DRAFT
General Mission Analysis Tool (GMAT) Acceptance Test Plan

GMAT Build Date: May 18, 2007

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May 21, 2007

Contents

1 Acceptance Test Plan Overview **17**

1.1 GMAT Introduction 17

1.2 Testing Methodology 17

1.2.1 Propagation 18

1.2.2 Calculation Parameters 19

1.2.3 Integrators 20

1.2.4 Stopping Conditions 21

1.2.5 Libration Point 21

1.2.6 Delta V 22

1.2.7 Performance 22

1.2.8 Control Flow 22

2 Propagation **23**

2.1 Initial Orbit State Conditions 23

2.1.1 Earth Based Test Cases 23

2.1.2 Non-Earth Based Test Cases 25

2.2 Other Initial State Conditions 25

2.2.1 Earth Orientation Parameters(EOP) data 27

2.2.2 Other Planetary Parameters 29

2.3 Naming Convention 31

2.3.1 Comparison Script Information 32

2.4 Test Case Results 32

2.5 FF/STK Comparison 42

3 Calculation Parameters 45

3.1 Initial Orbit State Conditions 45

3.2 Central Body Dependent Parameters 45

3.2.1 Naming Convention 45

3.2.2 Comparison Script Information 46

3.2.3 Test Case Results 46

3.3 Coordinate System Dependent Parameters 50

3.3.1 Naming Convention 50

3.3.2 Comparison Script Information 51

3.3.3 Test Case Results 51

4 Integrators 61

4.1 Initial Orbit Conditions 61

4.2 Naming Convention 61

4.3 Comparison Script Information 62

4.4 Test Case Results 62

5 Stopping Conditions 65

5.1 Initial Orbit Conditions 66

5.2 Naming Convention 70

5.3 Comparison Script Information 70

5.4 Test Case Results 71

6 Libration Points 75

6.1 Initial Orbit Conditions 75

6.2 Naming Convention 76

6.3 Comparison Script Information 77

6.4 Test Case Results 77

7 Delta V 79

7.1 Initial Orbit Conditions 79

7.2 Naming Convention 82

7.3 Comparison Script Information 82

7.4 Test Case Results 82

8 ControlFlow **85**

8.1 Test Case Results 85

A Acronyms **87**

B Initial Conditions **89**

B.1 Propagator Test Cases 89

B.2 Calculation Parameter Test Cases 105

B.3 Integrator Test Cases 106

B.4 Stopping Condition Test Cases 106

B.5 Libration Point Test Cases 106

B.6 DeltaV Test Cases 106

B.7 Performance 106

C Comparison Scripts Guide **107**

C.1 Folder Architecture 107

C.2 Install Instructions 107

C.3 Warnings/Script Hints 108

C.4 BuildRun_Script_GMAT.m script 109

  C.4.1 Purpose 109

  C.4.2 Inputs 109

  C.4.3 Outputs 109

  C.4.4 Script Algorithm 109

C.5 Comparison_Tool1_Tool2_PV.m 109

  C.5.1 Purpose 109

  C.5.2 Inputs 110

C.5.3 Outputs 110

C.5.4 Script Algorithm 110

C.6 Comparison_Tool1_Tool2_CS.m 111

C.6.1 Purpose 111

C.6.2 Inputs 111

C.6.3 Outputs 111

C.6.4 Script Algorithm 112

C.7 Comparison_Tool1_Tool2_Cb.m 112

C.7.1 Purpose 113

C.7.2 Inputs 113

C.7.3 Outputs 113

C.7.4 Script Algorithm 113

C.8 Comparison_Tool1_Tool2_Libr.m 114

C.8.1 Purpose 114

C.8.2 Inputs 115

C.8.3 Outputs 115

C.8.4 Script Algorithm 115

C.9 Comparison_Integ.m 115

C.9.1 Purpose 115

C.9.2 Inputs 115

C.9.3 Outputs 116

C.9.4 Script Algorithm 116

C.10 Comparison_DeltaV.m 117

C.10.1 Purpose 117

C.10.2 Inputs 117

C.10.3 Outputs 117

C.10.4 Script Algorithm 117

C.11 Comparison_StopCond.m 117

C.11.1 Purpose 117

C.11.2 Inputs 117

C.11.3 Outputs 117

C.11.4 Script Algorithm 117

C.12 STK_Repropagate.m 117

C.12.1 Purpose 117

C.12.2 Inputs 117

C.12.3 Outputs 118

C.12.4 Script Algorithm 118

C.13 TimeComparo.m 118

C.13.1 Purpose 118

C.13.2 Inputs 118

C.13.3 Outputs 118

C.13.4 Script Algorithm 118

D STK Setup **119**

D.1 Support Files Needed 119

D.2 STK modules used 119

D.3 Scenario Setup 120

D.3.1 HPOP 120

D.3.2 STK 120

D.4 Astrogator Elements 121

D.4.1 Calculation Objects: Cartesian Elements 121

D.4.2 Calculation Objects: Geodetic Elements 122

D.4.3 Calculation Objects: Keplerian Elements 123

D.4.4 Calculation Objects: Other Orbit Elements 125

D.4.5 Calculation Objects: Target Vector Elements 125

D.4.6 Calculation Objects: Spherical Elements 125

D.4.7 Calculation Objects: Vector Elements 127

D.4.8 Coordinate Systems: Central Body Inertial Elements 129

D.4.9 Propagators Elements 129
D.4.10 Axes Elements 129
D.4.11 Coordinate System Elements 129
D.4.12 Vectors Elements 130
D.4.13 Vectors: Vehicle Local Elements 130
D.5 Report Styles 131
D.6 Scripts Used 131

E FF Setup **133**

List of Figures

List of Tables

2.1 Satellite Initial Conditions 24
2.2 Apogee and Perigee Altitudes for Test Satellites 24
2.3 Integrator,Propagator, and Output Frequency 24
2.4 Non-Earth Keplerian Orbital Elements 25
2.5 Universal Test Case Parameters 26
2.6 EOP Format Accuracy 28
2.7 Planetary Gravitational Constants(mu values) 29
2.8 Flattening Coefficient 29
2.9 Equatorial Radius 30
2.10 Acceptance Matrix 33
2.11 GMAT/STK GEO STK Test Case Comparison 33
2.12 GMAT/STK GPS STK Test Case Comparison 33
2.13 GMAT/STK ISS STK Test Case Comparison 34
2.14 GMAT/STK Molniya STK Test Case Comparison 34
2.15 GMAT/STK SunSync STK Test Case Comparison 35
2.16 GMAT/STK Mars1 STK Test Case Comparison 36
2.17 GMAT/STK Mercury1 STK Test Case Comparison 36
2.18 GMAT/STK Moon STK Test Case Comparison 36
2.19 GMAT/STK Neptune1 STK Test Case Comparison 36
2.20 GMAT/STK Pluto1 STK Test Case Comparison 36
2.21 GMAT/STK Saturn1 STK Test Case Comparison 37
2.22 GMAT/STK Uranus1 STK Test Case Comparison 37

2.23 GMAT/STK Venus1 STK Test Case Comparison 37
2.24 GMAT/STK DeepSpace STK Test Case Comparison 38
2.25 GMAT/STK EML2 STK Test Case Comparison 38
2.26 GMAT/STK ESL2 STK Test Case Comparison 38
2.27 FF/GMAT GEO GMAT Test Case Comparison 39
2.28 FF/GMAT GPS GMAT Test Case Comparison 39
2.29 FF/GMAT ISS GMAT Test Case Comparison 39
2.30 FF/GMAT Molniya GMAT Test Case Comparison 39
2.31 FF/GMAT SunSync GMAT Test Case Comparison 40
2.32 FF/GMAT EML2 GMAT Test Case Comparison 41
2.33 FF/GMAT ESL2 GMAT Test Case Comparison 41
2.34 FF/STK GEO STK Test Case Comparison 42
2.35 FF/STK GPS STK Test Case Comparison 42
2.36 FF/STK ISS STK Test Case Comparison 42
2.37 FF/STK Molniya STK Test Case Comparison 42
2.38 FF/STK SunSync STK Test Case Comparison 43
2.39 FF/STK EML2 STK Test Case Comparison 44
2.40 FF/STK ESL2 STK Test Case Comparison 44

3.1 GMAT/STK Central Body Dependent Parameter Differences (1) 47
3.2 GMAT/STK Central Body Dependent Parameter Differences (2) 47
3.3 GMAT/STK Central Body Dependent Parameter Differences (3) 47
3.4 GMAT/STK Central Body Dependent Parameter Differences (4) 48
3.5 GMAT/STK Central Body Dependent Parameter Differences (5) 48
3.6 FF/GMAT Central Body Dependent Parameter Differences (1) 49
3.7 FF/GMAT Central Body Dependent Parameter Differences (2) 49
3.8 FF/GMAT Central Body Dependent Parameter Differences (3) 49
3.9 FF/GMAT Central Body Dependent Parameter Differences (4) 49
3.10 FF/GMAT Central Body Dependent Parameter Differences (5) 49

3.11 FF/STK Central Body Dependent Parameter Differences (1) 50

3.12 FF/STK Central Body Dependent Parameter Differences (2) 50

3.13 FF/STK Central Body Dependent Parameter Differences (3) 50

3.14 FF/STK Central Body Dependent Parameter Differences (4) 50

3.15 FF/STK Central Body Dependent Parameter Differences (5) 50

3.16 GMAT/STK Coordinate System Dependent Parameter Differences (Position) 53

3.17 GMAT/STK Coordinate System Dependent Parameter Differences (Velocity) 54

3.18 GMAT/STK Coordinate System Dependent Parameter Differences (Specific Angular Momentum) 55

3.19 GMAT/STK Coordinate System Dependent Parameter Differences (Velocity Vector-based) . . . 56

3.20 GMAT/STK Coordinate System Dependent Parameter Differences (Angle-based) 57

3.21 FF/GMAT Coordinate System Dependent Parameter Differences (Position) 58

3.22 FF/GMAT Coordinate System Dependent Parameter Differences (Velocity) 58

3.23 FF/GMAT Coordinate System Dependent Parameter Differences (Specific Angular Momentum) 58

3.24 FF/GMAT Coordinate System Dependent Parameter Differences (Velocity Vector-based) 58

3.25 FF/GMAT Coordinate System Dependent Parameter Differences (Angle-based) 58

3.26 FF/STK Coordinate System Dependent Parameter Differences (Position) 59

3.27 FF/STK Coordinate System Dependent Parameter Differences (Velocity) 59

3.28 FF/STK Coordinate System Dependent Parameter Differences (Specific Angular Momentum) . . 59

3.29 FF/STK Coordinate System Dependent Parameter Differences (Velocity Vector-based) 59

3.30 FF/STK Coordinate System Dependent Parameter Differences (Angle-based) 59

4.1 Exact/GMAT GEO Integrator Test Case Comparison 62

4.2 Exact/GMAT ISS Integrator Test Case Comparison 63

5.1 Stopping Conditions 65

5.2 Initial Orbit Parameters (EarthPM & EarthMJ2000EqPM) 66

5.3 Initial Orbit Parameters (EarthAll & EarthMJ2000EqAll) 67

5.4 Initial Orbit Parameters (EarthPMhyper & EarthMJ2000EqPMhyper) 68

5.5 Initial Orbit Parameters (MoonPM) 68

5.6 Initial Orbit Parameters (MarsPM) 69

5.7 Exact/GMAT EarthPM StopCond Test Case Comparison 71

5.8 Exact/GMAT EarthAll StopCond Test Case Comparison 71

5.9 Exact/GMAT EarthPMhyper StopCond Test Case Comparison 72

5.10 Exact/GMAT MoonPM StopCond Test Case Comparison 72

5.11 Exact/GMAT MarsPM StopCond Test Case Comparison 72

5.12 Exact/GMAT EarthMJ2000EqPM StopCond Test Case Comparison 72

5.13 Exact/GMAT EarthMJ2000EqAll StopCond Test Case Comparison 73

5.14 Exact/GMAT EarthMJ2000EqPMhyper StopCond Test Case Comparison 73

5.15 Exact/GMAT MoonMJ2000EqPM StopCond Test Case Comparison 73

5.16 Exact/GMAT MarsMJ2000EqPM StopCond Test Case Comparison 73

5.17 Exact/GMAT Earth3MultiSatsPM StopCond Test Case Comparison 73

6.1 Initial Orbit Parameters (Sun-Earth(SE) Libration Points) 75

6.2 Initial Orbit Parameters (Sun-Earth-Moon(SEM) Libration Points) 76

6.3 GMAT/STK SEM LibrationTest Test Case Comparison 77

6.4 GMAT/STK SE LibrationTest Test Case Comparison 77

7.1 Initial Orbit Parameters (Earth Impulsive Burns) 80

7.2 Initial Orbit Parameters (Mars Impulsive Burns) 80

7.3 Initial Orbit Parameters (Moon Impulsive Burns) 81

7.4 Initial Orbit Parameters (Sun Impulsive Burns) 81

7.5 Exact/GMAT IEarth DeltaV Test Case Comparison 83

7.6 Exact/GMAT IMars DeltaV Test Case Comparison 83

7.7 Exact/GMAT IMoon DeltaV Test Case Comparison 83

7.8 Exact/GMAT ISun DeltaV Test Case Comparison 83

8.1 Loop Test Case Results 86

B.1 Initial Orbit Parameters (ISS) 89

B.2 Initial Orbit Parameters (Sun-Sync) 90

B.3 Initial Orbit Parameters (GPS) 91

B.4 Initial Orbit Parameters (Molniya) 92

B.5 Initial Orbit Parameters (GEO) 93

B.6 Initial Orbit Parameters (Mars) 94

B.7 Initial Orbit Parameters (Mercury) 95

B.8 Initial Orbit Parameters (Moon) 96

B.9 Initial Orbit Parameters (Neptune) 97

B.10 Initial Orbit Parameters (Pluto) 98

B.11 Initial Orbit Parameters (Saturn) 99

B.12 Initial Orbit Parameters (Uranus) 100

B.13 Initial Orbit Parameters (Venus) 101

B.14 Initial Orbit Parameters (DeepSpace) 102

B.15 Initial Orbit Parameters (EML2) 103

B.16 Initial Orbit Parameters (ESL2) 104

B.17 Initial Orbit Parameters (Hyperbolic) 105

D.1 STK support files 119

D.2 STK modules used 120

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 (TODEq)
  - 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)

- 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 ??) 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 8) 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,[1] due to a similar objective of testing the numerical implementation of the program's 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 .[1] 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 24. The perigee and apogee altitudes of the test case orbits can be seen in Table 2.2, on Page 24.

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.[2] 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.[3]

Table 2.1: Satellite Initial Conditions

Category	Orbit Type	X(km)	Y(km)	Z(km)	Vx(km/s)	Vy(km/s)	Vz(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 24.

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."[6]

"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."*[4]

"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",[4] 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."[5]

"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."[5]

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 ΔAT, has been used since 1972 in order to keep —UTC-UT1—$\leq$ 0.9sec. 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: GMAT/STK GEO STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.0002573600464	1.793784749e-008
EarthLuna-0-0-0	0.000319469177	2.246260344e-008
EarthSunLuna-EGM96-JR-SRP	0.000157111986	1.101136958e-008
EarthSunLuna-EGM96-MSISE90-SRP	0.0001571119996	1.101136862e-008
EarthSunLuna-JGM2-JR-SRP	0.0001132816464	7.859884531e-009
EarthSunLuna-JGM2-MSISE90-SRP	0.0001132816525	7.859884883e-009
EarthSunLuna-JGM3-JR-SRP	0.0002438654858	1.730633303e-008
EarthSunLuna-JGM3-MSISE90-SRP	0.0002438654861	1.730633311e-008
EarthSun-0-0-0	2.279168371e-005	1.614468765e-009
Earth-0-0-0	2.111395905e-005	1.410324921e-009
Earth-0-0-SRP	4.571760608e-005	2.618694012e-009
Earth-0-JR-0	2.111395905e-005	1.410324921e-009
Earth-0-MSISE90-0	2.111395905e-005	1.410324921e-009
Earth-EGM96-0-0	0.0001110202624	8.029310693e-009
Earth-JGM2-0-0	2.954895496e-005	2.05598806e-009
Earth-JGM3-0-0	1.603674008e-005	1.08902881e-009

Table 2.12: GMAT/STK GPS STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.857890303e-005	2.696491985e-009
EarthLuna-0-0-0	2.280562281e-005	3.320021018e-009
EarthSunLuna-EGM96-JR-SRP	0.1959052443	2.485425413e-005
EarthSunLuna-EGM96-MSISE90-SRP	0.1959347769	2.485881465e-005
EarthSunLuna-JGM2-JR-SRP	0.1959143599	2.485563669e-005
EarthSunLuna-JGM2-MSISE90-SRP	0.1959227868	2.485702347e-005
EarthSunLuna-JGM3-JR-SRP	0.1959136649	2.485560304e-005
EarthSunLuna-JGM3-MSISE90-SRP	0.1959104274	2.485513888e-005
EarthSun-0-0-0	1.81527305e-006	2.257416233e-010
Earth-0-0-0	2.704817671e-006	3.741292798e-010
Earth-0-0-SRP	0.0878120195	9.617041298e-006
Earth-0-JR-0	2.704817671e-006	3.741292798e-010
Earth-0-MSISE90-0	1.54909103e-005	2.226217304e-009
Earth-EGM96-0-0	3.230673797e-005	4.260188402e-009
Earth-JGM2-0-0	3.207859422e-005	4.299912419e-009
Earth-JGM3-0-0	3.197574489e-005	4.255726699e-009

Table 2.13: GMAT/STK ISS STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.236533809e-005	1.385493045e-008
EarthLuna-0-0-0	2.656381117e-005	3.027548132e-008
EarthSunLuna-EGM96-JR-SRP	278.7490457	0.3182017608
EarthSunLuna-EGM96-MSISE90-SRP	56.19367014	0.06443183746
EarthSunLuna-JGM2-JR-SRP	265.043753	0.3028869043
EarthSunLuna-JGM2-MSISE90-SRP	56.19388165	0.06443206028
EarthSunLuna-JGM3-JR-SRP	278.7489221	0.3182016489
EarthSunLuna-JGM3-MSISE90-SRP	56.19332541	0.06443145135
EarthSun-0-0-0	1.433764674e-005	1.600957323e-008
Earth-0-0-0	2.047203147e-005	2.325251323e-008
Earth-0-0-SRP	0.244823116	0.0002550285075
Earth-0-JR-0	251.765217	0.2867219205
Earth-0-MSISE90-0	54.12970949	0.06180127344
Earth-EGM96-0-0	0.0003663016096	4.164070917e-007
Earth-JGM2-0-0	0.0002104591217	2.411877645e-007
Earth-JGM3-0-0	0.0002166929687	2.47505086e-007

Table 2.14: GMAT/STK Molniya STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.0001645654561	1.252157429e-007
EarthLuna-0-0-0	0.0001587779228	1.205662193e-007
EarthSunLuna-EGM96-JR-SRP	13.53119687	0.009730652052
EarthSunLuna-EGM96-MSISE90-SRP	7.25773273	0.004949260662
EarthSunLuna-JGM2-JR-SRP	13.53346199	0.009731885706
EarthSunLuna-JGM2-MSISE90-SRP	7.260932491	0.00495105133
EarthSunLuna-JGM3-JR-SRP	13.53295584	0.009731601686
EarthSunLuna-JGM3-MSISE90-SRP	7.260582648	0.004951077623
EarthSun-0-0-0	0.000348717827	2.914208443e-007
Earth-0-0-0	0.0002791429809	2.328568085e-007
Earth-0-0-SRP	0.571576837	0.0004793217459
Earth-0-JR-0	15.70095053	0.01312840386
Earth-0-MSISE90-0	7.009963698	0.005861407998
Earth-EGM96-0-0	0.001747777921	1.46609522e-006
Earth-JGM2-0-0	0.00156516582	1.313722882e-006
Earth-JGM3-0-0	0.001286385724	1.080857462e-006

Table 2.15: GMAT/STK SunSync STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	4.699222822e-005	5.325204802e-008
EarthLuna-0-0-0	1.738032476e-005	1.943588041e-008
EarthSunLuna-EGM96-JR-SRP	185.5519514	0.2108884067
EarthSunLuna-EGM96-MSISE90-SRP	45.12786362	0.05132420504
EarthSunLuna-JGM2-JR-SRP	185.5519345	0.2108883121
EarthSunLuna-JGM2-MSISE90-SRP	45.12684175	0.05132310311
EarthSunLuna-JGM3-JR-SRP	185.5517129	0.2108881509
EarthSunLuna-JGM3-MSISE90-SRP	45.12759811	0.0513239131
EarthSun-0-0-0	4.687777606e-006	5.023688912e-009
Earth-0-0-0	4.483249915e-005	5.068280737e-008
Earth-0-0-SRP	0.1578758295	0.0001369580266
Earth-0-JR-0	172.0259163	0.1950745493
Earth-0-MSISE90-0	42.66516434	0.04839009284
Earth-EGM96-0-0	7.308356983e-005	8.466691171e-008
Earth-JGM2-0-0	8.928348594e-005	9.655432558e-008
Earth-JGM3-0-0	6.997911597e-005	7.571452902e-008

Table 2.16: GMAT/STK Mars1 STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.1994303898	0.0001681334573
Mars-0-0-0	0.1873874394	0.0001577557948
Mars-0-0-SRP	0.7867928767	0.0006572167727
Mars-MARS50C-0-0	0.4488316637	0.0003800813667
Mars-MARS50C-0-SRP	1.214053862	0.001021133703

Table 2.17: GMAT/STK Mercury1 STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.1124163711	9.591759819e-005
Mercury-0-0-0	0.02585481636	2.218352736e-005
Mercury-0-0-SRP	58.83805392	0.05048777188

Table 2.18: GMAT/STK Moon STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.0002146368472	1.355643864e-007
Luna-0-0-0	0.03443001175	2.456930533e-005
Luna-0-0-SRP	0.03471809841	2.413271946e-005
Luna-LP165P-0-0	0.0002701673647	1.922174669e-007
Luna-LP165P-0-SRP	0.1350043985	9.596583571e-005

Table 2.19: GMAT/STK Neptune1 STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.9974264518	0.0005074875215
Neptune-0-0-0	1.171036908	0.0005920828399
Neptune-0-0-SRP	0.6214495234	0.0003128000507

Table 2.20: GMAT/STK Pluto1 STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.8883195792	0.0004683900657
Pluto-0-0-0	0.2632397208	0.0001382385307
Pluto-0-0-SRP	0.7534556636	0.0003932329143

Table 2.21: GMAT/STK Saturn1 STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.1414864331	4.873107384e-005
Saturn-0-0-0	0.4497282767	0.0001561546333
Saturn-0-0-SRP	0.3124746558	0.000102600788

Table 2.22: GMAT/STK Uranus1 STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.2465709269	7.912323063e-005
Uranus-0-0-0	1.320413817	0.0004243963023
Uranus-0-0-SRP	1.156382201	0.0002904419051

Table 2.23: GMAT/STK Venus1 STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.02561929021	2.548815625e-005
Venus-0-0-0	0.01793453836	1.768517227e-005
Venus-0-0-SRP	0.3477682342	0.0003453235732
Venus-MGNP180U-0-0	0.007510965788	7.525754724e-006
Venus-MGNP180U-0-SRP	0.4083837321	0.0004049592692

Table 2.24: GMAT/STK DeepSpace STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.02027141264	3.996534351e-009

Table 2.25: GMAT/STK EML2 STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	522765.4104	2.863727549
AllPlanets-0-0-SRP	162722.736	0.8844521611
EarthSunLuna-0-0-0	191050.7674	1.043593205
EarthSunLuna-JGM2-0-0	83170.98289	0.4533442704

Table 2.26: GMAT/STK ESL2 STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	29036.76192	0.01713687194
AllPlanets-0-0-SRP	228360.2465	0.1774325007

Table 2.27: FF/GMAT GEO GMAT Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.02466296086	2.348952999e-006
EarthLuna-0-0-0	0.02466037174	2.264158243e-006
EarthSun-0-0-0	4.79785384e-005	8.493947765e-007
Earth-0-0-0	5.214381207e-005	6.89627309e-007
Earth-0-0-SRP	2.899321865	0.0001245219489
Earth-JGM2-0-0	0.02515954067	2.313999898e-006

Table 2.28: FF/GMAT GPS GMAT Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.001885974435	1.052020705e-006
EarthLuna-0-0-0	0.001874007099	9.43361654e-007
EarthSun-0-0-0	3.432176702e-006	8.317293859e-007
Earth-0-0-0	5.489921041e-006	7.9829921e-007
Earth-0-0-SRP	0.5814667923	6.084184505e-005
Earth-JGM2-0-0	0.01104317452	2.140216499e-006

Table 2.29: FF/GMAT ISS GMAT Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	5.610904349e-006	8.224014796e-007
EarthLuna-0-0-0	1.133489824e-005	8.407000067e-007
EarthSun-0-0-0	9.638402495e-006	8.134703987e-007
Earth-0-0-0	2.358180759e-005	8.186468434e-007
Earth-0-0-SRP	0.1095353597	0.0001183226844
Earth-JGM2-0-0	0.2076314901	0.0002404721693

Table 2.30: FF/GMAT Molniya GMAT Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.01444526657	1.203396044e-005
EarthLuna-0-0-0	0.01424235005	1.19546892e-005
EarthSun-0-0-0	0.0003311394147	8.232647373e-007
Earth-0-0-0	5.789754939e-005	8.078947532e-007
Earth-0-0-SRP	2.735360369	0.002258471401
Earth-JGM2-0-0	3.064693947	0.002562937467

Table 2.31: FF/GMAT SunSync GMAT Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.624452888e-005	8.363014362e-007
EarthLuna-0-0-0	3.641972152e-005	8.139327674e-007
EarthSun-0-0-0	1.62185169e-005	8.470799538e-007
Earth-0-0-0	8.93851495e-006	8.215195e-007
Earth-0-0-SRP	0.04776731849	4.873717267e-005
Earth-JGM2-0-0	0.09458368297	0.0001055216409

Table 2.32: FF/GMAT EML2 GMAT Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	732436.6987	4.007738969
AllPlanets-0-0-SRP	370563.5763	2.010501473
EarthSunLuna-0-0-0	400326.9215	2.185454594
EarthSunLuna-JGM2-0-0	292445.684	1.595241714

Table 2.33: FF/GMAT ESL2 GMAT Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	5690806.264	3.131093893
AllPlanets-0-0-SRP	6881233.15	5.36031143

2.5 FF/STK Comparison

Table 2.34: FF/STK GEO STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.02441863704	2.331184604e-006
EarthLuna-0-0-0	0.02435631273	2.242954572e-006
EarthSunLuna-JGM2-HP-SRP	2.852626845	0.0001210061779
EarthSun-0-0-0	4.231055926e-005	8.493743904e-007
Earth-0-0-0	6.836800608e-005	6.88987973e-007
Earth-0-0-SRP	2.899330477	0.0001245232993
Earth-0-HP-0	6.836800608e-005	6.88987973e-007
Earth-JGM2-0-0	0.02513336324	2.312005795e-006

Table 2.35: FF/STK GPS STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.001903432726	1.05396749e-006
EarthLuna-0-0-0	0.001896072444	9.455905846e-007
EarthSunLuna-JGM2-HP-SRP	0.6785588953	6.968633054e-005
EarthSun-0-0-0	3.872950958e-006	8.316374468e-007
Earth-0-0-0	8.164858288e-006	7.983002389e-007
Earth-0-0-SRP	0.6692784196	6.82998191e-005
Earth-0-HP-0	8.164858288e-006	7.983002389e-007
Earth-JGM2-0-0	0.01104063243	2.139207943e-006

Table 2.36: FF/STK ISS STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	1.17832665e-005	8.274193497e-007
EarthLuna-0-0-0	2.023778135e-005	8.422716288e-007
EarthSunLuna-JGM2-HP-SRP	3.468138188	0.00397058468
EarthSun-0-0-0	2.067991746e-005	8.179978462e-007
Earth-0-0-0	4.404163183e-005	8.18654414e-007
Earth-0-0-SRP	0.1637932094	0.0001561216614
Earth-0-HP-0	3.213782043	0.003648358687
Earth-JGM2-0-0	0.2076446785	0.000240480153

Table 2.37: FF/STK Molniya STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	0.01457313187	1.215436857e-005
EarthLuna-0-0-0	0.01409431455	1.184376375e-005
EarthSunLuna-JGM2-HP-SRP	7.784661066	0.004770671083
EarthSun-0-0-0	0.0006798546862	1.003656755e-006
Earth-0-0-0	0.0003365057467	8.083517746e-007
Earth-0-0-SRP	2.16384821	0.001779529358
Earth-0-HP-0	15.27354394	0.01277094127
Earth-JGM2-0-0	3.063128789	0.002561623786

Table 2.38: FF/STK SunSync STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	3.408772257e-005	8.692021282e-007
EarthLuna-0-0-0	1.971678896e-005	8.200608417e-007
EarthSunLuna-JGM2-HP-SRP	0.7800584002	0.0008377097648
EarthSun-0-0-0	1.533280696e-005	8.472033081e-007
Earth-0-0-0	3.656123033e-005	8.215166636e-007
Earth-0-0-SRP	0.2052485046	0.0001828464608
Earth-0-HP-0	0.6524853805	0.0007361489016
Earth-JGM2-0-0	0.09463135069	0.0001055896859

Table 2.39: FF/STK EML2 STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	209675.042	1.144026162
AllPlanets-0-0-SRP	207842.4058	1.126072542
EarthSunLuna-0-0-0	209277.3283	1.141861547
EarthSunLuna-JGM2-0-0	209283.0998	1.141942278

Table 2.40: FF/STK ESL2 STK Test Case Comparison

Test Case	Position Difference(m)	Velocity Difference(m/s)
AllPlanets-0-0-0	5661795.443	3.114044494
AllPlanets-0-0-SRP	6652873.129	5.182879379

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: GMAT/STK Central Body Dependent Parameter Differences (1)

Test Case	Altitude (m)	Eccentricity	M. Anomaly (deg)	M. Motion (rad/sec)	Period (sec)
GEO-2Body	1.88447e-006	1.71688e-014	1.90007e-005	3.0114e-015	3.59432e-009
Hyperbolic-2Body	0.00422986	1.98064e-013	351.401	0.000223215	N/A
ISS-2Body	0.00543367	5.95719e-014	5.81025e-010	4.99015e-015	2.54659e-010
Mars1-2Body	0.0144309	9.74698e-011	7.84791e-007	1.62511e-013	2.29212e-006
Mercury1-2Body	0.00224375	2.36836e-011	1.7241e-007	5.54375e-014	7.66082e-007
Moon-2Body	0.00576446	2.74547e-011	6.47192e-007	4.03859e-014	8.68182e-007
Neptune1-2Body	0.129938	1.31684e-010	6.04911e-007	1.00481e-013	4.02816e-006
Pluto1-2Body	0.19231	1.83823e-009	2.95607e-005	3.82792e-012	0.000141823
Saturn1-2Body	0.752271	1.05362e-011	6.3449e-008	1.11997e-014	1.04643e-006
Uranus1-2Body	0.216614	5.31596e-011	6.35362e-007	8.48005e-014	8.31598e-006
Venus1-2Body	0.000632367	1.26323e-011	2.13253e-008	1.53591e-014	1.51652e-007

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

Test Case	Semi-major Axis (m)	True Anomaly (deg)	Semilatus Rectum(m)
GEO-2Body	1.17871e-006	1.90007e-005	7.42148e-007
Hyperbolic-2Body	1.72076e-006	7.41807e-012	1.32204e-005
ISS-2Body	2.08274e-007	5.77472e-010	1.70985e-007
Mars1-2Body	0.000741843	1.15747e-006	0.000794765
Mercury1-2Body	0.000199977	2.61636e-007	0.000175894
Moon-2Body	0.000103879	9.75722e-007	7.23717e-005
Neptune1-2Body	0.00597339	9.2047e-007	0.00497125
Pluto1-2Body	0.0111278	4.499e-005	0.0106515
Saturn1-2Body	0.00241793	9.55595e-008	0.00235179
Uranus1-2Body	0.0100126	9.19017e-007	0.00930848
Venus1-2Body	0.000101745	3.07957e-008	0.00013864

Table 3.3: GMAT/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	1.25146e-006	1.27329e-006	8.21565e-011	1.03029e-010
Hyperbolic-2Body	N/A	4.50927e-006	N/A	1.86873e-009
ISS-2Body	5.26597e-007	3.38332e-007	4.39648e-010	3.47278e-010
Mars1-2Body	0.000683647	0.000800039	2.75849e-007	4.86309e-007
Mercury1-2Body	0.000280259	0.000125894	7.84977e-008	7.33316e-008
Moon-2Body	0.000193031	1.47281e-005	7.36031e-008	1.26232e-008
Neptune1-2Body	0.0107941	0.00538058	2.2861e-006	2.18703e-006
Pluto1-2Body	0.0145814	0.00998796	2.30184e-006	3.55073e-006
Saturn1-2Body	0.002828	0.00203526	2.94648e-007	5.08262e-007
Uranus1-2Body	0.0133233	0.00759641	1.41239e-006	1.43534e-006
Venus1-2Body	0.000149412	0.000183741	6.66214e-008	1.50022e-007

Table 3.4: GMAT/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	2.6823e-007	3.24498e-008	3.14812e-007	0.00196854	0.00196864
Hyperbolic-2Body	1.64846e-006	5.65537e-008	1.35016e-007	0.00196849	0.00196858
ISS-2Body	1.74794e-006	1.07149e-007	1.3276e-007	0.00196849	0.0019686
Mars1-2Body	0.00149955	5.58338e-007	9.73051e-007	N/A	N/A
Mercury1-2Body	0.000332532	1.88133e-007	2.69651e-007	N/A	N/A
Moon-2Body	0.000140608	7.42402e-007	1.06364e-006	N/A	N/A
Neptune1-2Body	0.0333365	7.39515e-007	1.15656e-006	N/A	N/A
Pluto1-2Body	0.00339014	3.20069e-005	7.44124e-005	N/A	N/A
Saturn1-2Body	0.014334	1.24281e-006	5.18835e-007	N/A	N/A
Uranus1-2Body	0.028651	9.64237e-007	2.34538e-006	N/A	N/A
Venus1-2Body	0.000500677	2.22686e-008	3.82501e-008	N/A	N/A

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

Test Case	Beta Angle (deg)	(RxV)-Mag (m^2/sec)	R-Mag (m)
GEO-2Body	0.000773444	0.00180444	1.88447e-006
Hyperbolic-2Body	0.000706521	0.025655	1.35624e-005
ISS-2Body	0.00344889	0.000749424	4.62933e-007
Mars1-2Body	0.00315966	1.23719	0.0126011
Mercury1-2Body	0.00511923	0.220796	0.00224375
Moon-2Body	0.00394712	0.000777618	0.00576446
Neptune1-2Body	0.000741045	35.4559	0.0763421
Pluto1-2Body	0.000530341	4.01956	0.19231
Saturn1-2Body	0.00142058	26.1241	0.0181717
Uranus1-2Body	0.000807228	53.902	0.101524
Venus1-2Body	0.00414838	0.447268	0.000632365

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

Test Case	Altitude (m)	Eccentricity	M. Anomaly (deg)	M. Motion (rad/sec)	Period (sec)
GEO-2Body	8.20728e-006	1.93962e-010	6.42153e-006	5.69653e-016	7.75617e-009
ISS-2Body	0.433346	6.39335e-012	1.714e-009	4.2466e-015	7.69433e-010

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

Test Case	Semi-major Axis (m)	True Anomaly (deg)	Semilatus Rectum(m)
GEO-2Body	2.23372e-006	6.4215e-006	2.4811e-006
ISS-2Body	4.09273e-007	1.86708e-009	1.7917e-007

Table 3.8: FF/GMAT 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	3.00497e-006	2.39764e-008	2.39013e-008
ISS-2Body	3.98359e-007	6.89397e-007	2.91838e-008	2.88605e-008

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

Test Case	C3-Energy (m^2/sec^2)	Latitude (deg)	Longitude (deg)	MHA (deg)	LST (deg)
GEO-2Body	0.00014728	5.40781e-008	0	0.00300898	0.00300919
ISS-2Body	0.000444231	6.02545e-006	5.81869e-007	0.00300898	0.00300919

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

Test Case	Beta Angle (deg)	(RxV)-Mag (m^2/sec)	R-Mag (m)
GEO-2Body	45.7413	0.00429281	3.27418e-006
ISS-2Body	98.3649	0.00164437	1.18325e-006

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	1.77052e-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	1.77044e-005	1.92085e-006
ISS-2Body	4.47471e-007	1.67336e-009	1.55524e-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	2.74304e-006	2.03727e-006	2.38942e-008	2.38796e-008
ISS-2Body	5.23869e-007	6.24823e-007	2.87441e-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

3.3 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

CSParams precedes the *tool* field and 2Body precedes the *CS* field. The final CS file format is as followed: CSParams_*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 3.26- 3.30 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 3.16: GMAT/STK Coordinate System Dependent Parameter Differences (Position)

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)
GEO-2Body-EarthFixed	0.2281413654	0.04023080692	0.02037045935
GEO-2Body-EarthMJ2000Ec	2.294098067e-005	0.00032580283	0.0007504095265
GEO-2Body-EarthMJ2000Eq	2.294098067e-005	2.433989721e-005	4.46e-009
GEO-2Body-EarthMODEc	0.001272894679	0.001382489927	8.563802112e-006
GEO-2Body-EarthMODEq	0.001272895247	0.001271371502	0.000543207701
GEO-2Body-EarthMOEEc	2.295053037e-005	2.237175067e-005	9.603354556e-006
GEO-2Body-EarthMOEEq	2.295053037e-005	2.433989721e-005	4.162467864e-009
GEO-2Body-EarthTODEc	0.006357750408	0.006834058695	0.0006267073331
GEO-2Body-EarthTODEq	0.006357749726	0.006271528946	0.003423117541
GEO-2Body-EarthTOEEc	0.005487542296	0.005975813906	9.603354556e-006
GEO-2Body-EarthTOEEq	0.005487542239	0.005486127634	0.002404046552
Hyperbolic-2Body-EarthFixed	0.3488040966	0.5436684769	0.1095402695
Hyperbolic-2Body-EarthMJ2000Ec	1.6822014e-005	0.001917796908	0.004851564881
Hyperbolic-2Body-EarthMJ2000Eq	1.6822014e-005	1.979060471e-006	2.124579623e-006
Hyperbolic-2Body-EarthMODEc	0.008121191058	0.01077665365	7.392372936e-006
Hyperbolic-2Body-EarthMODEq	0.008121191058	0.0098834862	0.004294328392
Hyperbolic-2Body-EarthMOEEc	1.693842933e-005	2.211891115e-006	2.153683454e-006
Hyperbolic-2Body-EarthMOEEq	1.693842933e-005	1.979060471e-006	2.066371962e-006
Hyperbolic-2Body-EarthTODEc	0.01367426012	0.01960279769	0.003635126632
Hyperbolic-2Body-EarthTODEq	0.01367420191	0.02924879664	0.005363341188
Hyperbolic-2Body-EarthTOEEc	0.03536941949	0.04713787348	2.153683454e-006
Hyperbolic-2Body-EarthTOEEq	0.03536941949	0.04508509301	0.01691197394
ISS-2Body-EarthFixed	0.01006907041	0.01444909003	0.002770384526
ISS-2Body-EarthGSE	5.3005067e-005	3.604054655e-005	7.67059305e-006
ISS-2Body-EarthGSM	4.954046062e-005	0.003799987553	0.00293166886
ISS-2Body-EarthMJ2000Ec	1.033299668e-005	8.047527444e-005	0.0001261635134
ISS-2Body-EarthMJ2000Eq	1.033299668e-005	9.667473932e-006	9.215000318e-006
ISS-2Body-EarthMODEc	0.000210427288	0.0001799348865	7.613095931e-006
ISS-2Body-EarthMODEq	0.0002104279702	0.0001652065293	7.136577551e-005
ISS-2Body-EarthMOEEc	1.033140506e-005	1.099556357e-005	7.695803106e-006
ISS-2Body-EarthMOEEq	1.033140506e-005	9.666564438e-006	9.215000318e-006
ISS-2Body-EarthTODEc	0.0003583738817	0.0002511692401	0.0001079586127
ISS-2Body-EarthTODEq	0.0003583786565	0.0003260520316	0.0003840964382
ISS-2Body-EarthTOEEc	0.0009193927326	0.0007893422662	7.69603048e-006
ISS-2Body-EarthTOEEq	0.0009193925052	0.0006983391359	0.0002934716576
Mars1-2Body-MarsFixed	0.05898887696	0.05711927406	0.03425882358
Mars1-2Body-MarsMJ2000Ec	0.04854124924	0.06378650704	0.05515928102
Mars1-2Body-MarsMJ2000Eq	0.04854124947	0.06874534654	0.04854127501
Mercury1-2Body-MercuryFixed	0.009607810114	0.01088151507	0.009587843124
Mercury1-2Body-MercuryMJ2000Ec	0.008947269691	0.01142762343	0.01022404834
Mercury1-2Body-MercuryMJ2000Eq	0.008947269691	0.01220655815	0.008947248972
Moon-2Body-MoonFixed	0.02659000859	0.01816027718	0.0259134155
Moon-2Body-MoonMJ2000Ec	0.02282095541	0.02955069925	0.02583996015
Moon-2Body-MoonMJ2000Eq	0.02282095546	0.03242772568	0.02282108797
Neptune1-2Body-NeptuneFixed	0.4543228424	0.474102093	0.2913599029
Neptune1-2Body-NeptuneMJ2000Ec	0.2946186363	0.379445413	0.3350099975
Neptune1-2Body-NeptuneMJ2000Eq	0.2946186363	0.4144292316	0.30129434
Pluto1-2Body-PlutoFixed	0.6182226091	1.111364997	0.7629325749
Pluto1-2Body-PlutoMJ2000Ec	0.7527405821	0.9494719067	0.8475838174
Pluto1-2Body-PlutoMJ2000Eq	0.7527405819	1.085654527	0.7521445426
Saturn1-2Body-SaturnFixed	0.6340523651	0.6134889563	0.06666205172
Saturn1-2Body-SaturnMJ2000Ec	0.07298453147	0.09547611444	0.08217663634
Saturn1-2Body-SaturnMJ2000Eq	0.07298453147	0.1048656477	0.0737594446
Uranus1-2Body-UranusFixed	0.4395935848	0.5642743054	0.5180439475
Uranus1-2Body-UranusMJ2000Ec	0.385162361	0.5115039512	0.433244951
Uranus1-2Body-UranusMJ2000Eq	0.3851623601	0.5548048448	0.3789037312
Venus1-2Body-VenusFixed	0.003286658284	0.002153384223	0.002565443879
Venus1-2Body-VenusMJ2000Ec	0.002135182285	0.003261576126	0.002492622912

Table 3.17: GMAT/STK Coordinate System Dependent Parameter Differences (Velocity)

Test Case	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
GEO-2Body-EarthFixed	1.014408074e-005	1.788716823e-006	2.603041318e-007
GEO-2Body-EarthMJ2000Ec	1.658007065e-009	2.383426789e-008	5.472688969e-008
GEO-2Body-EarthMJ2000Eq	1.658007065e-009	1.708189146e-009	0
GEO-2Body-EarthMODEc	9.276047985e-008	1.009415607e-007	6.031009026e-010
GEO-2Body-EarthMODEq	9.276047985e-008	9.28549633e-008	3.961584403e-008
GEO-2Body-EarthMOEEc	1.658895243e-009	1.566302643e-009	6.827038934e-010
GEO-2Body-EarthMOEEq	1.658895243e-009	1.70885528e-009	3.03533858e-013
GEO-2Body-EarthTODEc	4.572472123e-007	5.051409152e-007	4.601985459e-008
GEO-2Body-EarthTODEq	4.572472123e-007	4.636103862e-007	2.603101342e-007
GEO-2Body-EarthTOEEc	4.000988846e-007	4.359142977e-007	6.827038934e-010
GEO-2Body-EarthTOEEq	4.000988846e-007	4.002142819e-007	1.75307769e-007
Hyperbolic-2Body-EarthFixed	3.961039852e-005	4.825957234e-005	7.70518005e-006
Hyperbolic-2Body-EarthMJ2000Ec	1.829647545e-010	2.841105129e-008	7.195000151e-008
Hyperbolic-2Body-EarthMJ2000Eq	1.900701818e-010	7.416289804e-011	7.505107646e-011
Hyperbolic-2Body-EarthMODEc	1.202220545e-007	3.21276783e-007	2.733924198e-010
Hyperbolic-2Body-EarthMODEq	1.202220545e-007	2.946597966e-007	1.280426876e-007
Hyperbolic-2Body-EarthMOEEc	1.829647545e-010	8.482103908e-011	5.306866058e-011
Hyperbolic-2Body-EarthMOEEq	1.829647545e-010	7.283063042e-011	7.416289804e-011
Hyperbolic-2Body-EarthTODEc	1.646727199e-007	2.454381143e-007	6.046185774e-008
Hyperbolic-2Body-EarthTODEq	1.646727199e-007	3.61354946e-007	2.50673704e-007
Hyperbolic-2Body-EarthTOEEc	5.242357659e-007	1.403959171e-006	5.306866058e-011
Hyperbolic-2Body-EarthTOEEq	5.242357659e-007	1.28404859e-006	5.625165889e-007
ISS-2Body-EarthFixed	1.122181903e-005	1.427654617e-005	3.056610076e-006
ISS-2Body-EarthGSE	3.753886091e-008	6.98910979e-008	8.158362874e-009
ISS-2Body-EarthGSM	3.523581427e-008	4.26608171e-006	3.338248789e-006
ISS-2Body-EarthMJ2000Ec	1.084418666e-008	9.146905455e-008	1.441839981e-007
ISS-2Body-EarthMJ2000Eq	1.084418666e-008	1.137612227e-008	1.016586815e-008
ISS-2Body-EarthMODEc	2.404640931e-007	2.0532398e-007	8.086198378e-009
ISS-2Body-EarthMODEq	2.404640931e-007	1.883493361e-007	8.178480115e-008
ISS-2Body-EarthMOEEc	1.084238255e-008	1.291988738e-008	8.192335699e-009
ISS-2Body-EarthMOEEq	1.084238255e-008	1.137490102e-008	1.016536855e-008
ISS-2Body-EarthTODEc	4.073232862e-007	2.878270955e-007	1.22599042e-007
ISS-2Body-EarthTODEq	4.073232862e-007	3.764446532e-007	4.359921313e-007
ISS-2Body-EarthTOEEc	1.051030152e-006	8.982550259e-007	8.192335699e-009
ISS-2Body-EarthTOEEq	1.051030152e-006	7.945391012e-007	3.338689325e-007
Mars1-2Body-MarsFixed	4.119460101e-005	5.040193685e-005	2.244996011e-005
Mars1-2Body-MarsMJ2000Ec	3.9224898e-005	5.612389309e-005	3.773446111e-005
Mars1-2Body-MarsMJ2000Eq	3.9224898e-005	5.5061041e-005	3.923428094e-005
Mercury1-2Body-MercuryFixed	8.297573739e-006	1.056043131e-005	6.28309893e-006
Mercury1-2Body-MercuryMJ2000Ec	7.406872116e-006	1.084578205e-005	6.911486272e-006
Mercury1-2Body-MercuryMJ2000Eq	7.406872116e-006	1.046935982e-005	7.379157396e-006
Moon-2Body-MoonFixed	2.015969569e-005	1.201479294e-005	1.474075317e-005
Moon-2Body-MoonMJ2000Ec	1.554381401e-005	2.227603246e-005	1.46090765e-005
Moon-2Body-MoonMJ2000Eq	1.554381401e-005	2.234036151e-005	1.554384002e-005
Neptune1-2Body-NeptuneFixed	0.002311382259	0.00232459858	0.0001281027884
Neptune1-2Body-NeptuneMJ2000Ec	0.0001425149572	0.0002082204933	0.0001364492723
Neptune1-2Body-NeptuneMJ2000Eq	0.0001425149572	0.0002067147653	0.0001464608648
Pluto1-2Body-PlutoFixed	0.0003613682175	0.0004667307785	0.0004682860251
Pluto1-2Body-PlutoMJ2000Ec	0.0003872987759	0.0005522331561	0.000344448214
Pluto1-2Body-PlutoMJ2000Eq	0.0003872987759	0.0005410307473	0.0003868007483
Saturn1-2Body-SaturnFixed	0.0001164046752	0.0001207579849	2.354126405e-005
Saturn1-2Body-SaturnMJ2000Ec	2.488907747e-005	3.488300981e-005	2.320261316e-005
Saturn1-2Body-SaturnMJ2000Eq	2.488907747e-005	3.502235213e-005	2.510042485e-005
Uranus1-2Body-UranusFixed	0.0001044264559	0.0001481343457	0.000160607621
Uranus1-2Body-UranusMJ2000Ec	0.0001229694768	0.000170892658	0.0001139574768
Uranus1-2Body-UranusMJ2000Eq	0.0001229694768	0.0001702024259	0.000120316952
Venus1-2Body-VenusFixed	3.298453583e-006	1.926899973e-006	2.241729913e-006
Venus1-2Body-VenusMJ2000Ec	2.213821571e-006	3.107874846e-006	2.148337952e-006

Table 3.18: GMAT/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	10.77395299	2.103745961	434.3113329
GEO-2Body-EarthMJ2000Ec	1.13710075e-005	2.306616807	1.000254997
GEO-2Body-EarthMJ2000Eq	0	0	0.001542503014
GEO-2Body-EarthMODEc	1.670208945	0.001840817276	0.001789885573
GEO-2Body-EarthMODEq	1.670203311	0.001656591829	0.002357410267
GEO-2Body-EarthMOEEc	2.159488468e-005	0.0008076312952	0.001688022166
GEO-2Body-EarthMOEEq	1.279825357e-005	2.844632424e-021	0.001542503014
GEO-2Body-EarthTODEc	8.5322038	1.939137292	0.8412171155
GEO-2Body-EarthTODEq	8.532204845	9.575566487	0.004365574569
GEO-2Body-EarthTOEEc	7.285380082	0.001295120455	0.001702574082
GEO-2Body-EarthTOEEq	7.285369859	1.252006488	0.001396983862
Hyperbolic-2Body-EarthFixed	12999.11505	5061.392323	11584.82954
Hyperbolic-2Body-EarthMJ2000Ec	0.0002509729892	1.80931238	0.7227790775
Hyperbolic-2Body-EarthMJ2000Eq	0.000197488248	0.01781154424	0.01760781743
Hyperbolic-2Body-EarthMODEc	1.183702615	0.007530616131	0.02339947969
Hyperbolic-2Body-EarthMODEq	1.183709749	0.01674925443	0.01817534212
Hyperbolic-2Body-EarthMOEEc	0.00026047443	0.008927599993	0.0233121682
Hyperbolic-2Body-EarthMOEEq	0.000217340812	0.01784064807	0.01766602509
Hyperbolic-2Body-EarthTODEc	2.066649429	1.515742042	0.6022310117
Hyperbolic-2Body-EarthTODEq	2.066692929	5.087713362	5.08732046
Hyperbolic-2Body-EarthTOEEc	5.182947816	0.00926957	0.02366141416
Hyperbolic-2Body-EarthTOEEq	5.182958375	0.6900227163	0.6991467671
ISS-2Body-EarthFixed	89.91428695	67.10288835	31.77834151
ISS-2Body-EarthGSE	0.2475171641	0.0290456228	0.0004511093721
ISS-2Body-EarthGSM	3.261639904	22.63645729	29.37958561
ISS-2Body-EarthMJ2000Ec	0.0007530616131	0.7919024938	0.2579763532
ISS-2Body-EarthMJ2000Eq	0.0007603375707	0.0005566107575	0.000301952241
ISS-2Body-EarthMODEc	0.4284956958	0.9411305655	0.001266016625
ISS-2Body-EarthMODEq	0.4284956958	0.8629867807	0.3752284101
ISS-2Body-EarthMOEEc	0.0007530616131	0.0002983142622	0.0004874891602
ISS-2Body-EarthMOEEq	0.0007603375707	0.0005566107575	0.000301952241
ISS-2Body-EarthTODEc	0.7472881407	2.260314432	0.2173910616
ISS-2Body-EarthTODEq	0.7472772268	3.630950232	2.533914085
ISS-2Body-EarthTOEEc	1.879539923	4.109922884	0.0004874891602
ISS-2Body-EarthTOEEq	1.879554475	4.081139195	1.909433195
Mars1-2Body-MarsFixed	23.98886318	22.21717	10.38143819
Mars1-2Body-MarsMJ2000Ec	0.9952709661	0.5993915693	0.5886722647
Mars1-2Body-MarsMJ2000Eq	0.9952691471	0.2261380806	0.7740909496
Mercury1-2Body-MercuryFixed	0.327698217	0.4808271115	0.2502738425
Mercury1-2Body-MercuryMJ2000Ec	0.1878624971	0.2510159902	0.2059750841
Mercury1-2Body-MercuryMJ2000Eq	0.1878634066	0.1111429479	0.2888264135
Moon-2Body-MoonFixed	5.71125554	5.283694918	0.1482353582
Moon-2Body-MoonMJ2000Ec	0.001037733455	0.04335993253	0.01902935765
Moon-2Body-MoonMJ2000Eq	0.001038642949	0.0002576208312	0.0003556124284
Neptune1-2Body-NeptuneFixed	42849.13634	43033.72977	96195.52572
Neptune1-2Body-NeptuneMJ2000Ec	29.59038829	77.10719365	79.3626532
Neptune1-2Body-NeptuneMJ2000Eq	29.59038829	84.00197472	57.43693328
Pluto1-2Body-PlutoFixed	12.66916559	15.03451797	18.39295624
Pluto1-2Body-PlutoMJ2000Ec	2.923446004	0.8473472235	3.204913128
Pluto1-2Body-PlutoMJ2000Eq	2.923445891	0.8302175236	3.147571306
Saturn1-2Body-SaturnFixed	7341.511315	7984.995318	864.7177019
Saturn1-2Body-SaturnMJ2000Ec	13.2243149	25.11031926	27.86074765
Saturn1-2Body-SaturnMJ2000Eq	13.22408207	16.91115992	24.03883263
Uranus1-2Body-UranusFixed	2955.545322	3574.169823	2353.711105
Uranus1-2Body-UranusMJ2000Ec	5.186127964	39.40385068	90.66710481
Uranus1-2Body-UranusMJ2000Eq	5.186419003	61.77691968	77.83877663
Venus1-2Body-VenusFixed	0.7762544101	0.3817622201	0.2173546818
Venus1-2Body-VenusMJ2000Ec	0.2975648385	0.6312984624	0.4800604074

Table 3.19: GMAT/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	3.278583187e-006	1.162789617	0.178531639
GEO-2Body-EarthMJ2000Ec	1.07913678e-010	2.742908123e-010	1.110862513e-009
GEO-2Body-EarthMJ2000Eq	1.07913678e-010	3.426237072e-011	0
GEO-2Body-EarthMODEc	1.070254996e-010	1.887912049e-009	1.108624303e-011
GEO-2Body-EarthMODEq	1.070254996e-010	1.733170052e-009	7.381565394e-010
GEO-2Body-EarthMOEEc	1.07913678e-010	3.628031209e-011	1.261213356e-011
GEO-2Body-EarthMOEEq	1.07913678e-010	3.427658157e-011	5.656303434e-015
GEO-2Body-EarthTODEc	1.070254996e-010	9.472358897e-009	9.347012053e-010
GEO-2Body-EarthTODEq	1.070254996e-010	8.702897958e-009	4.850753133e-009
GEO-2Body-EarthTOEEc	1.07913678e-010	8.130868423e-009	1.261213356e-011
GEO-2Body-EarthTOEEq	1.07913678e-010	7.460869256e-009	3.266776493e-009
Hyperbolic-2Body-EarthFixed	4.71472088e-005	2.061432909e-007	5.501368605e-008
Hyperbolic-2Body-EarthMJ2000Ec	1.616484724e-010	2.155502443e-010	7.097700205e-010
Hyperbolic-2Body-EarthMJ2000Eq	1.616484724e-010	1.421085472e-012	9.201528428e-013
Hyperbolic-2Body-EarthMODEc	1.616484724e-010	1.854090215e-009	1.578293052e-012
Hyperbolic-2Body-EarthMODEq	1.616484724e-010	1.910734682e-009	7.375620115e-010
Hyperbolic-2Body-EarthMOEEc	1.616484724e-010	1.591615728e-012	2.415845302e-013
Hyperbolic-2Body-EarthMOEEq	1.616484724e-010	1.449507181e-012	9.166001291e-013
Hyperbolic-2Body-EarthTODEc	1.616484724e-010	3.401112281e-009	5.87760951e-010
Hyperbolic-2Body-EarthTODEq	1.616484724e-010	5.039368034e-009	1.719470788e-009
Hyperbolic-2Body-EarthTOEEc	1.616484724e-010	8.096151305e-009	2.415845302e-013
Hyperbolic-2Body-EarthTOEEq	1.616484724e-010	8.594184919e-009	3.265999027e-009
ISS-2Body-EarthFixed	1.000267424e-006	1.289334008e-007	3.871187459e-008
ISS-2Body-EarthGSE	4.574118861e-010	5.30000932e-010	6.073808123e-011
ISS-2Body-EarthGSM	3.125233405e-008	2.998996962e-008	3.987214825e-008
ISS-2Body-EarthMJ2000Ec	4.636291351e-010	8.293685738e-010	1.106641889e-009
ISS-2Body-EarthMJ2000Eq	4.636291351e-010	1.526245796e-010	7.80993048e-011
ISS-2Body-EarthMODEc	4.52970994e-010	1.852903608e-009	6.026290578e-011
ISS-2Body-EarthMODEq	4.627409567e-010	2.479552563e-009	7.349498787e-010
ISS-2Body-EarthMOEEc	4.636291351e-010	1.305977548e-010	6.103206829e-011
ISS-2Body-EarthMOEEq	4.627409567e-010	1.526245796e-010	7.80993048e-011
ISS-2Body-EarthTODEc	4.627409567e-010	3.180247177e-009	9.443787974e-010
ISS-2Body-EarthTODEq	4.627409567e-010	4.238856377e-009	4.168732914e-009
ISS-2Body-EarthTOEEc	4.627409567e-010	8.094446002e-009	6.103206829e-011
ISS-2Body-EarthTOEEq	4.627409567e-010	1.066266009e-008	3.259224002e-009
Mars1-2Body-MarsFixed	9.592806993e-006	9.947378707e-007	3.948958787e-007
Mars1-2Body-MarsMJ2000Ec	8.899687209e-006	1.432667602e-006	6.136789708e-007
Mars1-2Body-MarsMJ2000Eq	8.899676995e-006	1.215923845e-006	6.201466789e-007
Mercury1-2Body-MercuryFixed	1.59941127e-006	3.112265077e-007	1.274611101e-007
Mercury1-2Body-MercuryMJ2000Ec	1.597606047e-006	3.378602003e-007	1.397476694e-007
Mercury1-2Body-MercuryMJ2000Eq	1.597606047e-006	2.85895851e-007	1.4250252e-007
Moon-2Body-MoonFixed	3.394075021e-006	1.115449194e-006	5.325181203e-007
Moon-2Body-MoonMJ2000Ec	3.384815983e-006	1.24027315e-006	5.264534106e-007
Moon-2Body-MoonMJ2000Eq	3.384815983e-006	1.048296383e-006	5.364797317e-007
Neptune1-2Body-NeptuneFixed	0.001546170623	1.309179918e-005	1.351642366e-005
Neptune1-2Body-NeptuneMJ2000Ec	3.205422061e-005	1.140866715e-006	4.847768089e-007
Neptune1-2Body-NeptuneMJ2000Eq	3.205422949e-005	9.779481331e-007	4.998895804e-007
Pluto1-2Body-PlutoFixed	*8.217843617e-005*	4.784315172e-005	2.956015004e-005
Pluto1-2Body-PlutoMJ2000Ec	8.345292613e-005	5.652545477e-005	2.377500014e-005
Pluto1-2Body-PlutoMJ2000Eq	8.345292613e-005	4.844967677e-005	2.512714485e-005
Saturn1-2Body-SaturnFixed	8.716019906e-006	4.920609911e-007	9.227543885e-008
Saturn1-2Body-SaturnMJ2000Ec	5.18404164e-006	1.242314625e-007	5.306250017e-008
Saturn1-2Body-SaturnMJ2000Eq	5.18404164e-006	1.061025898e-007	5.502680978e-008
Uranus1-2Body-UranusFixed	3.448082886e-005	7.157807744e-006	7.584381549e-007
Uranus1-2Body-UranusMJ2000Ec	2.627271023e-005	1.159199428e-006	5.016063795e-007
Uranus1-2Body-UranusMJ2000Eq	2.627271023e-005	9.843604971e-007	5.082584709e-007
Venus1-2Body-VenusFixed	5.125109226e-007	3.693500616e-008	1.783747905e-008
Venus1-2Body-VenusMJ2000Ec	5.126095104e-007	3.734896836e-008	1.708282227e-008

Table 3.20: GMAT/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	3.148e-007	9.529e-005
GEO-2Body-EarthMJ2000Ec	1.349e-005	1.111e-009	1.111e-009	2.715e-010	0
GEO-2Body-EarthMJ2000Eq	1.309e-005	0	1e-014	3.513e-011	0
GEO-2Body-EarthMODEc	1.381e-005	1.148e-011	3.233e-013	1.886e-009	1.864e-009
GEO-2Body-EarthMODEq	1.334e-005	7.381e-010	7.548e-010	1.734e-009	8.657e-010
GEO-2Body-EarthMOEEc	1.349e-005	1.291e-011	3.126e-013	3.401e-011	0
GEO-2Body-EarthMOEEq	1.343e-005	5.656e-015	0	3.513e-011	0
GEO-2Body-EarthTODEc	1.356e-005	9.281e-010	9.348e-010	9.5e-009	9.482e-009
GEO-2Body-EarthTODEq	1.095e-005	4.652e-009	3.537e-009	8.705e-009	1.046e-005
GEO-2Body-EarthTOEEc	1.36e-005	1.291e-011	3.233e-013	8.129e-009	8.107e-009
GEO-2Body-EarthTOEEq	8.314e-005	3.267e-009	1.764e-009	7.462e-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	7.617e-012	1.096e-009	1.111e-009	2.172e-010	1.4e-013
Hyperbolic-2Body-EarthMJ2000Eq	7.844e-012	8.207e-013	4.334e-013	1.251e-012	2.5e-013
Hyperbolic-2Body-EarthMODEc	1.18e-011	1.561e-012	3.411e-013	1.854e-009	1.858e-009
Hyperbolic-2Body-EarthMODEq	1.052e-009	7.379e-010	5.898e-013	2.405e-009	9.757e-010
Hyperbolic-2Body-EarthMOEEc	7.518e-012	2.984e-013	3.411e-013	1.393e-012	1.4e-013
Hyperbolic-2Body-EarthMOEEq	7.674e-012	8.313e-013	1.421e-013	1.251e-012	0
Hyperbolic-2Body-EarthTODEc	9.422e-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	1.696e-009
Hyperbolic-2Body-EarthTOEEc	7.702e-012	2.984e-013	3.375e-013	8.096e-009	8.107e-009
Hyperbolic-2Body-EarthTOEEq	4.561e-009	3.265e-009	5.531e-010	1.062e-008	4.29e-009
ISS-2Body-EarthFixed	3.206e-008	3.275e-008	3.965e-008	1.328e-007	1.38e-007
ISS-2Body-EarthGSE	7.614e-010	6.504e-011	5.684e-013	5.681e-010	4.463e-010
ISS-2Body-EarthGSM	2.427e-006	3.92e-008	4.043e-008	2.862e-008	7.132e-009
ISS-2Body-EarthMJ2000Ec	2.188e-009	1.109e-009	4.623e-010	8.22e-010	1.29e-009
ISS-2Body-EarthMJ2000Eq	5.556e-010	7.966e-011	5.471e-013	1.525e-010	5.4e-013
ISS-2Body-EarthMODEc	5.451e-010	6.455e-011	1.592e-012	1.853e-009	1.852e-009
ISS-2Body-EarthMODEq	1.206e-009	7.378e-010	5.283e-010	2.49e-009	1.291e-009
ISS-2Body-EarthMOEEc	5.49e-010	6.525e-011	4.121e-013	1.269e-010	7.105e-013
ISS-2Body-EarthMOEEq	5.525e-010	7.966e-011	5.471e-013	1.525e-010	5.542e-013
ISS-2Body-EarthTODEc	1.664e-009	9.461e-010	3.891e-010	3.178e-009	4.239e-009
ISS-2Body-EarthTODEq	3.32e-009	4.163e-009	3.569e-009	4.248e-009	4.395e-009
ISS-2Body-EarthTOEEc	5.487e-010	6.526e-011	4.05e-013	8.095e-009	8.095e-009
ISS-2Body-EarthTOEEq	2.92e-009	3.264e-009	2.689e-009	1.063e-008	5.96e-009
Mars1-2Body-MarsFixed	2.247e-006	5.221e-007	5.014e-008	9.731e-007	2.604e-007
Mars1-2Body-MarsMJ2000Ec	4.431e-008	8.568e-007	2.152e-009	1.285e-006	1.562e-009
Mars1-2Body-MarsMJ2000Eq	4.543e-008	7.205e-007	2.049e-009	1.377e-006	1.332e-009
Mercury1-2Body-MercuryFixed	7.263e-009	1.881e-007	1.462e-009	2.697e-007	5.066e-009
Mercury1-2Body-MercuryMJ2000Ec	8.609e-009	1.99e-007	1.004e-009	3.065e-007	2.237e-009
Mercury1-2Body-MercuryMJ2000Eq	7.477e-009	1.735e-007	1.664e-009	3.307e-007	1.026e-009
Moon-2Body-MoonFixed	2.966e-008	7.424e-007	2.672e-009	1.064e-006	1.418e-007
Moon-2Body-MoonMJ2000Ec	4.765e-009	7.387e-007	4.114e-010	1.173e-006	8.903e-010
Moon-2Body-MoonMJ2000Eq	6.126e-009	6.356e-007	1.155e-011	1.246e-006	6.068e-012
Neptune1-2Body-NeptuneFixed	4.002e-005	5.911e-007	1.341e-005	1.157e-006	7.627e-006
Neptune1-2Body-NeptuneMJ2000Ec	2.001e-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	5.512e-006	3.201e-005	7.484e-007	7.441e-005	8.117e-007
Pluto1-2Body-PlutoMJ2000Ec	5.338e-007	3.39e-005	4.962e-008	5.105e-005	3.472e-008
Pluto1-2Body-PlutoMJ2000Eq	5.077e-007	2.963e-005	3.899e-008	5.878e-005	5.172e-008
Saturn1-2Body-SaturnFixed	1.508e-007	5.809e-008	5.751e-008	5.188e-007	4.571e-007
Saturn1-2Body-SaturnMJ2000Ec	3.259e-009	7.328e-008	6.576e-010	1.179e-007	9.333e-010
Saturn1-2Body-SaturnMJ2000Eq	4.55e-009	6.548e-008	5.383e-010	1.273e-007	8.028e-010
Uranus1-2Body-UranusFixed	4.529e-006	8.4e-007	3.03e-007	2.345e-006	4.615e-007
Uranus1-2Body-UranusMJ2000Ec	1.129e-008	6.9e-007	8.766e-009	1.112e-006	5.248e-009
Uranus1-2Body-UranusMJ2000Eq	1.392e-008	6.011e-007	6.433e-009	1.201e-006	1e-008
Venus1-2Body-VenusFixed	1.012e-009	2.227e-008	1.379e-010	3.825e-008	1.158e-009
Venus1-2Body-VenusMJ2000Ec	2.027e-009	2.162e-008	4.209e-010	3.816e-008	8.709e-010

Table 3.21: FF/GMAT Coordinate System Dependent Parameter Differences (Position)

Test Case	X-Pos (m)	Y-Pos (m)	Z-Pos (m)
ISS-2Body-EarthMJ2000Eq	2.54757424e-005	2.516884479e-005	2.321598913e-005

Table 3.22: FF/GMAT Coordinate System Dependent Parameter Differences (Velocity)

Test Case	X-Vel (m/s)	Y-Vel (m/s)	Z-Vel (m/s)
ISS-2Body-EarthMJ2000Eq	4.993130354e-007	5.00476105e-007	4.961786537e-007

Table 3.23: FF/GMAT 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	0.0005493347999	0.001349690137	0.001567968866

Table 3.24: FF/GMAT 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	4.860067904e-007	296.2928006	67.36750845

Table 3.25: FF/GMAT Coordinate System Dependent Parameter Differences (Angle-based)

Test Case	Arg. of Per. (deg)	Decl. (deg)	Inc. (deg)	RA (deg)	RAAN (deg)
ISS-2Body-EarthMJ2000Eq	1.681e-009	5.884e-010	4.684e-010	7.628e-010	2.418e-010

Table 3.26: 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	3.470836418e-005	3.243098945e-005

Table 3.27: 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 3.28: 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 3.29: 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 3.30: 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	1.343e-009	6.518e-010	4.685e-010	8.637e-010	2.414e-010

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/GMAT GEO Integrator 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/GMAT ISS Integrator 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

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 & 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):

1. *tool*	STK	- Satellite Toolkit HPOP or Astrogator
	FF	- FreeFlyer
	GMAT	- General Mission Analysis Tool

2. *Cb*	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
	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

3. *stopCond*	A1ModJulian	- A1 Modified Julian Date
	Apoapsis	- Apoapsis of orbit based on TA
	Days	- Elapsed Days
	MA###	- ### degree Mean Anomaly
	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/GMAT EarthPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	3.637978807e-012
Apoapsis	1.207418308e-006
Days	3.637978807e-012
EA180	1.334851106e-006
EA45	1.122458571e-009
EA90	5.233573575e-010
MA180	1.468336194e-006
MA90	5.793253877e-009
Periapsis	0
Secs	2.09548034e-007
TA180	1.207418308e-006
TA90	2.69331224e-009

Table 5.8: Exact/GMAT 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/GMAT EarthPMhyper StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	3.637978807e-012
Days	0
HA45	5.94486238e-009
HA90	6.062620628e-009
MA45	4.032273182e-009
MA90	7.014335779e-010
Periapsis	0
Secs	2.09548034e-007
TA45	1.530786164e-008
TA90	3.041570551e-008

Table 5.10: Exact/GMAT MoonPM StopCond Test Case Comparison

Stopping Condition	Difference(s)
A1ModJulian	3.637978807e-012
Apoapsis	1.207418308e-006
Days	3.637978807e-012
EA180	0
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/GMAT 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/GMAT 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/GMAT 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/GMAT 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/GMAT MoonMJ2000EqPM StopCond Test Case Comparison

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

Table 5.16: Exact/GMAT MarsMJ2000EqPM StopCond Test Case Comparison

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

Table 5.17: Exact/GMAT Earth3MultiSatsPM StopCond Test Case Comparison

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

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: GMAT/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: GMAT/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

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/GMAT IEarth DeltaV 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/GMAT IMars DeltaV 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/GMAT IMoon DeltaV 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/GMAT ISun DeltaV 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

Chapter 8

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=1). 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.

8.1 Test Case Results

The results in Table 8.1 display the Pass and Fail outcome of each Control Flow test script.

Table 8.1: 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)
Coordinate System	Earth Mean J2000 Equator
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	2 Jun 2004 12:00:00.000 (UTCG)
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)
Coordinate System	Earth Mean J2000 Equator
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	2 Jun 2004 12:00:00.000 (UTCG)
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)
Coordinate System	Earth Mean J2000 Equator
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	3 Jun 2004 12:00:00.000 (UTCG)
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)
Coordinate System	Earth Mean J2000 Equator
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
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)
Coordinate System	Earth Mean J2000 Equator
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	8 Jun 2004 12:00:00.000 (UTCG)
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)
Coordinate System	Mars Mean J2000 Equator
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
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)
Coordinate System	Mercury Mean J2000 Equator
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
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)
Coordinate System	Moon Mean J2000 Equator
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
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)
Coordinate System	Neptune Mean J2000 Equator
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
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)
Coordinate System	Pluto Mean J2000 Equator
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
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)
Coordinate System	Saturn Mean J2000 Equator
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
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)
Coordinate System	Uranus Mean J2000 Equator
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
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)
Coordinate System	Venus Mean J2000 Equator
Start Time	1 Jun 2004 12:00:00.000 (UTCG)
Stop Time	4 Jun 2004 12:00:00.000 (UTCG)
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)
Coordinate System	Sun Mean J2000 Ecliptic
Start Time	01 Jan 2000 12:00:00.000 (UTCG)
Stop Time	01 Jan 2001 12:00:00.000 (UTCG)
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)
Coordinate System	Earth Mean J2000 Equator
Start Time	23 Jan 2010 00:00:03.999 (UTCG)
Stop Time	6 Feb 2010 00:00:03.999 (UTCG)
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)
Coordinate System	Earth Mean J2000 Equator
Start Time	5 Feb 2006 17:05:48.772 (UTCG)
Stop Time	4 Aug 2006 17:05:48.772 (UTCG)
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 ?? 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 normMat_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

Win/Mac/Linux compatible

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/[*Tool*1]_[*Tool*2]
- MATLAB .mat files with comparison data into the following folder:
  [*RootFolder*]/CompareResults/[*Tool*1]_[*Tool*2]
- 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 ??).

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

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

D.4.2 Calculation Objects: Geodetic Elements

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

D.4.3 Calculation Objects: Keplerian Elements

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

Orbit_Period_Mars
Orbit_Period_Mercury
Orbit_Period_Moon
Orbit_Period_Neptune
Orbit_Period_Pluto
Orbit_Period_Saturn
Orbit_Period_Uranus
Orbit_Period_Venus
RAAN_(fixed)
RAAN_(MJ2000Ec)
RAAN_(MODEc)
RAAN_(MOEEc)
RAAN_(MOEEq)
RAAN_(TODEc)
RAAN_(TOEEc)
RAAN_(TOEEq)
RAAN_(MarsFixed)
RAAN_(MarsMJ2000Ec)
RAAN_Mars_(MJ2000Eq)
RAAN_(MercuryFixed)
RAAN_(MercuryMJ2000Ec)
RAAN_Mercury_(MJ2000Eq)
RAAN_(MoonFixed)
RAAN_(MoonMJ2000Ec)
RAAN_Moon_(MJ2000Eq)
RAAN_(NeptuneFixed)
RAAN_(NeptuneMJ2000Ec)
RAAN_Neptune_(MJ2000Eq)
RAAN_(PlutoFixed)
RAAN_(PlutoMJ2000Ec)
RAAN_Pluto_(MJ2000Eq)
RAAN_(SaturnFixed)
RAAN_(SaturnMJ2000Ec)
RAAN_Saturn_(MJ2000Eq)
RAAN_(UranusFixed)
RAAN_(UranusMJ2000Ec)
RAAN_Uranus_(MJ2000Eq)
RAAN_(VenusFixed)
RAAN_(VenusMJ2000Ec)
RAAN_Venus_(MJ2000Eq)
Radius_Of_Apoapsis_Mars
Radius_Of_Apoapsis_Mercury
Radius_Of_Apoapsis_Moon
Radius_Of_Apoapsis_Neptune
Radius_Of_Apoapsis_Pluto
Radius_Of_Apoapsis_Saturn
Radius_Of_Apoapsis_Uranus
Radius_Of_Apoapsis_Venus
Radius_Of_Periapsis_Mars
Radius_Of_Periapsis_Mercury
Radius_Of_Periapsis_Moon
Radius_Of_Periapsis_Neptune
Radius_Of_Periapsis_Pluto
Radius_Of_Periapsis_Saturn
Radius_Of_Periapsis_Uranus
Radius_Of_Periapsis_Venus
Semimajor_Axis_Mars
Semimajor_Axis_Mercury
Semimajor_Axis_Moon
Semimajor_Axis_Neptune
Semimajor_Axis_Pluto
Semimajor_Axis_Saturn
Semimajor_Axis_Uranus
Semimajor_Axis_Venus
True_Anomaly_Mars
True_Anomaly_Mercury
True_Anomaly_Moon
True_Anomaly_Neptune
True_Anomaly_Pluto
True_Anomaly_Saturn
True_Anomaly_Uranus
True_Anomaly_Venus
RAAN_(EarthGSE)
RAAN_(EarthGSM)

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

Declination_(TOEEq)
Declination_(UranusFixed)
Declination_(UranusMJ2000Ec)
Declination_(VenusFixed)
Declination_(VenusMJ2000Ec)
Declination_Mars_(MJ2000Eq)
Declination_Mercury_(MJ2000Eq)
Declination_Moon_(MJ2000Eq)
Declination_Neptune_(MJ2000Eq)
Declination_Pluto_(MJ2000Eq)
Declination_Saturn_(MJ2000Eq)
Declination_Uranus_(MJ2000Eq)
Declination_Venus_(MJ2000Eq)
R_Mag_(MarsFixed)
R_Mag_(MercuryFixed)
R_Mag_(MoonFixed)
R_Mag_(NeptuneFixed)
R_Mag_(PlutoFixed)
R_Mag_(SaturnFixed)
R_Mag_(UranusFixed)
R_Mag_(VenusFixed)
R_Mag_Mars
R_Mag_Mercury
R_Mag_Moon
R_Mag_Neptune
R_Mag_Pluto
R_Mag_Saturn
R_Mag_Uranus
R_Mag_Venus
R_Mag_(EarthGSE)
R_Mag_(EarthGSM)
Right_Asc_(MJ2000Ec)
Right_Asc_(MODEc)
Right_Asc_(MOEEc)
Right_Asc_(MOEEq)
Right_Asc_(MarsFixed)
Right_Asc_(MarsMJ2000Ec)
Right_Asc_(MercuryFixed)
Right_Asc_(EarthGSM)

Right_Asc_Pluto_(MJ2000Eq)
Right_Asc_Saturn_(MJ2000Eq)
Right_Asc_Uranus_(MJ2000Eq)
Right_Asc_Venus_(MJ2000Eq)
V_Mag_(MJ2000Ec)
V_Mag_(MODEc)
V_Mag_(MOEEc)
V_Mag_(MOEEq)
V_Mag_(MarsFixed)
V_Mag_(MarsMJ2000Ec)
V_Mag_(MercuryFixed)
V_Mag_(MercuryMJ2000Ec)
V_Mag_(MoonFixed)
V_Mag_(MoonMJ2000Ec)
V_Mag_(NeptuneFixed)
V_Mag_(NeptuneMJ2000Ec)
V_Mag_(PlutoFixed)
V_Mag_(PlutoMJ2000Ec)
V_Mag_(SaturnMJ2000Ec)
V_Mag_(SaturnsFixed)
V_Mag_(TODEc)
V_Mag_(TOEEc)
V_Mag_(TOEEq)
V_Mag_(UranusFixed)
V_Mag_(UranusMJ2000Ec)
V_Mag_(VenusFixed)
V_Mag_(VenusMJ2000Ec)
V_Mag_Mars_(MJ2000Eq)
V_Mag_Mercury_(MJ2000Eq)
V_Mag_(EarthGSE)
V_Mag_(EarthGSM)
V_Mag_Moon_(MJ2000Eq)
V_Mag_Neptune_(MJ2000Eq)
V_Mag_Pluto_(MJ2000Eq)
V_Mag_Saturn_(MJ2000Eq)
V_Mag_Uranus_(MJ2000Eq)
V_Mag_Venus_(MJ2000Eq)
Right_Asc_(EarthGSE)

D.4.7 Calculation Objects: Vector Elements

(RxV)_Mag
(RxV)_Mag_(MarsFixed)
(RxV)_Mag_(MarsMJ2000)
(RxV)_Mag_(MarsMJ2000Ec)
(RxV)_Mag_(MercuryFixed)
(RxV)_Mag_(MercuryMJ2000)
(RxV)_Mag_(MercuryMJ2000Ec)
(RxV)_Mag_(MoonFixed)
(RxV)_Mag_(MoonMJ2000)
(RxV)_Mag_(MoonMJ2000Ec)
(RxV)_Mag_(NeptuneFixed)
(RxV)_Mag_(NeptuneMJ2000)
(RxV)_Mag_(NeptuneMJ2000Ec)
(RxV)_Mag_(PlutoFixed)
(RxV)_Mag_(PlutoMJ2000)
(RxV)_Mag_(PlutoMJ2000Ec)
(RxV)_Mag_(SaturnFixed)
(RxV)_Mag_(SaturnMJ2000)
(RxV)_Mag_(SaturnMJ2000Ec)
(RxV)_Mag_(UranusFixed)
(RxV)_Mag_(UranusMJ2000)
(RxV)_Mag_(UranussMJ2000Ec)
(RxV)_Mag_(VenusFixed)
(RxV)_Mag_(VenusMJ2000)
(RxV)_Mag_(VenusMJ2000Ec)
(RxV)_X
(RxV)_X_(Fixed)
(RxV)_X_(MJ2000Ec)
(RxV)_X_(MODEc)
(RxV)_X_(MODEq)
(RxV)_X_(MOEEq)
(RxV)_X_(MarsFixed)
(RxV)_X_(MarsMJ2000Ec)
(RxV)_X_(MarsMJ2000Eq)
(RxV)_X_(MercuryFixed)
(RxV)_X_(MercuryMJ2000Ec)
(RxV)_X_(MercuryMJ2000Eq)
(RxV)_X_(MoonFixed)
(RxV)_X_(MoonMJ2000Ec)
(RxV)_X_(MoonMJ2000Eq)
(RxV)_X_(NeptuneFixed)
(RxV)_X_(NeptuneMJ2000Ec)
(RxV)_X_(NeptuneMJ2000Eq)
(RxV)_X_(PlutoFixed)
(RxV)_X_(PlutoMJ2000Ec)
(RxV)_X_(PlutoMJ2000Eq)
(RxV)_X_(SaturnFixed)
(RxV)_X_(SaturnMJ2000Ec)
(RxV)_X_(SaturnMJ2000Eq)
(RxV)_X_(EarthGSE)
(RxV)_Y_(EarthGSE)
(RxV)_Z_(EarthGSE)
EarthGSM_Position_X
(RxV)_Z_(MOEEq)
(RxV)_Z_(MarsFixed)
(RxV)_Z_(MarsMJ2000Ec)
(RxV)_Z_(MarsMJ2000Eq)
(RxV)_Z_(MercuryFixed)
(RxV)_Z_(MercuryMJ2000Ec)
(RxV)_Z_(MercuryMJ2000Eq)
(RxV)_Z_(MoonFixed)
(RxV)_Z_(MoonMJ2000Ec)
(RxV)_Z_(MoonMJ2000Eq)
(RxV)_Z_(NeptuneFixed)
(RxV)_Z_(NeptuneMJ2000Ec)
(RxV)_Z_(NeptuneMJ2000Eq)
(RxV)_Z_(PlutoFixed)
(RxV)_Z_(PlutoMJ2000Ec)
(RxV)_Z_(PlutoMJ2000Eq)
(RxV)_Z_(SaturnFixed)
(RxV)_Z_(SaturnMJ2000Ec)
(RxV)_Z_(SaturnMJ2000Eq)
(RxV)_Z_(TODEc)
(RxV)_Z_(TODEq)
(RxV)_Z_(TOEEc)
(RxV)_Z_(TOEEq)
(RxV)_Z_(UranusFixed)
(RxV)_Z_(UranusMJ2000Ec)
(RxV)_Z_(UranusMJ2000Eq)
(RxV)_Z_(VenusFixed)
(RxV)_Z_(VenusMJ2000Ec)
(RxV)_Z_(VenusMJ2000Eq)
(RxV)_X_(MOEEc)
Vector_Dec_(Fixed)
Vector_Dec_(MJ2000Ec)
Vector_Dec_(MODEc)
Vector_Dec_(MODEq)
Vector_Dec_(MOEEc)
Vector_Dec_(MOEEq)
Vector_Dec_(MarsFixed)
Vector_Dec_(MarsMJ2000Ec)
Vector_Dec_(MarsMJ2000Eq)
Vector_Dec_(MercuryFixed)
Vector_Dec_(MercuryMJ2000Ec)
Vector_Dec_(MercuryMJ2000Eq)
Vector_Dec_(MoonFixed)
Vector_Dec_(MoonMJ2000Ec)
Vector_Dec_(MoonMJ2000Eq)
Vector_Dec_(NeptuneFixed)
Vector_Dec_(NeptuneMJ2000Ec)
Vector_Dec_(NeptuneMJ2000Eq)
(RxV)_Z_(MOEEc)
(RxV)_X_(EarthGSM)
(RxV)_Y_(EarthGSM)
(RxV)_Z_(EarthGSM)
EarthGSM_Velocity_X

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

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

D.4.8 Coordinate Systems: Central Body Inertial Elements

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

D.4.9 Propagators Elements

Moon_LP165P
CisLunar
EarthMoon_L2_AllPlanets
EarthMoon_L2_AllPlanets_and_SRP
EarthMoon_L2_ESM
EarthMoon_L2_ESM_JGM
EarthMoon_L2_ESM_LP165P
EarthSun_L2_AllPlanets
EarthSun_L2_AllPlanets_and_SRP
Earth_J2
Earth_Point_Mass
Heliocentric
Lunar
Mars_2-Body
Mars_AllPlanets
Mars_MARS50C
Mars_MARS50C_and_SRP
Mars_SRP
Mercury_2-Body
Mercury_AllPlanets
Mercury_SRP
Moon_2-Body
Moon_LP165P_and_SRP
Moon_SRP
Neptune_2-Body
Neptune_AllPlanets
Neptune_SRP
Pluto_2-Body
Pluto_AllPlanets
Pluto_SRP
Saturn_2-Body
Saturn_AllPlanets
Saturn_SRP
Sun_AllPlanets
Sun_AllPlanets_and_SRP
Uranus_2-Body
Uranus_AllPlanets
Uranus_SRP
Venus_2-Body
Venus_AllPlanets
Venus_MGNP180U
Venus_MGNP180U_and_SRP
Venus_SRP
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)_(fixed)
Cross_Product_(RxV)_(MarsFixed)
Cross_Product_(RxV)_(MarsMJ2000)
Cross_Product_(RxV)_(MarsMJ2000Ec)
Cross_Product_(RxV)_(MercuryFixed)
Cross_Product_(RxV)_(MercuryMJ2000)
Cross_Product_(RxV)_(MercuryMJ2000Ec)
Cross_Product_(RxV)_(MoonFixed)
Cross_Product_(RxV)_(MoonMJ2000)
Cross_Product_(RxV)_(MoonMJ2000Ec)
Cross_Product_(RxV)_(NeptuneFixed)
Cross_Product_(RxV)_(NeptuneMJ2000)
Cross_Product_(RxV)_(NeptuneMJ2000Ec)
Cross_Product_(YofGSM)
EarthSun_J2K_Velocity
DiPole_Vector_GSM
Cross_Product_(RxV)_(PlutoFixed)
Cross_Product_(RxV)_(PlutoMJ2000)
Cross_Product_(RxV)_(PlutoMJ2000Ec)
Cross_Product_(RxV)_(SaturnFixed)
Cross_Product_(RxV)_(SaturnMJ2000)
Cross_Product_(RxV)_(SaturnMJ2000Ec)
Cross_Product_(RxV)_(UranusFixed)
Cross_Product_(RxV)_(UranusMJ2000)
Cross_Product_(RxV)_(UranusMJ2000Ec)
Cross_Product_(RxV)_(VenusFixed)
Cross_Product_(RxV)_(VenusMJ2000)
Cross_Product_(RxV)_(VenusMJ2000Ec)
Cross_Product_(RxV)_(EarthGSE)
Cross_Product_(RxV)_(EarthGSM)
Cross_Product_(ZofGSE)
EarthSun_Vector

D.4.13 Vectors: Vehicle Local Elements

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

D.5 Report Styles

Classical_Orbit_Elements
Earth_MJ2000_Position_Velocity
GMAT_Apoapsis_Periapsis
GMAT_CSParameters_Fixed
GMAT_CSParameters_MJ2000Ec
GMAT_CSParameters_MJ2000Eq
GMAT_CSParameters_MODEc
GMAT_CSParameters_MODEq
GMAT_CbParameters
GMAT_CbParameters_Mars
GMAT_CSParameters_MOEEq
GMAT_CSParameters_MarsFixed
GMAT_CSParameters_Mars_MJ2000Ec
GMAT_CSParameters_Mars_MJ2000Eq
GMAT_CSParameters_MercuryFixed
GMAT_CSParameters_Mercury_MJ2000Ec
GMAT_CSParameters_Mercury_MJ2000Eq
GMAT_CSParameters_MoonFixed
GMAT_CSParameters_Moon_MJ2000Ec
GMAT_CSParameters_Moon_MJ2000Eq
GMAT_CSParameters_NeptuneFixed
GMAT_CSParameters_Neptune_MJ2000Ec
GMAT_CSParameters_Neptune_MJ2000Eq
Pluto_MJ2000_Position_Velocity
Saturn_MJ2000_Position_Velocity
Sun_MJ2000Ec_Position_Velocity
Sun_MJ2000_Position_Velocity
Uranus_MJ2000_Position_Velocity
Venus_MJ2000_Position_Velocity
Greenwich_Hour_Angle
GMAT_CSParameters_TODEq
GMAT_CSParameters_TOEEc
GMAT_CSParameters_TOEEq
GMAT_CSParameters_UranusFixed
GMAT_CSParameters_Uranus_MJ2000Ec
GMAT_CSParameters_Uranus_MJ2000Eq
GMAT_CSParameters_VenusFixed
GMAT_CSParameters_Venus_MJ2000Ec
GMAT_CSParameters_Venus_MJ2000Eq
GMAT_CSParameters_MOEEc
GMAT_CbParameters_Mercury
GMAT_CbParameters_Moon
GMAT_CbParameters_Neptune
GMAT_CbParameters_Pluto
GMAT_CbParameters_Saturn
GMAT_CbParameters_Uranus
GMAT_CbParameters_Venus
J2000_ECI_Position_Velocity
Mars_MJ2000_Position_Velocity
Mercury_MJ2000_Position_Velocity
Moon_MJ2000_Position_Velocity
Neptune_MJ2000_Position_Velocity
GMAT_CSParameters_PlutoFixed
GMAT_CSParameters_Pluto_MJ2000Ec
GMAT_CSParameters_Pluto_MJ2000Eq
GMAT_CSParameters_SaturnFixed
GMAT_CSParameters_Saturn_MJ2000Ec
GMAT_CSParameters_Saturn_MJ2000Eq
GMAT_CSParameters_TODEc

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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Index

Acceptance Matrix, 32, 33
Acronyms, 87

Cb, 18, 19, 45, 105
Control Flow, 22, 85
CS, 18, 19, 45, 105

DE200, 17
DE405, 17, 29
DeepSpace, 25, 38, 102
Delta V, 18, 22, 82, 106

EGM96, 24
EML2, 25, 27, 38, 41, 44, 103
EOP, 27, 28
ESL2, 25, 38, 41, 44, 104

FF, 133
FreeFlyer, 18, 26, 32, 39, 41, 42, 44, 46, 49–52, 58, 59

GEO, 23, 32, 39, 42, 45, 61, 93, 105, 106
GPS, 23, 32, 39, 42, 91

IERS, 27
Initial Conditions, 106
Integrators, 18, 20, 21, 62, 106
ISS, 23, 32, 39, 42, 45, 61, 89, 105, 106

JGM2, 24
JGM3, 24
JR, 24

LaTex, 18
Libration Point, 21
Libration Points, 18, 21, 77, 106

MATLAB, 17, 18
Molniya, 23, 32, 39, 42, 92
Molynia, 23
MSISE, 24
mu, 29

ODTBX, 23

Performance, 18, 22, 106
Propagation, 18, 23, 45, 61
Propagators, 44

SLP, 17
SRP, 24, 32
STK, 18, 27, 32, 36, 38, 42, 44, 46, 50–52, 59, 77, 131
    Astrogator, 18, 26
    HPOP, 18, 23, 25, 26
Stopping Condition, 106
Stopping Conditions, 18, 21, 71
SunSync, 23, 39, 42, 90
Sunsync, 32
Swingby, 18

UTC-UT1, 30