The Consultative Committee for Space Data Systems

ORBIT DATA MESSAGES V2.0 TEST PLAN/REPORT

CCSDS RECORD

CCSDS 502.1-Y-1

YELLOW BOOK
May 2010

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FOREWORD

This document records the plans for prototype testing and results of that testing for the Orbit Data Messages Version 2 Blue Book. As a record of prototype testing, it is expected that expansion, deletion, or modification of this document will **not** occur. This document is subject to CCSDS document management and change control procedures, which are defined in the *Procedures Manual for the Consultative Committee for Space Data Systems*. Current versions of CCSDS documents are maintained at the CCSDS Web site:

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1 INTRODUCTION

1.1 PURPOSE

The purpose of this document is to describe the prototype testing conducted on the CCSDS Orbit Data Messages (ODM), CCSDS 502.0-P-1.1 (reference [3]). An initial draft of this plan was prepared by the members of the CCSDS Navigation Working Group at the CCSDS Fall 2008 meetings conducted in Berlin, Germany. Work on the report continued at the CCSDS Spring 2009 meetings conducted in Colorado Springs, Colorado, USA, and was completed in Summer 2009.

1.2 SCOPE

The scope of this document is testing of the Orbit Data Messages version 2. The ODM is part of the technical program of the CCSDS Navigation Working Group. Document 502.0-P-1.1 is an update to the existing CCSDS/ISO Standard Orbit Data Messages CCSDS 502.0-B-1/ISO 22644 originally published in September 2004 (reference [2]). ODM document 502.0-P-1.1 completed a joint CCSDS Agency Review and ISO TC20/SC14/WG3 review in September 2008; the process is described in reference [1]. In applicable places the prototyping includes results based on modifications to the reference [3] provided via the Review Item Discrepancy (RID) process described in reference [1].

1.3 APPLICABILITY

The ODM describes standard formats for the interagency exchange of data required for spacecraft tracking and navigation (specifically, orbit parameters and orbit ephemeris). There are three distinct message types that make up the Orbit Data Messages. These are:

– Orbit Parameter Message (OPM)

– Orbit Mean Elements Message (OMM)

– Orbit Ephemeris Message (OEM)

This document applies to the prototype testing required to advance the ODM version 2 and its three constituent messages from Red Book to Blue Book status.

1.4 RATIONALE

The CCSDS Procedures Manual states that for a Recommendation to become a Blue Book, the standard must be tested in an operational manner. The following requirements for an implementation exercise were excerpted from reference [1]:

> “At least two independent and interoperable prototypes or implementations must have been developed and demonstrated in an operationally relevant environment, either real or simulated.”

This document outlines the Navigation Working Group's approach to meeting this requirement for the ODM 502.0-P-1.1.

1.5 DOCUMENT STRUCTURE

The first sections of this document describe the Test Plan for the prototyping activity; the last sections of the document provide a Test Report of the realized plan. Acronyms are provided in Annex A.

1.6 REFERENCES

The following documents are referenced in this document. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this document are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS documents.

[1] *Procedures Manual for the Consultative Committee for Space Data Systems*. CCSDS A00.0-Y-9. Yellow Book. Issue 9. Washington, D.C.: CCSDS, November 2003.

[2] *Orbit Data Messages*. Recommendation for Space Data System Standards, CCSDS 502.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2004.

[3] Orbit Data Messages. Draft Recommendation for Space Data System Standards, CCSDS 502.0-P-1.1. Pink Book. Issue 1.1. Washington, D.C.: CCSDS, July 2008.

2 SUMMARY CONCLUSION/RECOMMENDATION

The test plan and test reports documented herein substantiate that the organizations participating in the CCSDS Navigation Working Group have successfully conducted prototype testing of the Orbit Parameter Message, Orbit Mean Elements Message, and Orbit Ephemeris Message described in the Orbit Data Messages (ODM) 502.0-P-1.1 document. During the testing, messages of the various types were produced by 7 different organizations, and the ability to read/process the messages was demonstrated in 5 different organizations. Based on the diversity of agencies able to read/write the messages, and the positive test results, the Navigation Working Group recommends that the revised ODM 502.0-P-1.1 document be promoted to a Blue Book CCSDS Recommended Standard.

3 ORBIT DATA MESSAGES (ODM) TESTING GOALS

The test of the ODM will exercise the following three message types that together constitute the Orbit Data Messages:

– Orbit Parameter Message (updated from version 1 (reference [2]))

– Orbit Mean Element Message (initial version)

– Orbit Ephemeris Message (updated from version 1 (reference [2]))

The tests described in Section 5 and Section 6 of this plan will be conducted in order to meet the CCSDS requirements described in Section 2. In Section 7 and Section 8, the results of the testing are presented.

3.1 OPM OVERVIEW

The OPM is an ASCII file in "keyword=value" format. It contains a single state vector that must be propagated by the recipient. The file is organized into 3 sections: the Header section, Metadata section, and the Data section. The Header Section contains identification information (version, creation date, originator). The Metadata section contains information regarding the object to which the state vector applies, applicable reference frame and time system. The Data Section contains the Cartesian state vector components of the orbit (required); the Keplerian elements of the orbit (optional); the spacecraft parameters necessary to calculate solar radiation pressure and atmospheric drag (optional); maneuver parameters, if applicable (optional); and a 6x6 position/velocity covariance matrix (optional). There is also an optional section that can contain user defined parameters.

3.2 OMM OVERVIEW

The OMM is an ASCII file in "keyword=value" format. It contains a single orbit state that must be propagated by the recipient. The file is organized into 3 sections: the Header section, Metadata section, and the Data section. The Header Section contains identification information (version, creation date, originator). The Metadata section contains information regarding the object to which the orbit state applies, applicable reference frame and time system. The Data Section contains the Keplerian elements of the orbit (required), the spacecraft parameters necessary to calculate solar radiation pressure and atmospheric drag (optional), and TLE-related parameters (optional). There is also an optional section that can contain user defined parameters.

3.3 OEM OVERVIEW

The OEM is an ASCII file in a hybrid "keyword=value" format (header and metadata are keyword=value, data lines and covariance lines have a positional field layout). The OEM contains state vectors for an object at multiple points in time. The file is organized into 3 sections: the Header section, Metadata section, and the Data section. The Header Section contains identification information (version, creation date, originator). The Metadata section contains information regarding the object to which the orbit applies, applicable reference frame, time system, interpolation parameters, and data start/stop times. The Data Section contains the Cartesian state vector components of the orbit (epoch, x, y, z, x', y', z') (required); acceleration components (x'', y'', z'') (optional); and one or more 6x6 position/velocity covariance matrices (optional). The recipient must interpolate to obtain arbitrary states between ephemeris points.

4 TEST PLAN OVERVIEW

Prototyping of the ODM will be performed as shown in the following table, which lists the applicable spacecraft, participating member agencies of the Navigation Working Group (CNES, CSSI, ESA, GMV, JAXA, NASA/GSFC and NASA/JPL), direction of message transfer, and message type.

Test #	Spacecraft	Agencies, Direction	Msg Type
1	SOHO	NASA/GSFC => NASA/JPL	OPM
2	SOHO	NASA/GSFC => NASA/JPL	OPM
3	SOHO	NASA/GSFC =>NASA/JPL	OPM
4	ISS/Zarya	CNES => CSSI => CNES	OMM
5	Iridium 33 debris	GMV => CSSI => GMV	OMM
6	SELENE	JAXA => NASA/JPL	OEM
7	MEX/ODY	ESA => NASA/JPL, NASA/JPL => ESA	OEM
8	SOHO	NASA/GSFC => NASA/JPL	OPM
9	ISS/Zarya	CNES => CSSI => CNES	OMM

5 TEST PLAN DETAILS

5.1 TEST CASE #1: SIMPLE OPM

5.1.1 TEST DESCRIPTION

For this test, NASA/GSFC will send an OPM describing a SOHO spacecraft state to NASA/JPL. In this simple case, there will be no Keplerian elements, no maneuver, no spacecraft parameters, and no covariance matrix; this is essentially just the state vector.

5.1.2 EXPECTED RESULTS

It is anticipated that NASA/JPL will be able to successfully process and propagate the state. Assuming that these criteria are met, the test will be considered successful. In the event of discrepancies, troubleshooting will be conducted by the participants in the test.

5.2 TEST CASE #2: OPM WITH 254 CHARACTER LINE, FINITE MANEUVER

5.2.1 TEST DESCRIPTION

For this test, NASA/GSFC will send an OPM to NASA/JPL which contains a finite maneuver and which encompasses the maximum line limit (254 characters/line, not including termination characters). The suggested spacecraft is SOHO, with the maneuver selected by the SOHO navigation team.

5.2.2 EXPECTED RESULTS

It is anticipated that NASA/JPL will be able to successfully process and propagate the state. Assuming that these criteria are met, the test will be considered successful. In the event of discrepancies, troubleshooting will be conducted by the participants in the test.

5.3 TEST CASE #3: OPM WITH IMPULSIVE MANEUVER & COVARIANCE MATRIX

5.3.1 TEST DESCRIPTION

For this test, NASA/GSFC will send an OPM to NASA/JPL. The OPM will include a set of orbital elements at time t, and will include an impulsive maneuver design with MAN_EPOCH_IGNITION = t. The recipient will produce a corresponding OEM with a single state that corresponds to the post-maneuver state. The covariance matrix will be transformed from the keyword format of the OPM into the lower triangular format of the OEM. NASA/JPL will send the OEM back to NASA/GSFC.

5.3.2 EXPECTED RESULTS

It is anticipated that (1) the output state in the OEM is the post-maneuver state, and (2) the output covariance in the OEM is the same as the input OPM, but converted to the lower triangular form. Assuming that these criteria are met, the test will be considered successful. In the event of discrepancies, troubleshooting will be conducted by the participants in the test.

5.4 TEST CASE #4: OMM WITHOUT COVARIANCE MATRIX

5.4.1 TEST DESCRIPTION

For this test, CNES will generate from an existing TLE of their choice an OMM that encapsulates the orbit state. CNES will send the OMM to CSSI. CSSI will convert the OMM to a TLE and return it to CNES. CNES will compare the original TLE with the TLE received from CSSI.

5.4.2 EXPECTED RESULTS

It is anticipated that the original TLE selected by CNES will match the twice transformed TLE received from CSSI (CNES: TLE=>OMM, CSSI: OMM=>TLE represents two transformations of the data). Assuming that this criterion is met, the test will be considered successful. In the event of discrepancies, troubleshooting will be conducted by the participants in the test.

5.5 TEST CASE #5: OMM WITH SYNTHETIC COVARIANCE MATRIX

5.5.1 TEST DESCRIPTION

For this test, GMV will generate from a set of TLEs of their choice an OMM that encapsulates the orbit state and a synthetic covariance matrix. GMV will send the OMM with the covariance to CSSI. CSSI will convert the OMM to a TLE, and from that calculate an initial state and propagate it along with the covariance matrix. CSSI will return an OMM with the propagated state and covariance matrix to GMV.

5.5.2 EXPECTED RESULTS

It is anticipated that the mean elements and metadata in the final OMM received from CSSI by GMV will match those in the original OMM sent by GMV to CSSI. CSSI should be able to utilize the covariance matrix in the propagations. Assuming that this criterion is met, the test will be considered successful. In the event of discrepancies, troubleshooting will be conducted by the participants in the test.

5.6 TEST CASE #6: OEM WITH MULTIPLE COVARIANCES, NO ACCELERATIONS

5.6.1 TEST DESCRIPTION

For this test, JAXA will send a SELENE OEM to NASA/JPL. The test OEM will include two covariance matrices calculated from the SELENE phasing orbit trajectory. The ephemeris data lines will not contain the optional accelerations. NASA/JPL will extract the covariance matrix from the OEM. NASA/JPL will also submit the OEM to the conversion utility utilized by the metric predicts generation system.

5.6.2 EXPECTED RESULTS

It is anticipated that the NASA/JPL metric predicts generation system will accept the OEM and produce the NASA/JPL internal format used for the generation of tracking predicts. Assuming that these criteria are met, the test will be considered successful. In the event of discrepancies, troubleshooting will be conducted by the participants in the test.

5.7 TEST CASE #7: OEM WITH OPTIONAL ACCELERATIONS

5.7.1 TEST DESCRIPTION

Part A: For this portion of the test, ESA will send an OEM for the MEX spacecraft to NASA/JPL. The OEM data lines will contain the optional accelerations. ESA will also send to JPL a small set of arbitrary epochs that are not explicitly in the OEM. JPL will process the OEM and interpolate between states to calculate the states at the arbitrary epochs. The results of the interpolations will be returned to ESA. ESA will compare the interpolated states with their truth ephemeris.

Part B: For this portion of the test, NASA/JPL will send an OEM for the Mars Odyssey spacecraft to ESA. The OEM data lines will contain the optional accelerations. JPL will also send to ESA a small set of arbitrary epochs that are not explicitly in the OEM. ESA will process the OEM and interpolate between states to calculate the states at the arbitrary epochs. The results of the interpolations will be returned to JPL. JPL will compare the interpolated states with their truth ephemeris.

5.7.2 EXPECTED RESULTS

It is anticipated that both ESA and NASA/JPL will be able to process the OEMs successfully. The interpolated states should agree to an acceptable accuracy. Assuming that these criteria are met, the test will be considered successful. In the event of discrepancies, troubleshooting will be conducted by the participants in the test.

5.8 TEST CASE #8: OPM WITH USER DEFINED PARAMETERS

5.8.1 TEST DESCRIPTION

Variant of Test Case #1

For this test, NASA/GSFC will send an OPM to NASA/JPL. In general this must be a syntactically valid OPM. The only special requirement on this OPM is that it contain some number of User Defined Parameters. NOTE: In general the use of User Defined Parameters must be agreed in advance between the exchange partners because they may require custom programming.

5.8.2 EXPECTED RESULTS

It is anticipated that the consumer's prototype will not crash when encountering the User Defined Parameters. For this test, that is all that is necessary, given that in general User Defined Parameters must be agreed in advance by exchange partners and may require special programming. Assuming that these criteria are met, the test will be considered successful. In the event of discrepancies, troubleshooting will be conducted by the participants in the test.

5.9 TEST CASE #9: OMM WITH USER DEFINED PARAMETERS

5.9.1 TEST DESCRIPTION

Variant of Test Case #4 with User Defined Parameters

For this test, CNES will send an OMM to CSSI. In general this must be a syntactically valid OMM. The only special requirement on this OMM is that it contain some number of User Defined Parameters. NOTE: In general the use of User Defined Parameters must be agreed in advance between the exchange partners because they may require custom programming.

5.9.2 EXPECTED RESULTS

It is anticipated that the consumer's prototype will not crash when encountering the User Defined Parameters. For this test, that is all that is necessary, given that in general User Defined Parameters must be agreed in advance by exchange partners and may require special programming. Assuming that these criteria are met, the test will be considered successful. In the event of discrepancies, troubleshooting will be conducted by the participants in the test.

6 TEST REPORT OVERVIEW

Engineers at CNES, CSSI, ESA, NASA/GSFC, JAXA, and NASA/JPL will prepare test data sheets as applicable, and send them to the Navigation Working Group via email.

The Test Report Details will be consolidated in Section 8 of this document. A summarization of the test process and the recommendation of the Navigation Working Group may be found in Section 3 of the report. The report will be submitted to the CCSDS Engineering Steering Group (CESG) and CCSDS Management Council (CMC), along with results of the Agency Reviews. At that time, a formal request will be submitted to the CMC for progression of the ODM to CCSDS Blue Book status.

The next page contains a format for the test data sheets that will be used to report the results of individual tests. The form includes sections for the producer of the message and the consumer of the message (producing agency, producing test engineer, consuming agency, and consuming test engineer).

SAMPLE

Orbit Data Messages P1.1 Prototype Test Data Sheet

1	Report Date:	
2	Program Under Test:	Orbit Data Messages P1.1 (ODM) Prototype
3	Test Case Number:	
4	Agencies Participating in this Test Case:	
5	Agency Responsible for Producing Test Message	
6	Producing Test Engineer:	
7	Agency Responsible for Consuming Test Message	
8	Consuming Test Engineer:	
9	Spacecraft:	
10	Results (Pass, Partial Pass, Fail):	
11	Variances from Expected Result:	
12	Comments:	

7 TEST REPORT DETAILS

7.1 TEST CASE #1: SIMPLE OPM

<table>
<tr><td>1</td><td>Report Date:</td><td>01-Jul-2009</td></tr>
<tr><td>2</td><td>Program Under Test:</td><td>Orbit Data Messages P1.1 (ODM) Prototype</td></tr>
<tr><td>3</td><td>Test Case Number:</td><td>#1</td></tr>
<tr><td>4</td><td>Agencies Participating in this Test Case:</td><td>NASA/GSFC, NASA/JPL</td></tr>
<tr><td>5</td><td>Agency Responsible for Producing Test Message</td><td>NASA/GSFC</td></tr>
<tr><td>6</td><td>Producing Test Engineer:</td><td>Stefan Novak</td></tr>
<tr><td>7</td><td>Agency Responsible for Consuming Test Message</td><td>NASA/JPL</td></tr>
<tr><td>8</td><td>Consuming Test Engineer:</td><td>David Berry</td></tr>
<tr><td>9</td><td>Spacecraft:</td><td>SOHO</td></tr>
<tr><td>10</td><td>Results (Pass, Partial Pass, Fail):</td><td>Pass</td></tr>
<tr><td>11</td><td>Variances from Expected Result:</td><td>None.</td></tr>
<tr><td>12</td><td>Comments:</td><td>A SOHO OPM was received by JPL from GSFC. The state was processed by JPL using the program opm2mpy and propagated 7 days into the future using the JPL navigation software (spherical shape model, simple gravity model, solar pressure model). The propagated ephemeris was compared to a SOHO ephemeris that GSFC had submitted to the DSN for routine tracking operations. The initial state in the ephemeris and the OPM state differed by about 1 m in position and 2 mm/s in relative velocity. After 7 days propagation, the positions in the propagated ephemeris from OPM compared to the ephemeris submitted by GSFC differed by a max about 5.5 km, as shown below (avg 3.56 km), with velocities differing by a max of about 9.6 mm/s (avg 5.9 mm/s):

Comparison of 1000 'J2000'-referenced geometric states
of 'SOHO' (-21) relative to 'SOLAR SYSTEM BARYCENTER' (0)
from SPK 'merge_de421_output.gravity-solar.bsp'
#
with 1000 'J2000'-referenced geometric states
of 'SOHO' (-21) relative to 'SOLAR SYSTEM BARYCENTER' (0)
from SPK 'merge_de421_soho_84day_20090407_01.bsp_V0.1'
#
evenly-spaced with 605.40540531454 second (0d 0h 10m 5.405405s) step size
within the time interval
#
from '2009 APR 28 00:01:06.185 TDB' (294148866.18552 TDB seconds)
to   '2009 MAY 05 00:01:06.185 TDB' (294753666.18542 TDB seconds)

Relative differences in state vectors:

                              maximum   average
  Position: 3.7137163902363E-08   2.3865844160820E-08
  Velocity: 3.3274326927766E-07   2.0459084883677E-07

Absolute differences in state vectors:

                              maximum   average
  Position (km):   5.5511654081691E+00   3.5655566891711E+00
  Velocity (km/s):   9.6484034917749E-06   5.9379094317643E-06

Considering that the states in the GSFC ephemeris were integrated with an unknown integrator and unknown models, and the initial state was taken about 3 weeks from the start of the GSFC ephemeris, this is viewed as acceptable performance.</td></tr>
</table>

7.2 TEST CASE #2: OPM WITH 254 CHARACTER LINE, FINITE MANEUVER

1	Report Date:	08/14/2009
2	Program Under Test:	Orbit Data Messages P1.1 (ODM) Prototype
3	Test Case Number:	2
4	Agencies Participating in this Test Case:	NASA/GSFC, NASA/JPL
5	Agency Responsible for Producing Test Message	NASA/GSFC
6	Producing Test Engineer:	Stefan Novak
7	Agency Responsible for Consuming Test Message	NASA/JPL
8	Consuming Test Engineer:	David Berry
9	Spacecraft:	SOHO
10	Results (Pass, Partial Pass, Fail):	Pass
11	Variances from Expected Result:	There was no MASS parameter in the input OPM, so it had to be added in order to have the maneuver process properly. Also, the sign of the DELTA_MASS is required by the standard to be negative, however, it was positive in the input OPM. This was detected by the prototype, and corrected prior to proceeding.
12	Comments:	A SOHO OPM was received at JPL from GSFC. The OPM had a maximum line length of 254, per the specification. There was also a finite maneuver defined by design. The state was processed using the JPL program opm2mpy and propagated 3 days into the future using the JPL Monte navigation software (spherical shape model, simple gravity model, solar pressure model). The text line length of 254 caused no problems for the prototype. The log output from the prototype follows, showing the begin and end of the finite maneuver.

OPM to MPY Log Output

```
node24% v2-opm2mpy-test
========================================================================
 Test opm2mpy using GSFC OPMs;
========================================================================
$ opm2mpy.py odmv2-testcase2-254.txt odmv2-testcase2-254.mpy
$ cp odmv2-testcase2-254.mpy opm.mpy
$ integ.mpy
Initializing Database
Update database
Integrating Trajectory
Outputting SPK
$ cp outputs/log.txt odmv2-testcase2-254.log

Input Orbit Parameter Message file             = 'odmv2-testcase2-254.txt'.
Output MPython User Interface Model Setup File = 'odmv2-testcase2-254.mpy'.
Integration log file                           = 'odmv2-testcase2-254.log'.

========================================================================
# MONTE User Interface Run
# Start  : 2009/08/14 22:38 UTC
# Version: 8.2.0
# Case.Files = [
#    '/nav/common/import/ephem/de421.boa',
#    'Gin',
#    ]

Run.init(
   Gin = 'inputs/lockfile.boa',
   NewLog = True,
   Remove = [
      'outputs/case.db',
      'outputs/gin.boa',
      'outputs/log-short.txt',
      'outputs/log.txt',
      'outputs/traj.boa',
      ],
   )

# User   : dberry
# Start  : 2009/08/14 22:38 UTC

#    CPU time: 0.020 sec
# Actual Time: 0.033 sec
===============================================================================
Boa.update(
   Files = [
      './gin_initial.mpy',
      './eop.boa',
      './opm.mpy',
      ],
   Input = './outputs/gin.boa',
   InputLog = None,
   )

# User   : dberry
# Start  : 2009/08/14 22:38 UTC

#    CPU time: 0.050 sec
# Actual Time: 0.067 sec
===============================================================================
Trj.integ(
   Partials = True,
   MaxMemory = 250.0,
   Propagator = 'opm-diva',
   Traj = './outputs/traj.boa',
```

```
   )

# User   : dberry
# Start  : 2009/08/14 22:38 UTC


Requested memory usage: 250 MBytes
Diff line cache set to: 312500 lines

Integration summary for propagator 'opm-diva'

Number of integ. steps   : 27
Number of integ. restarts: 0
Minimum integ. step size :  1.000000000000000e-03 *sec
Maximum integ. step size :  4.320000000000000e+05 *sec
Tolerance on state equations:  1.000000000000000e-10 *km/sec
Tolerance on mass equations :  1.000000000000000e-10 *kg/sec

Active force models:
   'SOHO: Solar Pressure'
   'SOHO: Gravity'
   'SOHO: Finite Burn'

Initial integration epoch: 12-MAY-2009 15:31:06.1853 ET
Final integration epoch  : 15-MAY-2009 15:31:06.1852 ET
Termination condition    : Reached end time

Body          : SOHO
Initial Center: Earth
Integ Frame   : EME2000
Initial State (km, km/sec)
Pos:  6.877543635852445e+05  9.412878555399991e+05  5.200808110128602e+05
Vel: -4.139655186028603e-01  2.917446221789313e-01  1.175678191944320e-01

Final Center  : Solar System Barycenter
Integ Frame   : EME2000
Final State (km, km/sec)
Pos: -8.702514534102289e+07 -1.118180939080832e+08 -4.836953453020954e+07
Vel:  2.340851818176611e+01 -1.559998364279348e+01 -6.779340603538392e+00

Body        : SOHO
Initial Mass:  1.743294300000000e+03 *kg
Final Mass  :  1.743269093042465e+03 *kg

#    CPU time: 0.010 sec
# Actual Time: 0.013 sec
==============================================================================
Trj.events(
   Output = None,
   Traj = [
      './outputs/traj.boa',
      ],
   )

# User   : dberry
# Start  : 2009/08/14 22:38 UTC

  12-MAY-2009 15:31:06.1853 ET   DIVA: Beginning propagation
  12-MAY-2009 15:30:34.0000 TAI  SOHO: Finite Burn: Burn 'FINITE_BURN_1'
starting.
  12-MAY-2009 15:34:02.6822 TAI  SOHO: Finite Burn: Burn 'FINITE_BURN_1' ending.
  15-MAY-2009 15:31:06.1852 ET   DIVA: Ending propagation (reached end time)
#    CPU time: 0.010 sec
# Actual Time: 0.006 sec
==============================================================================
Out.spk(
   Body = '',
```

```
   Output = 'output.gravity-solar-finitemaneuver.bsp',
   EndTime = None,
   BeginTime = None,
   Traj = './outputs/traj.boa',
   )

# User   : dberry
# Start  : 2009/08/14 22:38 UTC

#    CPU time: 0.010 sec
# Actual Time: 0.012 sec
==============================================================================
node24%
```

7.3 TEST CASE #3: OPM WITH IMPULSIVE MANEUVER & COVARIANCE MATRIX

1	Report Date:	26-Jul-2009
2	Program Under Test:	Orbit Data Messages P1.1 (ODM) Prototype
3	Test Case Number:	3
4	Agencies Participating in this Test Case:	NASA/GSFC, NASA/JPL
5	Agency Responsible for Producing Test Message	NASA/GSFC
6	Producing Test Engineer:	Stefan Novak
7	Agency Responsible for Consuming Test Message	NASA/JPL
8	Consuming Test Engineer:	David Berry
9	Spacecraft:	SOHO
10	Results (Pass, Partial Pass, Fail):	Pass
11	Variances from Expected Result:	It was necessary to change the sign on the delta-mass in the maneuver (it was positive, however, the OPM standard specifies must be negative).
12	Comments:	See input OPM and output OEM below. There are some numerical differences between the input position and the output position at the 10^{-6} m level, probably due to ASCII/binary conversion.

```
CCSDS_OPM_VERS = 2.0
COMMENT For this test, NASA/GSFC will send an OPM to NASA/JPL.
COMMENT The OPM will include a set of orbital elements at time t, and
COMMENT will include a impulsive maneuver design with
COMMENT MAN_EPOCH_IGNITION = t.
CREATION_DATE = 2009-05-18T13:06:00
ORIGINATOR = GSFC
OBJECT_NAME = SOHO
OBJECT_ID = 2009-000A
CENTER_NAME = EARTH
REF_FRAME = EME2000
TIME_SYSTEM = UTC
EPOCH = 2009-05-12T15:30:00
X = 687754.36358524448
Y = 941287.85553999904
Z = 520080.81101286016
X_DOT = -0.41396551860286032
Y_DOT = 0.29174462217893128
Z_DOT = 0.11756781919443198
COMMENT The below contains the covariance matrix.
COV_REF_FRAME = EME2000
CX_X = 0.7819594E-03
CY_X = -0.0596
CY_Y = 0.1841916E-02
CZ_X = -0.8158
CZ_Y = -0.5284
CZ_Z = 0.1363635E-01
CX_DOT_X = -0.0085
CX_DOT_Y = 0.0103
CX_DOT_Z = 0.0087
CX_DOT_X_DOT = 0.2955507E-14
CY_DOT_X = 0.1079
CY_DOT_Y = 0.1733
CY_DOT_Z = -0.1909
CY_DOT_X_DOT = -0.0211
CY_DOT_Y_DOT = 0.8367280E-14
CZ_DOT_X = 0.2734
CZ_DOT_Y = -0.1781
CZ_DOT_Z = -0.1358
CZ_DOT_X_DOT = -0.7659
CZ_DOT_Y_DOT = -0.5343
CZ_DOT_Z_DOT = 0.6280805E-13
COMMENT The below contains information for the impulsive maneuver.
MAN_EPOCH_IGNITION = 2009-05-12T15:30:00.000
MAN_DURATION = 0
MAN_DELTA_MASS = 0.0252069575402913408
MAN_REF_FRAME = EME2000
MAN_DV_1 = 0.000028562811624
MAN_DV_2 = 3.0883529021E-7
MAN_DV_3 = 1.4646782842E-8
```

Figure 7-1: Input OPM for Test Case 3

```
CCSDS_OEM_VERS = 2.0
CREATION_DATE = 2009-07-13T05:18:18.177
ORIGINATOR = JPL

META_START
OBJECT_NAME = SOHO
OBJECT_ID = 2009-000A
CENTER_NAME = EARTH
REF_FRAME = EME2000
TIME_SYSTEM = UTC
START_TIME = 2009-05-12T15:30:00
STOP_TIME = 2009-05-12T15:30:00
META_STOP

2009-05-12T15:30:00 687754.36358524451 941287.85553999909 520080.81101286015 -0.41396551860286029 0.29174462217893127
0.11756781919443197

COVARIANCE_START
EPOCH = 2009-05-12T15:30:00
COV_REF_FRAME = EME2000
7.8195940e-04
-5.9600000e-02 1.8419160e-03
-8.1580000e-01 -5.2840000e-01 1.3636350e-02
-8.5000000e-03 1.0300000e-02 8.7000000e-03 2.9555070e-15
1.0790000e-01 1.7330000e-01 -1.9090000e-01 -2.1100000e-02 8.3672800e-15
2.7340000e-01 -1.7810000e-01 -1.3580000e-01 -7.6590000e-01 -5.3430000e-01 6.2808050e-14
COVARIANCE_STOP
```

Figure 7-2: Output OEM for Test Case 3

7.4 TEST CASE #4: OMM WITHOUT COVARIANCE MATRIX

1	Report Date:	7 April 2009
2	Program Under Test:	Orbit Data Messages P1.1 (ODM) Prototype
3	Test Case Number:	4
4	Agencies Participating in this Test Case:	CNES-CSSI
5	Agency Responsible for Producing Test Message	CNES
6	Producing Test Engineer:	Alain Lamy
7	Agency Responsible for Consuming Test Message	CSSI
8	Consuming Test Engineer:	David Finkleman
9	Spacecraft:	ISS-Zarya
10	Results (Pass, Partial Pass, Fail):	Pass
11	Variances from Expected Result:	None
12	Comments:	A TLE for the ISS-Zarya was selected by CNES, and converted to OMM format. The OMM file was sent to CSSI by email. CSSI converted it back to TLE. The fields ‘ephemeris type’ of the generated TLE was given the value ‘0’ and the ‘classification field’ the value ‘U’. The comparison between the generated TLE and the original TLE showed identity. NOTE: 6 meter or less distance between original and twice processed recreated TLE for 3 day propagation.

7.5 TEST CASE #5: OMM WITH SYNTHETIC COVARIANCE MATRIX

1	Report Date:	13 July 2009
2	Program Under Test:	Orbit Data Messages P1.1 (ODM) Prototype
3	Test Case Number:	5
4	Agencies Participating in this Test Case:	GMV, CSSI
5	Agency Responsible for Producing Test Message	GMV, CSSI
6	Producing Test Engineer:	Francisco Martinez, David Finkleman
7	Agency Responsible for Consuming Test Message	CSSI, GMV
8	Consuming Test Engineer:	David Finkleman, Francisco Martinez
9	Spacecraft:	Iridium 33
10	Results (Pass, Partial Pass, Fail):	Pass
11	Variances from Expected Result:	None
12	Comments:	GMV sent an Iridium OMM accompanied by the TLE from which it had been generated. The generation process is summarized as: - Selected TLE from Iridium 33 - TLE propagated one orbit forward and another orbit backward with SGP4 - Positions in J2000 generated from the propagated orbit - Adjust a numerical orbit (with ESA software package NAPEOS) to the positions - Extract the covariance of the orbital fit (NOTE: the covariance is not an actual covariance for the TLE but the matrix has covariance properties.) - Generate the OMM with the TLE details and the extracted covariance. CSSI propagated the TLE to a new epoch and exported an OMM from that point back to GMV. During the process, there was significant discussion between the participants about the meaning and use of covariance information in conjunction with TLE orbit data (e.g., covariances with OMM are arguable; you can't use covariances in SGP4. One must reduce the TLE information in the OMM to at least an initial state and then propagate the initial state and the covariance matrix consistently from there). Use of the synthetic covariance matrix is a complex topic that should be addressed in an update to the Navigation Green Book. Also there was discussion about whether satellite name and other redundant data elements in the TLE format need be reproduced exactly or simply filled with nulls or defaults since only one item of identifying data is sufficient. There was some agreement that exchanging covariance with the OMM may possibly not be very useful, however, it was also agreed that the covariance construct should not be removed given that it is optional and it could potentially be useful in some application, even if that application cannot be explicitly defined at present.

7.6 TEST CASE #6: OEM WITH MULTIPLE COVARIANCES, NO ACCELERATIONS

1	Report Date:	08-Apr-2009
2	Program Under Test:	Orbit Data Messages P1.1 (ODM) Prototype
3	Test Case Number:	6
4	Agencies Participating in this Test Case:	JAXA, NASA/JPL
5	Agency Responsible for Producing Test Message	JAXA
6	Producing Test Engineer:	Ryo Nakamura
7	Agency Responsible for Consuming Test Message	NASA/JPL
8	Consuming Test Engineer:	Bob Stavert
9	Spacecraft:	Kaguya (SELENE)
10	Results (Pass, Partial Pass, Fail):	Pass
11	Variances from Expected Result:	The Version 2 OEM submitted to the DSN/SPS test subsystem failed conversion, as was more or less anticipated since it uses an unmodified version of the OEM converter. The OEM V2 was converted to SPK using the modified program oem2spkp and submitted to SPS; the SPK file was accepted. From this, we can infer that when the SPS legacy version of oem2spk is replaced with the updated version, the version 2 OEM will be accepted.
12	Comments:	The ephemeris provided by JAXA was processed with a prototype variant of the program oem2spk that is used in Deep Space Network Operations to translate from the OEM Version 1 to the internally used SPICE/SPK format. The operational program was modified to be able to process a CCSDS_OEM_VERS version number of 2.0 and to extract the two covariance matrices for use by the navigation team. The output of the prototype oem2spkp is in a format that can be used by the DSN for generation of pointing and frequency predicts.

7.7 TEST CASE #7: OEM WITH OPTIONAL ACCELERATIONS

1	Report Date:	26-Jun-2009
2	Program Under Test:	Orbit Data Messages P1.1 (ODM) Prototype
3	Test Case Number:	#7
4	Agencies Participating in this Test Case:	ESA/ESOC, NASA/JPL
5	Agency Responsible for Producing Test Message	Part A: ESA/ESOC Part B: NASA/JPL
6	Producing Test Engineer:	Part A: Frank Budnik Part B: David Berry
7	Agency Responsible for Consuming Test Message	Part A: NASA/JPL Part B: ESA/ESOC
8	Consuming Test Engineer:	Part A: David Berry Part B: Frank Budnik
9	Spacecraft:	Part A: Mars Express Part B: Mars Odyssey
10	Results (Pass, Partial Pass, Fail):	Pass
11	Variances from Expected Result:	Part A: The Version 2 OEM submitted to the DSN/SPS test subsystem failed conversion, as was more or less anticipated since it uses an unmodified version of the oem2spk converter. The OEM V2 was converted to SPK using the modified program oem2spkp and submitted to SPS; the SPK file was accepted. From this, we can infer that when the SPS legacy version of oem2spk is replaced with the updated version, the version 2 OEM will be accepted. The SPK file converted from the OEM V2 was also converted to NIO type and uploaded successfully to the SPS.
12	Comments:	Both JPL and ESA were able to process the OEM Version 2 with optional accelerations. Both approaches involved conversion of the Version 2 OEM to an internal orbit file format, which was compared with a truth ephemeris generated using the Version 1 OEM. The differences were numerical noise. Interpolation of the spacecraft states from the orbit files at the epochs provided were successfully compared with the provided arbitrary spacecraft state. <u>ESA's differences were</u>: Use of orbit file derived from OEM Version 1: Interpolated states rms-position differences: < 5.5D-07 km Interpolated states rms-velocity differences: < 2.8D-08 km/s Use of orbit file derived from OEM Version 2: Interpolated states rms-position differences: < 0.8D-07 km Interpolated states rms-velocity differences: < 1.0D-10 km/s <u>JPL's differences were</u>: Use of orbit file derived from OEM Version 2: Interpolated states rms-position differences = 1.28e-05 *km Interpolated states rms-velocity differences = 2.20e-07 *km/sec

7.8 TEST CASE #8: OPM WITH USER DEFINED PARAMETERS

1	Report Date:	05-Jul-2009
2	Program Under Test:	Orbit Data Messages P1.1 (ODM) Prototype
3	Test Case Number:	8
4	Agencies Participating in this Test Case:	NASA/GSFC, NASA/JPL
5	Agency Responsible for Producing Test Message	NASA/GSFC
6	Producing Test Engineer:	Stefan Novak
7	Agency Responsible for Consuming Test Message	NASA/JPL
8	Consuming Test Engineer:	David Berry
9	Spacecraft:	SOHO
10	Results (Pass, Partial Pass, Fail):	Pass
11	Variances from Expected Result:	It was necessary to update the JPL prototype to not error out in the presence of the User Defined Parameters. Also, the test OPM did not contain a spacecraft mass, which caused the maneuver it contained to not be processed correctly. Once the prototype was modified to bypass User Defined Parameters, and the spacecraft mass was added to the message, the message was parsed successfully.
12	Comments:	Since User Defined Parameters are, strictly speaking, "outside the standard", it is not unexpected that modification to the prototype was necessary.

7.9 TEST CASE #9: OMM WITH USER DEFINED PARAMETERS

1	Report Date:	14 April 2009
2	Program Under Test:	Orbit Data Messages P1.1 (ODM) Prototype
3	Test Case Number:	9
4	Agencies Participating in this Test Case:	CNES, CSSI
5	Agency Responsible for Producing Test Message	CNES
6	Producing Test Engineer:	Alain Lamy
7	Agency Responsible for Consuming Test Message	CSSI
8	Consuming Test Engineer:	David Finkleman
9	Spacecraft:	ISS-Zarya
10	Results (Pass, Partial Pass, Fail):	Pass
11	Variances from Expected Result:	None

12	Comments:	The same TLE as in test 4 was considered and converted to OMM. Additional user defined parameters have been added:
		`USER_DEFINED_USEABLE_TIME_RANGE = 10`
		`USER_DEFINED_EPHEM_TYPE = 0`
		`USER_DEFINED_CLASSIFICATION = U`
		
		The resulting OMM file was sent to CSSI and successfully processed.

ANNEX A

ACRONYMS

CCSDS	Consultative Committee for Space Data Systems
CESG	CCSDS Engineering Steering Group
CMC	CCSDS Management Council
CNES	Centre National d'Études Spatiales
CSSI	Center for Space Standards and Innovation
CWE	Common Working Environment
DSN	Deep Space Network
ESA	European Space Agency
ESOC	European Space Operations Center
GSFC	Goddard Space Flight Center
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
NASA	National Aeronautics and Space Administration
ODM	Orbit Data Messages
RID	Review Item Discrepancy