1.136868377e-013	2.131628207e-014
Uranus1-2Body-UranusMJ2000Ec	1.065814104e-011	1.136868377e-013	1.421085472e-014
Uranus1-2Body-UranusMJ2000Eq	1.065814104e-011	1.136868377e-013	1.421085472e-014
Venus1-2Body-VenusFixed	1.776356839e-012	1.136868377e-013	1.421085472e-014

Table 3.50: WinGMAT/LinuxGMAT Coordinate System Dependent Parameter Differences (Angle-based)

Test Case	Arg. of Per. (deg)	Decl. (deg)	Inc. (deg)	RA (deg)	RAAN (deg)
GEO-2Body-EarthFixed	1.302e-011	1.041e-017	0	1.137e-013	1.137e-013
GEO-2Body-EarthMJ2000Ec	1.137e-013	1.066e-014	7.105e-015	1.137e-013	0
GEO-2Body-EarthMJ2000Eq	1.137e-013	0	0	1.137e-013	0
GEO-2Body-EarthMODEc	1.137e-013	1.066e-014	1.066e-014	1.137e-013	1.506e-012
GEO-2Body-EarthMODEq	1.137e-013	1.041e-017	3.7e-012	1.137e-013	1.137e-013
GEO-2Body-EarthMOEEc	1.137e-013	1.066e-014	1.066e-014	1.137e-013	0
GEO-2Body-EarthMOEEq	9.948e-014	1.578e-030	0	1.137e-013	0
GEO-2Body-EarthTODEc	1.137e-013	1.066e-014	1.066e-014	1.137e-013	1.62e-012
GEO-2Body-EarthTODEq	1.137e-013	1.041e-017	3.894e-012	1.137e-013	1.137e-013
GEO-2Body-EarthTOEEc	1.137e-013	1.066e-014	1.066e-014	1.137e-013	2.217e-012
GEO-2Body-EarthTOEEq	1.137e-013	1.084e-018	4.179e-013	1.137e-013	0
Hyperbolic-2Body-EarthFixed	1.137e-013	1.421e-014	1.137e-013	1.137e-013	1.137e-013
Hyperbolic-2Body-EarthMJ2000Ec	0	1.066e-014	1.066e-014	1.137e-013	0
Hyperbolic-2Body-EarthMJ2000Eq	0	1.066e-014	0	1.137e-013	0
Hyperbolic-2Body-EarthMODEc	0	1.066e-014	1.066e-014	1.137e-013	1.466e-012
Hyperbolic-2Body-EarthMODEq	0	1.066e-014	1.421e-014	1.137e-013	2.843e-012
Hyperbolic-2Body-EarthMOEEc	0	1.066e-014	1.066e-014	1.137e-013	0
Hyperbolic-2Body-EarthMOEEq	0	1.066e-014	0	1.137e-013	0
Hyperbolic-2Body-EarthTODEc	0	1.066e-014	1.066e-014	1.137e-013	1.555e-012
Hyperbolic-2Body-EarthTODEq	0	1.066e-014	1.421e-014	1.137e-013	3.004e-012
Hyperbolic-2Body-EarthTOEEc	0	1.066e-014	1.066e-014	1.137e-013	2.16e-012
Hyperbolic-2Body-EarthTOEEq	0	1.066e-014	1.421e-014	1.137e-013	3.411e-013
ISS-2Body-EarthFixed	1.851e-013	1.421e-014	1.421e-014	1.137e-013	2.842e-013
ISS-2Body-EarthGSE	1.137e-013	1.066e-014	1.421e-014	1.137e-013	1.137e-013
ISS-2Body-EarthGSM	1.137e-013	1.421e-014	1.421e-014	1.137e-013	1.137e-013
ISS-2Body-EarthMJ2000Ec	9.948e-014	1.421e-014	1.421e-014	1.137e-013	1.421e-014
ISS-2Body-EarthMJ2000Eq	1.137e-013	1.421e-014	1.421e-014	1.137e-013	1.421e-014
ISS-2Body-EarthMODEc	9.948e-014	1.421e-014	1.421e-014	1.137e-013	1.421e-014
ISS-2Body-EarthMODEq	1.137e-013	1.421e-014	1.421e-014	1.137e-013	1.421e-014
ISS-2Body-EarthMOEEc	1.137e-013	1.421e-014	1.421e-014	1.137e-013	1.421e-014
ISS-2Body-EarthMOEEq	1.137e-013	1.421e-014	1.421e-014	1.137e-013	1.421e-014
ISS-2Body-EarthTODEc	1.137e-013	1.421e-014	1.421e-014	1.137e-013	1.421e-014
ISS-2Body-EarthTODEq	1.137e-013	1.421e-014	1.421e-014	9.948e-014	1.421e-014
ISS-2Body-EarthTOEEc	1.137e-013	1.421e-014	1.421e-014	1.137e-013	1.421e-014
ISS-2Body-EarthTOEEq	1.137e-013	1.421e-014	1.421e-014	1.137e-013	1.421e-014
Mars1-2Body-MarsFixed	2.476e-013	1.066e-014	2.132e-014	1.137e-013	1.137e-013
Mars1-2Body-MarsMJ2000Ec	1.066e-014	1.421e-014	1.421e-014	1.137e-013	9.948e-014
Mars1-2Body-MarsMJ2000Eq	1.421e-014	1.421e-014	1.421e-014	1.137e-013	0
Mercury1-2Body-MercuryFixed	2.22e-014	1.421e-014	1.421e-014	1.137e-013	1.137e-013
Mercury1-2Body-MercuryMJ2000Ec	1.066e-014	1.421e-014	1.421e-014	1.137e-013	1.137e-013
Mercury1-2Body-MercuryMJ2000Eq	1.421e-014	1.421e-014	1.421e-014	1.137e-013	0
Moon-2Body-MoonFixed	1.599e-013	1.421e-014	2.132e-014	1.137e-013	3.553e-014
Moon-2Body-MoonMJ2000Ec	1.066e-014	1.421e-014	1.421e-014	1.137e-013	1.137e-013
Moon-2Body-MoonMJ2000Eq	1.421e-014	1.421e-014	1.421e-014	1.137e-013	0
Neptune1-2Body-NeptuneFixed	1.08e-012	1.421e-014	2.132e-014	1.137e-013	1.705e-013
Neptune1-2Body-NeptuneMJ2000Ec	1.066e-014	1.421e-014	1.421e-014	1.137e-013	1.137e-013
Neptune1-2Body-NeptuneMJ2000Eq	1.421e-014	1.421e-014	1.421e-014	1.137e-013	0
Pluto1-2Body-PlutoFixed	2.274e-013	1.421e-014	1.421e-014	1.137e-013	2.842e-013
Pluto1-2Body-PlutoMJ2000Ec	1.066e-014	1.421e-014	1.421e-014	1.137e-013	9.948e-014
Pluto1-2Body-PlutoMJ2000Eq	1.421e-014	1.421e-014	1.421e-014	1.137e-013	0
Saturn1-2Body-SaturnFixed	1.024e-012	1.421e-014	2.842e-014	1.137e-013	1.99e-013
Saturn1-2Body-SaturnMJ2000Ec	1.066e-014	1.421e-014	1.421e-014	1.137e-013	9.948e-014
Saturn1-2Body-SaturnMJ2000Eq	1.421e-014	1.421e-014	1.421e-014	1.137e-013	0
Uranus1-2Body-UranusFixed	3.979e-013	1.421e-014	9.948e-014	1.137e-013	1.137e-013
Uranus1-2Body-UranusMJ2000Ec	1.066e-014	1.421e-014	1.421e-014	1.137e-013	1.137e-013
Uranus1-2Body-UranusMJ2000Eq	1.421e-014	1.421e-014	1.421e-014	1.137e-013	0
Venus1-2Body-VenusFixed	1.066e-014	1.421e-014	1.421e-014	1.137e-013	3.695e-012
Venus1-2Body-VenusMJ2000Ec	1.066e-014	1.421e-014	1.421e-014	1.137e-013	9.948e-014



## Chapter 4

# Integrators

GMAT's integrators were tested on a system level in order to verify that all the integrators were working correctly. In order to minimize the effects of other forces/elements, the two-body cases from the Propagators section were used, with some modification, for testing the integrators. The report output interval and integrators were the only parameter changed when using the Propagator two body test cases. Data was outputted in ten minute intervals.

### 4.1 Initial Orbit Conditions

The ISS and GEO two-body case's initial orbit parameters were used from the Propagation section (Chapter 2) for the test cases in this section.

Refer to Appendix B.1 Tables B.1- B.13 for a listing of all Propagation initial orbit states used for the Integrator test cases.

### 4.2 Naming Convention

This section describes the naming convention for integrator scripts and output reports. The naming convention consists of an ordered series of option strings, separated by underscores (-). Currently, options are allowed for the following fields, and will be present in the file name in order:

1. *tool* - The tool used to generate the test case
2. *traj* - The trajectory to use. This includes initial conditions, physical parameters, and time step
3. *integ* - The integrator to use

The word Integrator precedes the *tool* field and 2Body follows the *integ* field. The final integrator file format is as followed:

Integrator\_*tool*\_*traj*\_*integ*\_2Body.report

The *tool* field should always be the first option field. Future additional fields should be added to the end of the list of fields. Each field has a finite list of options, as follows (future options should be added to this list):

- 1. *tool* STK - Satellite Toolkit HPOP or Astrogator  
FF - FreeFlyer  
GMAT - General Mission Analysis Tool
- 2. *traj* ISS - leo orbit  
GEO - geo orbit

NOTE: Some test cases contain *traj* variations. In this case *traj* precedes the modification. For example, if an ISS trajectory is needed with a different Cd, *traj* could be ISSdiffCd1.

- 3. *integ* RKV89 - RungaKutta 8(9)  
RKN68 - DormandElMikkawyPrince 6(8)  
RKF56 - RungeKuttaFehlberg 5(6)  
PD45 - PrinceDormand 4(5)  
PD78 - PrinceDormand 7(8)  
BS - BulirschStoer  
ABM - AdamsBashforthMoulton

### 4.3 Comparison Script Information

Comparison\_Integ.m is the script used to perform the integrator comparisons needed for the Integrators section of the Acceptance Test Plan. This script was designed to allow the user to select a GMAT Build or the exact analytic solution to compare to one another.

Refer to Appendix C for more details about this script and others used in the Acceptance Test Plan document.

## 4.4 Test Case Results

The following results are for the Integrator section. The GMAT Integrator results are being compared to an exact analytical two-body solution. We'd like the comparison data to be as close to zero as possible. A detailed acceptance metric/matrix will be developed at a later date.

Table 4.1: Exact/WinGMAT GEO Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
ABM-2Body	0.0001127712184	8.178707643e-009
BS-2Body	6.290317204e-005	4.535189696e-009
PD45-2Body	3.297921562e-005	2.320908148e-009
PD78-2Body	1.822370346e-005	1.253046654e-009
RKF56-2Body	3.459697578e-005	2.564071918e-009
RKN68-2Body	1.793126562e-005	1.297793489e-009
RKV89-2Body	0.0001127712184	8.178707643e-009

Table 4.2: Exact/WinGMAT ISS Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
ABM-2Body	1.052211123e-005	1.172665432e-008
BS-2Body	1.691079091e-005	1.926879767e-008
PD45-2Body	3.080434654e-005	3.521816658e-008
PD78-2Body	2.772621462e-005	3.15224572e-008
RKF56-2Body	3.336029534e-005	3.80119779e-008
RKN68-2Body	3.617025125e-006	3.875411333e-009
RKV89-2Body	1.052211123e-005	1.172665432e-008

### 4.4.1 Win/Mac GMAT Comparison

Table 4.3: WinGMAT/MacGMAT GEO Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
ABM-2Body	4.990522323e-005	3.634067315e-009
BS-2Body	4.499516895e-005	3.048485196e-009
PD45-2Body	3.360510852e-005	2.346776158e-009
PD78-2Body	1.721559725e-005	1.110205705e-009
RKF56-2Body	4.772019229e-005	3.510581894e-009
RKN68-2Body	6.394945484e-005	4.727059048e-009
RKV89-2Body	4.990522323e-005	3.634067315e-009

Table 4.4: WinGMAT/MacGMAT ISS Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
ABM-2Body	3.476512236e-005	3.980331596e-008
BS-2Body	3.902337183e-005	4.465750423e-008
PD45-2Body	1.214759222e-005	1.361758077e-008
PD78-2Body	1.808533949e-005	2.043945469e-008
RKF56-2Body	2.234706582e-005	2.518943482e-008
RKN68-2Body	4.459241486e-006	4.808133777e-009
RKV89-2Body	3.476512236e-005	3.980331596e-008



## 4.4.2 Win/Linux GMAT Comparison

Table 4.5: WinGMAT/LinuxGMAT GEO Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
ABM-2Body	1.818989404e-008	1.256073967e-012
BS-2Body	1.626953583e-008	1.256073967e-012
PD45-2Body	1.818989404e-008	1.256073967e-012
PD78-2Body	1.626953583e-008	8.950904183e-013
RKF56-2Body	1.466516141e-008	1.256073967e-012
RKN68-2Body	1.818989404e-008	1.256073967e-012
RKV89-2Body	1.818989404e-008	1.256073967e-012

Table 4.6: WinGMAT/LinuxGMAT ISS Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
ABM-2Body	2.572439484e-009	1.986027323e-012
BS-2Body	2.033691978e-009	2.512147934e-012
PD45-2Body	2.572439484e-009	2.512147934e-012
PD78-2Body	2.572439484e-009	2.512147934e-012
RKF56-2Body	2.572439484e-009	2.512147934e-012
RKN68-2Body	2.033691978e-009	2.512147934e-012
RKV89-2Body	2.572439484e-009	1.986027323e-012



## Chapter 5

# Stopping Conditions

GMAT's Stopping Conditions were tested on a system level in order to determine if it stops correctly on user selected conditions. Refer to Table 5.1 for a list of the stopping conditions tested and the units used for the output of data.

Table 5.1: Stopping Conditions

Stopping Condition	Stopping Value	Unit Used
Epoch (A1 Modified Julian Date)	23158.042037434974	Days
Apoapsis	180	TA in degrees
Elapsed Days	6 Hours	Days
Elapsed Days (Multiple Satellites)	5 Hours	Days
Mean Anomaly	45, 90, & 180	MA in degrees
Periapsis	0	TA in degrees
Elapsed Seconds	3600	Seconds
True Anomaly	45, 90, & 180	TA in degrees
XY Plane Intersection	Z=0	Km
XZ Plane Intersection	Y=0	Km
YZ Plane Intersection	X=0	Km

## 5.1 Initial Orbit Conditions

For a listing of the initial conditions used to produce the data for the Stopping Conditions Section, refer to Table 5.2 for the Earth based non-hyperbolic point mass test cases, Table 5.3 for the Earth based non-hyperbolic all forces test cases, and Table 5.4 for the Earth based hyperbolic point mass test cases.

Table 5.2: Initial Orbit Parameters (EarthPM & EarthMJ2000EqPM)

Initial State Parameter	Parameter Value (unit)
Coordinate System (CS)	Earth Mean J2000 Equator
X	-8043.9600382977915 (km)
Y	-1564.9950345568864 (km)
Z	3750.9601677510364 (km)
VX	0.99861303787927636 (km)
VY	-6.8834168529193462 (km)
VZ	-0.46566090709653452 (km)
Mass (No Fuel)	850 (kg)
Cd	2.2
Cr	1.8
Drag Area	15 ( $m^2$ )
Drag Model	None
NSG Model	None
SRP Area	1 ( $m^2$ )
SRP	Off
Integrator Type	RungaKutta 8(9)
Integrator Init. StepSize	60 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	2700 (sec)
Report Precision	16 significant figures
Report StepSize	Only initial state
Report CS/Cb	Same as initial state CS

Table 5.3: Initial Orbit Parameters (EarthAll & EarthMJ2000EqAll)

Initial State Parameter	Parameter Value (unit)
Coordinate System (CS)	Earth Mean J2000 Equator
X	-8043.9600382977915 (km)
Y	-1564.9950345568864 (km)
Z	3750.9601677510364 (km)
VX	0.99861303787927636 (km)
VY	-6.8834168529193462 (km)
VZ	-0.46566090709653452 (km)
Mass (No Fuel)	850 (kg)
Cd	2.2
Cr	1.8
Drag Area	15 ( $m^2$ )
Drag Model	Jacchia Roberts
Drag F107/F107A	150/150
Drag Kp	3
NSG Model	JGM2
Degree x Order	4x4
SRP Area	1 ( $m^2$ )
SRP	On
Integrator Type	RungaKutta 8(9)
Integrator Init. StepSize	60 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	2700 (sec)
Report Precision	16 significant figures
Report StepSize	Only initial state
Report CS/Cb	Same as initial state CS

Table 5.4: Initial Orbit Parameters (EarthPMhyper &amp; EarthMJ2000EqPMhyper)

Initial State Parameter	Parameter Value (unit)
Coordinate System (CS)	Earth Mean J2000 Equator
X	12371.791482634855 (km)
Y	5050.7627227610719 (km)
Z	5050.762722761071 (km)
VX	-7.9859921512608487 (km)
VY	2.44520073255755 (km)
VZ	2.4452007325575495 (km)
Mass (No Fuel)	850 (kg)
Cd	2.2
Cr	1.8
Drag Area	15 ( $m^2$ )
Drag Model	None
NSG Model	None
SRP Area	1 ( $m^2$ )
SRP	Off
Integrator Type	RungaKutta 8(9)
Integrator Init. StepSize	60 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	2700 (sec)
Report Precision	16 significant figures
Report StepSize	Only initial state
Report CS/Cb	Same as initial state CS

Table 5.5: Initial Orbit Parameters (MoonPM)

Initial State Parameter	Parameter Value (unit)
Coordinate System (CS)	Earth Mean J2000 Equator
X	-1486.792117191545200 (km)
Y	0.0 (km)
Z	1486.792117191543000 (km)
VX	-0.142927729144255 (km)
VY	-1.631407624437537 (km)
VZ	0.142927729144255 (km)
Mass (No Fuel)	850 (kg)
Cd	2.2
Cr	1.8
Drag Area	15 ( $m^2$ )
Drag Model	None
NSG Model	None
SRP Area	1 ( $m^2$ )
SRP	Off
Integrator Type	RungaKutta 8(9)
Integrator Init. StepSize	60 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	2700 (sec)
Report Precision	16 significant figures
Report StepSize	Only initial state
Report CS/Cb	Same as initial state CS

Table 5.6: Initial Orbit Parameters (MarsPM)

Initial State Parameter	Parameter Value (unit)
Coordinate System (CS)	Earth Mean J2000 Equator
X	-2737.481646173082000 (km)
Y	0.0 (km)
Z	2737.481646173082000 (km)
VX	-0.311321695052649 (km)
VY	-3.553492313930950 (km)
VZ	0.311321695052650 (km)
Mass (No Fuel)	850 (kg)
Cd	2.2
Cr	1.8
Drag Area	15 ( $m^2$ )
Drag Model	None
NSG Model	None
SRP Area	1 ( $m^2$ )
SRP	Off
Integrator Type	RungaKutta 8(9)
Integrator Init. StepSize	60 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	2700 (sec)
Report Precision	16 significant figures
Report StepSize	Only initial state
Report CS/Cb	Same as initial state CS

## 5.2 Naming Convention

This section describes the naming convention for stopping condition scripts and output reports generated for use in GMAT's Acceptance Test Plan. The naming convention consists of an ordered series of option strings, separated by underscores ( \_ ). Currently, options are allowed for the following fields, and will be present in the file name in order:

1. *tool* - The tool used to generate the test cases.
2. *Cb* - The Central Body used for the stopping condition, including the force model setup.
3. *stopCond* - The stopping condition used for the test case.

The word StopCond precedes the *tool* field. The final stopping condition file format is as followed:  
StopCond\_*tool*\_*Cb*\_*stopCond*.report

The *tool* field should always be the first option field. Future additional fields should be added to the end of the list of fields. Each field has a finite list of options, as follows (future options should be added to this list):

- |                    |                   |   |
|--------------------|-------------------|---|
|                    | STK               | - Satellite Toolkit HPOP or Astrogator  |
| 1. <i>tool</i>     | FF                | - FreeFlyer   |
|                    | GMAT              | - General Mission Analysis Tool   |
|                    | EarthPM           | - Earth central body with point mass force model                              |
|                    | EarthMJ2000EqPM   | - Same as EarthPM and plane intersection calculations based on EarthMJ2000Eq  |
|                    | EarthAll          | - Earth central body with all force model types turned on                     |
| 2. <i>Cb</i>       | EarthMJ2000EqAll  | - Same as EarthAll and plane intersection calculations based on EarthMJ2000Eq |
|                    | Earth#MultiSatsPM | - Same as EarthPM and the test case involves # satellites                     |
|                    | MarsPM            | - Mars central body with point mass force model                               |
|                    | MoonPM            | - Moon central body with point mass force model                               |
|                    | A1ModJulian       | - A1 Modified Julian Date   |
|                    | Apoapsis          | - Apoapsis of orbit based on TA   |
|                    | Days              | - Elapsed Days  |
|                    | MA###             | - ### degree Mean Anomaly   |
| 3. <i>stopCond</i> | Periapsis         | - Periapsis of orbit based on TA  |
|                    | Seconds           | - Elapsed Seconds   |
|                    | TA###             | - ### degree True Anomaly   |
|                    | XYplane           | - XY Plane Intersection   |
|                    | XZplane           | - XZ Plane Intersection   |
|                    | YZplane           | - YZ Plane Intersection   |

## 5.3 Comparison Script Information

Comparison.StopCond.m is the script used to perform the comparisons needed for the Stopping Condition chapter of the Acceptance Test Plan. This script was designed to allow the user to select a GMAT Build and/or the exact solution to compare to one another.

Refer to Appendix C for more details on this script and others used in the Acceptance Test Plan document.



## 5.4 Test Case Results

The following results are for the Stopping Condition section. The GMAT Stopping Condition results are being compared to the exact desired stopping condition. We'd like the comparison data to be as close to zero as possible. A detailed acceptance metric/matrix will be developed at a later date.

Refer to Table 5.1 to determine the units used in the Difference(s) column of the Stopping Condition comparison results.

Table 5.7: Exact/WinGMAT EarthPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	3.637978807e-012
Apoapsis	1.207418308e-006
Days	3.637978807e-012
EA180	0
EA45	1.122458571e-009
EA90	5.233573575e-010
MA180	0
MA90	5.793253877e-009
Periapsis	0
Secs	2.09548034e-007
TA180	0
TA90	2.69331224e-009

Table 5.8: Exact/WinGMAT EarthAll StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	7.275957614e-012
Apoapsis	0
Days	7.276013125e-012
EA180	0
EA45	1.370133873e-008
EA90	1.320385934e-008
MA180	0
MA90	1.408977823e-008
Periapsis	0
Secs	4.190951586e-007
TA180	0
TA90	8.076597169e-010

Table 5.9: Exact/WinGMAT EarthPMhyper StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	3.637978807e-012
Days	0
HA45	5.94486238e-009
HA90	6.062620628e-009
MA45	4.032202128e-009
MA90	7.014335779e-010
Periapsis	0
Secs	2.09548034e-007
TA45	1.530788296e-008
TA90	3.041570551e-008

Table 5.10: Exact/WinGMAT MoonPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	3.637978807e-012
Apoapsis	1.207418308e-006
Days	3.637978807e-012
EA180	1.478779296e-006
EA90	3.193633802e-009
MA180	1.774535207e-006
MA90	8.953790598e-009
Periapsis	0
Secs	2.09548034e-007
TA180	1.207418308e-006
TA90	9.594344874e-009

Table 5.11: Exact/WinGMAT MarsPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	3.637978807e-012
Apoapsis	0
Days	0
EA180	0
EA90	2.220498629e-008
MA180	0
MA90	1.276124806e-008
Periapsis	0
Secs	2.09548034e-007
TA180	0
TA90	1.505739533e-008

Table 5.12: Exact/WinGMAT EarthMJ2000EqPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
XYplane	1.967496619e-007
XZplane	1.187821727e-006
YZplane	4.2192789e-007

Table 5.13: Exact/WinGMAT EarthMJ2000EqAll StopCond Test Case Comparison

Stopping Condition	Difference(s)
XYplane	8.57494129e-008
XZplane	1.575498128e-006
YZplane	2.401038834e-008

Table 5.14: Exact/WinGMAT EarthMJ2000EqPMhyper StopCond Test Case Comparison

Stopping Condition	Difference(s)
XYplane	9.138221522e-007
XZplane	9.138204291e-007
YZplane	3.637831914e-006

Table 5.15: Exact/WinGMAT MoonMJ2000EqPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
XYplane	1.752778189e-007
XZplane	0
YZplane	1.752923708e-007

Table 5.16: Exact/WinGMAT MarsMJ2000EqPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
XYplane	2.384185791e-007
XZplane	0
YZplane	2.235174179e-007

Table 5.17: Exact/WinGMAT Earth3MultiSatsPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
Days	7.276e-012 7.276e-012 7.276e-012

## 5.4.1 Win/Mac GMAT Comparison

Table 5.18: WinGMAT/MacGMAT EarthPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	1.091393642e-011
Apoapsis	1.207418308e-006
Days	3.637978807e-012
EA180	0
EA45	1.249863146e-008
EA90	1.641892311e-008
MA180	0
MA90	1.010349138e-009
Periapsis	0
Secs	3.143209142e-007
TA180	0
TA90	1.477332034e-008

Table 5.19: WinGMAT/MacGMAT EarthAll StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	1.091393642e-011
Apoapsis	0
Days	1.091399193e-011
EA180	0
EA45	2.758255135e-008
EA90	6.509765171e-009
MA180	0
MA90	1.209116363e-009
Periapsis	0
Secs	6.286431926e-007
TA180	0
TA90	2.392090437e-008

Table 5.20: WinGMAT/MacGMAT EarthPMhyper StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	1.091393642e-011
Days	0
HA45	3.278302074e-010
HA90	5.154717542e-009
MA45	4.688160971e-009
MA90	1.775092073e-009
Periapsis	8.537736463e-007
Secs	6.286431926e-007
TA45	7.957417836e-009
TA90	9.00868713e-010

Table 5.21: WinGMAT/MacGMAT MoonPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	0
Apoapsis	1.207418308e-006
Days	3.637978807e-012
EA180	1.478779296e-006
EA90	1.050977971e-008
MA180	1.774535207e-006
MA90	3.044107189e-010
Periapsis	0
Secs	3.143218237e-007
TA180	1.207418308e-006
TA90	1.47603032e-008

Table 5.22: WinGMAT/MacGMAT MarsPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	0
Apoapsis	0
Days	7.276013125e-012
EA180	0
EA90	1.924313153e-008
MA180	0
MA90	2.515002961e-008
Periapsis	0
Secs	0
TA180	0
TA90	7.037499472e-010

Table 5.23: WinGMAT/MacGMAT EarthMJ2000EqPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
XYplane	1.078823641e-006
XZplane	1.354494348e-006
YZplane	2.313548366e-006

Table 5.24: WinGMAT/MacGMAT EarthMJ2000EqAll StopCond Test Case Comparison

Stopping Condition	Difference(s)
XYplane	7.639199145e-007
XZplane	2.233082799e-006
YZplane	1.636945122e-006

Table 5.25: WinGMAT/MacGMAT EarthMJ2000EqPMhyper StopCond Test Case Comparison

Stopping Condition	Difference(s)
XYplane	2.779416424e-007
XZplane	2.779415402e-007
YZplane	7.390968164e-006

Table 5.26: WinGMAT/MacGMAT MoonMJ2000EqPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
XYplane	4.745961633e-007
XZplane	0
YZplane	4.745961633e-007

Table 5.27: WinGMAT/MacGMAT MarsMJ2000EqPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
XYplane	2.980232239e-007
XZplane	0
YZplane	2.980232239e-007

Table 5.28: WinGMAT/MacGMAT Earth3MultiSatsPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
Days	0 0 0

## 5.4.2 Win/Linux GMAT Comparison

Table 5.29: WinGMAT/LinuxGMAT EarthPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	0
Apoapsis	0
Days	0
EA180	0
EA45	1.421085472e-014
EA90	0
MA180	0
MA90	0
Periapsis	0
Secs	0
TA180	0
TA90	0

Table 5.30: WinGMAT/LinuxGMAT EarthAll StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	1.091393642e-011
Apoapsis	0
Days	0
EA180	0
EA45	4.691976585e-009
EA90	3.45775959e-008
MA180	0
MA90	1.808709271e-008
Periapsis	0
Secs	3.143213689e-007
TA180	0
TA90	5.133045988e-009

Table 5.31: WinGMAT/LinuxGMAT EarthPMhyper StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	0
Days	0
HA45	0
HA90	0
MA45	0
MA90	0
Periapsis	0
Secs	0
TA45	0
TA90	0

Table 5.32: WinGMAT/LinuxGMAT MoonPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	0
Apoapsis	0
Days	0
EA180	0
EA90	0
MA180	0
MA90	0
Periapsis	0
Secs	0
TA180	0
TA90	0

Table 5.33: WinGMAT/LinuxGMAT MarsPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	0
Apoapsis	0
Days	0
EA180	0
EA90	0
MA180	0
MA90	0
Periapsis	0
Secs	0
TA180	0
TA90	0

Table 5.34: WinGMAT/LinuxGMAT EarthMJ2000EqPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
XYplane	0
XZplane	0
YZplane	0

Table 5.35: WinGMAT/LinuxGMAT EarthMJ2000EqAll StopCond Test Case Comparison

Stopping Condition	Difference(s)
XYplane	4.666101248e-007
XZplane	8.586826219e-007
YZplane	9.998882629e-007

Table 5.36: WinGMAT/LinuxGMAT EarthMJ2000EqPMhyper StopCond Test Case Comparison

Stopping Condition	Difference(s)
XYplane	0
XZplane	0
YZplane	0



Table 5.37: WinGMAT/LinuxGMAT MoonMJ2000EqPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
XYplane	0
XZplane	0
YZplane	0

Table 5.38: WinGMAT/LinuxGMAT MarsMJ2000EqPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
XYplane	0
XZplane	0
YZplane	0

Table 5.39: WinGMAT/LinuxGMAT Earth3MultiSatsPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
Days	0 0 0



## Chapter 6

# Libration Points

The libration point tests are designed to verify the location of various libration points. In each software tool used the location of the libration point is defined by the tool and then converted to a MJ2000Eq representation for comparison purposes.

### 6.1 Initial Orbit Conditions

Table 6.1: Initial Orbit Parameters (Sun-Earth(SE) Libration Points)

Initial State Parameter	Parameter Value (unit)
Coordinate System (CS)	Sun-Earth L#* MJ2000Eq
X	0 (km)
Y	0 (km)
Z	0 (km)
VX	0 (km)
VY	0 (km)
VZ	0 (km)
Mass (No Fuel)	850 (kg)
Cd	2.2
Cr	1.8
Drag Area	15 ( $m^2$ )
Drag Model	None
NSG Model	None
SRP Area	1 ( $m^2$ )
SRP	Off
Integrator Type	N/A
Integrator Init. StepSize	N/A
Integrator Accuracy	N/A
Integrator Max. StepSize	N/A
Report Precision	16 significant figures
Report StepSize	Only initial state
Report CS/Cb	Earth MJ2000Eq

NOTES: (\*) All five libration points are defined in the test script.

Table 6.2: Initial Orbit Parameters (Sun-Earth-Moon(SEM) Libration Points)

Initial State Parameter	Parameter Value (unit)
Coordinate System (CS)	Sun-Earth-Moon L#* MJ2000Eq
X	0 (km)
Y	0 (km)
Z	0 (km)
VX	0 (km)
VY	0 (km)
VZ	0 (km)
Mass (No Fuel)	850 (kg)
Cd	2.2
Cr	1.8
Drag Area	15 ( $m^2$ )
Drag Model	None
NSG Model	None
SRP Area	1 ( $m^2$ )
SRP	Off
Integrator Type	N/A
Integrator Init. StepSize	N/A
Integrator Accuracy	N/A
Integrator Max. StepSize	N/A
Report Precision	16 significant figures
Report StepSize	Only initial state
Report CS/Cb	Earth MJ2000Eq

NOTES: (\*) All five libration points are defined in the test script.

## 6.2 Naming Convention

This section describes the naming convention for libration point scripts and output reports generated for use in GMAT's Acceptance Test Plan. The naming convention consists of an ordered series of option strings, separated by underscores (-). Currently, options are allowed for the following fields, and will be present in the file name in order:

1. *tool* - The tool used to generate the trajectory.
2. *libType* - The type of libration point used for the test case.
3. *libPoint* - The libration point used for the test case.

The word LibrationTest precedes the *tool* field. The final stopping condition file format is as followed:  
 LibrationTest\_*tool*\_*libType*\_*libPoint*.report

The *tool* field should always be the first option field. Future additional fields should be added to the end of the list of fields. Each field has a finite list of options, as follows (future options should be added to this list):

1. *tool*
  - STK - Satellite Toolkit HPOP or Astrogator
  - FF - FreeFlyer
  - GMAT - General Mission Analysis Tool
  - OD - Orbital Determination Toolbox
2. *libType*
  - SEML - Sun Earth Moon
  - SEL - Sun Earth
3. *libPoint* # - The libration Point number

## 6.3 Comparison Script Information

Comparison\_Tool1\_Tool2\_Libr.m is the script used to perform the comparisons needed for the Libration Points chapter of the Acceptance Test Plan. This script was designed to allow the user to select two tools from a list for comparison. The Tools available are presented in this chapter's Naming Convention section.

Refer to Appendix C for more details on this script and others used in the Acceptance Test Plan document.

## 6.4 Test Case Results

The following results are for the Libration Points section. The current GMAT Build is compared to STK for the Libration Points section. We'd like the comparison data to be as close to zero as possible. A detailed acceptance metric/matrix will be developed at a later date.

Table 6.3: WinGMAT/STK SEM LibrationTest Test Case Comparison

Libration Point	Position Difference(m)	Velocity Difference(m/s)
1	2.997694537e-006	1.082467449e-011
2	7.217749953e-006	-2.896988205e-011
3	8.940696716e-005	1.548983164e-009
4	-0.0006556510925	18.76805413
5	0.0005066394806	-1.37023761

Table 6.4: WinGMAT/STK SE LibrationTest Test Case Comparison

Libration Point	Position Difference(m)	Velocity Difference(m/s)
1	2.997694537e-006	1.082467449e-011
2	7.217749953e-006	-2.896988205e-011
3	8.940696716e-005	1.548983164e-009
4	-0.0006556510925	18.76805413
5	0.0005066394806	-1.37023761

### 6.4.1 Win/Mac GMAT Comparison

Table 6.5: WinGMAT/MacGMAT SEM LibrationTest Test Case Comparison

Libration Point	Position Difference(m)	Velocity Difference(m/s)
1	0	1.040834086e-014
2	0	8.743006319e-013
3	0	0
4	0	0
5	0	0

Table 6.6: WinGMAT/MacGMAT SE LibrationTest Test Case Comparison

Libration Point	Position Difference(m)	Velocity Difference(m/s)
1	0	1.040834086e-014
2	0	8.743006319e-013
3	0	0
4	0	0
5	0	0

**6.4.2 Win/Linux GMAT Comparison**

Table 6.7: WinGMAT/LinuxGMAT SEM LibrationTest Test Case Comparison

Libration Point	Position Difference(m)	Velocity Difference(m/s)
1	0	1.040834086e-014
2	0	0
3	0	0
4	0	0
5	0	0

Table 6.8: WinGMAT/LinuxGMAT SE LibrationTest Test Case Comparison

Libration Point	Position Difference(m)	Velocity Difference(m/s)
1	0	1.040834086e-014
2	0	0
3	0	0
4	0	0
5	0	0





## Chapter 7

### Delta V

Once an initial state was created for these Delta V test cases, a set amount of Delta V was applied. For the impulsive burn test cases delta V values of 0.1, 0.1, and 0.1 were applied in the X,Y, and Z axes respectively for either the Cartesian or VNB axes. Each test case generate a report that contains the Cartesian elements of the state before and after the impulsive burn.

#### 7.1 Initial Orbit Conditions

Initial conditions for the impulsive burn delta V test cases are presented in Tables 7.1- 7.4.

Table 7.1: Initial Orbit Parameters (Earth Impulsive Burns)

Initial State Parameter	Parameter Value (unit)
Start & Stop Time	01 Jan 2000 11:59:28.000 (UTCG)
Central Body	Earth
Coordinate System	Earth Mean J2000 Equator
X	7378.0 (km)
Y	0.0 (km)
Z	0.0 (km)
VX	0.0 (km)
VY	5.1973811193846027 (km)
VZ	5.1973811193846018 (km)
Mass (No Fuel)	850 (kg)
Cd	2.2
Cr	1.8
Drag	15 ( $m^2$ )
Drag Model	None
PMG Bodies	Only Central Body
NSG Model	None
SRP Area	1 ( $m^2$ )
SRP	Off
Integrator Type	RungaKutta 8(9)
Integrator Init.	60 (sec)
Integrator Max. StepSize	2700 (sec)
Integrator Accuracy	1e-13
Report Precision	16 significant figures
Report CS/Cb	Same as initial state CS

Table 7.2: Initial Orbit Parameters (Mars Impulsive Burns)

Initial State Parameter	Parameter Value (unit)
Start & Stop Time	01 Jan 2000 11:59:28.000 (UTCG)
Central Body	Mars
Coordinate System	Mars Mean J2000 Equator
X	4500.0 (km)
Y	0.0 (km)
Z	0.0 (km)
VX	0.0 (km)
VY	2.1814448386859766 (km)
VZ	2.1814448386859713 (km)
Mass (No Fuel)	850 (kg)
Cd	2.2
Cr	1.8
Drag	15 ( $m^2$ )
Drag Model	None
PMG Bodies	Only Central Body
NSG Model	None
SRP Area	1 ( $m^2$ )
SRP	Off
Integrator Type	RungaKutta 8(9)
Integrator Init.	60 (sec)
Integrator Max. StepSize	2700 (sec)
Integrator Accuracy	1e-13
Report Precision	16 significant figures
Report CS/Cb	Same as initial state CS

Table 7.3: Initial Orbit Parameters (Moon Impulsive Burns)

Initial State Parameter	Parameter Value (unit)
Start & Stop Time	01 Jan 2000 11:59:28.000 (UTCG)
Central Body	Moon
Coordinate System	Moon Mean J2000 Equator
X	2050.0 (km)
Y	0.0 (km)
Z	0.0 (km)
VX	0.0 (km)
VY	1.093528701 (km)
VZ	1.093528701 (km)
Mass (No Fuel)	850 (kg)
Cd	2.2
Cr	1.8
Drag	15 ( $m^2$ )
Drag Model	None
PMG Bodies	Only Central Body
NSG Model	None
SRP Area	1 ( $m^2$ )
SRP	Off
Integrator Type	RungaKutta 8(9)
Integrator Init.	60 (sec)
Integrator Max. StepSize	2700 (sec)
Integrator Accuracy	1e-13
Report Precision	16 significant figures
Report CS/Cb	Same as initial state CS

Table 7.4: Initial Orbit Parameters (Sun Impulsive Burns)

Initial State Parameter	Parameter Value (unit)
Start & Stop Time	01 Jan 2000 11:59:28.000 (UTCG)
Central Body	Sun
Coordinate System	Sun Mean J2000 Equator
X	1000000.0 (km)
Y	0.0 (km)
Z	0.0 (km)
VX	0.0 (km)
VY	257.597010870 (km)
VZ	257.597010870 (km)
Mass (No Fuel)	850 (kg)
Cd	2.2
Cr	1.8
Drag	15 ( $m^2$ )
Drag Model	None
PMG Bodies	Only Central Body
NSG Model	None
SRP Area	1 ( $m^2$ )
SRP	Off
Integrator Type	RungaKutta 8(9)
Integrator Init.	60 (sec)
Integrator Max. StepSize	2700 (sec)
Integrator Accuracy	1e-13
Report Precision	16 significant figures
Report CS/Cb	Same as initial state CS

## 7.2 Naming Convention

This section describes the naming convention for Delta V scripts and output reports generated for use in GMAT's Acceptance Test Plan. The naming convention consists of an ordered series of option strings, separated by underscores (`_`). Currently, options are allowed for the following fields, and will be present in the file name in order:

1. *tool* - The tool used to generate the trajectory.
2. *deltaVbody* - The type of Delta V applied and the central body the test case uses.
3. *axes* - Axes type used for burn maneuver.

The word DeltaV precedes the *tool* field. The final stopping condition file format is as followed:

DeltaV\_*tool\_deltaVbody\_axes*.report

The *tool* field should always be the first option field. Future additional fields should be added to the end of the list of fields. Each field has a finite list of options, as follows (future options should be added to this list):

1. *tool*
  - STK - Satellite Toolkit HPOP or Astrogator
  - FF - FreeFlyer
  - GMAT - General Mission Analysis Tool
  - OD - Orbital Determination Toolbox
2. *deltaVbody*
  - IEarth - Earth centered impulsive burn
  - IMars - Mars centered impulsive burn
  - IMoon - Moon centered impulsive burn
  - ISun - Sun centered impulsive burn
3. *axes*
  - VNB - Velocity, Velocity Normal, Velocity BiNormal axes
  - Cartesian - Typical X,Y,Z,Vx,Vy,Vz axes

## 7.3 Comparison Script Information

Comparison\_DeltaV.m is the script used to perform the comparisons needed for the Delta V chapter of the Acceptance Test Plan. This script was designed to allow the user to select a GMAT Build and/or the exact solution to compare to one another.

Refer to Appendix C for more details on this script and others used in the Acceptance Test Plan document.

## 7.4 Test Case Results

The following results are for the Delta V section. The GMAT Delta V results are being compared to the exact desired Delta V values. We'd like the comparison data to be as close to zero as possible. A detailed acceptance metric/matrix will be developed at a later date.

Table 7.5: Exact/WinGMAT IEarth Test Case Comparison

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
Cartesian	0	0	0	0	8.881784197e-013	8.881784197e-013
VNB	0	0	0	0	2.664535259e-012	8.881784197e-013

Table 7.6: Exact/WinGMAT IMars Test Case Comparison

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
Cartesian	0	0	0	1.387778781e-012	8.881784197e-013	0
VNB	0	0	0	1.387778781e-012	3.108624469e-012	8.881784197e-013

Table 7.7: Exact/WinGMAT IMoon Test Case Comparison

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
Cartesian	0	0	0	2.775557562e-014	0	0
VNB	0	0	0	2.775557562e-014	0	0

Table 7.8: Exact/WinGMAT ISun Test Case Comparison

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
Cartesian	0	0	0	1.387778781e-012	0	0
VNB	0	0	0	0	0	0

**7.4.1 Win/Mac GMAT Comparison**

Table 7.9: WinGMAT/MacGMAT IEarth Test Case Comparison

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
Cartesian	0	0	0	0	0	0
VNB	0	0	0	0	0	0

Table 7.10: WinGMAT/MacGMAT IMars Test Case Comparison

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
Cartesian	0	0	0	0	0	0
VNB	0	0	0	0	0	0

Table 7.11: WinGMAT/MacGMAT IMoon Test Case Comparison

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
Cartesian	0	0	0	0	0	0
VNB	0	0	0	0	0	0

Table 7.12: WinGMAT/MacGMAT ISun Test Case Comparison

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
Cartesian	0	0	0	0	0	0
VNB	0	0	0	0	0	0

**7.4.2 Win/Linux GMAT Comparison**

Table 7.13: WinGMAT/LinuxGMAT IEarth Test Case Comparison

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
Cartesian	0	0	0	0	0	0
VNB	0	0	0	0	0	0

Table 7.14: WinGMAT/LinuxGMAT IMars Test Case Comparison

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
Cartesian	0	0	0	0	0	0
VNB	0	0	0	0	0	0

Table 7.15: WinGMAT/LinuxGMAT IMoon Test Case Comparison

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
Cartesian	0	0	0	0	0	0
VNB	0	0	0	0	0	0

Table 7.16: WinGMAT/LinuxGMAT ISun Test Case Comparison

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
Cartesian	0	0	0	0	0	0
VNB	0	0	0	0	0	0





## Chapter 8

# Performance

One of the many goals of GMAT is to perform at satisfactory speed when running a script. By running similar scripts in GMAT and reference software, time performance comparisons could be made. We generated several test cases centered around the Earth and a minimal set of test cases about a few non-Earth bodies. Many of the test cases were extracted from the previous Chapters and used in these tests.

The performance tests cases were created from the propagator test cases with some slight variations. We were interested in test cases focused on only point mass bodies, non-spherical gravity present, solar radiation pressure turned on, or drag effects. Isolation of the mentioned perturbation forces allows us to see how long each process take for GMAT to complete. The deepspace, non-earth, and libration point test cases only focused on point mass bodies.

Propagation duration times for the GEO, GPS, LEO, Molniya, and SunSync cases were increased to obtain a more accurate measurement of the time between GMAT and the reference software packages. This could have been done for the other test cases but the amount time needed to modify the automation scripts was not worth the extra data. The reason extra code would have been needed was to account for the differences in propagation modules for STK. STK-HPOP is used for the GEO, GPS, LEO, Molniya, and Sunsync test cases and STK-Astrogator is used for the others.

### 8.1 Test Machine Specifications

All tests presented in this Acceptance Test Plan document were performed on a desktop machine with the following specifications:

Computer Type - PC  
OS - Microsoft Windows XP  
RAM - 2.0 GB  
Processor - Intel(R) Pentium(R) 4 CPU 3.40GHz  
Architecture - 32-bit  
Manufacturer - Dell  
STK Version - STK 6.2.0  
FF Version - FF 5.6.5.35

## 8.2 Initial Orbit Conditions

All of the initial orbit parameters for the test cases in this section were obtained from the Propagation section (Chapter 2) test cases. One of the differences is the propagation duration is extended to 30 days, excluding the DeepSpace, ESL2, and EML2 cases. Another difference is the use of NSG, PMG, Drag, and SRP. Refer to the Performance naming conventions section (Section 8.3) for the types of settings used.

Refer to Appendix B.1 Tables B.1- B.13 for a listing of all Propagator initial orbit states used for the Performance test cases.

## 8.3 Naming Convention

This section describes the naming convention for Performance scripts and output reports generated for use in GMAT's Acceptance Test Plan. The naming convention consists of an ordered series of option strings, separated by underscores (`_`). Currently, options are allowed for the following fields, and will be present in the file name in order:

1. *tool* - Tool used to generate the trajectory.
2. *traj* - Type of trajectory.
3. *forces* - Forces applied.
4. *output* - Flag noting if there is output.

The word Performance precedes the *tool* field. The final stopping condition file format is as followed:

Performance.*tool*\_*traj*\_*forces*\_*output*.report or  
Performance.*tool*\_*traj*PM\_*forces*\_*output*.report

The *tool* field should always be the first option field. Future additional fields should be added to the end of the list of fields. Each field has a finite list of options, as follows (future options should be added to this list):

- |                |           |  |
|----------------|-----------|--|
|                | STK       | - Satellite Toolkit HPOP or Astrogator |
|                | FF        | - FreeFlyer                            |
| 1. <i>tool</i> | GMAT      | - General Mission Analysis Tool        |
|                | OD        | - Orbital Determination Toolbox        |
|                | Deepspace | - deep space orbit                     |
|                | EML2      | - Earth Moon L2 orbit                  |
|                | GEO       | - GEO orbit                            |
|                | GPS       | - MEO orbit                            |
| 2. <i>traj</i> | ISS       | - LEO orbit                            |
|                | Mars1     | - eccentric low orbit                  |
|                | Molniya   | - HEO orbit                            |
|                | Moon      | - eccentric low orbit                  |
|                | SunSync   | - LEO orbit                            |

NOTE: Some test cases contain *traj* variations. In this case *traj* precedes the modification. For example, an ISS trajectory is used and the point mass code is used in GMAT instead of JGM2 0x0. In this case the *traj* is ISSPM.

- |                  |            |  |
|------------------|------------|--|
|                  | AllPlanets | - Sun, Mercury, Venus, Earth, Moon, Mars, Mercury, Jupiter, and Pluto point mass gravity included. |
| 3. <i>forces</i> | 1PM        | - Central body is the only point mass included.  |
|                  | Drag       | - JR is used for Earth cases.  |
|                  | NSG        | - JGM2 20x20 is used.  |
|                  | SRP        | - SRP is turned on   |

## 8.4 Comparison Script Information

TimeComparo.m is the script used to perform the comparison data needed for the Performance chapter of the Acceptance Test Plan. This script was designed to allow the user to select from a list of dates and then generates output that includes all available performance results from GMAT, STK, and FF. The dates represent the times when all of the performance test cases were run from the BuildRun.Script\_GMAT.m script.

STK\_Repropagate.m is the script that generates the performance times for STK. The data generated is then exported into an excel document for use with the TimeComparo.m script.

Refer to Appendix C for more details of this script and others used in the Acceptance Test Plan document.

## 8.5 Test Results

We strive to make GMAT perform just as good or better than the reference software packages. For the test cases with performance numbers that are not nearly equivalent or better, work is being done to improve GMAT's performance without affecting its numerical accuracy.

The main performance output parameters of interest are the time taken to run the script, the amount of integration step taken during that run, and the time per integration step. The results in this section are outputted in seconds. Tables 8.1- 8.6 contain these performance parameters by tool.

Tables 8.7- 8.12 contain a percentage difference between GMAT and the other reference software used. The data indicates GMAT's performance data was divided into the reference softwares same performance data to obtain a percentage. A value of 100% indicates both tools were the same, greater than 100% indicates GMAT performed worse, and less than 100% indicates GMAT performed better.

Table 8.1: Performance Test Case Comparisons

Test Case	GMAT TimeToRun(sec)	STK TimeToRun(sec)	FF TimeToRun(sec)
DeepSpacePM-AllPlanets-noOutput.m	NaN	NaN	NaN
DeepSpacePM-AllPlanets-output.m	NaN	NaN	NaN
DeepSpace-AllPlanets-noOutput.m	NaN	NaN	NaN
DeepSpace-AllPlanets-output.m	NaN	NaN	NaN
EML2PM-AllPlanets-noOutput.m	NaN	NaN	NaN
EML2PM-AllPlanets-output.m	NaN	NaN	NaN
EML2-AllPlanets-noOutput.m	NaN	NaN	NaN
EML2-AllPlanets-output.m	NaN	NaN	NaN
GEOPM-1PM-noOutput.m	2.365369677	0.9100139264	NaN
GEOPM-1PM-output.m	3.624228889	2.025697121	NaN
GEOPM-AllPlanets-noOutput.m	9.262963421	4.056012761	NaN
GEOPM-AllPlanets-output.m	10.63963856	5.203490891	NaN
GEOPM-SRP-noOutput.m	3.221224485	1.527696956	NaN
GEOPM-SRP-output.m	4.613150554	2.711619773	NaN
GEO-1PM-noOutput.m	5.080978504	0.9100139264	NaN
GEO-1PM-output.m	9.065021783	2.025697121	NaN
GEO-AllPlanets-noOutput.m	12.82652415	4.056012761	NaN
GEO-AllPlanets-output.m	14.62352863	5.203490891	NaN
GEO-Drag-noOutput.m	9.083949943	1.076942908	NaN
GEO-Drag-output.m	9.863043934	2.161930469	NaN
GEO-NSG-noOutput.m	9.079661186	3.27783425	NaN
GEO-NSG-output.m	9.063319947	4.456671393	NaN
GEO-SRP-noOutput.m	9.086620394	1.527696956	NaN
GEO-SRP-output.m	9.037045099	2.711619773	NaN
GPSPM-1PM-noOutput.m	2.324964709	0.9494172025	NaN
GPSPM-1PM-output.m	3.695722836	2.657454174	NaN
GPSPM-AllPlanets-noOutput.m	9.27329574	4.106867269	NaN
GPSPM-AllPlanets-output.m	10.67132599	5.382557951	NaN
GPSPM-SRP-noOutput.m	4.068783658	1.55785984	NaN
GPSPM-SRP-output.m	5.080100348	2.793106498	NaN
GPS-1PM-noOutput.m	5.085208763	0.9494172025	NaN
GPS-1PM-output.m	9.064168882	2.657454174	NaN
GPS-AllPlanets-noOutput.m	12.82362876	4.106867269	NaN
GPS-AllPlanets-output.m	14.21737953	5.382557951	NaN
GPS-Drag-noOutput.m	9.078539423	1.11248804	NaN
GPS-Drag-output.m	9.829883966	2.366961555	NaN
GPS-NSG-noOutput.m	6.989305121	3.277017722	NaN
GPS-NSG-output.m	9.049662625	4.556902511	NaN
GPS-SRP-noOutput.m	9.063283294	1.55785984	NaN
GPS-SRP-output.m	10.14604839	2.793106498	NaN
ISSPM-1PM-noOutput.m	3.371743671	3.532383306	NaN
ISSPM-1PM-output.m	9.505570289	8.654091176	NaN
ISSPM-AllPlanets-noOutput.m	34.23165034	17.8158481	NaN
ISSPM-AllPlanets-output.m	40.2429021	23.11573611	NaN
ISSPM-SRP-noOutput.m	14.61508594	6.507057014	NaN

Table 8.2: Performance Test Case Comparisons

Test Case	GMAT TimeToRun(sec)	STK TimeToRun(sec)	FF TimeToRun(sec)
ISSPM-SRP-output.m	25.07031637	11.69117678	NaN
ISS-1PM-noOutput.m	9.069769649	3.532383306	NaN
ISS-1PM-output.m	14.29912081	8.654091176	NaN
ISS-AllPlanets-noOutput.m	39.95640016	17.8158481	NaN
ISS-AllPlanets-output.m	46.03288368	23.11573611	NaN
ISS-Drag-noOutput.m	25.20274035	6.702129963	NaN
ISS-Drag-output.m	31.62018206	11.94099205	NaN
ISS-NSG-noOutput.m	18.25562254	14.51133002	NaN
ISS-NSG-output.m	26.18732275	19.74322161	NaN
ISS-SRP-noOutput.m	27.42110369	6.507057014	NaN
ISS-SRP-output.m	37.81563076	11.69117678	NaN
Mars1PM-1PM-noOutput.m	NaN	NaN	NaN
Mars1PM-1PM-output.m	NaN	NaN	NaN
Mars1PM-AllPlanets-noOutput.m	NaN	NaN	NaN
Mars1PM-AllPlanets-output.m	NaN	NaN	NaN
Mars1-1PM-noOutput.m	NaN	NaN	NaN
Mars1-1PM-output.m	NaN	NaN	NaN
Mars1-AllPlanets-noOutput.m	NaN	NaN	NaN
Mars1-AllPlanets-output.m	NaN	NaN	NaN
MolniyaPM-1PM-noOutput.m	2.520149293	1.138387756	NaN
MolniyaPM-1PM-output.m	4.727116994	2.810948095	NaN
MolniyaPM-AllPlanets-noOutput.m	13.49447664	5.357828495	NaN
MolniyaPM-AllPlanets-output.m	15.48603786	7.016379791	NaN
MolniyaPM-SRP-noOutput.m	4.93236051	2.014259857	NaN
MolniyaPM-SRP-output.m	9.064659894	3.669778142	NaN
Molniya-1PM-noOutput.m	5.931093645	1.138387756	NaN
Molniya-1PM-output.m	9.067935171	2.810948095	NaN
Molniya-AllPlanets-noOutput.m	17.02801742	5.357828495	NaN
Molniya-AllPlanets-output.m	18.94455575	7.016379791	NaN
Molniya-Drag-noOutput.m	11.14562516	1.48759834	NaN
Molniya-Drag-output.m	12.81850503	3.148300748	NaN
Molniya-NSG-noOutput.m	9.06083695	4.249729672	NaN
Molniya-NSG-output.m	9.881694573	5.892727931	NaN
Molniya-SRP-noOutput.m	9.723377636	2.014259857	NaN
Molniya-SRP-output.m	11.63239417	3.669778142	NaN
MoonPM-1PM-noOutput.m	NaN	NaN	NaN
MoonPM-1PM-output.m	NaN	NaN	NaN
Moon-1PM-noOutput.m	NaN	NaN	NaN
Moon-1PM-output.m	NaN	NaN	NaN
SunSyncPM-1PM-noOutput.m	3.357036607	3.408378327	NaN
SunSyncPM-1PM-output.m	9.442151447	8.631484337	NaN
SunSyncPM-AllPlanets-noOutput.m	33.3628759	17.53388808	NaN
SunSyncPM-AllPlanets-output.m	39.61642969	22.77039115	NaN
SunSyncPM-SRP-noOutput.m	14.48378093	6.372961703	NaN
SunSyncPM-SRP-output.m	25.21344992	11.62540558	NaN

Table 8.3: Performance Test Case Comparisons

Test Case	GMAT TimeToRun(sec)	STK TimeToRun(sec)	FF TimeToRun(sec)
SunSync-1PM-noOutput.m	9.077130362	3.408378327	NaN
SunSync-1PM-output.m	14.25260635	8.631484337	NaN
SunSync-AllPlanets-noOutput.m	39.61202214	17.53388808	NaN
SunSync-AllPlanets-output.m	45.78612287	22.77039115	NaN
SunSync-Drag-noOutput.m	24.86261533	6.570531171	NaN
SunSync-Drag-output.m	31.29207997	11.86876567	NaN
SunSync-NSG-noOutput.m	18.61135222	14.13227078	NaN
SunSync-NSG-output.m	27.37641393	19.3581896	NaN
SunSync-SRP-noOutput.m	26.72110975	6.372961703	NaN
SunSync-SRP-output.m	37.03988272	11.62540558	NaN

Table 8.4: Performance Test Case Comparisons

Test Case	GMAT 10000xTime/Step	STK 10000xTime/Step	FF 10000xTime/Step
DeepSpacePM-AllPlanets-noOutput.m	NaN	NaN	NaN
DeepSpacePM-AllPlanets-output.m	NaN	NaN	NaN
DeepSpace-AllPlanets-noOutput.m	NaN	NaN	NaN
DeepSpace-AllPlanets-output.m	NaN	NaN	NaN
EML2PM-AllPlanets-noOutput.m	NaN	NaN	NaN
EML2PM-AllPlanets-output.m	NaN	NaN	NaN
EML2-AllPlanets-noOutput.m	NaN	NaN	NaN
EML2-AllPlanets-output.m	NaN	NaN	NaN
GEOPM-1PM-noOutput.m	2.736746126	1.052891272	NaN
GEOPM-1PM-output.m	4.193253372	2.343743053	NaN
GEOPM-AllPlanets-noOutput.m	10.71730119	4.69282976	NaN
GEOPM-AllPlanets-output.m	12.31012213	6.020468461	NaN
GEOPM-SRP-noOutput.m	3.726974992	1.767554039	NaN
GEOPM-SRP-output.m	5.337441344	3.13735945	NaN
GEO-1PM-noOutput.m	5.878720935	1.052891272	NaN
GEO-1PM-output.m	10.4882816	2.343743053	NaN
GEO-AllPlanets-noOutput.m	14.84036116	4.69282976	NaN
GEO-AllPlanets-output.m	16.91950553	6.020468461	NaN
GEO-Drag-noOutput.m	10.51018158	1.24602905	NaN
GEO-Drag-output.m	11.41159775	2.501365809	NaN
GEO-NSG-noOutput.m	10.50521947	3.79247281	NaN
GEO-NSG-output.m	10.48631256	5.156394068	NaN
GEO-SRP-noOutput.m	10.51327131	1.767554039	NaN
GEO-SRP-output.m	10.45591241	3.13735945	NaN
GPSPM-1PM-noOutput.m	2.68999735	1.098481086	NaN
GPSPM-1PM-output.m	4.275972274	3.074689545	NaN
GPSPM-AllPlanets-noOutput.m	10.72925574	4.751668714	NaN
GPSPM-AllPlanets-output.m	12.34678467	6.227650065	NaN
GPSPM-SRP-noOutput.m	3.450168454	1.801410545	NaN
GPSPM-SRP-output.m	4.307725217	3.229771621	NaN
GPS-1PM-noOutput.m	5.883615368	1.098481086	NaN
GPS-1PM-output.m	10.48729478	3.074689545	NaN
GPS-AllPlanets-noOutput.m	14.83701117	4.751668714	NaN
GPS-AllPlanets-output.m	16.44958872	6.227650065	NaN
GPS-Drag-noOutput.m	10.50392158	1.287154969	NaN
GPS-Drag-output.m	11.37323148	2.738587938	NaN
GPS-NSG-noOutput.m	8.085730126	3.791528082	NaN
GPS-NSG-output.m	10.46929966	5.27236204	NaN
GPS-SRP-noOutput.m	7.738459097	1.801410545	NaN
GPS-SRP-output.m	8.662951156	3.229771621	NaN
ISSPM-1PM-noOutput.m	0.8663044812	0.9223173727	NaN
ISSPM-1PM-output.m	2.442272883	2.25961283	NaN
ISSPM-AllPlanets-noOutput.m	8.795162081	4.651536018	NaN
ISSPM-AllPlanets-output.m	10.33963724	6.035282657	NaN
ISSPM-SRP-noOutput.m	2.173053102	1.699636154	NaN



Table 8.5: Performance Test Case Comparisons

Test Case	GMAT 10000xTime/Step	STK 10000xTime/Step	FF 10000xTime/Step
ISSPM-SRP-output.m	3.727595511	3.05372255	NaN
ISS-1PM-noOutput.m	2.330302317	0.9223173727	NaN
ISS-1PM-output.m	3.673883202	2.25961283	NaN
ISS-AllPlanets-noOutput.m	10.26602609	4.651536018	NaN
ISS-AllPlanets-output.m	11.82726129	6.035282657	NaN
ISS-Drag-noOutput.m	6.416339609	1.741039086	NaN
ISS-Drag-output.m	8.05014946	3.101959229	NaN
ISS-NSG-noOutput.m	3.455671717	3.778008335	NaN
ISS-NSG-output.m	4.957091456	5.140125387	NaN
ISS-SRP-noOutput.m	4.07785136	1.699636154	NaN
ISS-SRP-output.m	5.623643858	3.05372255	NaN
Mars1PM-1PM-noOutput.m	NaN	NaN	NaN
Mars1PM-1PM-output.m	NaN	NaN	NaN
Mars1PM-AllPlanets-noOutput.m	NaN	NaN	NaN
Mars1PM-AllPlanets-output.m	NaN	NaN	NaN
Mars1-1PM-noOutput.m	NaN	NaN	NaN
Mars1-1PM-output.m	NaN	NaN	NaN
Mars1-AllPlanets-noOutput.m	NaN	NaN	NaN
Mars1-AllPlanets-output.m	NaN	NaN	NaN
MolniyaPM-1PM-noOutput.m	1.809412186	0.9989362548	NaN
MolniyaPM-1PM-output.m	3.393966825	2.46660942	NaN
MolniyaPM-AllPlanets-noOutput.m	9.698488317	4.708523152	NaN
MolniyaPM-AllPlanets-output.m	11.12982454	6.166077679	NaN
MolniyaPM-SRP-noOutput.m	2.835504748	1.767514792	NaN
MolniyaPM-SRP-output.m	5.211072086	3.22023354	NaN
Molniya-1PM-noOutput.m	4.258395782	0.9989362548	NaN
Molniya-1PM-output.m	6.510579531	2.46660942	NaN
Molniya-AllPlanets-noOutput.m	12.23804615	4.708523152	NaN
Molniya-AllPlanets-output.m	13.61546338	6.166077679	NaN
Molniya-Drag-noOutput.m	7.904138115	1.305483405	NaN
Molniya-Drag-output.m	9.090493606	2.762879112	NaN
Molniya-NSG-noOutput.m	6.50081572	3.759824535	NaN
Molniya-NSG-output.m	7.089750734	5.213419385	NaN
Molniya-SRP-noOutput.m	5.574052761	1.767514792	NaN
Molniya-SRP-output.m	6.668421333	3.22023354	NaN
MoonPM-1PM-noOutput.m	NaN	NaN	NaN
MoonPM-1PM-output.m	NaN	NaN	NaN
Moon-1PM-noOutput.m	NaN	NaN	NaN
Moon-1PM-output.m	NaN	NaN	NaN
SunSyncPM-1PM-noOutput.m	0.8684386917	0.8905438109	NaN
SunSyncPM-1PM-output.m	2.442609542	2.25524112	NaN
SunSyncPM-AllPlanets-noOutput.m	8.630934134	4.581268277	NaN
SunSyncPM-AllPlanets-output.m	10.24872065	5.949465982	NaN
SunSyncPM-SRP-noOutput.m	2.172100138	1.665132522	NaN
SunSyncPM-SRP-output.m	3.781204529	3.037495251	NaN

Table 8.6: Performance Test Case Comparisons

Test Case	GMAT 10000xTime/Step	STK 10000xTime/Step	FF 10000xTime/Step
SunSync-1PM-noOutput.m	2.348181488	0.8905438109	NaN
SunSync-1PM-output.m	3.687035997	2.25524112	NaN
SunSync-AllPlanets-noOutput.m	10.24758043	4.581268277	NaN
SunSync-AllPlanets-output.m	11.84481254	5.949465982	NaN
SunSync-Drag-noOutput.m	6.382393873	1.712145917	NaN
SunSync-Drag-output.m	8.032878955	3.092757366	NaN
SunSync-NSG-noOutput.m	3.417686247	3.701970079	NaN
SunSync-NSG-output.m	5.027253917	5.070907558	NaN
SunSync-SRP-noOutput.m	4.003942303	1.665132522	NaN
SunSync-SRP-output.m	5.550127024	3.037495251	NaN

Table 8.7: GMAT/STK Performance Test Case Comparisons

Test Case	% Time to Run	% Int. Steps	% Time Per Step
DeepSpacePM-AllPlanets-noOutput.m	NaN	NaN	NaN
DeepSpacePM-AllPlanets-output.m	NaN	NaN	NaN
DeepSpace-AllPlanets-noOutput.m	NaN	NaN	NaN
DeepSpace-AllPlanets-output.m	NaN	NaN	NaN
EML2PM-AllPlanets-noOutput.m	NaN	NaN	NaN
EML2PM-AllPlanets-output.m	NaN	NaN	NaN
EML2-AllPlanets-noOutput.m	NaN	NaN	NaN
EML2-AllPlanets-output.m	NaN	NaN	NaN
GEOPM-1PM-noOutput.m	259.9267559	100	259.9267559
GEOPM-1PM-output.m	178.9126742	100	178.9126742
GEOPM-AllPlanets-noOutput.m	228.3760917	100	228.3760917
GEOPM-AllPlanets-output.m	204.4711672	100	204.4711672
GEOPM-SRP-noOutput.m	210.8549391	100	210.8549391
GEOPM-SRP-output.m	170.1252735	100	170.1252735
GEO-1PM-noOutput.m	558.3407415	100	558.3407415
GEO-1PM-output.m	447.5013412	100	447.5013412
GEO-AllPlanets-noOutput.m	316.2348076	100	316.2348076
GEO-AllPlanets-output.m	281.0330399	100	281.0330399
GEO-Drag-noOutput.m	843.4941054	100	843.4941054
GEO-Drag-output.m	456.2146691	100	456.2146691
GEO-NSG-noOutput.m	277.0018401	100	277.0018401
GEO-NSG-output.m	203.3652282	100	203.3652282
GEO-SRP-noOutput.m	594.7920731	100	594.7920731
GEO-SRP-output.m	333.271102	100	333.271102
GPSPM-1PM-noOutput.m	244.8833561	100	244.8833561
GPSPM-1PM-output.m	139.0700496	100	139.0700496
GPSPM-AllPlanets-noOutput.m	225.799743	100	225.799743
GPSPM-AllPlanets-output.m	198.2575216	100	198.2575216
GPSPM-SRP-noOutput.m	261.1777744	136.36679	191.5259386
GPSPM-SRP-output.m	181.8799373	136.36679	133.3755362
GPS-1PM-noOutput.m	535.6137164	100	535.6137164
GPS-1PM-output.m	341.0846731	100	341.0846731
GPS-AllPlanets-noOutput.m	312.2484345	100	312.2484345
GPS-AllPlanets-output.m	264.1379741	100	264.1379741
GPS-Drag-noOutput.m	816.0572608	100	816.0572608
GPS-Drag-output.m	415.2954637	100	415.2954637
GPS-NSG-noOutput.m	213.2824939	100.0115701	213.2578198
GPS-NSG-output.m	198.5924123	100.0115701	198.5694377
GPS-SRP-noOutput.m	581.777838	135.4301573	429.5777615
GPS-SRP-output.m	363.2531878	135.4301573	268.2217869
ISSPM-1PM-noOutput.m	95.45237251	101.6240633	93.92693956
ISSPM-1PM-output.m	109.8390356	101.6240633	108.0836881
ISSPM-AllPlanets-noOutput.m	192.1415705	101.6187567	189.0808122
ISSPM-AllPlanets-output.m	174.0931023	101.6187567	171.3198507
ISSPM-SRP-noOutput.m	224.6036251	175.6719342	127.8540173

Table 8.8: GMAT/STK Performance Test Case Comparisons

Test Case	% Time to Run	% Int. Steps	% Time Per Step
ISSPM-SRP-output.m	214.4379204	175.6719342	122.0672621
ISS-1PM-noOutput.m	256.7606306	101.6240633	252.6573158
ISS-1PM-output.m	165.2296067	101.6240633	162.5890575
ISS-AllPlanets-noOutput.m	224.274477	101.6187567	220.701851
ISS-AllPlanets-output.m	199.1408946	101.6187567	195.9686391
ISS-Drag-noOutput.m	376.0407585	102.0366281	368.5350696
ISS-Drag-output.m	264.8036438	102.0366281	259.5182227
ISS-NSG-noOutput.m	125.8025455	137.5370997	91.4680808
ISS-NSG-output.m	132.6395624	137.5370997	96.43911546
ISS-SRP-noOutput.m	421.4056159	175.6405903	239.9249599
ISS-SRP-output.m	323.4544431	175.6405903	184.1570007
Mars1PM-1PM-noOutput.m	NaN	NaN	NaN
Mars1PM-1PM-output.m	NaN	NaN	NaN
Mars1PM-AllPlanets-noOutput.m	NaN	NaN	NaN
Mars1PM-AllPlanets-output.m	NaN	NaN	NaN
Mars1-1PM-noOutput.m	NaN	NaN	NaN
Mars1-1PM-output.m	NaN	NaN	NaN
Mars1-AllPlanets-noOutput.m	NaN	NaN	NaN
Mars1-AllPlanets-output.m	NaN	NaN	NaN
MolniyaPM-1PM-noOutput.m	221.3788122	122.2183222	181.1338989
MolniyaPM-1PM-output.m	168.1680641	122.2183222	137.596443
MolniyaPM-AllPlanets-noOutput.m	251.8646623	122.2778803	205.9772885
MolniyaPM-AllPlanets-output.m	220.7126513	122.2778803	180.5008811
MolniyaPM-SRP-noOutput.m	244.8721049	152.6412776	160.4232542
MolniyaPM-SRP-output.m	247.0083897	152.6412776	161.8228002
Molniya-1PM-noOutput.m	521.0082077	122.2183222	426.2930453
Molniya-1PM-output.m	322.593476	122.2183222	263.9485391
Molniya-AllPlanets-noOutput.m	317.8156492	122.2778803	259.9126256
Molniya-AllPlanets-output.m	270.0047077	122.2778803	220.8123882
Molniya-Drag-noOutput.m	749.2361921	123.7472576	605.4568051
Molniya-Drag-output.m	407.1563062	123.7472576	329.0224884
Molniya-NSG-noOutput.m	213.2097251	123.3123949	172.9021038
Molniya-NSG-output.m	167.6930394	123.3123949	135.9904165
Molniya-SRP-noOutput.m	482.7270723	153.0712531	315.3610247
Molniya-SRP-output.m	316.9781312	153.0712531	207.0788112
MoonPM-1PM-noOutput.m	NaN	NaN	NaN
MoonPM-1PM-output.m	NaN	NaN	NaN
Moon-1PM-noOutput.m	NaN	NaN	NaN
Moon-1PM-output.m	NaN	NaN	NaN
SunSyncPM-1PM-noOutput.m	98.49366133	101.0007055	97.51779543
SunSyncPM-1PM-output.m	109.391978	101.0007055	108.3081326
SunSyncPM-AllPlanets-noOutput.m	190.2765419	100.9980927	188.3961735
SunSyncPM-AllPlanets-output.m	173.9822097	100.9980927	172.2628667
SunSyncPM-SRP-noOutput.m	227.269229	174.2246492	130.4460821
SunSyncPM-SRP-output.m	216.8823252	174.2246492	124.4842943

Table 8.9: GMAT/STK Performance Test Case Comparisons

Test Case	% Time to Run	% Int. Steps	% Time Per Step
SunSync-1PM-noOutput.m	266.3181575	101.0007055	263.6795023
SunSync-1PM-output.m	165.1234689	101.0007055	163.4874411
SunSync-AllPlanets-noOutput.m	225.9169328	100.9980927	223.6843557
SunSync-AllPlanets-output.m	201.0774543	100.9980927	199.0903482
SunSync-Drag-noOutput.m	378.3958205	101.5087555	372.7716084
SunSync-Drag-output.m	263.6506681	101.5087555	259.7319481
SunSync-NSG-noOutput.m	131.6939968	142.6483301	92.32074203
SunSync-NSG-output.m	141.4203213	142.6483301	99.13913554
SunSync-SRP-noOutput.m	419.2887231	174.3709665	240.4578764
SunSync-SRP-output.m	318.6115313	174.3709665	182.7205169

Table 8.10: GMAT/FF Performance Test Case Comparisons

Test Case	% Time to Run	% Int. Steps	% Time Per Step
DeepSpacePM-AllPlanets-noOutput.m	NaN	NaN	NaN
DeepSpacePM-AllPlanets-output.m	NaN	NaN	NaN
DeepSpace-AllPlanets-noOutput.m	NaN	NaN	NaN
DeepSpace-AllPlanets-output.m	NaN	NaN	NaN
EML2PM-AllPlanets-noOutput.m	NaN	NaN	NaN
EML2PM-AllPlanets-output.m	NaN	NaN	NaN
EML2-AllPlanets-noOutput.m	NaN	NaN	NaN
EML2-AllPlanets-output.m	NaN	NaN	NaN
GEOPM-1PM-noOutput.m	NaN	NaN	NaN
GEOPM-1PM-output.m	NaN	NaN	NaN
GEOPM-AllPlanets-noOutput.m	NaN	NaN	NaN
GEOPM-AllPlanets-output.m	NaN	NaN	NaN
GEOPM-SRP-noOutput.m	NaN	NaN	NaN
GEOPM-SRP-output.m	NaN	NaN	NaN
GEO-1PM-noOutput.m	NaN	NaN	NaN
GEO-1PM-output.m	NaN	NaN	NaN
GEO-AllPlanets-noOutput.m	NaN	NaN	NaN
GEO-AllPlanets-output.m	NaN	NaN	NaN
GEO-Drag-noOutput.m	NaN	NaN	NaN
GEO-Drag-output.m	NaN	NaN	NaN
GEO-NSG-noOutput.m	NaN	NaN	NaN
GEO-NSG-output.m	NaN	NaN	NaN
GEO-SRP-noOutput.m	NaN	NaN	NaN
GEO-SRP-output.m	NaN	NaN	NaN
GPSPM-1PM-noOutput.m	NaN	NaN	NaN
GPSPM-1PM-output.m	NaN	NaN	NaN
GPSPM-AllPlanets-noOutput.m	NaN	NaN	NaN
GPSPM-AllPlanets-output.m	NaN	NaN	NaN
GPSPM-SRP-noOutput.m	NaN	NaN	NaN
GPSPM-SRP-output.m	NaN	NaN	NaN
GPS-1PM-noOutput.m	NaN	NaN	NaN
GPS-1PM-output.m	NaN	NaN	NaN
GPS-AllPlanets-noOutput.m	NaN	NaN	NaN
GPS-AllPlanets-output.m	NaN	NaN	NaN
GPS-Drag-noOutput.m	NaN	NaN	NaN
GPS-Drag-output.m	NaN	NaN	NaN
GPS-NSG-noOutput.m	NaN	NaN	NaN
GPS-NSG-output.m	NaN	NaN	NaN
GPS-SRP-noOutput.m	NaN	NaN	NaN
GPS-SRP-output.m	NaN	NaN	NaN
ISSPM-1PM-noOutput.m	NaN	NaN	NaN
ISSPM-1PM-output.m	NaN	NaN	NaN
ISSPM-AllPlanets-noOutput.m	NaN	NaN	NaN
ISSPM-AllPlanets-output.m	NaN	NaN	NaN
ISSPM-SRP-noOutput.m	NaN	NaN	NaN

Table 8.11: GMAT/FF Performance Test Case Comparisons

Test Case	% Time to Run	% Int. Steps	% Time Per Step
ISSPM-SRP-output.m	NaN	NaN	NaN
ISS-1PM-noOutput.m	NaN	NaN	NaN
ISS-1PM-output.m	NaN	NaN	NaN
ISS-AllPlanets-noOutput.m	NaN	NaN	NaN
ISS-AllPlanets-output.m	NaN	NaN	NaN
ISS-Drag-noOutput.m	NaN	NaN	NaN
ISS-Drag-output.m	NaN	NaN	NaN
ISS-NSG-noOutput.m	NaN	NaN	NaN
ISS-NSG-output.m	NaN	NaN	NaN
ISS-SRP-noOutput.m	NaN	NaN	NaN
ISS-SRP-output.m	NaN	NaN	NaN
Mars1PM-1PM-noOutput.m	NaN	NaN	NaN
Mars1PM-1PM-output.m	NaN	NaN	NaN
Mars1PM-AllPlanets-noOutput.m	NaN	NaN	NaN
Mars1PM-AllPlanets-output.m	NaN	NaN	NaN
Mars1-1PM-noOutput.m	NaN	NaN	NaN
Mars1-1PM-output.m	NaN	NaN	NaN
Mars1-AllPlanets-noOutput.m	NaN	NaN	NaN
Mars1-AllPlanets-output.m	NaN	NaN	NaN
MolniyaPM-1PM-noOutput.m	NaN	NaN	NaN
MolniyaPM-1PM-output.m	NaN	NaN	NaN
MolniyaPM-AllPlanets-noOutput.m	NaN	NaN	NaN
MolniyaPM-AllPlanets-output.m	NaN	NaN	NaN
MolniyaPM-SRP-noOutput.m	NaN	NaN	NaN
MolniyaPM-SRP-output.m	NaN	NaN	NaN
Molniya-1PM-noOutput.m	NaN	NaN	NaN
Molniya-1PM-output.m	NaN	NaN	NaN
Molniya-AllPlanets-noOutput.m	NaN	NaN	NaN
Molniya-AllPlanets-output.m	NaN	NaN	NaN
Molniya-Drag-noOutput.m	NaN	NaN	NaN
Molniya-Drag-output.m	NaN	NaN	NaN
Molniya-NSG-noOutput.m	NaN	NaN	NaN
Molniya-NSG-output.m	NaN	NaN	NaN
Molniya-SRP-noOutput.m	NaN	NaN	NaN
Molniya-SRP-output.m	NaN	NaN	NaN
MoonPM-1PM-noOutput.m	NaN	NaN	NaN
MoonPM-1PM-output.m	NaN	NaN	NaN
Moon-1PM-noOutput.m	NaN	NaN	NaN
Moon-1PM-output.m	NaN	NaN	NaN
SunSyncPM-1PM-noOutput.m	NaN	NaN	NaN
SunSyncPM-1PM-output.m	NaN	NaN	NaN
SunSyncPM-AllPlanets-noOutput.m	NaN	NaN	NaN
SunSyncPM-AllPlanets-output.m	NaN	NaN	NaN
SunSyncPM-SRP-noOutput.m	NaN	NaN	NaN
SunSyncPM-SRP-output.m	NaN	NaN	NaN

Table 8.12: GMAT/FF Performance Test Case Comparisons

Test Case	% Time to Run	% Int. Steps	% Time Per Step
SunSync-1PM-noOutput.m	NaN	NaN	NaN
SunSync-1PM-output.m	NaN	NaN	NaN
SunSync-AllPlanets-noOutput.m	NaN	NaN	NaN
SunSync-AllPlanets-output.m	NaN	NaN	NaN
SunSync-Drag-noOutput.m	NaN	NaN	NaN
SunSync-Drag-output.m	NaN	NaN	NaN
SunSync-NSG-noOutput.m	NaN	NaN	NaN
SunSync-NSG-output.m	NaN	NaN	NaN
SunSync-SRP-noOutput.m	NaN	NaN	NaN
SunSync-SRP-output.m	NaN	NaN	NaN



## Chapter 9

# ControlFlow

The Control Flow tests were designed to verify that the control flow commands (If, While, and For) function as expected. There are scripts that test the control flow commands by themselves, nested, and using different user defined parameters, such as arrays, numbers, variables, and spacecraft parameters. Each test script was designed to store flags that contained details of the command execution for each test case and reported to a text file.

Due to the layout of the report, a Matlab script can easily create a pass and fail table based on the values of the flag variables. In the report output the main columns to pay attention to are the ranOK and ansFlag columns. The ansFlag variable tells us if there was an incorrect control flow execution (ansFlag=-99), correct control flow execution (ansFlag=1), or the control flow didn't get executed (ansFlag=0). The ranOK variable tells us if each test case inside the test script ran correctly (ranOK = 1) or not (ranOK = 0). The only scripts that do not generate the ranOK column are the IfLoopTest##\_##, IfLoopTest##, and IfIfLoopTest##\_##.m, because the ansFlag column is sufficient.

### 9.1 Test Case Results

The results in Table 9.1 display the Pass and Fail outcome of each Control Flow test script.

Table 9.1: Loop Test Case Results

TestName	Pass/Fail	Failed/TotalTests
For	Pass	0/15
ForFor	Pass	0/9
ForIf41-14	Pass	0/20
ForIf42-24	Pass	0/21
ForIf43-34	Pass	0/20
ForIf51-15	Pass	0/16
ForIf52-25	Pass	0/20
ForIf53-35	Pass	0/20
ForWhile42	Pass	0/8
If11	Pass	0/9
If12-21	Pass	0/18
If22	Pass	0/9
If32-23	Pass	0/18
If33	Pass	0/9
If42-24	Pass	0/16
If44	Pass	0/8
If52-25	Pass	0/16
If55	Pass	0/8
IfFor	Pass	0/9
IfIf41-14	Pass	0/16
IfIf42-24	Pass	0/16
IfIf43-34	Pass	0/20
IfIf51-15	Pass	0/16
IfIf52-25	Pass	0/16
IfIf53-35	Pass	0/16
IfWhile	Pass	0/8
While42-24	Pass	0/16
While43-34	Pass	0/16
While52-25	Pass	0/16
While53-35	Pass	0/16
WhileFor	Pass	0/9
WhileIf41-14	Pass	0/16
WhileIf42-24	Pass	0/16
WhileIf43-34	Pass	0/16
WhileIf51-15	Pass	0/17
WhileIf52-25	Pass	0/16
WhileIf53-35	Pass	0/16
WhileTarget	Pass	0/1
WhileWhile42-24	Pass	0/16

## Appendix A

### Acronyms

Cb	- Central Body
Cd	- Drag coefficient
COTS	- Commercial Off The Shelf software
Cr	- Coefficient of reflexivity
CS	- Coordinate System
EGM	- Earth Gravity Model
EOP	- Earth Orientation Parameters
FDAB	- Flight Dynamics Analysis Branch
FF	- Free Flyer
GEO	- Geosynchronous Orbit
GMAT	- General Mission Analysis Tool
GPS	- Global Positioning Satellite
HEO	- Highly Elliptical Orbit
HPOP	- High Precision Orbit Propagator
IAU	- International Astronomical Union
IERS	- International Earth Rotation and Reference Systems Service
ISS	- International Space Station
JGM	- Joint Gravity Model
JR	- Jacchia Roberts
GMAT	- General Mission Analysis Tool
LEO	- Low Earth Orbit
LOD	- Length of Day
MEO	- Medium Earth Orbit
mas	- milliarcseconds
MSISE	- Mass Spectrometer and Incoherent Scatter Radar Exosphere
NSG	- Non-Spherical Gravity
PIP	- Professional Intern Program
PMG	- Point Mass Gravity
SRP	- Solar Radiation Pressure
STK	- Satellite Tool Kit
TAI	- International Atomic Time
TLE	- Two Line Element
USNO	- U.S. Naval Observatory
UT	- Universal time
UTC	- Coordinated Universal Time



## Appendix B

### Initial Conditions

The text and tables in this appendix allow someone to have an easier time duplicating the test case setups described in the previous chapters. The same information was presented in the previous chapters but this appendix has the information arranged different for ease of duplication reasons.

#### B.1 Propagator Test Cases

Table B.1: Initial Orbit Parameters (ISS)

Initial State Parameter	Parameter Value (unit)
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	2 Jun 2004 12:00:00.000 (UTCG)
Coordinate System	Earth Mean J2000 Equator
X	-4453.783586 (km)
Y	-5038.203756 (km)
Z	-426.384456 (km)
VX	3.831888 (km)
VY	-2.887221 (km)
VZ	-6.018232 (km)
Mass (No Fuel)	1000 (kg) (some exceptions)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Fixed
Integrator Init. StepSize	5 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	5 (sec)
Report Precision	16 significant figures
Report StepSize	60 (sec)
Report CS/Cb	Same as initial state CS

Table B.2: Initial Orbit Parameters (Sun-Sync)

Initial State Parameter	Parameter Value (unit)
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	2 Jun 2004 12:00:00.000 (UTCG)
Coordinate System	Earth Mean J2000 Equator
X	-2290.301063 (km)
Y	-6379.471940 (km)
Z	0.0 (km)
VX	-0.883923 (km)
VY	0.317338 (km)
VZ	7.610832 (km)
Mass (No Fuel)	1000 (kg) (some exceptions)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Fixed
Integrator Init. StepSize	5 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	5 (sec)
Report Precision	16 significant figures
Report StepSize	60 (sec)
Report CS/Cb	Same as initial state CS

Table B.3: Initial Orbit Parameters (GPS)

Initial State Parameter	Parameter Value (unit)
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	3 Jun 2004 12:00:00.000 (UTCG)
Coordinate System	Earth Mean J2000 Equator
X	5525.33668 (km)
Y	-15871.18494 (km)
Z	-20998.992446 (km)
VX	2.750341 (km)
VY	2.434198 (km)
VZ	-1.068884 (km)
Mass (No Fuel)	1000 (kg) (some exceptions)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Fixed
Integrator Init. StepSize	60 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	60 (sec)
Report Precision	16 significant figures
Report StepSize	120 (sec)
Report CS/Cb	Same as initial state CS

Table B.4: Initial Orbit Parameters (Molniya)

Initial State Parameter	Parameter Value (unit)
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
Coordinate System	Earth Mean J2000 Equator
X	-1529.894287 (km)
Y	-2672.877357 (km)
Z	-6150.115340 (km)
VX	8.717518 (km)
VY	-4.989709 (km)
VZ	0.0 (km)
Mass (No Fuel)	1000 (kg) (some exceptions)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Fixed
Integrator Init. StepSize	5 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	5 (sec)
Report Precision	16 significant figures
Report StepSize	300 (sec)
Report CS/Cb	Same as initial state CS



Table B.5: Initial Orbit Parameters (GEO)

Initial State Parameter	Parameter Value (unit)
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	8 Jun 2004 12:00:00.000 (UTCG)
Coordinate System	Earth Mean J2000 Equator
X	36607.358256 (km)
Y	-20921.723703 (km)
Z	0.0 (km)
VX	1.525636 (km)
VY	2.669451 (km)
VZ	0.0 (km)
Mass (No Fuel)	1000 (kg) (some exceptions)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Fixed
Integrator Init. StepSize	60 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	60 (sec)
Report Precision	16 significant figures
Report StepSize	600 (sec)
Report CS/Cb	Same as initial state CS

Table B.6: Initial Orbit Parameters (Mars)

Initial State Parameter	Parameter Value (unit)
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
Coordinate System	Mars Mean J2000 Equator
X	-2737.481646173082000 (km)
Y	0.0 (km)
Z	2737.481646173082000 (km)
VX	-0.311321695052649 (km)
VY	-3.553492313930950 (km)
VZ	0.311321695052650 (km)
Mass (No Fuel)	1000 (kg)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Fixed
Integrator Init. StepSize	5 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	5 (sec)
Report Precision	16 significant figures
Report StepSize	300 (sec)
Report CS/Cb	Same as initial state CS

Table B.7: Initial Orbit Parameters (Mercury)

Initial State Parameter	Parameter Value (unit)
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
Coordinate System	Mercury Mean J2000 Equator
X	-2164.769322630887000 (km)
Y	0.0 (km)
Z	2164.769322630886100 (km)
VX	-0.251096955137200 (km)
VY	-2.866074270797602 (km)
VZ	0.251096955137201 (km)
Mass (No Fuel)	1000 (kg)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Fixed
Integrator Init. StepSize	5 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	5 (sec)
Report Precision	16 significant figures
Report StepSize	300 (sec)
Report CS/Cb	Same as initial state CS

Table B.8: Initial Orbit Parameters (Moon)

Initial State Parameter	Parameter Value (unit)
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
Coordinate System	Moon Mean J2000 Equator
X	-1486.792117191545200 (km)
Y	0.0 (km)
Z	1486.792117191543000 (km)
VX	-0.142927729144255 (km)
VY	-1.631407624437537 (km)
VZ	0.142927729144255 (km)
Mass (No Fuel)	1000 (kg)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Fixed
Integrator Init. StepSize	5 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	5 (sec)
Report Precision	16 significant figures
Report StepSize	300 (sec)
Report CS/Cb	Same as initial state CS

Table B.9: Initial Orbit Parameters (Neptune)

Initial State Parameter	Parameter Value (unit)
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
Coordinate System	Neptune Mean J2000 Equator
X	-20815.089640681723000 (km)
Y	0.0 (km)
Z	20815.089640681723000 (km)
VX	-1.426423063858300 (km)
VY	-16.281497481173282 (km)
VZ	1.426423063858303 (km)
Mass (No Fuel)	1000 (kg)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Fixed
Integrator Init. StepSize	5 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	5 (sec)
Report Precision	16 significant figures
Report StepSize	300 (sec)
Report CS/Cb	Same as initial state CS

Table B.10: Initial Orbit Parameters (Pluto)

Initial State Parameter	Parameter Value (unit)
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
Coordinate System	Pluto Mean J2000 Equator
X	-1067.516740143530600 (km)
Y	0.0 (km)
Z	1067.516740143529700 (km)
VX	-0.075474392886505 (km)
VY	-0.861480838897026 (km)
VZ	0.075474392886505 (km)
Mass (No Fuel)	1000 (kg)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Fixed
Integrator Init. StepSize	5 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	5 (sec)
Report Precision	16 significant figures
Report StepSize	300 (sec)
Report CS/Cb	Same as initial state CS

Table B.11: Initial Orbit Parameters (Saturn)

Initial State Parameter	Parameter Value (unit)
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
Coordinate System	Saturn Mean J2000 Equator
X	-47577.347750129338000 (km)
Y	0.0 (km)
Z	47577.347750129360000 (km)
VX	-2.222652848522210 (km)
VY	-25.369834288049386 (km)
VZ	2.222652848522210 (km)
Mass (No Fuel)	1000 (kg)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Fixed
Integrator Init. StepSize	5 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	5 (sec)
Report Precision	16 significant figures
Report StepSize	300 (sec)
Report CS/Cb	Same as initial state CS

Table B.12: Initial Orbit Parameters (Uranus)

Initial State Parameter	Parameter Value (unit)
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
Coordinate System	Uranus Mean J2000 Equator
X	-26762.258109447845000 (km)
Y	0.0 (km)
Z	26762.258109447823000 (km)
VX	-1.158158360792704 (km)
VY	-13.219466869135891 (km)
VZ	1.158158360792704 (km)
Mass (No Fuel)	1000 (kg)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Fixed
Integrator Init. StepSize	5 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	5 (sec)
Report Precision	16 significant figures
Report StepSize	300 (sec)
Report CS/Cb	Same as initial state CS



Table B.13: Initial Orbit Parameters (Venus)

Initial State Parameter	Parameter Value (unit)
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
Coordinate System	Venus Mean J2000 Equator
X	-4832.074380872521000 (km)
Y	0.0 (km)
Z	4832.074380872517400 (km)
VX	-0.645356787452373 (km)
VY	-7.366240195908405 (km)
VZ	0.645356787452373 (km)
Mass (No Fuel)	1000 (kg)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Fixed
Integrator Init. StepSize	5 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	5 (sec)
Report Precision	16 significant figures
Report StepSize	300 (sec)
Report CS/Cb	Same as initial state CS

Table B.14: Initial Orbit Parameters (DeepSpace)

Initial State Parameter	Parameter Value (unit)
Start Time	01 Jan 2000 12:00:00.000 (UTCG)
Stop Time	01 Jan 2001 12:00:00.000 (UTCG)
Central Body	Sun
Coordinate System	Sun Mean J2000 Ecliptic
X	30043412.094803076000000 (km)
Y	143707423.481292670000000 (km)
Z	2198384.040184043300000 (km)
VX	-29.715920923036403 (km)
VY	6.056690472247896 (km)
VZ	0.123271169290614 (km)
Mass (No Fuel)	1000 (kg)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Variable
Integrator Init. StepSize	30000 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	30000 (sec)
Report Precision	16 significant figures
Report StepSize	86400 (sec)
Report CS/Cb	Same as initial state CS

Table B.15: Initial Orbit Parameters (EML2)

Initial State Parameter	Parameter Value (unit)
Start Time	23 Jan 2010 00:00:03.999 (UTCG)
Stop Time	6 Feb 2010 00:00:03.999 (UTCG)
Coordinate System	Earth Mean J2000 Equator
X	406326.22661300009 (km)
Y	177458.38761599999 (km)
Z	145838.58078999998 (km)
VX	-0.517274673822 (km)
VY	0.774650366561 (km)
VZ	0.331416602654 (km)
Mass (No Fuel)	1000 (kg)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Variable
Integrator Init. StepSize	1200 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	1200 (sec)
Report Precision	16 significant figures
Report StepSize	2400 (sec)
Report CS/Cb	Same as initial state CS

Table B.16: Initial Orbit Parameters (ESL2)

Initial State Parameter	Parameter Value (unit)
Start Time	5 Feb 2006 17:05:48.772 (UTCG)
Stop Time	4 Aug 2006 17:05:48.772 (UTCG)
Coordinate System	Earth Mean J2000 Equator
X	1010800.968074728 (km)
Y	-910963.5377102628 (km)
Z	-295145.6311353027 (km)
VX	0.2642852647102676 (km)
VY	0.286744175490658 (km)
VZ	0.07338744995264675 (km)
Mass (No Fuel)	1000 (kg)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	Case dependent
NSG Model	Case dependent
SRP Area	20 ( $m^2$ )
SRP	Case dependent
Integration Method	Tool/Program Dependent
Integrator StepSize control	Variable
Integrator Init. StepSize	15000 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	15000 (sec)
Report Precision	16 significant figures
Report StepSize	43200 (sec)
Report CS/Cb	Same as initial state CS

## B.2 Calculation Parameter Test Cases

The Cb and CS initial orbit state conditions for the ISS, GEO, Mars1, Mercury1, Moon, Neptune1, Pluto1, Saturn1, Uranus1 and Venus1 test cases are the same as the vales presented in Tables B.1, B.5, B.6- B.13. The only exception is that the Report StepSize is 600 seconds.

Table B.17: Initial Orbit Parameters (Hyperbolic)

Initial State Parameter	Parameter Value (unit)
Coordinate System	Earth Mean J2000 Equator
Start Time	01 Jun 2004 12:00:00.000 (UTCG)
Stop Time	02 Jun 2004 12:00:00.000 (UTCG)
X	12371.791482634855 (km)
Y	5050.7627227610719 (km)
Z	5050.762722761071 (km)
VX	-7.9859921512608487 (km)
VY	2.44520073255755 (km)
VZ	2.4452007325575495 (km)
Mass (No Fuel)	1000 (kg)
Cd	2.2
Cr	1.2
Drag Area	20 ( $m^2$ )
Drag Model	None
NSG Model	None
SRP Area	20 ( $m^2$ )
SRP	None
Integration Method	Tool/Program Dependent
Integrator StepSize control	Fixed
Integrator Init. StepSize	5 (sec)
Integrator Accuracy	1e-13
Integrator Max. StepSize	5 (sec)
Report Precision	16 significant figures
Report StepSize	600 (sec)
Report CS/Cb	Case Dependent

## **B.3 Integrator Test Cases**

The integrator initial orbit state conditions for the ISS and GEO test cases are the same as the vales presented in Tables B.1 and B.5. The only exception is that each test case uses one of the following Integration Methods: ABM, BS, PD45, PD78, RKF56, RKN68, and RKV89.

## **B.4 Stopping Condition Test Cases**

Refer to Tables 5.2- 5.6 in Chapter 5 for initial orbit state values for the Stopping Condition test cases.

## **B.5 Libration Point Test Cases**

Refer to Tables 6.1- 6.2 in Chapter 6 for initial orbit state values for the Stopping Condition test cases.

## **B.6 DeltaV Test Cases**

Refer to Tables 7.1- 7.4 in Chapter 7 for initial orbit state values for the Performance test cases.

## **B.7 Performance**

Refer to Tables ??- ?? in Chapter 8 for initial orbit state values for the Performance test cases.

## Appendix C

# Comparison Scripts Guide

Using specific naming conventions, outlined in this acceptance test plan, and a folder architecture, highlighted below for the test cases, several semi-automated scripts were generated to compare all of the GMAT test case results with other tools. Most of these scripts have the ability to also compare results of older versions of GMAT.

### C.1 Folder Architecture

The folder architecture for the files needed for the comparison scripts is presented below:

- GMAT\_RegSetup/
  - output/AcceptTest/CompareResults/
    - [Tool1]-[Tool2]
  - input/AcceptTest/
  - output/AcceptTest/[Tool]\_reports/
  - output/AcceptTest/Good\_reports/
    - FF
    - STK
- GMATDocuments/
  - AcceptTest

### C.2 Install Instructions

1. Copy the GMAT\_RegSetup and GMATDocuments folders to the same location on your hard drive.
2. Check to make sure the folders listed in Section C.1
3. Make sure the GMAT executable folder has a Matlab folder with the latest GMAT commands and keywords
4. Open Matlab
5. Set the path in Matlab to include the GMAT matlab folder

6. Open GMAT and start the Matlab server
7. Make sure Excel is closed
8. Set current directory to the main  
GMAT\_results/GMAT\_scripts folder and then type BuildCompare\_GMATteam in the command window  
or
9. Open one of the following files and run (F5 in Windows):  
*Click ok to change the current Matlab directory if prompted*
  - (a) BuildRun\_Script\_GMAT.m
  - (b) Comparison\_Tool1\_Tool2\_PV.m
  - (c) Comparison\_Tool1\_Tool2\_CS.m
  - (d) Comparison\_Tool1\_Tool2\_Cb.m
  - (e) Comparison\_Tool1\_Tool2\_Libr.m
  - (f) Comparison\_Integ.m
  - (g) Comparison\_DeltaV.m
  - (h) Comparison\_StopCond.m
  - (i) TimeComparo.m
  - (j) LoopTestSummary.m

### C.3 Warnings/Script Hints

- The following scripts were not designed for the user to hit one button, run multiple calculations, and output data without user interaction. User interaction is necessary in all of these scripts.
- The [ ] notation indicates multiple words can be used. For example, [Tool] means replace the bracketed expression with words such as FF,STK, and GMAT.
- As of November 2005, the Excel data created by the comparison scripts will be saved in one file name [Tool1]-[Tool2]\_Results\_[DD-MMM-YYYY].xls in their respective [Tool1]-[Tool2] folder in the CompareResults folder.
- Be careful adding MATLAB .m files that contain the text GMAT in their file name. These scripts use the text GMAT as an indicator to know if the file is a GMAT compatible script.
- The adherence to the naming conventions are very strict in these scripts. Make sure when adding reports, scripts, or folders to use case sensitive filenames that agree with the naming conventions at all times.
- Several output formats are overwritten when running each script. The Excel documents are saved with the current date as part of the filename. If the filename exists it will be replaced. The same overwriting process occurs with the Matlab .mat files.
- In order to compare old GMAT Builds to one another, a new folder must be created with the date of the GMAT Build. For example, the [Month] [Day] build performed well so after running the scripts that generate all the comparison data for the [Month] [Day] Build, a new folder must be created. The folder can be named YYMMDDGMAT\_reports with the appropriate GMAT Build Year Month and Date replacing YYMMDD. Now simply copy the contents of GMAT\_reports into YYMMDDGMAT\_reports and the data can be used to compare future build of GMAT to one another.
- All the .mat files, except for the TimeComparo files, are formatted in a similar way. They contain the following variables mat\_Tool11, mat\_Tool21, mat\_header, maxDiffs, and diffMat\_Tool1\_Tool2 or norm-Mat\_Tool1\_Tool2.

The mat\_header variable contains what parameters each column represents for the other variables The mat\_Tool11 and mat\_Tool21 variables contain the report file data minus any headers. Tool1 is the alphabetical first tool selected and Tool2 is the other tool selected



- Common mistakes made with these scripts:
  - Adding report files and not following the naming convention (i.e. FF\_ISS\_Earth\_0\_0\_0 was misnamed as FF\_ISS\_Earth\_0\_0).
  - Outputting other tools and not following the proper ordering of parameters for comparison
  - Report files were outputted in the wrong time interval increment
  - Report files were outputted without enough numerical precision. GMAT outputs data at a fixed width of 12 numerical characters (default). Other programs should be the same or better.

## C.4 BuildRun\_Script\_GMAT.m script

Win compatible / Mac & Linux ?

### C.4.1 Purpose

This script was designed to send multiple GMAT scripts from Matlab to GMAT to be built and ran. In early versions of GMAT, there was no capability to run multiple scripts, but since current versions of GMAT contain this capability this script is not as vital in the Acceptance test plan.

Its secondary purpose is to record the individual time elapsed to run each test case and output the results to a .mat file for later use.

### C.4.2 Inputs

- All .m files located in the GMAT\_RegSetup/input/AcceptTest/ folder that follow the GMAT comparison naming convention described in Sections 2.3, 3.2.1, 3.3.1, and 4.2

### C.4.3 Outputs

- When choosing to build multiple scripts and the all command is used a mat file is created, which keeps a log of the time it takes to run each case. The script also displays the case name and the time it takes for GMAT to run the file in Matlab's command window.
- Any other output data is dependent on the GMAT script.

### C.4.4 Script Algorithm

## C.5 Comparison\_Tool1\_Tool2\_PV.m

Win/Mac/Linux compatible

### C.5.1 Purpose

This script is used to perform the position and velocity comparisons needed for the Propagator Section ( 2) of the Acceptance Test Plan. This script takes the normalized position and velocity vector differences between the

two selected programs.

### C.5.2 Inputs

- Folder to search for files:  $[RootFolder]/[Tool]_reports$ .  
(Refer to Section 2.3 for the naming convention of these report files.)
- The report files must be formatted the same way. The first column is time (Mod. Julian Date), second-fourth columns are the position vector components  $(x, y, z)$ , and fifth-seventh columns are the velocity vector components  $(Vx, Vy, Vz)$ . The data must be separated by spaces.
- Currently the location of the report's first row of numerical data is coded into the script. FreeFlyer is the fourth row, STK is the seventh row, GMAT is the first row, OD toolbox is the first row, and any other tools added will automatically search the first row.

### C.5.3 Outputs

- Comparison data is displayed in MATLAB's command window for all test cases.
- Excel documents with comparison data and pass/fail information.
- MATLAB .mat files with comparison data.
- Latex documents with comparison data.

### C.5.4 Script Algorithm

- Display welcome message
- Display menu for Tool1 options based on  $[Tool]_reports$  folder
- Wait for user to choose tool from menu
  - Implement error system for incorrect choice
- Display menu for Tool2 options based on  $[Tool]_reports$  folder
- Wait for user to choose tool from menu
  - Implement error system for incorrect choice
- Alphabetize Tool1 and Tool2 for naming purposes and rename if necessary
- Store the row location of the first instance of numerical data for both Tools' report files
- Initialize variables and folder locations
- Display a menu of Tool1 \*.report files
  - Generate error report if no \*.report files are located in  $[Tool1]_report$  folder
- Wait for user to choose report comparison option
  - Implement error system for incorrect choice
  - Open Excel Connection if compare all choice selected
- Display filename, position difference, and velocity difference header
- Begin Loop. Loop once for single comparison and several times for comparing all files.
  - Check the Tool2 folder for the same report
    - Display error message if no report found

- Continue if match found or exit loop if no match found
- Read both output files and save the data to different matrices
- Check to see if the row sizes are the same in both matrices
  - Display error if row sizes do not match
- Take difference of both Tools report data
- Normalize the results based on position and velocity
- Determine the maximum normalized position and velocity difference
- Store propagation duration of the test cases in a variable
- Add acceptable differences values for Excel output
- Save comparison data to .mat file
  - \* If compare all reports chosen, format data for output to Latex
  - \* Use BasicLatexTable script to save data to LaTeX file
  - \* Save comparison results, acceptance errors, and duration to Excel
- Close Excel connection if open.
- End Loop. Allow user to rerun script

## C.6 Comparison\_Tool1\_Tool2\_CS.m

Win/Mac/Linux compatible

### C.6.1 Purpose

This script is used to perform the coordinate system dependent comparisons needed for the Calculation Parameters Section ( 3) of the Acceptance Test Plan. The comparison involves taking the maximum absolute value of the differences of the variables listed in the Inputs section of this help guide.

### C.6.2 Inputs

- Folder to search for files: [*RootFolder*]/[Tool]\_reports.  
(Refer to Section 3.3.1 for the naming convention of these report files.)
- The report files must be formatted the same way. Time, [*X,Y,andZ*] Position(km), [*X,Y,andZ*] Velocity(km/sec), Mag. of Velocity(km/sec), Right Ascension of Velocity(deg), [*X,Y,andZ*] RxV-Specific Angular Momentum( $km^2/sec$ ), Arg. of Perigee(deg), Declination(deg), Declination of Velocity(deg), Inclination(deg), Right Ascension(deg), Right Ascension of Ascending Node(deg)
- Currently the location of the reports first row of numerical data is coded into the script. FreeFlyer is the fourth row, STK is the seventh row, GMAT is the second row, OD toolbox is the first row, and any other tools added will automatically search the first row.

### C.6.3 Outputs

- Excel documents with comparison data
- MATLAB .mat files with comparison data
- Latex documents with comparison data

### C.6.4 Script Algorithm

- Display welcome message
- Display menu for Tool1 options based on [Tool]\_reports folder
- Wait for user to choose tool from menu
  - Implement error system for incorrect choice
- Display menu for Tool2 options based on [Tool]\_reports folder
- Wait for user to choose tool from menu
  - Implement error system for incorrect choice
- Alphabetize Tool1 and Tool2 for naming purposes and rename if necessary
- Store the row location of the first instance of numerical data for both Tools' report files
- Initialize variables and folder locations
- Display a menu of Tool1 \*.report files
  - Generate error report if no \*.report files are located in [Tool1]\_report folder
- Wait for user to choose report comparison option
  - Implement error system for incorrect choice
  - Open Excel Connection if compare all choice selected
- Display filename, position difference, and velocity difference header
- Begin Loop. Loop once for single comparison and several times for comparing all files.
  - Check the Tool2 folder for the same report
    - Display error message if no report found
  - Continue if match found or exit loop if no match found
  - Read both output files and save the data to different matrices
  - Check to see if the row sizes are the same in both matrices
    - Display error if row sizes do not match
  - Take difference of both Tools report data
  - Determine the maximum difference for each coordinate system dependent parameter
  - Store propagation duration of the test cases in a variable
  - Save comparison data to .mat file
    - \* If compare all reports chosen, format data for output to Latex
    - \* Use BasicLatexTable script to save data to LaTeX file
    - \* Save comparison results, acceptance errors, and duration to Excel
  - Close Excel connection if open.
- End Loop. Allow user to rerun script

## C.7 Comparison\_Tool1\_Tool2\_Cb.m

### C.7.1 Purpose

This script is used to perform the central body dependent comparisons needed for the Calculation Parameters Section ( 3) of the Acceptance Test Plan. The comparison involves taking the maximum absolute value of the differences of the variables listed in the Inputs section of this help guide.

### C.7.2 Inputs

- Folder to search for files:  $[RootFolder]/[Tool]_reports$ .  
(Refer to Section 3.2.1 for the naming convention of these report files.)
- The report files must be formatted the same way. Time, Altitude (km), Beta Angle (deg), C3\_Energy ( $km^2/sec^2$ ), Eccentricity, Latitude (deg), Longitude (deg), (RxV)\_Mag ( $km^2/sec$ ), Mean Anomaly (deg), Mean Motion ( $rad/sec$ ), Period (sec), Apoapsis Radius (km), Perigee Radius (km), R\_Mag (km), Semi-major Axis (km), True Anomaly (deg), Semilatus Rectum(km), Apoapsis Velocity ( $km/sec$ ), Periapsis Velocity ( $km/sec$ ), Greenwich Hour Angle(deg), Local Sidereal Time
- Due to the inability of FF and STK tools to output all the parameters listed in the previous bullet, exceptions for FF and STK are built into the code.

STK: Semilatus Rectum, Apoapsis Velocity, Perigee Velocity, Greenwich Hour Angle, and Local Sidereal Time can not be outputted in the same report file. Out of the aforementioned parameters Greenwich Hour Angle is the only parameter that can be outputted in a separate file. All the other parameters are calculated in MATLAB based on the results STK could generate.

FF: (RxV)\_Mag and R\_Mag could not be outputted easily. Instead the [XYZ] components were outputted and the script computes the magnitude of the vectors. Apoapsis Velocity, Periapsis Velocity, and Local Sidereal Time are all created in this script based on available parameters.

Modifications to the code will need to be made to add a new tool that cannot output all of the central body parameters that GMAT does.

- Currently the location of the reports first row of numerical data is coded into the script. FreeFlyer is the fourth row, STK is the seventh row, GMAT is the second row, OD toolbox is the first row, and any other tools added will automatically search the first row.

### C.7.3 Outputs

- Excel documents with comparison data
- MATLAB .mat files with comparison data
- Latex documents with comparison data

### C.7.4 Script Algorithm

- Display welcome message
- Display menu for Tool1 options based on  $[Tool]_reports$  folder
- Wait for user to choose tool from menu  
Implement error system for incorrect choice

- Display menu for Tool2 options based on [Tool]\_reports folder
- Wait for user to choose tool from menu
  - Implement error system for incorrect choice
- Alphabetize Tool1 and Tool2 for naming purposes and rename if necessary
- Store the row location of the first instance of numerical data for both Tools' report files
- Initialize variables and folder locations
- Display a menu of Tool1 \*.report files
  - Generate error report if no \*.report files are located in [Tool1]\_report folder
- Wait for user to choose report comparison option
  - Implement error system for incorrect choice
  - Open Excel Connection if compare all choice selected
- Display filename, position difference, and velocity difference header
- Begin Loop. Loop once for single comparison and several times for comparing all files.
  - Check the Tool2 folder for the same report
    - Display error message if no report found
  - Continue if match found or exit loop if no match found
  - Read both output files and save the data to different matrices
  - Check to see if the row sizes are the same in both matrices
    - Display error if row sizes do not match
  - Take difference of both Tools report data
  - Code in exceptions for STK, FF, and any other tools that don't output all the desired GMAT central body dependent parameters
  - Determine the maximum difference for each central body dependent parameter
  - Store propagation duration of the test cases in a variable
  - Save comparison data to .mat file
    - \* If compare all reports chosen, format data for output to Latex
    - \* Use BasicLatexTable script to save data to LaTeX file
    - \* Save comparison results, acceptance errors, and duration to Excel
  - Close Excel connection if open.
- End Loop. Allow user to rerun script

## C.8 Comparison\_Tool1\_Tool2\_Libr.m

Win/Mac/Linux compatible

### C.8.1 Purpose

This script is used to perform the position and velocity comparisons needed for the Libration Points Section ( 6) of the Acceptance Test Plan. This script takes the normalized position and velocity vector differences between the two selected programs.

### C.8.2 Inputs

- Folder to search for files: [Root Folder]/[Tool]\_reports.  
(Refer to Section 6.2 for the naming convention of these report files.)
- The report files must be formatted the same way. The first column is time (Mod. Julian Date), second-fourth columns are the position vector components ( $x, y, z$ ), and fifth-seventh columns are the velocity vector components ( $Vx, Vy, Vz$ ). The data must be separated by spaces.
- Currently the location of the report's first row of numerical data is coded into the script. FreeFlyer is the fourth row, STK is the seventh row, GMAT is the first row, OD toolbox is the first row, and any other tools added will automatically search the first row.

### C.8.3 Outputs

- Comparison data is displayed in MATLAB's command window for all test cases.
- Excel documents with comparison data and pass/fail information.
- MATLAB .mat files with comparison data.
- Latex documents with comparison data.

### C.8.4 Script Algorithm

[INSERT script Algorithm]

## C.9 Comparison\_Integ.m

Win/Mac/Linux compatible

### C.9.1 Purpose

This script is used to perform the integrator comparisons needed for the Integrator Section ( 4) of the Acceptance Test Plan. The comparison involves taking the difference of the position and velocity vector and then normalizing these two vectors to get the position and velocity difference. This script behaves similar to the Comparison\_Tool1\_Tool2\_PV.m script but the components being varied are the integrators for two body test cases.

### C.9.2 Inputs

- Folder to search for files: [RootFolder]/[Tool]\_reports.
- Naming convention: Integrator\_[Tool]\_[Trajectory]\_[IntegratorType]\_2Body.report
- The report files must be formatted the same way. The first column is time, second-fourth columns are the position vector ( $x,y,z$ ), and fifth-seventh columns are the velocity vector ( $x,y,z$ ). The data must be separated by spaces.
- Currently the location of the reports' first row of numerical data is coded into the script. FreeFlyer is the fourth row, STK is the seventh row, GMAT is the second row, OD toolbox is the first row, and any other tools added will automatically search the first row.

### C.9.3 Outputs

- Excel documents with comparison data into the following folder:  
[RootFolder]/CompareResults/[Tool1]-[Tool2]
- MATLAB .mat files with comparison data into the following folder:  
[RootFolder]/CompareResults/[Tool1]-[Tool2]
- Latex documents with comparison data into the following folder:  
[RootFolder]/Latex\_Docs

### C.9.4 Script Algorithm

- Display welcome message
- Display menu for Tool1 options based on [Tool]\_reports folder (Can only be Exact or GMAT folders)
- Wait for user to choose tool from menu
  - Implement error system for incorrect choice
- Display menu for Tool2 options based on [Tool]\_reports folder (Can only be Exact or GMAT folders)
- Wait for user to choose tool from menu
  - Implement error system for incorrect choice
- Alphabetize Tool1 and Tool2 for naming purposes and rename if necessary
- Store the row location of the first instance of numerical data for both Tools' report files
- Initialize variables and folder locations
- Display a menu of Tool1 \*.report files
  - Generate error report if no \*.report files are located in [Tool1]\_report folder
- Wait for user to choose report comparison option
  - Implement error system for incorrect choice
  - Open Excel Connection if compare all choice selected
- Display filename, position difference, and velocity difference header
- Begin Loop. Loop once for single comparison and several times for comparing all files.
  - Check the Tool2 folder for the same report
    - Display error message if no report found
  - Continue if match found or exit loop if no match found
  - Read both output files and save the data to different matrices
  - Check to see if the row sizes are the same in both matrices
    - Display error if row sizes do not match
  - Take difference of both Tools report data
  - Normalize the results based on position and velocity
  - Determine the maximum normalized position and velocity difference
  - Store propagation duration of the test cases in a variable
  - Save comparison data to .mat file
    - \* If compare all reports chosen, format data for output to Latex
    - \* Use BasicLatexTable script to save data to LaTeX file
    - \* Save comparison results, acceptance errors, and duration to Excel
  - Close Excel connection if open.
- End Loop. Allow user to rerun script



## C.10 Comparison\_DeltaV.m

Win/Mac/Linux compatible

### C.10.1 Purpose

### C.10.2 Inputs

### C.10.3 Outputs

### C.10.4 Script Algorithm

## C.11 Comparison\_StopCond.m

Win/Mac/Linux compatible

### C.11.1 Purpose

### C.11.2 Inputs

### C.11.3 Outputs

### C.11.4 Script Algorithm

## C.12 STK\_Repropagate.m

Win compatible

### C.12.1 Purpose

The STK\_Repropagate script was designed to reduce the time it took to generate STK report files, after modifications to the STK scenario were made, and obtain more accurate STK run times. Through STK's connect module Matlab connect with STK and propagates satellites, generates reports, and outputs run times.

### C.12.2 Inputs

- STK scenario folders that follow the GMAT Acceptance Test Plan naming convention, in the following folder: `[RootFolder]/TruthFiles/STK`

### C.12.3 Outputs

- STK report file saved into *[RootFolder]/STK\_reports*.
- Matlab .mat file with the time taken to propagate each satellite.

### C.12.4 Script Algorithm

## C.13 TimeComparo.m

Win/Mac/Linux compatible

### C.13.1 Purpose

When running the BuildRun.Script.GMAT.m script there is an all option after selecting the build & run multiple cases choice. By using this all option, the GMAT performance times for all the test cases are saved to a .mat file. This script uses those saved performance times and, based on a pre-selected amount of test cases, creates a new excel file that contains GMAT, FF, and STK performance times for those pre-selected cases.

### C.13.2 Inputs

- Template file containing pre-selected cases: *[RootFolder]/NonGMATrunTimes.xls*
- Folder to search for files: *[RootFolder]/CompareResults*
- Naming convention:  
*[Date]/\_Time2RunAll.mat*

### C.13.3 Outputs

- Excel document with comparison data

### C.13.4 Script Algorithm

## Appendix D

### STK Setup

The STK setups were very crucial in determining a preliminary standard to compare GMAT to. In the initial stages of the Acceptance Test Plan STK scenarios were obtained from Emergent Space, as mentioned in Section 2.1. These Earth based cases were created in STK-HPOP and modified to provide a setup that was as equivalent to GMAT as was possible. Non-Earth test cases could not be created with STK-HPOP, so STK-Astrogator was used. In order to use STK-Astrogator several Astrogator elements needed to be created. Section D.4 details all the elements needed for the non-Earth STK test cases.

#### D.1 Support Files Needed

All alterations to STK scenarios were performed with STK 6.1 on the desktop machine described in the Performance Section (Section 8.1).

In order to duplicate data generated by STK for this Acceptance Test Plan, the same files presented in Table D.1 are needed.

Table D.1: STK support files

Filename(s)	File('s) and/or Folder('s) Location	Information in Section
EOP.dat	[STK Root Directory]\DynamicEarthData	2.2.1
EOP.dat.all	[STK Root Directory]\DynamicEarthData	2.2.1
All planetary cb files	[STK Root Directory]\STKData\CentralBodies	2.2.2
Non-spherical grav (nsg) files	[STK Root Directory]\STKData\CentralBodies	2.3
Report Styles	[STK individual user folder]\Config\Styles	D.5
Non-Earth Astrogator Elements	[STK Root Directory]\STKData\Astrogator	D.4
Leap Seconds File	[STK Root Directory]\STKData\Astro	2.2.2

#### D.2 STK modules used

Refer to Appendix B for a easy initial orbit state format to use as input into STK. Table D.2 displays the STK module to use in order to duplicate the results seen in this Acceptance Test Plan document.

Table D.2: STK modules used

Test Cases	Test Group(s)	STK-type
ISS, GEO, SunSync, Molniya, GPS, Hyperbolic	Propagator, Cb, CS	STK-HPOP
DeepSpace, EML2, ESL2, All non-Earth cases	Propagator	STK-Astrogator
ISS, GEO	Integrator	STK-2Body

### D.3 Scenario Setup

The following are guidelines we followed when creating STK Scenarios, excluding HPOP or Astrogator specific guidelines:

- Initial Scenario Epoch is the same as the satellite epoch
- Make sure all support files (Table D.1) are present and match the information in this document.
- \*.cb planetary files need to contain the values in Tables 2.5, 2.7, and 2.9
- Remember the Modified Julian Date used in GMAT and STK are different.  
(i.e.  $UTC\_GMAT\_ModJulian = UTC\_STK\_ModJulian + 29999.5$ )

#### D.3.1 HPOP

- Planetary information should be taken from the JPL DE file
- Satellite properties must be consistent with table the values in Table 2.5

[INSERT Screen captures of HPOP]

#### D.3.2 STK

- All Astrogator support files (Table D.1) are essential in reproducing the values in this document.
- Make sure the maximum propagation is greater than the test case propagation duration or turn off the feature in STK.

[INSERT Screen captures of Astrogator]

## D.4 Astrogator Elements

For the non-Earth cases a large number of Astrogator elements were created in order to compare STK to GMAT's results.

### D.4.1 Calculation Objects: Cartesian Elements

Vx_EarthMJ2000Ec	Vx_Neptune_Centered_Mean_J2000_Earth_Ec
Vx_EarthMODEc	Vx_Neptune_Centered_Mean_J2000_Earth_Eq
Vx_EarthMODEq	Vy_Neptune_Centered_Mean_J2000_Earth_Ec
Vx_EarthMOEEc	Vy_Neptune_Centered_Mean_J2000_Earth_Eq
Vx_EarthMOEEq	Vz_Neptune_Centered_Mean_J2000_Earth_Ec
Vx_EarthTODEc	Vz_Neptune_Centered_Mean_J2000_Earth_Eq
Vx_EarthTODEq	Vx_NeptuneFixed
Vx_EarthTOEEc	Vy_NeptuneFixed
Vx_EarthTOEEq	Vz_NeptuneFixed
Vy_EarthMJ2000Ec	Vx_Pluto_Centered_Mean_J2000_Earth_Ec
Vy_EarthMODEc	Vx_Pluto_Centered_Mean_J2000_Earth_Eq
Vy_EarthMODEq	Vy_Pluto_Centered_Mean_J2000_Earth_Ec
Vy_EarthMOEEc	Vy_Pluto_Centered_Mean_J2000_Earth_Eq
Vy_EarthMOEEq	Vz_Pluto_Centered_Mean_J2000_Earth_Ec
Vy_EarthTODEc	Vz_Pluto_Centered_Mean_J2000_Earth_Eq
Vy_EarthTODEq	Vx_PlutoFixed
Vy_EarthTOEEc	Vy_PlutoFixed
Vy_EarthTOEEq	Vz_PlutoFixed
Vz_EarthMJ2000Ec	Vx_Saturn_Centered_Mean_J2000_Earth_Ec
Vz_EarthMODEc	Vx_Saturn_Centered_Mean_J2000_Earth_Eq
Vz_EarthMODEq	Vy_Saturn_Centered_Mean_J2000_Earth_Ec
Vz_EarthMOEEc	Vy_Saturn_Centered_Mean_J2000_Earth_Eq
Vz_EarthMOEEq	Vz_Saturn_Centered_Mean_J2000_Earth_Ec
Vz_EarthTODEc	Vz_Saturn_Centered_Mean_J2000_Earth_Eq
Vz_EarthTODEq	Vx_SaturnFixed
Vz_EarthTOEEc	Vy_SaturnFixed
Vz_EarthTOEEq	Vz_SaturnFixed
Vx_Mars_Centered_Mean_J2000_Earth_Ec	Vx_Sun_Centered_Mean_J2000_Earth_Ec
Vx_Mars_Centered_Mean_J2000_Earth_Eq	Vx_Sun_Centered_Mean_J2000_Earth_Eq
Vy_Mars_Centered_Mean_J2000_Earth_Ec	Vy_Sun_Centered_Mean_J2000_Earth_Ec
Vy_Mars_Centered_Mean_J2000_Earth_Eq	Vy_Sun_Centered_Mean_J2000_Earth_Eq
Vz_Mars_Centered_Mean_J2000_Earth_Ec	Vz_Sun_Centered_Mean_J2000_Earth_Ec
Vz_Mars_Centered_Mean_J2000_Earth_Eq	Vz_Sun_Centered_Mean_J2000_Earth_Eq
Vx_MarsFixed	Vx_SunFixed
Vy_MarsFixed	Vy_SunFixed
Vz_MarsFixed	Vz_SunFixed
Vx_Mercury_Centered_Mean_J2000_Earth_Ec	Vx_Uranus_Centered_Mean_J2000_Earth_Ec
Vx_Mercury_Centered_Mean_J2000_Earth_Eq	Vx_Uranus_Centered_Mean_J2000_Earth_Eq
Vy_Mercury_Centered_Mean_J2000_Earth_Ec	Vy_Uranus_Centered_Mean_J2000_Earth_Ec
Vy_Mercury_Centered_Mean_J2000_Earth_Eq	Vy_Uranus_Centered_Mean_J2000_Earth_Eq
Vz_Mercury_Centered_Mean_J2000_Earth_Ec	Vz_Uranus_Centered_Mean_J2000_Earth_Ec
Vz_Mercury_Centered_Mean_J2000_Earth_Eq	Vz_Uranus_Centered_Mean_J2000_Earth_Eq
Vx_MercuryFixed	Vx_UranusFixed
Vy_MercuryFixed	Vy_UranusFixed
Vz_MercuryFixed	Vz_UranusFixed

Vx_Moon_Centered_Mean_J2000_Earth_Ec	Vx_Venus_Centered_Mean_J2000_Earth_Ec
Vx_Moon_Centered_Mean_J2000_Earth_Eq	Vx_Venus_Centered_Mean_J2000_Earth_Eq
Vy_Moon_Centered_Mean_J2000_Earth_Ec	Vy_Venus_Centered_Mean_J2000_Earth_Ec
Vy_Moon_Centered_Mean_J2000_Earth_Eq	Vy_Venus_Centered_Mean_J2000_Earth_Eq
Vz_Moon_Centered_Mean_J2000_Earth_Ec	Vz_Venus_Centered_Mean_J2000_Earth_Ec
Vz_Moon_Centered_Mean_J2000_Earth_Eq	Vz_Venus_Centered_Mean_J2000_Earth_Eq
Vx_MoonFixed	Vx_VenusFixed
Vy_MoonFixed	Vy_VenusFixed
Vz_MoonFixed	Vz_VenusFixed
X_EarthGSE	X_EarthGSM
Y_EarthGSE	Y_EarthGSM
Z_EarthGSE	Z_EarthGSM
Vx_EarthGSE	Vx_EarthGSM
Vy_EarthGSE	Vy_EarthGSM
Vz_EarthGSE	Vz_EarthGSM

#### D.4.2 Calculation Objects: Geodetic Elements

Altitude_Mars	Altitude_Pluto
Latitude_Mars	Latitude_Pluto
Longitude_Mars	Longitude_Pluto
Altitude_Mercury	Altitude_Saturn
Latitude_Mercury	Latitude_Saturn
Longitude_Mercury	Longitude_Saturn
Altitude_Moon	Altitude_Uranus
Latitude_Moon	Latitude_Uranus
Longitude_Moon	Longitude_Uranus
Altitude_Neptune	Altitude_Venus
Latitude_Neptune	Latitude_Venus
Longitude_Neptune	Longitude_Venus

## D.4.3 Calculation Objects: Keplerian Elements

Argument_of_Periapsis_(fixed)	Inclination_(fixed)
Argument_of_Periapsis_(MJ2000Ec)	Inclination_(MJ2000Ec)
Argument_of_Periapsis_(MODEc)	Inclination_(MODEc)
Argument_of_Periapsis_(MOEEc)	Inclination_(MOEEc)
Argument_of_Periapsis_(MOEEq)	Inclination_(MOEEq)
Argument_of_Periapsis_(TODEc)	Inclination_(TODEc)
Argument_of_Periapsis_(TOEEc)	Inclination_(TOEEc)
Argument_of_Periapsis_(TOEEq)	Inclination_(TOEEq)
Argument_of_Periapsis_(EarthGSE)	Inclination_(EarthGSE)
Argument_of_Periapsis_(EarthGSM)	Inclination_(EarthGSM)
Argument_of_Periapsis_(MarsFixed)	Inclination_(MarsFixed)
Argument_of_Periapsis_(MarsMJ2000Ec)	Inclination_(MarsMJ2000Ec)
Argument_of_Periapsis_Mars_(MJ2000Eq)	Inclination_Mars_(MJ2000Eq)
Argument_of_Periapsis_(MercuryFixed)	Inclination_(MercuryFixed)
Argument_of_Periapsis_(MercuryMJ2000Ec)	Inclination_(MercuryMJ2000Ec)
Argument_of_Periapsis_Mercury_(MJ2000Eq)	Inclination_Mercury_(MJ2000Eq)
Argument_of_Periapsis_(MoonFixed)	Inclination_(MoonFixed)
Argument_of_Periapsis_(MoonMJ2000Ec)	Inclination_(MoonMJ2000Ec)
Argument_of_Periapsis_Moon_(MJ2000Eq)	Inclination_Moon_(MJ2000Eq)
Argument_of_Periapsis_(NeptuneFixed)	Inclination_(NeptuneFixed)
Argument_of_Periapsis_(NeptuneMJ2000Ec)	Inclination_(NeptuneMJ2000Ec)
Argument_of_Periapsis_Neptune_(MJ2000Eq)	Inclination_Neptune_(MJ2000Eq)
Argument_of_Periapsis_(PlutoFixed)	Inclination_(PlutoFixed)
Argument_of_Periapsis_(PlutoMJ2000Ec)	Inclination_(PlutoMJ2000Ec)
Argument_of_Periapsis_Pluto_(MJ2000Eq)	Inclination_Pluto_(MJ2000Eq)
Argument_of_Periapsis_(SaturnFixed)	Inclination_(SaturnFixed)
Argument_of_Periapsis_(SaturnMJ2000Ec)	Inclination_(SaturnMJ2000Ec)
Argument_of_Periapsis_Saturn_(MJ2000Eq)	Inclination_Saturn_(MJ2000Eq)
Argument_of_Periapsis_(UranusFixed)	Inclination_(UranusFixed)
Argument_of_Periapsis_(UranusMJ2000Ec)	Inclination_(UranusMJ2000Ec)
Argument_of_Periapsis_Uranus_(MJ2000Eq)	Inclination
Argument_of_Periapsis_(VenusFixed)	Inclination_(VenusFixed)
Argument_of_Periapsis_(VenusMJ2000Ec)	Inclination_(VenusMJ2000Ec)
Argument_of_Periapsis_Venus_(MJ2000Eq)	Inclination_Venus_(MJ2000Eq)
Eccentricity_Mars	Mean_Motion_Mars
Eccentricity_Mercury	Mean_Motion_Mercury
Eccentricity_Moon	Mean_Motion_Moon
Eccentricity_Neptune	Mean_Motion_Neptune
Eccentricity_Pluto	Mean_Motion_Pluto
Eccentricity_Saturn	Mean_Motion_Saturn
Eccentricity_Uranus	Mean_Motion_Uranus
Eccentricity_Venus	Mean_Motion_Venus

Orbit_Period_Mars	Radius.Of_Apoapsis_Mars
Orbit_Period_Mercury	Radius.Of_Apoapsis_Mercury
Orbit_Period_Moon	Radius.Of_Apoapsis_Moon
Orbit_Period_Neptune	Radius.Of_Apoapsis_Neptune
Orbit_Period_Pluto	Radius.Of_Apoapsis_Pluto
Orbit_Period_Saturn	Radius.Of_Apoapsis_Saturn
Orbit_Period_Uranus	Radius.Of_Apoapsis_Uranus
Orbit_Period_Venus	Radius.Of_Apoapsis_Venus
RAAN_(fixed)	Radius.Of_Periapsis_Mars
RAAN_(MJ2000Ec)	Radius.Of_Periapsis_Mercury
RAAN_(MODEc)	Radius.Of_Periapsis_Moon
RAAN_(MOEEc)	Radius.Of_Periapsis_Neptune
RAAN_(MOEEq)	Radius.Of_Periapsis_Pluto
RAAN_(TOEEc)	Radius.Of_Periapsis_Saturn
RAAN_(TOEEc)	Radius.Of_Periapsis_Uranus
RAAN_(TOEEq)	Radius.Of_Periapsis_Venus
RAAN_(MarsFixed)	Semimajor_Axis_Mars
RAAN_(MarsMJ2000Ec)	Semimajor_Axis_Mercury
RAAN_Mars_(MJ2000Eq)	Semimajor_Axis_Moon
RAAN_(MercuryFixed)	Semimajor_Axis_Neptune
RAAN_(MercuryMJ2000Ec)	Semimajor_Axis_Pluto
RAAN_Mercury_(MJ2000Eq)	Semimajor_Axis_Saturn
RAAN_(MoonFixed)	Semimajor_Axis_Uranus
RAAN_(MoonMJ2000Ec)	Semimajor_Axis_Venus
RAAN_Moon_(MJ2000Eq)	True_Anomaly_Mars
RAAN_(NeptuneFixed)	True_Anomaly_Mercury
RAAN_(NeptuneMJ2000Ec)	True_Anomaly_Moon
RAAN_Neptune_(MJ2000Eq)	True_Anomaly_Neptune
RAAN_(PlutoFixed)	True_Anomaly_Pluto
RAAN_(PlutoMJ2000Ec)	True_Anomaly_Saturn
RAAN_Pluto_(MJ2000Eq)	True_Anomaly_Uranus
RAAN_(SaturnFixed)	True_Anomaly_Venus
RAAN_(SaturnMJ2000Ec)	RAAN_(EarthGSE)
RAAN_Saturn_(MJ2000Eq)	RAAN_(EarthGSM)
RAAN_(UranusFixed)	
RAAN_(UranusMJ2000Ec)	
RAAN_Uranus_(MJ2000Eq)	
RAAN_(VenusFixed)	
RAAN_(VenusMJ2000Ec)	
RAAN_Venus_(MJ2000Eq)	



## D.4.4 Calculation Objects: Other Orbit Elements

Beta\_Angle\_Mars  
 Beta\_Angle\_Mercury  
 Beta\_Angle\_Moon  
 Beta\_Angle\_Neptune  
 Beta\_Angle\_Pluto  
 Beta\_Angle\_Saturn  
 Beta\_Angle\_Uranus  
 Beta\_Angle\_Venus

## D.4.5 Calculation Objects: Target Vector Elements

C3\_Energy\_Mars  
 C3\_Energy\_Mercury  
 C3\_Energy\_Moon  
 C3\_Energy\_Neptune  
 C3\_Energy\_Pluto  
 C3\_Energy\_Saturn  
 C3\_Energy\_Uranus  
 C3\_Energy\_Venus

## D.4.6 Calculation Objects: Spherical Elements

Declination_(EarthGSE)	Right_Asc_(MercuryMJ2000Ec)
Declination_(EarthGSM)	Right_Asc_(MoonFixed)
Declination_(MJ2000Ec)	Right_Asc_(MoonMJ2000Ec)
Declination_(MODEc)	Right_Asc_(NeptuneFixed)
Declination_(MOEEc)	Right_Asc_(NeptuneMJ2000Ec)
Declination_(MOEEq)	Right_Asc_(PlutoFixed)
Declination_(MarsFixed)	Right_Asc_(PlutoMJ2000Ec)
Declination_(MarsMJ2000Ec)	Right_Asc_(SaturnFixed)
Declination_(MercuryFixed)	Right_Asc_(SaturnMJ2000Ec)
Declination_(MercuryMJ2000Ec)	Right_Asc_(TODEc)
Declination_(MoonFixed)	Right_Asc_(TOEEc)
Declination_(MoonMJ2000Ec)	Right_Asc_(TOEEq)
Declination_(NeptuneFixed)	Right_Asc_(UranusFixed)
Declination_(NeptuneMJ2000Ec)	Right_Asc_(UranusMJ2000Ec)
Declination_(PlutoFixed)	Right_Asc_(VenusFixed)
Declination_(PlutoMJ2000Ec)	Right_Asc_(VenusMJ2000Ec)
Declination_(SaturnMJ2000Ec)	Right_Asc_Mars_(MJ2000Eq)
Declination_(SaturnsFixed)	Right_Asc_Mercury_(MJ2000Eq)
Declination_(TODEc)	Right_Asc_Moon_(MJ2000Eq)
Declination_(TOEEc)	Right_Asc_Neptune_(MJ2000Eq)

Declination_(TOEEq)	Right_Asc_Pluto_(MJ2000Eq)
Declination_(UranusFixed)	Right_Asc_Saturn_(MJ2000Eq)
Declination_(UranusMJ2000Eq)	Right_Asc_Uranus_(MJ2000Eq)
Declination_(VenusFixed)	Right_Asc_Venus_(MJ2000Eq)
Declination_(VenusMJ2000Eq)	V_Mag_(MJ2000Eq)
Declination_Mars_(MJ2000Eq)	V_Mag_(MODEc)
Declination_Mercury_(MJ2000Eq)	V_Mag_(MOEEc)
Declination_Moon_(MJ2000Eq)	V_Mag_(MOEEq)
Declination_Neptune_(MJ2000Eq)	V_Mag_(MarsFixed)
Declination_Pluto_(MJ2000Eq)	V_Mag_(MarsMJ2000Eq)
Declination_Saturn_(MJ2000Eq)	V_Mag_(MercuryFixed)
Declination_Uranus_(MJ2000Eq)	V_Mag_(MercuryMJ2000Eq)
Declination_Venus_(MJ2000Eq)	V_Mag_(MoonFixed)
R_Mag_(MarsFixed)	V_Mag_(MoonMJ2000Eq)
R_Mag_(MercuryFixed)	V_Mag_(NeptuneFixed)
R_Mag_(MoonFixed)	V_Mag_(NeptuneMJ2000Eq)
R_Mag_(NeptuneFixed)	V_Mag_(PlutoFixed)
R_Mag_(PlutoFixed)	V_Mag_(PlutoMJ2000Eq)
R_Mag_(SaturnFixed)	V_Mag_(SaturnMJ2000Eq)
R_Mag_(UranusFixed)	V_Mag_(SaturnsFixed)
R_Mag_(VenusFixed)	V_Mag_(TODEc)
R_Mag_Mars	V_Mag_(TOEEc)
R_Mag_Mercury	V_Mag_(TOEEq)
R_Mag_Moon	V_Mag_(UranusFixed)
R_Mag_Neptune	V_Mag_(UranusMJ2000Eq)
R_Mag_Pluto	V_Mag_(VenusFixed)
R_Mag_Saturn	V_Mag_(VenusMJ2000Eq)
R_Mag_Uranus	V_Mag_Mars_(MJ2000Eq)
R_Mag_Venus	V_Mag_Mercury_(MJ2000Eq)
R_Mag_(EarthGSE)	V_Mag_(EarthGSE)
R_Mag_(EarthGSM)	V_Mag_(EarthGSM)
Right_Asc_(MJ2000Eq)	V_Mag_Moon_(MJ2000Eq)
Right_Asc_(MODEc)	V_Mag_Neptune_(MJ2000Eq)
Right_Asc_(MOEEc)	V_Mag_Pluto_(MJ2000Eq)
Right_Asc_(MOEEq)	V_Mag_Saturn_(MJ2000Eq)
Right_Asc_(MarsFixed)	V_Mag_Uranus_(MJ2000Eq)
Right_Asc_(MarsMJ2000Eq)	V_Mag_Venus_(MJ2000Eq)
Right_Asc_(MercuryFixed)	Right_Asc_(EarthGSE)
Right_Asc_(EarthGSM)	

## D.4.7 Calculation Objects: Vector Elements

(RxV)_Mag	(RxV)_Z_(MOEEq)
(RxV)_Mag_(MarsFixed)	(RxV)_Z_(MarsFixed)
(RxV)_Mag_(MarsMJ2000)	(RxV)_Z_(MarsMJ2000Ec)
(RxV)_Mag_(MarsMJ2000Eq)	(RxV)_Z_(MarsMJ2000Eq)
(RxV)_Mag_(MercuryFixed)	(RxV)_Z_(MercuryFixed)
(RxV)_Mag_(MercuryMJ2000)	(RxV)_Z_(MercuryMJ2000Ec)
(RxV)_Mag_(MercuryMJ2000Eq)	(RxV)_Z_(MercuryMJ2000Eq)
(RxV)_Mag_(MoonFixed)	(RxV)_Z_(MoonFixed)
(RxV)_Mag_(MoonMJ2000)	(RxV)_Z_(MoonMJ2000Ec)
(RxV)_Mag_(MoonMJ2000Eq)	(RxV)_Z_(MoonMJ2000Eq)
(RxV)_Mag_(NeptuneFixed)	(RxV)_Z_(NeptuneFixed)
(RxV)_Mag_(NeptuneMJ2000)	(RxV)_Z_(NeptuneMJ2000Ec)
(RxV)_Mag_(NeptuneMJ2000Eq)	(RxV)_Z_(NeptuneMJ2000Eq)
(RxV)_Mag_(PlutoFixed)	(RxV)_Z_(PlutoFixed)
(RxV)_Mag_(PlutoMJ2000)	(RxV)_Z_(PlutoMJ2000Ec)
(RxV)_Mag_(PlutoMJ2000Eq)	(RxV)_Z_(PlutoMJ2000Eq)
(RxV)_Mag_(SaturnFixed)	(RxV)_Z_(SaturnFixed)
(RxV)_Mag_(SaturnMJ2000)	(RxV)_Z_(SaturnMJ2000Ec)
(RxV)_Mag_(SaturnMJ2000Eq)	(RxV)_Z_(SaturnMJ2000Eq)
(RxV)_Mag_(UranusFixed)	(RxV)_Z_(TODEc)
(RxV)_Mag_(UranusMJ2000)	(RxV)_Z_(TODEq)
(RxV)_Mag_(UranussMJ2000Eq)	(RxV)_Z_(TOEEc)
(RxV)_Mag_(VenusFixed)	(RxV)_Z_(TOEEq)
(RxV)_Mag_(VenusMJ2000)	(RxV)_Z_(UranusFixed)
(RxV)_Mag_(VenusMJ2000Eq)	(RxV)_Z_(UranusMJ2000Ec)
(RxV)_X	(RxV)_Z_(UranusMJ2000Eq)
(RxV)_X_(Fixed)	(RxV)_Z_(VenusFixed)
(RxV)_X_(MJ2000Eq)	(RxV)_Z_(VenusMJ2000Ec)
(RxV)_X_(MODEc)	(RxV)_Z_(VenusMJ2000Eq)
(RxV)_X_(MODEq)	(RxV)_X_(MOEEc)
(RxV)_X_(MOEEq)	Vector_Dec_(Fixed)
(RxV)_X_(MarsFixed)	Vector_Dec_(MJ2000Eq)
(RxV)_X_(MarsMJ2000Eq)	Vector_Dec_(MODEc)
(RxV)_X_(MercuryFixed)	Vector_Dec_(MODEq)
(RxV)_X_(MercuryMJ2000Eq)	Vector_Dec_(MOEEc)
(RxV)_X_(MercuryMJ2000Eq)	Vector_Dec_(MOEEq)
(RxV)_X_(MoonFixed)	Vector_Dec_(MarsFixed)
(RxV)_X_(MoonMJ2000Eq)	Vector_Dec_(MarsMJ2000Eq)
(RxV)_X_(MoonMJ2000Eq)	Vector_Dec_(MarsMJ2000Eq)
(RxV)_X_(NeptuneFixed)	Vector_Dec_(MercuryFixed)
(RxV)_X_(NeptuneMJ2000Eq)	Vector_Dec_(MercuryMJ2000Eq)
(RxV)_X_(NeptuneMJ2000Eq)	Vector_Dec_(MercuryMJ2000Eq)
(RxV)_X_(PlutoFixed)	Vector_Dec_(MoonFixed)
(RxV)_X_(PlutoMJ2000Eq)	Vector_Dec_(MoonMJ2000Eq)
(RxV)_X_(PlutoMJ2000Eq)	Vector_Dec_(MoonMJ2000Eq)
(RxV)_X_(SaturnFixed)	Vector_Dec_(NeptuneFixed)
(RxV)_X_(SaturnMJ2000Eq)	Vector_Dec_(NeptuneMJ2000Eq)
(RxV)_X_(SaturnMJ2000Eq)	Vector_Dec_(NeptuneMJ2000Eq)
(RxV)_X_(EarthGSE)	(RxV)_Z_(MOEEc)
(RxV)_Y_(EarthGSE)	(RxV)_X_(EarthGSM)
(RxV)_Z_(EarthGSE)	(RxV)_Y_(EarthGSM)
EarthGSM_Position_X	(RxV)_Z_(EarthGSM)
	EarthGSM_Velocity_X

EarthGSM_Position_Y	EarthGSM_Velocity_Y
EarthGSM_Position_Z	EarthGSM_Velocity_Z
Vector_Dec_(EarthGSE)	Vector_Dec_(EarthGSM)
Vector_RA_(EarthGSE)	Vector_RA_(EarthGSM)
Vector_Dec_(PlutoFixed)	(RxV)_X_(TODEc)
Vector_Dec_(PlutoMJ2000Ec)	(RxV)_X_(TODEq)
Vector_Dec_(PlutoMJ2000Eq)	(RxV)_X_(TOEEc)
Vector_Dec_(SaturnFixed)	(RxV)_X_(TOEEq)
Vector_Dec_(SaturnMJ2000Ec)	(RxV)_X_(UranusFixed)
Vector_Dec_(SaturnMJ2000Eq)	(RxV)_X_(UranusMJ2000Ec)
Vector_Dec_(TODEc)	(RxV)_X_(UranusMJ2000Eq)
Vector_Dec_(TODEq)	(RxV)_X_(VenusFixed)
Vector_Dec_(TOEEc)	(RxV)_X_(VenusMJ2000Ec)
Vector_Dec_(TOEEq)	(RxV)_X_(VenusMJ2000Eq)
Vector_Dec_(UranusFixed)	(RxV)_Y
Vector_Dec_(UranusMJ2000Ec)	(RxV)_Y_(Fixed)
Vector_Dec_(UranusMJ2000Eq)	(RxV)_Y_(MJ2000Ec)
Vector_Dec_(VenusFixed)	(RxV)_Y_(MODEc)
Vector_Dec_(VenusMJ2000Ec)	(RxV)_Y_(MODEq)
Vector_Dec_(VenusMJ2000Eq)	(RxV)_Y_(MOEEc)
Vector_RA_(Fixed)	(RxV)_Y_(MOEEq)
Vector_RA_(MJ2000Ec)	(RxV)_Y_(MarsFixed)
Vector_RA_(MODEc)	(RxV)_Y_(MarsMJ2000Ec)
Vector_RA_(MODEq)	(RxV)_Y_(MarsMJ2000Eq)
Vector_RA_(MOEEc)	(RxV)_Y_(MercuryFixed)
Vector_RA_(MOEEq)	(RxV)_Y_(MercuryMJ2000Ec)
Vector_RA_(MarsFixed)	(RxV)_Y_(MercuryMJ2000Eq)
Vector_RA_(MarsMJ2000Ec)	(RxV)_Y_(MoonFixed)
Vector_RA_(MarsMJ2000Eq)	(RxV)_Y_(MoonMJ2000Ec)
Vector_RA_(MercuryFixed)	(RxV)_Y_(MoonMJ2000Eq)
Vector_RA_(MercuryMJ2000Ec)	(RxV)_Y_(NeptuneFixed)
Vector_RA_(MercuryMJ2000Eq)	(RxV)_Y_(NeptuneMJ2000Ec)
Vector_RA_(MoonFixed)	(RxV)_Y_(NeptuneMJ2000Eq)
Vector_RA_(MoonMJ2000Ec)	(RxV)_Y_(PlutoFixed)
Vector_RA_(MoonMJ2000Eq)	(RxV)_Y_(PlutoMJ2000Ec)
Vector_RA_(NeptuneFixed)	(RxV)_Y_(PlutoMJ2000Eq)
Vector_RA_(NeptuneMJ2000Ec)	(RxV)_Y_(SaturnFixed)
Vector_RA_(NeptuneMJ2000Eq)	(RxV)_Y_(SaturnMJ2000Ec)
Vector_RA_(PlutoFixed)	(RxV)_Y_(SaturnMJ2000Eq)
Vector_RA_(PlutoMJ2000Ec)	(RxV)_Y_(TODEc)
Vector_RA_(PlutoMJ2000Eq)	(RxV)_Y_(TODEq)
Vector_RA_(SaturnFixed)	(RxV)_Y_(TOEEc)
Vector_RA_(SaturnMJ2000Ec)	(RxV)_Y_(TOEEq)
Vector_RA_(SaturnMJ2000Eq)	(RxV)_Y_(UranusMJ2000Ec)
Vector_RA_(TODEc)	(RxV)_Y_(UranusMJ2000Eq)
Vector_RA_(TODEq)	(RxV)_Y_(UranussFixed)
Vector_RA_(TOEEc)	(RxV)_Y_(VenusFixed)
Vector_RA_(TOEEq)	(RxV)_Y_(VenusMJ2000Ec)
Vector_RA_(UranusFixed)	(RxV)_Y_(VenusMJ2000Eq)
Vector_RA_(UranusMJ2000Ec)	(RxV)_Z
Vector_RA_(UranusMJ2000Eq)	(RxV)_Z_(Fixed)
Vector_RA_(VenusFixed)	(RxV)_Z_(MJ2000Ec)
Vector_RA_(VenusMJ2000Ec)	(RxV)_Z_(MODEc)
Vector_RA_(VenusMJ2000Eq)	(RxV)_Z_(MODEq)

## D.4.8 Coordinate Systems: Central Body Inertial Elements

Mars_Centered_Mean_J2000	Mars_Centered_MJ2000Ec
Mercury_Centered_Mean_J2000	Mercury_Centered_MJ2000Ec
Moon_Centered_Mean_J2000	Moon_Centered_MJ2000Ec
Neptune_Centered_Mean_J2000	Neptune_Centered_MJ2000Ec
Pluto_Centered_Mean_J2000	Pluto_Centered_MJ2000Ec
Saturn_Centered_Mean_J2000	Saturn_Centered_MJ2000Ec
Uranus_Centered_Mean_J2000	Uranus_Centered_MJ2000Ec
Venus_Centered_Mean_J2000	Venus_Centered_MJ2000Ec
Sune_Centered_MJ2000Ec	

## D.4.9 Propagators Elements

Moon_LP165P	Moon_LP165P_and_SRP
CisLunar	Moon_SRP
EarthMoon_L2_AllPlanets	Neptune_2-Body
EarthMoon_L2_AllPlanets_and_SRP	Neptune_AllPlanets
EarthMoon_L2_ESM	Neptune_SRP
EarthMoon_L2_ESM_JGM	Pluto_2-Body
EarthMoon_L2_ESM_LP165P	Pluto_AllPlanets
EarthSun_L2_AllPlanets	Pluto_SRP
EarthSun_L2_AllPlanets_and_SRP	Saturn_2-Body
Earth_J2	Saturn_AllPlanets
Earth_Point_Mass	Saturn_SRP
Heliocentric	Sun_AllPlanets
Lunar	Sun_AllPlanets_and_SRP
Mars_2-Body	Uranus_2-Body
Mars_AllPlanets	Uranus_AllPlanets
Mars_MARS50C	Uranus_SRP
Mars_MARS50C_and_SRP	Venus_2-Body
Mars_SRP	Venus_AllPlanets
Mercury_2-Body	Venus_MGNP180U
Mercury_AllPlanets	Venus_MGNP180U_and_SRP
Mercury_SRP	Venus_SRP
Moon_2-Body	Moon_AllPlanets

## D.4.10 Axes Elements

Earth\_GSE Earth\_GSM

## D.4.11 Coordinate System Elements

Earth\_GSE Earth\_GSM

**D.4.12 Vectors Elements**

Cross_Product_(RxV)	Cross_Product_(RxV)_(PlutoFixed)
Cross_Product_(RxV)_(fixed)	Cross_Product_(RxV)_(PlutoMJ2000)
Cross_Product_(RxV)_(MarsFixed)	Cross_Product_(RxV)_(PlutoMJ2000Ec)
Cross_Product_(RxV)_(MarsMJ2000)	Cross_Product_(RxV)_(SaturnFixed)
Cross_Product_(RxV)_(MarsMJ2000Ec)	Cross_Product_(RxV)_(SaturnMJ2000)
Cross_Product_(RxV)_(MercuryFixed)	Cross_Product_(RxV)_(SaturnMJ2000Ec)
Cross_Product_(RxV)_(MercuryMJ2000)	Cross_Product_(RxV)_(UranusFixed)
Cross_Product_(RxV)_(MercuryMJ2000Ec)	Cross_Product_(RxV)_(UranusMJ2000)
Cross_Product_(RxV)_(MoonFixed)	Cross_Product_(RxV)_(UranusMJ2000Ec)
Cross_Product_(RxV)_(MoonMJ2000)	Cross_Product_(RxV)_(VenusFixed)
Cross_Product_(RxV)_(MoonMJ2000Ec)	Cross_Product_(RxV)_(VenusMJ2000)
Cross_Product_(RxV)_(NeptuneFixed)	Cross_Product_(RxV)_(VenusMJ2000Ec)
Cross_Product_(RxV)_(NeptuneMJ2000)	Cross_Product_(RxV)_(EarthGSE)
Cross_Product_(RxV)_(NeptuneMJ2000Ec)	Cross_Product_(RxV)_(EarthGSM)
Cross_Product_(YofGSM)	Cross_Product_(ZofGSE)
EarthSun_J2K_Velocity	EarthSun_Vector
DiPole_Vector_GSM	

**D.4.13 Vectors: Vehicle Local Elements**

Position_(MarsFixed)	Velocity_(MarsFixed)
Position_(MarsMJ2000Ec)	Velocity_(MarsMJ2000Ec)
Position_(MercuryFixed)	Velocity_(MercuryFixed)
Position_(MercuryMJ2000Ec)	Velocity_(MercuryMJ2000Ec)
Position_(MoonFixed)	Velocity_(MoonFixed)
Position_(MoonMJ2000Ec)	Velocity_(MoonMJ2000Ec)
Position_(NeptuneFixed)	Velocity_(NeptuneFixed)
Position_(NeptuneMJ2000Ec)	Velocity_(NeptuneMJ2000Ec)
Position_(PlutoFixed)	Velocity_(PlutoFixed)
Position_(PlutoMJ2000Ec)	Velocity_(PlutoMJ2000Ec)
Position_(SaturnFixed)	Velocity_(SaturnFixed)
Position_(SaturnMJ2000Ec)	Velocity_(SaturnMJ2000Ec)
Position_(UranusFixed)	Velocity_(UranusFixed)
Position_(UranusMJ2000Ec)	Velocity_(UranusMJ2000Ec)
Position_(VenusFixed)	Velocity_(VenusFixed)
Position_(VenusMJ2000Ec)	Velocity_(VenusMJ2000Ec)
Position_Mars_(MJ2000)	Velocity_Mars_(MJ2000)
Position_Mercury_(MJ2000)	Velocity_Mercury_(MJ2000)
Position_Moon_(MJ2000)	Velocity_Moon_(MJ2000)
Position_Neptune_(MJ2000)	Velocity_Neptune_(MJ2000)
Position_Saturn_(MJ2000)	Velocity_Saturn_(MJ2000)
Position_Uranus_(MJ2000)	Velocity_Uranus_(MJ2000)
Position_Venus_(MJ2000)	Velocity_Venus_(MJ2000)
Position_(EarthGSE)	Velocity_(EarthGSE)
Position_(EarthGSM)	Velocity_(EarthGSM)

## D.5 Report Styles

Classical_Orbit_Elements	GMAT_CSPParameters_TODEq
Earth_MJ2000_Position_Velocity	GMAT_CSPParameters_TOEEc
GMAT_Apoapsis_Periapsis	GMAT_CSPParameters_TOEEq
GMAT_CSPParameters_Fixed	GMAT_CSPParameters_UranusFixed
GMAT_CSPParameters_MJ2000Ec	GMAT_CSPParameters_Uranus_MJ2000Ec
GMAT_CSPParameters_MJ2000Eq	GMAT_CSPParameters_Uranus_MJ2000Eq
GMAT_CSPParameters_MODEc	GMAT_CSPParameters_VenusFixed
GMAT_CSPParameters_MODEq	GMAT_CSPParameters_Venus_MJ2000Ec
GMAT_CbParameters	GMAT_CSPParameters_Venus_MJ2000Eq
GMAT_CbParameters_Mars	GMAT_CSPParameters_MOEEc
GMAT_CSPParameters_MOEEq	GMAT_CbParameters_Mercury
GMAT_CSPParameters_MarsFixed	GMAT_CbParameters_Moon
GMAT_CSPParameters_Mars_MJ2000Ec	GMAT_CbParameters_Neptune
GMAT_CSPParameters_Mars_MJ2000Eq	GMAT_CbParameters_Pluto
GMAT_CSPParameters_MercuryFixed	GMAT_CbParameters_Saturn
GMAT_CSPParameters_Mercury_MJ2000Ec	GMAT_CbParameters_Uranus
GMAT_CSPParameters_Mercury_MJ2000Eq	GMAT_CbParameters_Venus
GMAT_CSPParameters_MoonFixed	J2000_ECI_Position_Velocity
GMAT_CSPParameters_Moon_MJ2000Ec	Mars_MJ2000_Position_Velocity
GMAT_CSPParameters_Moon_MJ2000Eq	Mercury_MJ2000_Position_Velocity
GMAT_CSPParameters_NeptuneFixed	Moon_MJ2000_Position_Velocity
GMAT_CSPParameters_Neptune_MJ2000Ec	Neptune_MJ2000_Position_Velocity
GMAT_CSPParameters_Neptune_MJ2000Eq	GMAT_CSPParameters_PlutoFixed
Pluto_MJ2000_Position_Velocity	GMAT_CSPParameters_Pluto_MJ2000Ec
Saturn_MJ2000_Position_Velocity	GMAT_CSPParameters_Pluto_MJ2000Eq
Sun_MJ2000Ec_Position_Velocity	GMAT_CSPParameters_SaturnFixed
Sun_MJ2000_Position_Velocity	GMAT_CSPParameters_Saturn_MJ2000Ec
Uranus_MJ2000_Position_Velocity	GMAT_CSPParameters_Saturn_MJ2000Eq
Venus_MJ2000_Position_Velocity	GMAT_CSPParameters_TODEc
Greenwich_Hour_Angle	

## D.6 Scripts Used

The main script used with STK is the STK\_Repropagate.m Matlab script. STK\_Repropagate.m connects to STK, propagates satellites in the scenario, generates reports, and outputs performance run times. The STK\_Repropagate script was designed to reduce the time it took to generate STK report files, after modifications to the STK scenario were made, and obtain accurate STK run times.

Refer to Appendix C for more details of this script and others used in the Acceptance Test Plan document.





## Appendix E

### FF Setup

[INSERT explanation of how the FF scenarios were setup]



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