The Consultative Committee for Space Data Systems

DRAFT RECOMMENDATION FOR SPACE DATA SYSTEM STANDARDS

ORBIT DATA MESSAGES

CCSDS 502.0-P-0.~~6~~7

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FOREWORD

This document is a technical Draft Recommendation for Orbit Data Messages (ODMs) and has been prepared by the Consultative Committee for Space Data Systems (CCSDS). The set of orbit data messages described in this Recommendation is the baseline concept for trajectory representation in data interchange applications that are cross-supported between Agencies of the CCSDS.

This Recommendation establishes a common framework and provides a common basis for the interchange of orbit data. It allows implementing organizations within each Agency to proceed coherently with the development of compatible derived standards for the flight and ground systems that are within their cognizance. Derived Agency standards may implement only a subset of the optional features allowed by the Recommendation and may incorporate features not addressed by this Recommendation.

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- Swedish Space Corporation (SSC)/Sweden.
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CCSDS 502.0-B-1	Orbit Data Messages, Issue 1	September 2004	Current Issue
CCSDS 502.0-P-1.1 NOTE: should have been number 502.0-P-0.1	Orbit Data Messages, Issue 1.1 (NOTE: Should have been numbered Issue 0.1)	October 2006	First proposed revised recommendation to accommodate requirements of ISO TC20/SC14
CCSDS 502.0-P-0.2	Orbit Data Messages, Issue 0.2	January 2007	Updates to proposed revised recommendation to accommodate requirements of ISO TC20/SC14
CCSDS 502.0-P-0.3	Orbit Data Messages, Issue 0.3	March 2007	Updates to proposed revised recommendation based on Colorado Springs discussions
CCSDS 502.0-P-0.4	Orbit Data Messages, Issue 0.4	May 2007	Updates to proposed revised recommendation based on Darmstadt discussions
CCSDS 502.0-P-0.5	Orbit Data Messages, Issue 0.5	October 2007	Updates from CCSDS Fall 2007 Meetings
CCSDS 502.0-P-0.6	Orbit Data Messages, Issue 0.6	March 2008	Updates from reviewer comments to P0.4, cleanup, preparation for CCSDS Agency Review and ISO review
CCSDS 502.0-P-0.7	Orbit Data Messages, Issue 0.7	April 2008	Updates from CCSDS Spring 2008 Meetings, preparation for CCSDS Agency Review and ISO review

CONTENTS

ANNEX A VALUES FOR TIME_SYSTEM and REFERENCE_FRAME A-1

CONTENTS (continued)

Table **Page**

1 INTRODUCTION

1.1 PURPOSE

This Orbit Data Message (ODM) DRAFT Recommendation specifies three standard message formats for use in transferring spacecraft orbit information between space agencies and commercial or governmental spacecraft operators: the Orbit Parameter Message (OPM), the Orbit Mean-Elements Message (OMM), and the Orbit Ephemeris Message (OEM). Such exchanges are used for:

a) pre-flight planning for tracking or navigation support;

b) scheduling tracking support;

c) carrying out tracking operations (sometimes called metric predicts);

d) performing orbit comparisons;

e) carrying out navigation operations such as orbit propagation and orbit reconstruction;

f) assessing mutual physical and electromagnetic interference among satellites orbiting the same celestial body (primarily Earth, Moon and Mars);

g) performing orbit conjunction (collision avoidance) studies; and

h) developing and executing collaborative maneuvers to mitigate interference or enhance mutual operations.

This Recommendation includes sets of requirements and criteria that the message formats have been designed to meet. For exchanges where these requirements do not capture the needs of the participating agencies and satellite operators another mechanism may be selected.

1.2 SCOPE AND APPLICABILITY

This document contains three orbit data messages designed for applications involving data interchange in space data systems. The rationale behind the design of each message is described in Annex C and may help the application engineer to select a suitable message. Definition of the orbit accuracy underlying a particular orbit message is outside of the scope of this Recommendation and should be specified via Interface Control Document (ICD) between data exchange participants (or specified via COMMENT sections in the message itself). Applicability information specific to each orbit data message format appears in sections 3, 4, and 5, as well as in subsection C3.

This Recommendation is applicable only to the message format and content, but not to its transmission. The transmission of the message between agencies and operators is outside the scope of this document and should be specified in the ICD.

Description of the message formats based on the use of eXtensible Markup Language (XML) is detailed in an integrated XML schema document for all Navigation Data Message Recommendations. See reference [5].

1.3 CONVENTIONS AND DEFINITIONS

The following conventions apply throughout this Recommendation:

a) the words 'shall' and 'must' imply a binding and verifiable specification;

b) the word 'should' implies an optional, but desirable, specification;

c) the word 'may' implies an optional specification;

d) the words 'is', 'are', and 'will' imply statements of fact.

e) The word "agencies" may also be construed as meaning "satellite operators" or "satellite service providers".

f) The notation "n/a" signifies "not applicable".

1.4 STRUCTURE OF THIS DOCUMENT

Chapter 2 provides a brief overview of the CCSDS-recommended Orbit Data Message types, the Orbit Parameter Message (OPM), Orbit Mean-Elements Message (OMM), and Orbit Ephemeris Message (OEM).

Chapter 3 provides details about the structure and content of the OPM.

Chapter 4 provides details about the structure and content of the OMM.

Chapter 5 provides details about the structure and content of the OEM.

Chapter 6 discusses the syntax considerations of the set of Orbit Data Messages (OPM, OMM, OEM).

Chapter 7 discusses security requirements for the Orbit Data Messages.

Annex A lists acceptable values for selected ODM keywords.

Annex B is a list of abbreviations and acronyms applicable to the ODM.

Annex C lists a set of requirements that were taken into consideration in the design of the OPM, OMM and OEM, along with tables and discussion regarding the applicability of the three message types to various navigation tasks/functions.

Annex D lists a number of items that should be covered in Interface Control Documents (ICD) prior to exchanging ODMs on a regular basis. There are several statements throughout the document that refer to the desirability or necessity of such a document; this annex lists all the suggested ICD items in a single place in the document. Also provided is a set of generic comment statements that may be added to one of the Orbit Data Messages to convey supplementary information for scenarios in which there is no ICD in place.

Annex E provides a summary of the changes introduced in this version 2 of the ODM, and documents the differences between ODM version 1 and ODM version 2.

Annex F provides a listing of informative references.

1.5 REFERENCES

The following documents contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this Recommendation 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 Recommendations.

[1] *Time Code Formats*. Recommendation for Space Data System Standards, CCSDS 301.0-B-3. Blue Book. Issue 3. Washington, D.C.: CCSDS, January 2002.

[2] *Spacewarn Bulletin*. Greenbelt, MD, USA: World Data Center for Satellite Information: WDC-SI. [http://nssdc.gsfc.nasa.gov/spacewarn]

[3] *Standard Frequencies and Time Signals*. Volume 7 of *Recommendations and Reports of the CCIR: XVth Plenary Assembly*. Geneva: CCIR,1990.

[4] *Information Technology—8-Bit Single-Byte Coded Graphic Character Sets—Part 1: Latin Alphabet No. 1*. International Standard, ISO/IEC 8859-1:1998. Geneva: ISO, 1998. [http://www.iso.ch]

[5] *XML Specification for Navigation Data Messages*. Draft Recommendation for Space Data System Standards, CCSDS 505.0-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, November 2005.

[6] NASA/JPL Solar System Dynamics Group [*http://ssd.jpl.nasa.gov*].

[7] XML Schema Part 2: Datatypes, W3C Recommendation 28 October 2004, http://www.w3.org/TR/2004/REC-xmlschema-2-20041028/

[8] IEEE Standard for Binary Floating-Point Arithmetic, IEEE Standard 754-1985, IEEE, http://grouper.ieee.org/groups/754/

2 OVERVIEW

2.1 ORBIT DATA MESSAGE TYPES

Three CCSDS-recommended Orbit Data Messages (ODMs) are described in this Recommendation: the Orbit Parameter Message (OPM), the Orbit Mean-Elements Message (OMM), and the Orbit Ephemeris Message (OEM).

The recommended orbit data messages are ASCII text format [4]. This document describes “keyword = value notation” formatted messages, while reference [5] describes XML formatted messages (the ICD should specify which of these formats will be exchanged). While binary-based orbit data message formats are computer efficient and minimize overhead on uplinked/downlinked data streams, there are ground-segment applications for which an ASCII character-based message is more appropriate. For example, when files or data objects are created using text editors or word processors, ASCII character-based orbit data format representations are necessary. They are also useful in transferring text files between heterogeneous computing systems, because the ASCII character set is nearly universally used and is interpretable by all popular systems. In addition, direct human-readable dumps of text files or objects to displays or printers are possible without preprocessing. The penalty for this convenience is some measure of inefficiency; this inefficiency may be mitigated by using data compression techniques.

NOTE As currently specified, an OPM, OMM or OEM file is to represent orbit data for a single participant. It is possible that the architecture may support multiple participants per file; this could be considered in the future.

2.2 ORBIT PARAMETER MESSAGE (OPM)

An OPM specifies the position and velocity of a single object at a specified epoch. Optionally, osculating Keplerian elements may be provided. This message is suited to exchanges that (1) involve automated interaction and/or human interaction, and (2) do not require high-fidelity dynamic modeling.

The OPM requires the use of a propagation technique to determine the position and velocity at times different from the specified epoch, leading to a higher level of effort for software implementation than for the OEM. A 6x6 position/velocity covariance matrix that may be used in the propagation process is optional. ~~The OPM is fully self-contained; no additional information is required. [xxx We should discuss this last statement… since it is recommended to use ODMs with an ICD, I wonder if this statement is in fact true. xxx]~~

The OPM allows for modeling of any number of maneuvers (as both finite and instantaneous events) and simple modeling of solar radiation pressure and atmospheric drag.

Though primarily intended for use by computers, the attributes of the OPM also make it suitable for applications such as exchanges by FAX or voice, or applications where the message is to be frequently interpreted by humans.

2.3 ORBIT MEAN-ELEMENTS MESSAGE (OMM)

An OMM specifies the orbital characteristics of a single object at a specified epoch, expressed in mean Keplerian elements. This message is suited to exchanges that (1) involve automated interaction and/or human interaction, and (2) do not require high-fidelity dynamic modeling. Such exchanges may be inter-agency exchanges, or ad hoc exchanges among satellite operators when interface control documents have not been negotiated. Ad hoc interactions usually involve more than one satellite, each satellite controlled and operated by a different operating authority.

The OMM includes keywords and values that can be used to generate canonical NORAD Two Line Element Sets (TLE) to accommodate the needs of heritage users. In order to be compatible with heritage applications, some keywords have required values in the OMM that are more constrained than similar keywords in the OPM or OEM. If the OMM is used to convey TLE-based information, the state must be propagated with the SGP4 propagator; incorrect results will be obtained if the state is used with any other propagator.

The OMM also contains an optional covariance matrix which reflects the uncertainty of the orbital elements. This information may be used to determine contact parameters that encompass uncertainties in predicted future states of orbiting objects of interest. The OMM is fully self-contained; no additional information is required. [xxx We should discuss this last statement… since it is recommended to use ODMs with an ICD, I wonder if this statement is in fact true. xxx]

Though primarily intended for use by computers, the attributes of the OMM also make it suitable for applications such as exchanges by FAX or voice, or applications where the message is to be frequently interpreted by humans.

2.4 ORBIT EPHEMERIS MESSAGE (OEM)

An OEM specifies the position and velocity of a single object at multiple epochs contained within a specified time range. The OEM is suited to exchanges that (1) involve automated interaction (e.g., computer-to-computer communication where frequent, fast automated time interpretation and processing is required), and (2) require higher fidelity or higher precision dynamic modeling than is possible with the OPM.

The OEM allows for dynamic modeling of any number of gravitational and non-gravitational accelerations. The OEM requires the use of an interpolation technique to interpret the position and velocity at times different from the tabular epochs. The OEM is fully self-contained; no additional information is required. [xxx We should discuss this last statement… since it is recommended to use ODMs with an ICD, I wonder if this statement is in fact true. xxx]

2.5 EXCHANGE OF MULTIPLE MESSAGES

For a given object, multiple OPM, OMM or OEM messages may be provided in a message exchange session to achieve ephemeris fidelity requirements. If ephemeris information for multiple objects is to be exchanged, then multiple OPM, OMM or OEM files must be used.

2.6 DEFINITIONS

Definitions of time systems, reference frames, planetary models, and maneuvers and other fundamental topics related to the interpretation and processing of state vectors and spacecraft ephemerides are provided in reference [F1]. As of this writing, the topics of covariance matrices, mean elements, and TLEs are not contained within that document, but will be added in the next update.

3 ORBIT PARAMETER MESSAGE (OPM)

3.1 OVERVIEW

a) Orbit information may be exchanged between two participants by sending a state vector (see reference [F1]) for a specified epoch using an Orbit Parameter Message (OPM). The message recipient must have an orbit propagator available that is able to propagate the OPM state vector to compute the orbit at other desired epochs. For this propagation, additional ancillary information (spacecraft properties such as mass, area, and maneuver planning data, if applicable) shall be included with the message.

b) Osculating Keplerian elements and Gravitational Coefficient may be included in the OPM in addition to the Cartesian state to aid the message recipient in performing consistency checks. If any Keplerian element is included, the entire set of elements must be provided.

c) If participants wish to exchange mean element information, then the Orbit Mean-Elements Message (OMM) should be the selected message type. See Section 4.

d) The use of the OPM shall be applicable under the following conditions:

   1) an orbit propagator consistent with the models used to develop the orbit data must be run at the receiver's site;

   2) the receiver's modeling of gravitational forces, solar radiation pressure, atmospheric drag and thrust phases (see reference [F1]) must fulfill accuracy requirements established between the exchange partners.

e) The OPM shall be a plain text file consisting of orbit data for a single object. It shall be easily readable by both humans and computers.

f) The OPM file naming scheme should be agreed to on a case-by-case basis between the exchange partners, and should be documented in an Interface Control Document (ICD). The method of exchanging OPMs should be decided on a case-by-case basis by the exchange partners and documented in an ICD.

g) Detailed syntax rules for the OPM are specified in Section 6.

3.2 OPM CONTENT/STRUCTURE

The OPM shall be represented as a combination of the following:

a) a header;

b) metadata (data about data);

c) data; and

d) optional comments (explanatory information).

3.2.1 OPM HEADER

Table 3-1~~Table 3-1~~ specifies for each header item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

Only those keywords shown in Table 3-1~~Table 3-1~~ shall be used in an OPM header.

Table 3~~3~~-1: OPM Header

Keyword	Description	Examples of Values	Obligatory
CCSDS_OPM_VERS	Format version in the form of 'x.y', where 'y' is incremented for corrections and minor changes, and 'x' is incremented for major changes.	2.0	Yes
COMMENT	Comments (allowed in the OPM Header only immediately after the OPM version number). See section 6.6 for formatting rules.	COMMENT This is a comment	No
CREATION_DATE	File creation date/time in UTC. For format specification, see 6.4(i)	2001-11-06T11:17:33 2002-204T15:56:23	Yes
ORIGINATOR	Creating agency or operator (value should be specified in an ICD). The country of origin should also be provided where the originator is not a national space agency.	CNES, ESOC, GSFC, GSOC, JPL, JAXA, INTELSAT/USA, USAF, INMARSAT/UK	Yes

3.2.2 OPM METADATA

Table 3-2~~Table 3-2~~ specifies for each metadata item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

Only those keywords shown in Table 3-2~~Table 3-2~~ shall be used in OPM metadata. For some keywords (OBJECT_NAME, OBJECT_ID, CENTER_NAME) there are no definitive lists of authorized values maintained by a control authority; the references listed in subsection 1.51.5 are the best known sources for authorized values to date. For the TIME_SYSTEM and REF_FRAME keywords, the approved values are listed in Annex A.

Table 33-2: OPM Metadata

Keyword	Description	Examples of Values	Obligatory
COMMENT	Comments (allowed at the beginning of the OPM Metadata). See section 6.6 for formatting rules.	COMMENT This is a comment	No
OBJECT_NAME	Spacecraft name for which the orbit state is provided. There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the SPACEWARN Bulletin (reference [22]), which include Object name and international designator of the participant.	EUTELSAT W1 MARS PATHFINDER STS 106 NEAR	Yes
OBJECT_ID	Object identifier of the object for which the orbit state is provided. There is no CCSDS-based restriction on the value for this keyword, but it is recommended that values be the international spacecraft designator (as published in the SPACEWARN Bulletin (reference [22])). Recommended values have the format YYYY-NNNP{PP}, where: YYYY = Year of launch. NNN = Three digit serial number of launch in year YYYY (with leading zeros). P{PP} = At least one capital letter for the identification of the part brought into space by the launch. In cases where the asset is not listed in the bulletin, or the SPACEWARN format is not used, the value should be provided in an ICD.	2000-052A 1996-068A 2000-053A 1996-008A	Yes
CENTER_NAME	Origin of reference frame, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this case the value for 'CENTER_NAME' is subject to the same rules as for 'OBJECT_NAME'). There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the NASA/JPL Solar System Dynamics Group (at http://ssd.jpl.nasa.gov (reference [6])).	EARTH EARTH BARYCENTER MOON SOLAR SYSTEM BARYCENTER SUN JUPITER BARYCENTER STS 106 EROS	Yes
REF_FRAME	Name of the reference frame in which the state vector and optional Keplerian element data are given. The value of this parameter must be selected from Annex A. The reference frame must be the same for all data elements, excluding the maneuvers and covariance matrix, for which applicable different reference frames may be specified.	ICRF ITRF-93 ITRF-97 ITRF2000 ITRFxxxx (Template for a future version) TOD (True Equator/Equinox of Date) EME2000 (Earth Mean Equator and Equinox of J2000) TDR (true of date rotating) GRC (Greenwich rotating coordinate frame)	Yes
TIME_SYSTEM	Time system used for state vector, maneuver, and covariance data (also see Table 3-3). The value of this parameter must be selected from Annex A.	UTC, TAI, TT, GPS, TDB, TCB	Yes

3.2.3 OPM DATA

Table 3-3~~Table 3-3~~ provides an overview of the five logical blocks in the OPM Data section (State Vector, Keplerian Elements, Spacecraft Parameters, Position/Velocity Covariance Matrix, and Maneuver Parameters), and specifies for each data item:

a) the keyword to be used;

b) a short description of the item;

c) the units to be used;

d) whether the item is obligatory or optional.

Only those keywords shown in Table 3-3~~Table 3-3~~ shall be used in OPM data. (Some important notes about the keywords in Table 3-3~~Table 3-3~~ appear immediately after the table.)

Table 33-3: OPM Data

Keyword	Description	Units	Obligatory
State Vector Components in the Specified Coordinate System			
`COMMENT`	–See section 6.6 for formatting rules.	n/a	No
`EPOCH`	Epoch of state vector & optional Keplerian elements. See Section 6.4 for formatting rules.	n/a	Yes
`X`	Position vector X-component	km	Yes
`Y`	Position vector Y-component	km	Yes
`Z`	Position vector Z-component	km	Yes
`X_DOT`	Velocity vector X-component	km/s	Yes
`Y_DOT`	Velocity vector Y-component	km/s	Yes
`Z_DOT`	Velocity vector Z-component	km/s	Yes
Osculating Keplerian Elements in the Specified Reference Frame (none or all parameters of this block must be given.)			
`COMMENT`	See section 6.6 for formatting rules.	n/a	No
`SEMI_MAJOR_AXIS`	Semi-major axis	km	No
`ECCENTRICITY`	Eccentricity	n/a	No
`INCLINATION`	Inclination	deg	No
`RA_OF_ASC_NODE`	Right ascension of ascending node	deg	No
`ARG_OF_PERICENTER`	Argument of pericenter	deg	No
`TRUE_ANOMALY` or `MEAN_ANOMALY`	True anomaly or mean anomaly	deg	No
`GM`	Gravitational Coefficient (Gravitational Constant x Central Mass)	km**3/s**2	No
Spacecraft Parameters			
`COMMENT`	See section 6.6 for formatting rules.	n/a	No
`MASS`	S/C Mass	kg	Yes
`SOLAR_RAD_AREA`	Solar Radiation Pressure Area (A_R).	m**2	Yes
`SOLAR_RAD_COEFF`	Solar Radiation Pressure Coefficient (C_R).	n/a	Yes
`DRAG_AREA`	Drag Area (A_D).	m**2	Yes
`DRAG_COEFF`	Drag Coefficient (C_D).	n/a	Yes
Position/Velocity Covariance Matrix (6x6 Lower Triangular Form. None or all parameters of this block must be given.)			
`COMMENT`	See section 6.6 for formatting rules.	n/a	No
`COV_REF_FRAME`	Coordinate system for covariance matrix (value must be selected from Annex A)	n/a	No
`CX_X`	Covariance matrix [1,1]	km**2	No
`CY_X`	Covariance matrix [2,1]	km**2	No
`CY_Y`	Covariance matrix [2,2]	km**2	No
`CZ_X`	Covariance matrix [3,1]	km**2	No
`CZ_Y`	Covariance matrix [3,2]	km**2	No
`CZ_Z`	Covariance matrix [3,3]	km**2	No
`CX_DOT_X`	Covariance matrix [4,1]	km**2/s	No
`CX_DOT_Y`	Covariance matrix [4,2]	km**2/s	No
`CX_DOT_Z`	Covariance matrix [4,3]	km**2/s	No
`CX_DOT_X_DOT`	Covariance matrix [4,4]	km**2/s**2	No
`CY_DOT_X`	Covariance matrix [5,1]	km**2/s	No
`CY_DOT_Y`	Covariance matrix [5,2]	km**2/s	No
`CY_DOT_Z`	Covariance matrix [5,3]	km**2/s	No

CY_DOT_X_DOT	Covariance matrix [5,4]	km**2/s**2	No
CY_DOT_Y_DOT	Covariance matrix [5,5]	km**2/s**2	No
CZ_DOT_X	Covariance matrix [6,1]	km**2/s	No
CZ_DOT_Y	Covariance matrix [6,2]	km**2/s	No
CZ_DOT_Z	Covariance matrix [6,3]	km**2/s	No
CZ_DOT_X_DOT	Covariance matrix [6,4]	km**2/s**2	No
CZ_DOT_Y_DOT	Covariance matrix [6,5]	km**2/s**2	No
CZ_DOT_Z_DOT	Covariance matrix [6,6]	km**2/s**2	No
~~COVARIANCE_SOLVE_FORS~~	~~Orbit determination solve for variable(s). Repeat this keyword as desired, but values beyond 6x6 matrix are not presented.~~	~~n/a~~	~~No~~
Maneuver Parameters (Repeat for each maneuver. None or all parameters of this block must be given.)			
COMMENT	~~–~~See section 6.6 for formatting rules.	n/a	No
MAN_EPOCH_IGNITION	Epoch of ignition. See section 6.4(i) for formatting rules.	n/a	No
MAN_DURATION	Maneuver duration (If = 0, impulsive maneuver)	s	No
MAN_DELTA_MASS	Mass change during maneuver (value is < 0)	kg	No
MAN_REF_FRAME	Coordinate system for velocity increment vector (value must be selected from Annex A)	n/a	No
MAN_DV_1	1st component of the velocity increment	km/s	No
MAN_DV_2	2nd component of the velocity increment	km/s	No
MAN_DV_3	3rd component of the velocity increment	km/s	No

NOTES

1 All values in the OPM are "at epoch", i.e., the value of the parameter at the time specified in the EPOCH keyword.

2 Table 3-3Table 3-3 is broken into five logical blocks, each of which has a descriptive heading. Those descriptive headings shall not be included in an OPM, unless they appear in a properly formatted COMMENT statement.

3 If the solar radiation coefficient, C_R, is set to zero, no solar radiation pressure shall be taken into account.

4 If the atmospheric drag coefficient, C_D, is set to zero, no atmospheric drag shall be taken into account.

5 Parameters for thrust phases may be optionally given for the computation of the trajectory during or after maneuver execution (see reference [F1] for the simplified modeling of such maneuvers). For impulsive maneuvers, MAN_DURATION must be set to zero. MAN_DELTA_MASS may be used for both finite and impulsive maneuvers; the value must be a negative number. Permissible reference frames for the velocity increment vector shall be those specified in Annex A.

6 Multiple sets of maneuver parameters may appear. For each maneuver, all the maneuver parameters shall be repeated in the order shown in Table 3-3Table 3-3.

7 Values in the covariance matrix shall be expressed in the reference frame as specified in the Position/Velocity Covariance Matrix logical block, and will shall be presented sequentially from upper left [1,1] to lower right [6,6], lower triangular form, row by row left to right. Variance and covariance values shall be expressed in standard double precision as related in section 6.4. This logical block of the OPM may be useful for risk assessment and establishing maneuver and mission margins. The intent is to provide causal connections between output orbit data and both physical hypotheses and measurement uncertainties. These causal relationships guide operators' corrective actions and mitigations.

8Covariance Solve Fors: These are parameters that are solved for as part of the orbit determination process. As many "solve fors" as is desired may be listed in the COVARIANCE_SOLVE_FOR keywords, but the covariance values beyond the 6x6 position/velocity covariance are not displayed.

3.3 OPM EXAMPLES

Figure 3-13-1 through Figure 3-4Figure 3-4 are examples of Orbit Parameter Messages. The first has only a state; the second has state, Keplerian elements, and maneuvers; the third and fourth include the position/velocity covariance matrix.

Figure 3-1~~Figure 3-1~~ and Figure 3-2~~Figure 3-2~~ are compatible with the ODM version 1.0 processing because they do not contain any of the unique features of the ODM version 2.0. Thus for these examples ~~"CCSDS_OPM_VERS = 1.0" could~~ a value of 1.0 could be specified for the 'CCSDS_OPM_VERS' keyword.

Figure 3-3~~Figure 3-3~~ and Figure 3-4~~Figure 3-4~~ include unique features of ODM version 2.0, thus "CCSDS_OPM_VERS = 2.0" must be specified.

```
CCSDS_OPM_VERS = 2.0
CREATION_DATE  = 1998-11-06T09:23:57
ORIGINATOR     = JAXA

COMMENT          GEOCENTRIC, CARTESIAN, EARTH FIXED
OBJECT_NAME    = GODZILLA 5
OBJECT_ID      = 1998-057A
CENTER_NAME    = EARTH
REF_FRAME      = ITRF-97
TIME_SYSTEM    = UTC

COMMENT          OBJECT_ID: 1998-057A
COMMENT $ITIM  = 1998 OCT 09 22:26:18.40000000, $ original launch time 21:58
COMMENT $ITIM  = 1998 OCT 09 22:23:18.40000000, $ reflects -3mn shift 21:55
COMMENT $ITIM  = 1998 OCT 09 22:28:18.40000000, $ reflects +5mn shift 22:00
COMMENT $ITIM  = 1998 OCT 09 22:58:18.40000000, $ reflects+30mn shift 22:30
COMMENT $ITIM  = 1998 OCT 09 23:18:18.40000000, $ reflects+20mn shift 22:50

EPOCH =          1998-12-18T14:28:15.1172
X =              6503.514000
Y =              1239.647000
Z =              -717.490000
X_DOT =            -0.873160
Y_DOT =             8.740420
Z_DOT =            -4.191076
MASS =           3000.000000
SOLAR_RAD_AREA =   18.770000
SOLAR_RAD_COEFF =   1.000000
DRAG_AREA =        18.770000
DRAG_COEFF =        2.500000
```

Figure 3~~3~~-1: OPM File Example Using Comments to Denote Updates

```
CCSDS_OPM_VERS    =  2.0

COMMENT  Generated by GSOC, R. Kiehling
COMMENT  Current intermediate orbit IO2 and maneuver planning data

CREATION_DATE     =  2000-06-03T05:33:00.000
ORIGINATOR        =  GSOC

OBJECT_NAME       =  EUTELSAT W4
OBJECT_ID         =  2000-028A
CENTER_NAME       =  EARTH
REF_FRAME         =  TOD
TIME_SYSTEM       =  UTC

COMMENT  State Vector
EPOCH             =  2006-06-03T00:00:00.000
X                 =    6655.9942        [km]
Y                 =  -40218.5751        [km]
Z                 =     -82.9177        [km]
X_DOT             =       3.11548208    [km/s]
Y_DOT             =       0.47042605    [km/s]
Z_DOT             =      -0.00101495    [km/s]

COMMENT  Keplerian elements
SEMI_MAJOR_AXIS   =   41399.5123        [km]
ECCENTRICITY      =       0.020842611
INCLINATION       =       0.117746      [deg]
RA_OF_ASC_NODE    =      17.604721      [deg]
ARG_OF_PERICENTER =     218.242943      [deg]
TRUE_ANOMALY      =      41.922339      [deg]
GM                =  398600.4415        [km**3/s**2]

COMMENT  Spacecraft parameters
MASS              =    1913.000         [kg]
SOLAR_RAD_AREA    =      10.000         [m**2]
SOLAR_RAD_COEFF   =       1.300
DRAG_AREA         =      10.000         [m**2]
DRAG_COEFF        =       2.300

COMMENT  2 planned maneuvers

COMMENT  First maneuver: AMF-3
COMMENT  Non-impulsive, thrust direction fixed in inertial frame
MAN_EPOCH_IGNITION =      2000-06-03T09:00:34.1
MAN_DURATION      =     132.60          [s]
MAN_DELTA_MASS    =     -18.418         [kg]
MAN_REF_FRAME     =       EME2000
MAN_DV_1          =      -0.02325700    [km/s]
MAN_DV_2          =       0.01683160    [km/s]
MAN_DV_3          =      -0.00893444    [km/s]

COMMENT  Second maneuver: first station acquisition maneuver
COMMENT  impulsive, thrust direction fixed in RTN frame
MAN_EPOCH_IGNITION =      2000-06-05T18:59:21.0
MAN_DURATION      =       0.00          [s]
MAN_DELTA_MASS    =      -1.469         [kg]
MAN_REF_FRAME     =       RTN
MAN_DV_1          =       0.00101500    [km/s]
MAN_DV_2          =      -0.00187300    [km/s]
MAN_DV_3          =       0.00000000    [km/s]
```

Figure ~~3~~3-2: OPM File Example with Optional Keplerian Elements and Two Maneuvers

```
CCSDS_OPM_VERS = 2.0

CREATION_DATE  = 1998-11-06T09:23:57
ORIGINATOR     = JAXA

COMMENT          GEOCENTRIC, CARTESIAN, EARTH FIXED
OBJECT_NAME    = GODZILLA 5
OBJECT_ID      = 1998-057A
CENTER_NAME    = EARTH
REF_FRAME      = ITRF-97
TIME_SYSTEM    = UTC

COMMENT          OBJECT_ID: 1998-057A
COMMENT $ITIM  = 1998 OCT 09 22:26:18.40000000, $ original launch time 21:58
COMMENT $ITIM  = 1998 OCT 09 22:23:18.40000000, $ reflects -3mn shift 21:55
COMMENT $ITIM  = 1998 OCT 09 22:28:18.40000000, $ reflects +5mn shift 22:00
COMMENT $ITIM  = 1998 OCT 09 22:58:18.40000000, $ reflects+30mn shift 22:30
COMMENT $ITIM  = 1998 OCT 09 23:18:18.40000000, $ reflects+20mn shift 22:50

EPOCH =          1998-12-18T14:28:15.1172
X =              6503.514000
Y =              1239.647000
Z =              -717.490000
X_DOT =            -0.873160
Y_DOT =             8.740420
Z_DOT =            -4.191076

MASS =           3000.000000
SOLAR_RAD_AREA =   18.770000
SOLAR_RAD_COEFF =   1.000000
DRAG_AREA =        18.770000
DRAG_COEFF =        2.500000

CX_X = 0.316
CY_X = 0.722
CY_Y = 0.518
CZ_X = 0.202
CZ_Y = 0.715
CZ_Z = 0.002
CX_DOT_X = 0.912
CX_DOT_Y = 0.306
CX_DOT_Z = 0.276
CX_DOT_X_DOT = 0.797
CY_DOT_X = 0.562
CY_DOT_Y = 0.899
CY_DOT_Z = 0.022
CY_DOT_X_DOT = 0.079
CY_DOT_Y_DOT = 0.415
CZ_DOT_X = 0.245
CZ_DOT_Y = 0.965
CZ_DOT_Z = 0.950
CZ_DOT_X_DOT = 0.435
CZ_DOT_Y_DOT = 0.621
CZ_DOT_Z_DOT = 0.991
```

Figure 33-3: OPM File Example With Covariance Matrix

```
CCSDS_OPM_VERS    =  2.0
COMMENT  Generated by GSOC, R. Kiehling
COMMENT  Current intermediate orbit IO2 and maneuver planning data
CREATION_DATE     =  2000-06-03T05:33:00.000
ORIGINATOR        =  GSOC
OBJECT_NAME       =  EUTELSAT W4
OBJECT_ID         =  2000-028A
CENTER_NAME       =  EARTH
REF_FRAME         =  TOD
TIME_SYSTEM       =  UTC
COMMENT  State Vector
EPOCH             =  2006-06-03T00:00:00.000
X                 =    6655.9942        [km]
Y                 =  -40218.5751        [km]
Z                 =     -82.9177        [km]
X_DOT             =       3.11548208    [km/s]
Y_DOT             =       0.47042605    [km/s]
Z_DOT             =      -0.00101495    [km/s]
COMMENT  Keplerian elements
SEMI_MAJOR_AXIS   =   41399.5123        [km]
ECCENTRICITY      =       0.020842611
INCLINATION       =       0.117746      [deg]
RA_OF_ASC_NODE    =      17.604721      [deg]
ARG_OF_PERICENTER =     218.242943      [deg]
TRUE_ANOMALY      =      41.922339      [deg]
GM                =  398600.4415        [km**3/s**2]
COMMENT  Spacecraft parameters
MASS              =    1913.000         [kg]
SOLAR_RAD_AREA    =      10.000         [m**2]
SOLAR_RAD_COEFF   =       1.300
DRAG_AREA         =      10.000         [m**2]
DRAG_COEFF        =       2.300
CX_X = 0.316
CY_X = 0.722
CY_Y = 0.518
CZ_X = 0.202
CZ_Y = 0.715
CZ_Z = 0.002
CX_DOT_X = 0.912
CX_DOT_Y = 0.306
CX_DOT_Z = 0.276
CX_DOT_X_DOT = 0.797
CY_DOT_X = 0.562
CY_DOT_Y = 0.899
CY_DOT_Z = 0.022
CY_DOT_X_DOT = 0.079
CY_DOT_Y_DOT = 0.415
CZ_DOT_X = 0.245
CZ_DOT_Y = 0.965
CZ_DOT_Z = 0.950
CZ_DOT_X_DOT = 0.435
CZ_DOT_Y_DOT = 0.621
CZ_DOT_Z_DOT = 0.991
```

Figure 33-4: OPM File Example with Optional Keplerian Elements, Covariance Matrix

3.4INCREASING THE ORBIT PROPAGATION FIDELITY OF AN OPM

Some OPM users may desire/require a higher fidelity propagation of the state vector. A higher fidelity technique may be desired/required in order to minimize inconsistencies in predictions generated by diverse, often operator unique propagation schemes. Nominally the OPM is only engineered for a relatively lower fidelity orbit propagation. However, with the inclusion of additional context information, it is possible for users to provide data that could be used to provide a relatively higher fidelity orbit propagation. For this relatively higher fidelity orbit propagation, a much greater amount of ancillary information regarding spacecraft properties and dynamical models should be provided. Higher fidelity orbit propagations may be useful in special studies such as orbit conjunction studies.

Spacecraft orbit determination and propagation are stochastic estimation problems. Observations are inherently uncertain, and not all of the phenomena that influence satellite motion are clearly discernible. State vectors and covariances are best propagated with models that include the same forces and phenomena that were used for determining the orbit. Including this information in an OPM allows exchange partners to compare the results of their respective orbit propagations.

With additional context information, the OPM may be used for assessing mutual physical or electromagnetic interference among Earth orbiting spacecraft, developing collaborative maneuvers, and propagating the orbits of active satellites, inactive man made objects, and near Earth debris fragments. The additional information facilitates dynamic modeling of any users' approach to conservative and non-conservative phenomena. It is meant to enable numerical integration of the governing equations, including measurement and process noise, in order to estimate future states of the satellites of interest.

The primary vehicle for the provision of additional optional ancillary information to be used when propagating an OPM is the COMMENT mechanism. A number of suggested COMMENT statements are included in Annex D. An online version of this annex is available on the CCSDS web page at <URL here>. This online version is suitable for downloading, editing, and inserting directly into an OPM. Note that this set of COMMENT statements is also suitable for use in situations where an ICD between exchange partners is neither required, desired, nor feasible.

4 ORBIT MEAN-ELEMENTS MESSAGE (OMM)

4.1 OVERVIEW

a) Orbit information may be exchanged between two participants by sending an orbital state based on mean orbital elements (see reference [F1]) for a specified epoch using an Orbit Mean-Elements Message (OMM). The message recipient must use appropriate orbit propagator algorithms in order to correctly propagate the OMM state vector to compute the orbit at other desired epochs.

b) The OMM is intended to allow replication of the data content of an existing TLE in a CCSDS standard format, but the message is designed tocan accommodate other implementations of mean elements. All essential fields of the "ad hocde facto standard" Two Line Element (TLE) are included in the OMM, in a style that is consistent with that of the other ODMs (i.e., the OPM and OEM). From the fields in the OMM, it is possible to generate a TLE (see Reference [F3]). Programs that convert OMM's to TLEs must be aware of the structural requirements of the TLE; including the checksum algorithm and the formatting requirements for the values in the TLE. The checksum and formatting requirements of the TLE do not apply to the values in an OMM. An OMM used to replicate a TLE must be used in conjunction with the SGP4 propagator. It should not be used with any other propagator, including the older SGP. Also, it should be noted that many of the SGP4 implementations in circulation are flawed as described in [F4].

c) If participants wish to exchange osculating element information, then the Orbit Parameter Message (OPM) should be the selected message type. See Section 3.

c)d) The use of the OMM shall be applicable under the following conditions:

1) an orbit propagator consistent with the models used to develop the orbit data must be run at the receiver's site;

2) the receiver's modeling of gravitational forces, solar radiation pressure, atmospheric drag, etc., and thrust phases (see reference [F1]) must fulfill accuracy requirements established between the exchange partners.

d)e) The OMM shall be a plain text file consisting of orbit data for a single object. It shall be easily readable by both humans and computers.

e)f) The OMM file naming scheme should be agreed to on a case-by-case basis between the exchange partners, and should be documented in an Interface Control Document (ICD). The method of exchanging OMMs shall should be decided on a case-by-case basis by the exchange partners and documented in an ICD.

f)g) Detailed syntax rules for the OMM are specified in Section 6.

4.2 OMM CONTENT/STRUCTURE

The OMM shall be represented as a combination of the following:

a) a header;

b) metadata (data about data);

c) data; and

d) optional comments (explanatory information).

4.2.1 OMM HEADER

Table 4-1~~Table 4-1~~ specifies for each header item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

Only those keywords shown in Table 4-1~~Table 4-1~~ shall be used in an OMM header.

Table 44-1: OMM Header

Keyword	Description	Examples of Values	Obligatory
`CCSDS_OMM_VERS`	Format version in the form of 'x.y', where 'y' is incremented for corrections and minor changes, and 'x' is incremented for major changes.	`2.0`	Yes
`COMMENT`	Comments (allowed in the OMM Header only immediately after the OMM version number). See section 6.6 for formatting rules.	`COMMENT  This is a comment`	No
`CREATION_DATE`	File creation date/time in UTC. For format specification, see 6.4(i)	`2001-11-06T11:17:33` `2002-204T15:56:23`	Yes
`ORIGINATOR`	Creating agency or operator (value should be specified in an ICD). The country of origin should also be provided where the originator is not a national space agency.	`CNES, ESOC, GSFC, GSOC, JPL, JAXA, INTELSAT/USA, USAF, INMARSAT/UK`	Yes

4.2.2 OMM METADATA

Table 4-2~~Table 4-2~~ specifies for each metadata item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

Only those keywords shown in Table 4-2~~Table 4-2~~ shall be used in OMM metadata. For some keywords (OBJECT_NAME, OBJECT_ID, CENTER_NAME) there are no definitive lists of authorized values maintained by a control authority; the references listed in subsection 1.5~~1.5~~ are the best known sources for authorized values to date. For the TIME_SYSTEM and REF_FRAME keywords, the approved values are shown in Annex A. ~~Some metadata keywords in the OMM have a constrained value set in the case that the data is meant to be convertible to/from a TLE.~~

Table 44-2: OMM Metadata

Keyword	Description	Examples of Values	Obligatory
COMMENT	Comments (allowed at the beginning of the OMM Metadata). See section 6.6 for formatting rules.	COMMENT This is a comment	No
OBJECT_NAME	Spacecraft name for which the orbit state is provided. There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the SPACEWARN Bulletin (reference [22]), which include Object name and international designator of the participant. ~~If MEAN_ELEMENT_THEORY = TLE, then this must be the SPACEWARN value.~~	TELCOM 2 SPACEWAY 2 INMARSAT 4-F2	Yes
OBJECT_ID	Object identifier of the object for which the orbit state is provided. There is no CCSDS-based restriction on the value for this keyword, but it is recommended that values be the international spacecraft designator (as published in the SPACEWARN Bulletin (reference [22])). Recommended values have the format YYYY-NNNP{PP}, where: YYYY = Year of launch. NNN = Three digit serial number of launch in year YYYY (with leading zeros). P{PP} = At least one capital letter for the identification of the part brought into space by the launch. In cases where the asset is not listed in the bulletin, or the SPACEWARN format is not used, the value should be provided in an ICD. ~~If MEAN_ELEMENT_THEORY = TLE, then this must be the SPACEWARN value.~~	2005-046B 2005-046A 2003-022A 2005-044A	Yes
CENTER_NAME	Origin of reference frame~~, which must be EARTH in the OMM.~~ There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the NASA/JPL Solar System Dynamics Group (at http://ssd.jpl.nasa.gov (reference [6])).	EARTH MARS MOON	Yes
REF_FRAME	Name of the reference frame in which the Keplerian element data are given. The value of this parameter must be selected from Annex A. ~~The value of this parameter shall be "TEME" (True Equator Mean Equinox) in the OMM if TLE data is being exchanged (i.e., MEAN_ELEMENT_THEORY = TLE). The specific version of TEME (of epoch, or of date) should be specified in the ICD or in a COMMENT.~~	TEME EME2000	Yes

TIME_SYSTEM	Time system used for the orbit state and covariance matrix. The value of this parameter must be selected from Annex A. ~~If MEAN_ELEMENT_THEORY = TLE, the value must be 'UTC'.~~	UTC	Yes
MEAN_ELEMENT_THEORY	Description of the Mean Element Theory. Indicates the proper method to employ to propagate the state.	TLE DSST USM	Yes

4.2.3 OMM DATA

Table 4-3~~Table 4-3~~ provides an overview of the 4 logical blocks in the OMM Data section (Keplerian Mean Elements, Spacecraft Parameters, TLE Related Parameters, and Position/Velocity Covariance Matrix), and specifies for each data item:

a) the keyword to be used;

b) a short description of the item;

c) the units to be used;

d) whether the item is obligatory or optional.

Only those keywords shown in Table 4-3~~Table 4-3~~ shall be used in OMM data. (Some important notes about the keywords in Table 4-3~~Table 4-3~~ appear immediately after the table.)

Table 44-3: OMM Data

Keyword	Description	Units	Obligatory
Mean Keplerian Elements in the Specified Reference Frame			
COMMENT	–See section 6.6 for formatting rules.	n/a	No
EPOCH	Epoch of Mean Keplerian elements. See Section 6.4(i) for formatting rules.	n/a	Yes
SEMI_MAJOR_AXIS or MEAN_MOTION	Semi-major axis in kilometers (preferred), or, if MEAN_ELEMENT_THEORY = TLE, the Keplerian Mean motion (in revolutions per day).	km rev/day	Yes
ECCENTRICITY	Eccentricity	n/a	Yes
INCLINATION	Inclination	deg	Yes
RA_OF_ASC_NODE	Right ascension of ascending node	deg	Yes
ARG_OF_PERICENTER	Argument of pericenter	deg	Yes
MEAN_ANOMALY	Mean anomaly	deg	Yes
GM	Gravitational Coefficient (Gravitational Constant x Central Mass). ~~If compatibility with SGP4 is desired, this value must be 398600.8 (see reference [F4]).~~	km**3/s**2	Yes
Spacecraft Parameters (this section not required if MEAN_ELEMENT_THEORY=TLE)			
COMMENT	See section 6.6 for formatting rules.	n/a	No
MASS	S/C Mass	kg	No
SOLAR_RAD_AREA	Solar Radiation Pressure Area (A_R).	m**2	No
SOLAR_RAD_COEFF	Solar Radiation Pressure Coefficient (C_R).	n/a	No
DRAG_AREA	Drag Area (A_D).	m**2	No
DRAG_COEFF	Drag Coefficient (C_D).	n/a	No
TLE Related Parameters (This section is only required if MEAN_ELEMENT_THEORY=TLE)			
NORAD_CAT_ID	NORAD Catalog Number ("Satellite Number") an integer of up to nine digits. This keyword is only required if MEAN_ELEMENT_THEORY=TLE.	01234	No
ELEMENT_SET_NO	Element set number for this satellite. Normally incremented sequentially, but may be out of sync if it is generated from a backup source. Used to distinguish different TLEs, and therefore only meaningful if TLE-based data is being exchanged (i.e., MEAN_ELEMENT_THEORY = TLE). (range = 0000 to 9999). ~~This keyword is only required if MEAN_ELEMENT_THEORY=TLE.~~	9999	No
REV_AT_EPOCH	Revolution Number	n/a	No
BSTAR	SGP4 drag-like coefficient (in units 1/(Earth radii)). Only required if MEAN_ELEMENT_THEORY=TLE	1/ER	No
MEAN_MOTION_DOT	First Time Derivative of the Mean Motion	rev/day**2	No
MEAN_MOTION_DDOT	Second Time Derivative of Mean Motion	rev/day**3	No
Position/Velocity Covariance Matrix (6x6 Lower Triangular Form. None or all parameters of this block must be given.)			
COMMENT	–See section 6.6 for formatting rules.	n/a	No
COV_REF_FRAME	Reference frame for the covariance matrix. The value must be selected from Annex A.	n/a	No
CX_X	Covariance matrix [1,1]	km**2	No
CY_X	Covariance matrix [2,1]	km**2	No
CY_Y	Covariance matrix [2,2]	km**2	No
CZ_X	Covariance matrix [3,1]	km**2	No

CZ_Y	Covariance matrix [3,2]	km**2	No
CZ_Z	Covariance matrix [3,3]	km**2	No
CX_DOT_X	Covariance matrix [4,1]	km**2/s	No
CX_DOT_Y	Covariance matrix [4,2]	km**2/s	No
CX_DOT_Z	Covariance matrix [4,3]	km**2/s	No
CX_DOT_X_DOT	Covariance matrix [4,4]	km**2/s**2	No
CY_DOT_X	Covariance matrix [5,1]	km**2/s	No
CY_DOT_Y	Covariance matrix [5,2]	km**2/s	No
CY_DOT_Z	Covariance matrix [5,3]	km**2/s	No
CY_DOT_X_DOT	Covariance matrix [5,4]	km**2/s**2	No
CY_DOT_Y_DOT	Covariance matrix [5,5]	km**2/s**2	No
CZ_DOT_X	Covariance matrix [6,1]	km**2/s	No
CZ_DOT_Y	Covariance matrix [6,2]	km**2/s	No
CZ_DOT_Z	Covariance matrix [6,3]	km**2/s	No
CZ_DOT_X_DOT	Covariance matrix [6,4]	km**2/s**2	No
CZ_DOT_Y_DOT	Covariance matrix [6,5]	km**2/s**2	No
CZ_DOT_Z_DOT	Covariance matrix [6,6]	km**2/s**2	No
~~COVARIANCE_SOLVE_FORS~~	~~Orbit determination solve for variable(s). Repeat this keyword as desired, but values beyond 6x6 matrix are not presented.~~	~~n/a~~	~~No~~

NOTES

1. All values in the OMM are "at epoch", i.e., the value of the parameter at the time specified in the EPOCH keyword.

2. Table 4-3~~Table 4-3~~ is broken into four logical blocks, each of which has a descriptive heading. Those descriptive headings shall not be included in an OMM, unless they appear in a properly formatted COMMENT statement.

3. This message is suited for directing antennas and planning contacts with satellites. It is not recommended for assessing mutual physical or electromagnetic interference among Earth orbiting spacecraft, developing collaborative maneuvers, or propagating precisely the orbits of active satellites, inactive man made objects, and near Earth debris fragments. It is not suitable for numerical integration of the governing equations.

~~4. For operations in Earth orbit based with a TLE based OMM, some special conventions must be observed, as follows:~~

- ~~The value associated with the CENTER_NAME keyword shall be 'EARTH'.~~

- ~~The value associated with the REFERENCE_FRAME keyword shall be 'TEME' (see Annex A).~~

- ~~The value associated with the TIME_SYSTEM keyword shall be 'UTC'.~~

- ~~The format of the OBJECT_NAME and OBJECT_ID keywords is that of the SPACEWARN bulletin (reference [2]).~~

~~5. The MEAN_MOTION_DOT and MEAN_MOTION_DDOT elements of the TLE are artifacts of techniques that are generally no longer in use. These two parameters are only used with the US Air Force SGP propagator, which has a different formulation for accounting for drag. These two keywords are not used with SGP4. Thus they are listed as optional in the OMM.~~

~~6. NORAD Two Line Element Sets are implicitly in a True Equator Mean Equinox (TEME) reference frame, which is ill defined in international standard or convention. TEME may be used only for NORAD Two Line Element sets. TEME may be used in no other circumstances.~~

~~7. MEAN_MOTION in the OMM is in units of rev/day as specified in the TLE. Using this number, a semi-major axis could be calculated because semi-major axis and "Mean Motion" from the TLE are not independent; specifying one implies the other.~~

~~8. If one desires to convert the MEAN_MOTION to SEMI_MAJOR_AXIS, or vice versa, it is necessary to use the same GM as is used in the SGP4.~~

~~9.~~4. Values in the covariance matrix shall be expressed in the reference frame as specified in the Position/Velocity Covariance Matrix logical block, and ~~will~~ shall be presented sequentially from upper left [1,1] to lower right [6,6], lower triangular form, row by row left to right. Variance and covariance values shall be expressed in standard double precision as related in section 6.4. This logical block of the OMM may be useful for risk assessment and establishing maneuver and mission margins. The intent is to provide causal connections between output orbit data and both physical hypotheses and measurement uncertainties. These causal relationships guide operators' corrective actions and mitigations.

~~10. Covariance Solve Fors: These are parameters that are solved for as part of the orbit determination process. As many "solve fors" as is desired may be listed in the COVARIANCE_SOLVE_FOR keywords, but the covariance values beyond the 6x6 position/velocity covariance are not displayed.~~

5. For operations in Earth orbit with a TLE based OMM, some special conventions must be observed, as follows:

- The value associated with the CENTER_NAME keyword shall be 'EARTH'.
- The value associated with the REFERENCE_FRAME keyword shall be 'TEME' (see Annex A).
- The value associated with the TIME_SYSTEM keyword shall be 'UTC'.
- The format of the OBJECT_NAME and OBJECT_ID keywords shall be that of the SPACEWARN bulletin (reference [2]).
- The MEAN_MOTION keyword should be used instead of SEMI_MAJOR_AXIS.

~~11.~~6. TLEs vary with the epoch of their creation, and users can draw relatively useful inferences of uncertainty from analysis over multiple epochs. It should be noted that such covariances are derived from mathematical and statistical processes without any causal value. One can propagate mean orbits and their uncertainties into the future, but the reasons for uncertainty are not revealed and the uncertainties provide little guidance for mitigating uncertainties.

7. For those who wish to use the OMM to represent a TLE, there are a number of considerations that apply with respect to precision of angle representation, use of certain fields by the propagator, reference frame, etc. For further information see references [F3] and [F4].

~~12.~~8. Maneuvers are not accommodated in the OMM.~~ as they are in the OPM, because maneuvers are not specified in the TLE.~~ Users of the OMM who wish to specify maneuvers must use ~~the~~ an OPM that specifies the osculating elements at EPOCH and the maneuver components at the same EPOCH.~~same methods currently in use to convey the effects of maneuvers on the mean Keplerian elements of the satellite's orbit.~~

13. In general, angles may be expressed in an OMM using any desired number of digits. The TLE has angles expressed to 4 decimal digits of degree units, but there is no reason why non-NORAD generated OMMs should not have more significant digits if the particular usage merits this. Users who wish to convert OMMs to TLEs must format the maximum accuracy angles in accordance with the TLE requirements, i.e., the angles should be rounded to the nearest 4 digit value (with modulo-360 correction) and not truncated.

14. xxx The units of “rev/day” were chosen for the MEAN_MOTION keyword to maintain compatibility with TLE, however, since the OMM accommodates other mean element theories, perhaps a “deg/sec” (all SI units) is now feasible. If this is done, then users who wish to exchange TLE-based data will need to convert rev/day to deg/sec xxx.

4.3 OMM EXAMPLES

Figure 4-2~~Figure 4-2~~ and Figure 4-3~~Figure 4-3~~ are examples of OMMs based on the TLE shown in Figure 4-1~~Figure 4-1~~.

```
GOES 9 [P]
1 23581U 95025A   07064.44075725 -.00000113  00000-0  10000-3 0  9250
2 23581   3.0539  81.7939 0005013 249.2363 150.1602  1.00273272 43169
```

Figure 44-1 Example Two Line Element Set (TLE)

```
CCSDS_OMM_VERS = 2.0
CREATION_DATE  = 2007-065T16:00:00
ORIGINATOR     = NOAA/USA

OBJECT_NAME    = GOES 9
OBJECT_ID      = 1995-025A
CENTER_NAME    = EARTH
REF_FRAME      = TEME
TIME_SYSTEM    = UTC
MEAN_ELEMENT_THEORY = TLE


COMMENT  USAF SGP4 IS THE ONLY PROPAGATOR THAT SHOULD BE USED FOR THIS DATA
EPOCH             = 2007-064T10:34:41.4264
MEAN_MOTION       = 1.00273272
ECCENTRICITY      = 0.0005013
INCLINATION       =   3.0539
RA_OF_ASC_NODE    =  81.7939
ARG_OF_PERICENTER = 249.2363
MEAN_ANOMALY      = 150.1602
GM                = 398600.8
NORAD_CAT_ID   = 23581
ELEMENT_SET_NO = 0925
REV_AT_EPOCH      = 4316
BSTAR             = 0.0001
MEAN_MOTION_DOT   = -0.00000113
MEAN_MOTION_DDOT  = 0.0
```

Figure 44-2: OMM File Example Without Covariance Matrix

```
CCSDS_OMM_VERS = 2.0
CREATION_DATE  = 2007-065T16:00:00
ORIGINATOR     = NOAA/USA

OBJECT_NAME    = GOES 9
OBJECT_ID      = 1995-025A
CENTER_NAME    = EARTH
REF_FRAME      = TEME
TIME_SYSTEM    = UTC
MEAN_ELEMENT_THEORY = TLE

COMMENT  USAF SGP4 IS THE ONLY PROPAGATOR THAT SHOULD BE USED FOR THIS DATA
EPOCH             = 2007-064T10:34:41.4264
MEAN_MOTION       = 1.00273272
ECCENTRICITY      = 0.0005013
INCLINATION       =   3.0539
RA_OF_ASC_NODE    =  81.7939
ARG_OF_PERICENTER = 249.2363
MEAN_ANOMALY      = 150.1602
GM                = 398600.8

NORAD_CAT_ID   = 23581
ELEMENT_SET_NO = 0925
REV_AT_EPOCH      = 4316
BSTAR             = 0.0001
MEAN_MOTION_DOT   = -0.00000113
MEAN_MOTION_DDOT  = 0.0

COV_REF_FRAME = TEME
CX_X = 0.316
CY_X = 0.722
CY_Y = 0.518
CZ_X = 0.202
CZ_Y = 0.715
CZ_Z = 0.002
CX_DOT_X = 0.912
CX_DOT_Y = 0.306
CX_DOT_Z = 0.276
CX_DOT_X_DOT = 0.797
CY_DOT_X = 0.562
CY_DOT_Y = 0.899
CY_DOT_Z = 0.022
CY_DOT_X_DOT = 0.079
CY_DOT_Y_DOT = 0.415
CZ_DOT_X = 0.245
CZ_DOT_Y = 0.965
CZ_DOT_Z = 0.950
CZ_DOT_X_DOT = 0.435
CZ_DOT_Y_DOT = 0.621
CZ_DOT_Z_DOT = 0.991
```

Figure 44-3: OMM File Example with Covariance Matrix

4.4 INCREASING THE ORBIT PROPAGATION FIDELITY OF AN OMM

Some OMM users may desire/require a higher fidelity propagation of the orbital elements. A higher fidelity technique may be desired/required in order to minimize inconsistencies in predictions generated by diverse, often operator unique propagation schemes. Nominally the OMM is only engineered for a relatively lower fidelity orbit propagation. However, with the inclusion of additional context information, it is possible for users to provide data that could be used to provide a relatively higher fidelity orbit propagation. For this relatively higher fidelity orbit propagation, a much greater amount of ancillary information regarding spacecraft properties and dynamical models should be provided. Higher fidelity orbit propagations may be useful in special studies such as orbit conjunction studies.

Spacecraft orbit determination and propagation are stochastic estimation problems. Observations are inherently uncertain, and not all of the phenomena that influence satellite motion are clearly discernible. Orbital elements and covariances are best propagated with models that include the same forces and phenomena that were used for determining the orbit. Including this information in an OMM allows exchange partners to compare the results of their respective orbit propagations.

With additional context information, the OMM may be used for assessing mutual physical or electromagnetic interference among Earth orbiting spacecraft, developing collaborative maneuvers, and propagating the orbits of active satellites, inactive man made objects, and near Earth debris fragments. The additional information facilitates dynamic modeling of any users' approach to conservative and non-conservative phenomena.

The primary vehicle for the provision of additional optional ancillary information to be used when propagating an OMM is the COMMENT mechanism. A number of suggested COMMENT statements are included in Annex D. An online version of this annex is available on the CCSDS web page at xxx <URL here> xxx. This online version is suitable for downloading, editing, and inserting directly into an OMM. Note that this set of COMMENT statements is also suitable for use in situations where an ICD between exchange partners is neither required, desired, nor feasible.

5 ORBIT EPHEMERIS MESSAGE (OEM)

5.1 OVERVIEW

Orbit information may be exchanged between two participants by sending an ephemeris in the form of a series of state vectors (Cartesian vectors providing position and velocity, and optionally accelerations) using an Orbit Ephemeris Message (OEM). The message recipient must have a means of interpolating across these state vectors to obtain the state at an arbitrary time contained within the span of the ephemeris.

The OEM may be used for assessing mutual physical or electromagnetic interference among Earth orbiting spacecraft, developing collaborative maneuvers, and propagating the orbits of active satellites, inactive man made objects, planetary bodies, near Earth debris fragments, etc. The OEM enables dynamic modeling of any users' approach to conservative and non-conservative phenomena.

The OEM shall be a plain text file consisting of orbit data for a single object. It shall be easily readable by both humans and computers.

The OEM file naming scheme ~~shall~~ should be agreed to on a case-by-case basis between the participants, typically using an Interface Control Document (ICD). The method of exchanging OEMs ~~shall~~ should be decided on a case-by-case basis by the participants and documented in an ICD.

Detailed syntax rules for the OEM are specified in Section 6.

5.2 OEM CONTENT/STRUCTURE

The OEM shall be represented as a combination of the following:

a) a header;

b) metadata (data about data);

c) ephemeris data;

d) optional covariance matrix data; and

e) optional comments (explanatory information).

OEM files must have a set of minimum required sections; some may be repeated. Table 5-1~~Table 5-1~~ outlines the contents of an OEM.

Table 55-1: OEM File Layout Specifications

Required Sections	Header Metadata Ephemeris Data (Appropriate comments should also be included, although they are not required.)
Allowable Repetitions of Sections	Covariance Matrix (optional) Metadata Ephemeris Data Covariance Matrix (optional) Metadata Ephemeris Data Covariance Matrix (optional) Metadata Ephemeris Data Covariance Matrix (optional) …etc. (Appropriate comments should also be included.)

5.2.1 OEM HEADER

The OEM header assignments are shown in Table 5-2Table 5-2, which specifies for each item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

Only those keywords shown in Table 5-2Table 5-2 shall be used in an OEM header.

Table 55-2: OEM Header

Keyword	Description	Examples of Values	Obligatory
CCSDS_OEM_VERS	Format version in the form of 'x.y', where 'y' is incremented for corrections and minor changes, and 'x' is incremented for major changes.	2.0	Yes
COMMENT	Comments (allowed in the OEM Header only immediately after the OEM version number). See section 6.6 for formatting rules.	COMMENT See section 6.6	No
CREATION_DATE	File creation date and time in UTC. For format specification, see 6.4.	2001-11-06T11:17:33 2002-204T15:56:23	Yes
ORIGINATOR	Creating agency or operator (value should be specified in an ICD). The country of origin should also be provided where the originator is not a national space agency.	CNES, ESOC, GSFC, GSOC, JPL, JAXA, INTELSAT/USA, USAF, INMARSAT/UK	Yes

5.2.2 OEM METADATA

The OEM metadata assignments are shown in Table 5-3Table 5-3, which specifies for each item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

Only those keywords shown in Table 5-3Table 5-3 shall be used in OEM metadata. For some keywords (OBJECT_NAME, OBJECT_ID, CENTER_NAME) there are no definitive lists of authorized values maintained by a control authority; the references listed in subsection 1.51.5 are the best known sources for authorized values to date. For the TIME_SYSTEM and REF_FRAME keywords, the approved values are listed in Annex A.

A single metadata group shall precede each ephemeris data block. Multiple occurrences of a metadata group followed by an ephemeris data block may be used.

~~A single covariance matrix data section may optionally follow each ephemeris data block.~~

Before each metadata group the string 'META_START' shall appear on a separate line and after each metadata group (and before the associated ephemeris data block) the string 'META_STOP' shall appear on a separate line.

Table 55-3: OEM Metadata

Keyword	Description	Examples of Values	Obligatory
META_START	The OEM message contains metadata, ephemeris data, and covariance data; this keyword is used to delineate the start of a metadata block within the message (metadata are provided in a block, surrounded by 'META_START' and 'META_STOP' markers to facilitate file parsing). This keyword must appear on a line by itself.	n/a	Yes
COMMENT	Comments allowed only immediately after the META_START keyword. See section 6.6 for formatting rules.	COMMENT This is a comment.	No
OBJECT_NAME	The name of the object for which the ephemeris is provided. There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the SPACEWARN Bulletin (reference [22]), which include Object name and international designator of the participant. In cases where the ephemeris of a celestial object is exchanged, this keyword is subject to the same rules as those for CENTER_NAME.	EUTELSAT W1 MARS PATHFINDER STS 106 NEAR MARS	Yes
OBJECT_ID	Object identifier of the object for which the ephemeris is provided. There is no CCSDS-based restriction on the value for this keyword, but it is recommended that values be the international spacecraft designator (as published in the SPACEWARN Bulletin (reference [22])). Recommended values have the format YYYY-NNNP{PP}, where: YYYY = Year of launch. NNN = Three-digit serial number of launch in year YYYY (with leading zeros). P{PP} = At least one capital letter for the identification of the part brought into space by the launch. In cases where the asset is not listed in reference [22], or the SPACEWARN format is not used, the value should be provided in an ICD. In the case where the object is a planet (i.e., the OEM is used for a planetary ephemeris), the OBJECT_ID and the OBJECT_NAME may be the same.	2000-052A 1996-068A 2000-053A 1996-008A	Yes
CENTER_NAME	Origin of reference frame, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this case the value for 'CENTER_NAME' is subject to the same rules as for 'OBJECT_NAME'). There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the NASA/JPL Solar System Dynamics Group (at http://ssd.jpl.nasa.gov (reference [6])).	EARTH EARTH BARYCENTER MOON SOLAR SYSTEM BARYCENTER SUN JUPITER BARYCENTER STS 106 EROS	Yes

Keyword	Description	Examples of Values	Obligatory
REF_FRAME	Name of the reference frame in which the ephemeris data are given. The value of this parameter must be selected from Annex A.	ICRF ITRF-93 ITRF-97 ITRF2000 ITRFxxxx (template for future versions) TOD (True Equator and Equinox of Date) EME2000 (Earth Mean Equator and Equinox of J2000) TDR (true of date rotating) GRC (Greenwich rotating coordinate frame... another name for TDR)	Yes
TIME_SYSTEM	Time system used for metadata, ephemeris data, and covariance data. The value of this parameter must be selected from Annex A.	UTC, TAI, TT, GPS, TDB, TCB	Yes
START_TIME	Start of TOTAL time span covered by ephemeris data and covariance data immediately following this metadata block. The START_TIME time tag at a new block of ephemeris data must be equal to or greater than the STOP_TIME time tag of the previous block. For format specification, see 6.4(i).	1996-12-18T14:28:15.1172 1996-277T07:22:54	Yes
USEABLE_START_TIME USEABLE_STOP_TIME	Optional start and end of USEABLE time span covered by ephemeris data immediately following this metadata block. To allow for proper interpolation near the ends of the ephemeris data block it may be necessary, depending upon the interpolation method to be used, to utilize these keywords with values within the time span covered by the ephemeris data records as denoted by the START/STOP_TIME time tags. For format specification, see 6.4(i). These keywords are optional items, and thus may not be necessary, depending on the recommended interpolation method. However, it is recommended to use the USEABLE_START_TIME and USEABLE_STOP_TIME capability in all cases.	1996-12-18T14:28:15.1172 1996-277T07:22:54	No
STOP_TIME	End of TOTAL time span covered by ephemeris data and covariance data immediately following this metadata block. The START_TIME time tag at a new block of ephemeris data must be equal to or greater than the STOP_TIME time tag of the previous block. For format specification, see 6.4(i).	1996-12-18T14:28:15.1172 1996-277T07:22:54	Yes
INTERPOLATION	This keyword may be used to specify the recommended interpolation method for ephemeris data in the immediately following set of ephemeris lines.	Hermite Linear Lagrange	No
INTERPOLATION_DEGREE	Recommended interpolation degree for ephemeris data in the immediately following set of ephemeris lines. Must be an integer value. This keyword must be used if the "INTERPOLATION" keyword is used.	5 1	No

Keyword	Description	Examples of Values	Obligatory
COVARIANCE_SOLVE_FORS	Orbit determination solve for variable(s). Repeat this keyword as desired, but values beyond 6x6 matrix are not presented.	DRAG COEFFICIENT	No
META_STOP	The OEM message contains metadata, ephemeris data, and covariance data; this keyword is used to delineate the end of a metadata block within the message (metadata are provided in a block, surrounded by 'META_START' and 'META_STOP' markers to facilitate file parsing). This keyword must appear on a line by itself.	n/a	Yes

A special application of the OEM is to represent a planetary ephemeris. In this case, the CENTER_NAME would be SOLAR SYSTEM BARYCENTER. There are a few possible conventions for the OBJECT_ID and OBJECT_NAME. For example, the OBJECT_ID and OBJECT_NAME could each be set to the planet name; or the OBJECT_ID could be set to the SPICE SPK number (see ref [F6]) and the OBJECT_NAME set to the planet name; or the OBJECT_ID could be set to the "conventional" enumeration of the planet numbers (i.e., Mercury = 1, Venus = 2, etc.). If the OEM is to be used in this manner, the convention should be noted in the ICD.

5.2.3 OEM DATA: EPHEMERIS DATA LINES

a) Ephemeris data lines in the OEM are separated from the metadata and the covariance matrix by means of two new optional keywords: EPHEMERIS_DATA_START and EPHEMERIS_DATA_STOP. The 'EPHEMERIS_DATA_START' keyword must be the first keyword in the Data Section of the OEM if there is a covariance matrix present. The 'EPHEMERIS_DATA_STOP' keyword must be the last keyword in the Ephemeris Data Section of the OEM if there is a covariance matrix present. Each of these keywords shall appear on a line by itself with no time tags or values.

b) If the EPHEMERIS_DATA_START and EPHEMERIS_DATA_STOP keywords are used, then the 'CCSDS_OEM_VERS' keyword must be set to '2.0'. If the EPHEMERIS_DATA_START and EPHEMERIS_DATA_STOP keywords are not used, then the 'CCSDS_OEM_VERS' keyword may be set to '1.0'.

c)a) Each set of ephemeris data, including the time tag, must be provided on a single line. The order in which data items are given shall be fixed: **Epoch**, **X, Y, Z, X_DOT, Y_DOT, Z_DOT, X_DDOT, Y_DDOT, Z_DDOT**. The position and velocity terms are obligatory; acceleration terms are optional. If acceleration terms are provided, then the 'CCSDS_OEM_VERS' keyword must be set to '2.0'. If acceleration terms are not provided, then the 'CCSDS_OEM_VERS' keyword may be set to '1.0'.

b) If it is desired to create a version 1.0 compatible OEM, do not include the acceleration terms.

d)c) At least one space character must be used to separate the items in each ephemeris data line.

e)d) Ephemeris data lines must be ordered by increasing time, and time tags must not be repeated, except in the case where the STOP_TIME of a set of ephemeris data lines is equal to the START_TIME of the following set of ephemeris data lines. The time step duration may vary within a given OEM.

f)e) The TIME_SYSTEM value must remain fixed within an OEM.

g)f) The occurrence of a second (or greater) metadata block after some ephemeris data indicates that interpolation using succeeding ephemeris data with ephemeris data occurring prior to that metadata block shall not be done. This method may be used for proper modeling of propulsive maneuvers or any other source of a discontinuity such as eclipse entry or exit.

h)g) Details about interpolation method should be specified using the INTERPOLATION and INTERPOLATION_DEGREE keywords within the OEM. All data blocks must contain a sufficient number of ephemeris data records to allow the recommended interpolation method to be carried out consistently throughout the OEM.

~~g)If it is desired to create a version 1.0 compatible OEM, do not include the acceleration terms and do not include a covariance matrix.~~

5.2.4 OEM DATA: COVARIANCE MATRIX LINES

a) A single covariance matrix data section may optionally follow each ephemeris data block.~~Covariance matrix data is optional in the OEM.~~ If a covariance matrix is present, then the 'CCSDS_OEM_VERS' keyword must be set to '2.0'.

b) If it is desired to create a version 1.0 compatible OEM, do not include the covariance matrix.

b)c) If present, the covariance matrix data lines in the OEM are separated from the ephemeris data by means of two new keywords: COVARIANCE_~~DATA_~~START and COVARIANCE_~~DATA_~~STOP. The 'COVARIANCE_~~DATA_~~START' keyword must appear before the first line of the covariance matrix data. The 'COVARIANCE_~~DATA_~~STOP' keyword must appear after the last line of covariance data. Each of these keywords shall appear on a line by itself with no time tags or values.

c)d) If the COVARIANCE_~~DATA_~~START and COVARIANCE_~~DATA_~~STOP keywords are used, then the 'CCSDS_OEM_VERS' keyword must be set to '2.0'. If the COVARIANCE_~~DATA_~~START and COVARIANCE_~~DATA_~~STOP keywords are not used, then the 'CCSDS_OEM_VERS' keyword may be set to '1.0' and the covariance matrix shall not be present.

d)e) Each row of the 6x6 lower triangular covariance matrix must be provided on a single line. The order in which data items are given shall be fixed: the Epoch of the navigation solution appears first on the first line, followed by the rows of the covariance matrix (six rows of from one to six numbers).

e)f) At least one space character must be used to separate the items in each covariance matrix data line.

f)g) Multiple covariance matrices may appear in the covariance matrix section; they may appear with any desired frequency (one for each navigation solution that makes up the overall ephemeris is recommended). The OEM may also contain propagated covariances, not just individual covariances associated with navigation solutions.

g)h) If there are multiple covariance matrices in the data section, they must be ordered by increasing time tag.

5.3 OEM EXAMPLE

Figure 5-15-1 , Figure 5-2Figure 5-2 and Figure 5-3Figure 5-3 are example OEMs. Note that some ephemeris data lines have been omitted to save space.

Figure 5-1Figure 5-1 is compatible with ODM version 1, and thus could also use either 'CCSDS_OEM_VERS = 1.0', (since it does not contain any of the unique features of the ODM version 2), or 'CCSDS_OEM_VERS = 2.0' (as shown). Figure 5-2Figure 5-2 and Figure 5-3Figure 5-3 contain features unique to the ODM version 2, and thus must use 'CCSDS_OEM_VERS = 2.0' must be specified.

```
CCSDS_OEM_VERS = 2.0
CREATION_DATE = 1996-11-04T17:22:31
ORIGINATOR = NASA/JPL

META_START
OBJECT_NAME          = Mars Global Surveyor
OBJECT_ID            = 1996-062A
CENTER_NAME          = Mars Barycenter
REF_FRAME            = EME2000
TIME_SYSTEM          = UTC
START_TIME           = 1996-12-18T12:00:00.331
USEABLE_START_TIME   = 1996-12-18T12:10:00.331
USEABLE_STOP_TIME    = 1996-12-28T21:23:00.331
STOP_TIME            = 1996-12-28T21:28:00.331
INTERPOLATION        = Hermite
INTERPOLATION_DEGREE = 7
META_STOP
COMMENT  This file was produced by M.R. Somebody, MSOO NAV/JPL, 1996 OCT 11. It is
COMMENT  to be used for DSN scheduling purposes only.

1996-12-18T12:00:00.331  2789.619 -280.045 -1746.755  4.73372 -2.49586 -1.04195
1996-12-18T12:01:00.331  2783.419 -308.143 -1877.071  5.18604 -2.42124 -1.99608
1996-12-18T12:02:00.331  2776.033 -336.859 -2008.682  5.63678 -2.33951 -1.94687

   < intervening data records omitted here >

1996-12-28T21:28:00.331 -3881.024 563.959 -682.773  -3.28827 -3.66735 1.63861


META_START
OBJECT_NAME           = Mars Global Surveyor
OBJECT_ID             = 1996-062A
CENTER_NAME           = Mars Barycenter
REF_FRAME             = EME2000
TIME_SYSTEM           = UTC
START_TIME            = 1996-12-28T21:29:07.267
USEABLE_START_TIME    = 1996-12-28T22:08:02.5
USEABLE_STOP_TIME     = 1996-12-30T01:18:02.5
STOP_TIME             = 1996-12-30T01:28:02.267
INTERPOLATION        = Hermite
INTERPOLATION_DEGREE = 7
META_STOP

COMMENT  This block begins after trajectory correction maneuver TCM-3.

1996-12-28T21:29:07.267 -2432.166 -063.042 1742.754  7.33702 -3.495867 -1.041945
1996-12-28T21:59:02.267 -2445.234 -878.141 1873.073  1.86043 -3.421256 -0.996366
1996-12-28T22:00:02.267 -2458.079 -683.858 2007.684  6.36786 -3.339563 -0.946654

   < intervening data records omitted here >

1996-12-30T01:28:02.267 2164.375 1115.811 -688.131  -3.53328 -2.88452 0.88535
```

Figure 5~~5~~-1: Version 1 OEM Compatible Example (No Acceleration, No Covariance)

```
CCSDS_OEM_VERS = 2.0

COMMENT  OEM WITH OPTIONAL ACCELERATIONS MUST BE OEM VERSION 2.0

CREATION_DATE = 1996-11-04T17:22:31
ORIGINATOR = NASA/JPL

META_START
OBJECT_NAME          = Mars Global Surveyor
OBJECT_ID            = 1996-062A
CENTER_NAME          = Mars Barycenter
REF_FRAME            = EME2000
TIME_SYSTEM          = UTC
START_TIME           = 1996-12-18T12:00:00.331
USEABLE_START_TIME   = 1996-12-18T12:10:00.331
USEABLE_STOP_TIME    = 1996-12-28T21:23:00.331
STOP_TIME            = 1996-12-28T21:28:00.331
INTERPOLATION        = Hermite
INTERPOLATION_DEGREE = 7
META_STOP

COMMENT  This file was produced by M.R. Somebody, MSOO NAV/JPL, 2000 OCT 11. It is
COMMENT  to be used for DSN scheduling purposes only.

1996-12-18T12:00:00.331  2789.6 -280.0 -1746.8  4.73 -2.50 -1.04  0.008 0.001 -0.159
1996-12-18T12:01:00.331  2783.4 -308.1 -1877.1  5.19 -2.42 -2.00  0.008 0.001  0.001
1996-12-18T12:02:00.331  2776.0 -336.9 -2008.7  5.64 -2.34 -1.95  0.008 0.001  0.159

   < intervening data records omitted here >

1996-12-28T21:28:00.331 -3881.0  564.0 -682.8 -3.29 -3.67  1.64  -0.003 0.000  0.000
```

Figure 5~~5~~-2   Version 2 OEM Example with Optional Accelerations

```
CCSDS_OEM_VERS = 2.0
CREATION_DATE = 1996-11-04T17:22:31
ORIGINATOR = NASA/JPL

META_START
OBJECT_NAME          = Mars Global Surveyor
OBJECT_ID            = 1996-062A
CENTER_NAME          = Mars Barycenter
REF_FRAME            = EME2000
TIME_SYSTEM          = UTC
START_TIME           = 1996-12-28T21:29:07.267
USEABLE_START_TIME   = 1996-12-28T22:08:02.5
USEABLE_STOP_TIME    = 1996-12-30T01:18:02.5
STOP_TIME            = 1996-12-30T01:28:02.267
INTERPOLATION       = Hermite
INTERPOLATION_DEGREE = 7
COVARIANCE_SOLVE_FORS = DRAG COEFFICIENT
META_STOP

EPHEMERIS_DATA_START
COMMENT  This block begins after trajectory correction maneuver TCM-3.

1996-12-28T21:29:07.267 -2432.166 -063.042 1742.754  7.33702 -3.495867 -1.041945
1996-12-28T21:59:02.267 -2445.234 -878.141 1873.073  1.86043 -3.421256 -0.996366
1996-12-28T22:00:02.267 -2458.079 -683.858 2007.684  6.36786 -3.339563 -0.946654

   < intervening data records omitted here >

1996-12-30T01:28:02.267 2164.375 1115.811 -688.131  -3.53328 -2.88452 0.88535
EPHEMERIS_DATA_STOP

COVARIANCE_DATA_START
1996-12-28T01:00:0021:29:07.267
0.316
0.722  0.518
0.202  0.715  0.002
0.912  0.306  0.276  0.797
0.562  0.899  0.022  0.079  0.415
0.245  0.965  0.950  0.435  0.621  0.991

1996-12-29T0121:00:00
0.427
0.722  0.629
0.202  0.715  0.113
0.912  0.306  0.276  0.808
0.562  0.899  0.022  0.079  0.526
0.245  0.965  0.950  0.435  0.621  0.002
COVARIANCE_DATA_STOP
```

Figure 55-3   Version 2 OEM Example with Optional Covariance Matrices

6 ORBIT DATA MESSAGE SYNTAX

6.1 GENERAL

This section details the syntax requirements for each of the Orbit Data Messages.

The Orbit Data Messages (OPM, OMM, OEM) shall observe the syntax described in 6.2 through 6.7.

6.2 ODM LINES

a) Each ODM file shall consist of a set of OPM, OMM or OEM lines. Each ODM line shall be one of the following:

- Header line;
- Metadata line;
- Data line; or
- Blank line.

b) Each OEM, OPM or OMM line must not exceed 254 ASCII characters and spaces (excluding line termination character[s]).

c) Only printable ASCII characters and blanks shall be used. Control characters (such as TAB, etc.) shall not be used, with the exception of the line termination characters specified below.

d) Blank lines may be used at any position within the file. Blank lines shall have no assignable meaning, and may be ignored.

a) The first header line must be the first non-blank line in the file.

e) All lines shall be terminated by a single Carriage Return or a single Line Feed, or a Carriage Return/Line Feed pair or a Line Feed/Carriage Return pair.

6.3 KEYWORD = VALUE NOTATION AND ORDER OF ASSIGNMENT STATEMENTS

a) For the OPM and OMM, all header, metadata, and data lines shall use 'keyword = value' notation, abbreviated as KVN.

b) For the OEM, all header and metadata elements shall use KVN notation.

c) OEM ephemeris data lines shall not use KVN format, rather, the OEM ephemeris data line has a fixed structure containing 7 required fields (epoch time, 3 position components, 3 velocity components), and 3 optional acceleration components. See Section ~~0~~5.2.3

d) OEM covariance data lines shall not use KVN format, rather, the OEM covariance data line has a fixed structure containing from 1 to 6 required fields (epoch time plus a row from the 6x6 lower triangular form covariance matrix). See Section 5.2.4~~5.2.4~~.

e) The keywords 'COMMENT, META_START, META_STOP , ~~EPHEMERIS_DATA_START, EPHEMERIS_DATA_STOP,~~ COVARIANCE_~~DATA_~~START, and COVARIANCE_~~DATA_~~STOP are exceptions to the KVN syntax assignment.

f) Only a single 'keyword = value' assignment shall be made on a line.

g) Keywords must be uppercase and must not contain blanks.

h) Any white space immediately preceding or following the keyword shall not be significant.

i) Any white space immediately preceding or following the 'equals' sign shall not be significant.

j) Any white space immediately preceding the end of line shall not be significant.

k) The order of occurrence of obligatory and optional KVN assignments shall be fixed as shown in the tables in Section 3, 4, and 5 that describe the OPM, OMM and OEM keywords.

6.4 VALUES

a) A non-~~null~~ empty value field must be specified for each obligatory keyword.

b) Integer values shall consist of a sequence of decimal digits with an optional leading sign ("+" or "-"). If the sign is omitted, "+" shall be assumed. Leading zeroes may be used. The range of values that may be expressed as an integer is:

-2,147,483,648 <= x <= +2,147,483,647 (i.e., $-2^{31} <= x <= 2^{31}-1$).

c) Non-integer numeric values may be expressed in either fixed-point or floating-point notation. Both representations may be used within an OPM, OMM, or OEM.

d) Non-integer numeric values expressed in fixed-point notation shall consist of a sequence of decimal digits separated by a period as a decimal point indicator, with an optional leading sign ("+" or "-"). If the sign is omitted, "+" shall be assumed. Leading and trailing zeroes may be used. At least 1 digit shall appear before and after a decimal point. The number of digits shall be 16 or less.

e) Non-integer numeric values expressed in floating point notation shall consist of a sign, a mantissa, an alphabetic character indicating the division between the mantissa and exponent, and an exponent, constructed according to the following rules:

   1) The sign may be "+" or "-". If the sign is omitted, "+" shall be assumed.

   2) The mantissa must be a string of no more than 16 decimal digits with a decimal point "." in the second position of the ASCII string, separating the integer portion of the mantissa from the fractional part of the mantissa.

   3) The character used to denote exponentiation shall be "E" or "e". If the character indicating the exponent and the following exponent are omitted, an exponent value of 0 shall be assumed (essentially yielding a fixed point value).

   4) The exponent must be an integer, and may have either a "+" or "-" sign (if the sign is omitted, then "+" shall be assumed).

   5) The maximum positive floating point value is approximately 1.798E+308, with 16 significant decimal digits precision. The minimum positive floating point value is approximately 4.94E-324, with 16 significant decimal digits precision.

NOTE These specifications for integer, fixed point and floating point values conform to the XML specifications for the data types four-byte integer 'xsd:int'~~"integer"~~, "decimal" and "double" respectively (reference [7]). The specifications for floating point values conform to the IEEE double precision type (references [7], [8]). Floating point numbers in IEEE extended-single or IEEE extended-double precision may be represented, but do require an ICD between exchange partners due to their implementation specific attributes (reference [8]). The special values 'NaN', '-Inf', '+Inf', and '-0' are not supported in the ODM.

f) ~~Text value fields may be constructed using mixed case. Case shall not be significant. (xxx All upper or all lower ??? xxx)~~Text value fields must be constructed using only all uppercase or all lowercase.

g) Blanks shall not be permitted within numeric values and time strings.

h) In value fields that are text, an underscore shall be equivalent to a single blank. Individual blanks shall be retained (shall be significant), but multiple blanks shall be equivalent to a single blank.

i) In value fields that represent a time tag or epoch, times shall be given in one of the following two formats:

YYYY-MM-DDThh:mm:ss[.d→d][Z]

or

YYYY-DDDThh:mm:ss[.d→d][Z]

where 'YYYY' is the year, 'MM' is the two-digit month, 'DD' is the two-digit day, 'DDD' is the three-digit day of year, 'T' is constant, 'hh:mm:ss[.d→d]' is the time in hours, minutes seconds, and optional fractional seconds; 'Z' is an optional time code terminator (the only permitted value is 'Z' for Zulu i.e. UTC). As many 'd' characters to the right of the period as required may be used to obtain the required precision. All fields shall have leading zeros. See reference [1], ASCII Time Code A or B.

j) There are ~~7~~ 8 types of ODM values that represent a time tag or epoch, as shown in the applicable tables. The time system for the CREATION_DATE shall be UTC; the time system for the EPOCH, MAN_EPOCH_IGNITION, START_TIME, USEABLE_START_TIME, USEABLE_STOP_TIME, ~~and~~ STOP_TIME, and the covariance matrix epoch time shall be as determined by the TIME_SYSTEM metadata keyword.

6.5 UNITS IN THE ORBIT DATA MESSAGES

6.5.1 OPM/OMM UNITS

For documentation purposes and clarity, units may be included as ASCII text after a value in the OPM and OMM. If units are displayed, they must exactly match the units specified in Table 3-3~~Table 3-3~~ and Table 4-3~~Table 4-3~~(including case). If units are displayed, then:

a) there must be at least one blank character between the value and the units text;

b) the units must be enclosed within square brackets (e.g., '[km]');

c) exponents of units shall be denoted with a double asterisk (i.e., '**', for example, m/s^2=m/s**2).

Note that some of the items in the applicable tables are dimensionless. The table shows a unit value of "n/a", which in this case means that there is no applicable units designator for these items (e.g., for ECCENTRICITY). The notation "[n/a]" should not appear in an OPM or OMM.

6.5.2 OEM UNITS

a) In an OEM ephemeris data line, units shall be km, km/s, and km/s**2 for position, velocity and acceleration components respectively, but the units shall not be displayed.

b) In an OEM covariance matrix line, units shall be km**2, km**2/s, or km**2/s**2 depending on whether the element is computed from two position components, one position component and one velocity component, or 2 velocity components. The units shall not be displayed.

6.6 COMMENTS IN THE ORBIT DATA MESSAGES

a) There are certain pieces of information that provide clarity and remove ambiguity about the interpretation of the information in a file, yet are not standardized so as to fit cleanly into the 'keyword = value' paradigm. Rather than force the information to fit into a space limited to one line, the ODM producer should put certain information into comments and use the ICD to provide further specifications.

b) Comments may be used to provide provenance information or to help describe dynamical events or other pertinent information associated with the data. This additional information is intended to aid in consistency checks and elaboration where needed, but shall not be required for successful processing of a file.

c) For the OPM, OMM, and OEM, comment lines shall be optional.

d) All comment lines shall begin with the 'COMMENT' keyword followed by at least ~~a single~~one space. This keyword must appear on every comment line, not just the first such line. The remainder of the line shall be the comment value. White space shall be retained (shall be significant) in comment values.

e) Placement of comments shall be as specified in the tables in Section 3, 4, and 5 that describe the OPM, OMM and OEM keywords.

f) Comments in the OPM may appear in the OPM Header immediately after the 'CCSDS_OPM_VERS' keyword, at the very beginning of the OPM Metadata section, and at the beginning of a logical block in the OPM Data section. Comments must not appear between the components of any logical block in the OPM Data section. The logical blocks in the OPM Data section are indicated in Table 3-3~~Table 3-3~~.

g) Comments in the OMM may appear in the OMM Header immediately after the 'CCSDS_OMM_VERS' keyword, at the very beginning of the OMM Metadata section, and at the beginning of a logical block in the OMM Data section. Comments must not appear between the components of any logical block in the OMM Data section. The logical blocks in the OMM Data section are indicated in Table 4-3~~Table 4-3~~.

h) Comments in the OEM may appear in the OEM Header immediately after the 'CCSDS_OEM_VERS' keyword, at the very beginning of the OEM Metadata section (after the 'META_START' keyword), at the beginning of the OEM

Ephemeris Data Section, and at the beginning of the OEM Covariance Data section (after the 'COVARIANCE_~~DATA_~~START' keyword). Comment lines must not appear within any block of ephemeris lines or covariance matrix lines.

i) Extensive comments in an ODM are recommended in cases where there is insufficient time to negotiate an ICD. For an example "Checklist ICD", see Annex D.

j) The following comments should be provided:

1) Information regarding the genesis, history, interpretation, intended use, etc. of the state vector, spacecraft, maneuver, or ephemeris that may be of use to the receiver of the OPM, OMM or OEM:

```
COMMENT Source: File created by JPL Multi-Mission Navigation Team as part
COMMENT of Launch Operations Readiness Test held on 20 April 2001.
```

2) Natural body ephemeris information:

When the Earth is not the center of motion, the ephemerides of the planets, satellites, asteroids, and/or comets (including associated constants) consistent with the ODM should be identified so that the recipient can, in a consistent manner, make computations involving other centers.

```
COMMENT Based on latest orbit solution which includes observations
COMMENT through 2000-May-15 relative to planetary ephemeris DE-0405.
```

3) OEM Accuracy vs. Efficiency: If the covariance data section of the OEM is not utilized, the producer of an OEM should report in comment lines what the expected accuracy of the ephemeris is, so the user can smooth or otherwise compress the data without affecting the accuracy of the trajectory. The OEM producer also should strive to achieve not only the best accuracy possible, taking into account prediction errors, but also consider the efficiency of the trajectory representation (e.g., step sizes of fractional seconds between ephemeris lines may be necessary for precision scientific reconstruction of an orbit, but are excessive from the standpoint of antenna pointing predicts generation).

6.7 ORBIT DATA MESSAGE KEYWORDS

6.7.1 VERSION KEYWORDS

a) The Header of the OPM, OMM and OEM shall provide a CCSDS Orbit Data Message version number that identifies the format version; this is included to anticipate future changes. The version keywords for the OPM, OMM, and OEM shall be CCSDS_OPM_VERS, CCSDS_OMM_VERS, and CCSDS_OEM_VERS respectively. The value shall have the form of 'x.y', where 'y' shall be incremented for corrections and minor changes, and 'x' shall be incremented for major changes. Version x.0 shall be reserved for versions accepted by the CCSDS as an official Recommended Standard ("Blue Book"). Testing shall be conducted using OPM, OMM and OEM version numbers less than 1.0 (e.g., 0.x). Exchange participants should specify in the ICD the specific OPM, OMM and OEM version numbers they will support. The following version numbers are supported:

Version Keyword	**Version Number**	**Applicable Blue Book**
CCSDS_OPM_VERS	1.0	Blue Book 1.0, 09/2004
CCSDS_OPM_VERS	2.0	Blue Book 2.0, xx/2008
CCSDS_OMM_VERS	2.0	Blue Book 2.0, xx/2008
CCSDS_OEM_VERS	1.0	Blue Book 1.0, 09/2004
CCSDS_OEM_VERS	2.0	Blue Book 2.0, xx/2008

6.7.2 GENERAL KEYWORDS

a) Only those keywords shown in Table 3-1~~Table 3-1~~ , Table 3-2~~Table 3-2~~, and Table 3-3~~Table 3-3~~ shall be used in an OPM. Some keywords represent obligatory items and some are optional. KVN assignments representing optional items may be skipped.

b) Only those keywords shown in Table 4-1~~Table 4-1~~, Table 4-2~~Table 4-2~~, and Table 4-3~~Table 4-3~~ shall be used in an OMM. Some keywords represent obligatory items and some are optional. KVN assignments representing optional items may be skipped.

c) Only those keywords shown in Table 5-2~~Table 5-2~~ and Table 5-3~~Table 5-3~~ shall be used in an OEM. Some keywords represent obligatory items and some are optional. KVN assignments representing optional items may be skipped.

7 SECURITY

7.1 GENERAL

This section presents the results of an analysis of security considerations applied to the technologies specified in this Recommended Standard.

7.2 SECURITY CONCERNS RELATED TO THIS RECOMMENDED STANDARD

7.2.1 DATA PRIVACY

Privacy of data formatted in compliance with the specifications of this Recommended Standard should be assured by the systems and networks on which this Recommended Standard is implemented.

7.2.2 DATA INTEGRITY

Integrity of data formatted in compliance with the specifications of this Recommended Standard should be assured by the systems and networks on which this Recommended Standard is implemented.

7.2.3 AUTHENTICATION OF COMMUNICATING ENTITIES

Authentication of communicating entities involved in the transport of data which complies with the specifications of this Recommended Standard should be provided by the systems and networks on which this Recommended Standard is implemented.

7.2.4 DATA TRANSFER BETWEEN COMMUNICATING ENTITIES

The transfer of data formatted in compliance with this Recommended Standard between communicating entities should be accomplished via secure mechanisms approved by the IT Security functionaries of exchange participants.

7.2.5 CONTROL OF ACCESS TO RESOURCES

This Recommended Standard assumes that control of access to resources will be managed by the systems upon which provider formatting and recipient processing are performed.

7.2.6 AUDITING OF RESOURCE USAGE

This Recommended Standard assumes that auditing of resource usage will be handled by the management of systems and networks on which this Recommended Standard is implemented.

7.3 POTENTIAL THREATS AND ATTACK SCENARIOS

There are no certain threats or attack scenarios that apply specifically to the technologies specified in this Recommended Standard. Potential threats or attack scenarios applicable to the systems and networks on which this Recommended Standard is implemented should be addressed by the management of those systems and networks. Protection from unauthorized access is especially important if the mission utilizes open ground networks such as the Internet to provide ground station connectivity for the exchange of data formatted in compliance with this Recommended Standard.

7.4 CONSEQUENCES OF NOT APPLYING SECURITY TO THE TECHNOLOGY

There are no known consequences of not applying security to the technologies specified in this Recommended Standard. The consequences of not applying security to the systems and networks on which this Recommended Standard is implemented could include potential loss, corruption, and theft of data.

7.5 DATA SECURITY IMPLEMENTATION SPECIFICS

Specific information-security interoperability provisions that may apply between agencies and other independent users involved in an exchange of data formatted in compliance with this Recommended Standard should be specified in an ICD.

ANNEX A

VALUES FOR TIME_SYSTEM AND REFERENCE_FRAME

(NORMATIVE)

The values in this Annex represent the set of acceptable values for the TIME_SYSTEM and REFERENCE_FRAME keywords in the OPM, OMM, and OEM. For details and description of these time systems, see Ref [F1]. If exchange partners wish to use different settings, they should be documented in the ICD.

A1 TIME_SYSTEM METADATA KEYWORD

Time System Value	Meaning
GMST	Greenwich Mean Sidereal Time
GPS	Global Positioning System
MET	Mission Elapsed Time [1]
MRT	Mission Relative Time [1]
SCLK	Spacecraft Clock (receiver) (requires rules for interpretation in ICD)
TAI	International Atomic Time
TCB	Barycentric Coordinated Time
TDB	Barycentric Dynamical Time
TT	Terrestrial Time
UT1	Universal Time
UTC	Coordinated Universal Time

[1] If MET or MRT are chosen as the TIME_SYSTEM then the epoch of either the start of the mission for MRT, or of the event for MET, should either be given in a comment in the message or provided in an ICD. The time system for the start of the mission or the event

should also be provided in the comment or the ICD. If these values are used for the TIME_SYSTEM, then the times given in the file denote a duration from the mission start or event. However, for clarity, an ICD should be used to fully specify the interpretation of the times if these values are to be used. Note that the time format should only utilize three digit days from the MET or MRT epoch, not months and days of the months.

A2 REFERENCE-_FRAME KEYWORD

Time SystemReference Frame Value	Meaning
EME2000	Earth Mean Equator and Equinox of J2000
GCRF	Geocentric Celestial Reference Frame
GRC	Greenwich Rotating Coordinates
ICRF	International Celestial Reference Frame
ITRF2000	International Terrestrial Reference Frame 2000
ITRF-93	International Terrestrial Reference Frame 1993
ITRF-97	International Terrestrial Reference Frame 1997
MCI	Mars Centered Inertial
RSW	another Another name for 'Radial, Transverse, Normal'
RTN	Radial, Transverse, Normal
TDR	True of Date, Rotating
TEME	True Equator Mean Equinox[2]
TOD	True of Date
NTW	xxx Has the y-axis (middle axis) aligned with the velocity vector (even in an eccentric orbit) along the velocity vector and N being perpendicular to the velocity pointed outwards from the Earth. However, I personally prefer the TNW frame which has the x-axis along the velocity vector and the y-axis perpendicular to the velocity vector pointings towards the Earth. Its a simple 90 degree notation, so

	either one is acceptable, but the definition should be clear in the text as to which one is being used. Also, the RTN definition should be explicit as well. System with the middle axis aligned with the velocity vector (even in an eccentric orbit).
TNW	A local orbital coordinate frame should be available that has the primary axis along the velocity vector of the satellite. Has the x-axis along the velocity vector, W along the orbital angular momentum vector, and N completes the right handed system. and the y-axis perpendicular to the velocity vector pointing towards the Earth. (Its a simple 90 degree notation from NTW, so either one is acceptable, but the definition should be clear in the text as to which one is being used. Also, the RTN definition should be explicit as well.) xxx

[2] NORAD Two Line Element Sets are implicitly in a True Equator Mean Equinox (TEME) reference frame, which is ill defined in international standard or convention. TEME may be used only for OMM's based on NORAD Two Line Element sets. TEME may be used may be used only for NORAD Two Line Element sets, and in no other circumstances. Note that there are subtle differences between TEME of Epoch and TEME of Date (see reference [F3] or [F4] or reference [1]). The effect is very small relative to TLE accuracy, and there is uncertainty regarding which of these is used by NORAD. The preferred option is TEME of Date. Users should specify in the ICD if their assumption is TEME of Epoch.

ANNEX B

ABBREVIATIONS AND ACRONYMS

(INFORMATIVE)

ASCII	American Standard Code for Information Interchange
CCIR	International Coordinating Committee for Radio Frequencies
CCSDS	Consultative Committee on Space Data Systems
ECI	Earth Centered Inertial
EME2000	Earth Mean Equator and Equinox of J2000 (Julian Date 2000)
GCRF	Geocentric Celestial Reference Frame
GPS	Global Positioning System
IAU	International Astronomical Union
ICD	Interface Control Document
ICRF	International Celestial Reference Frame
IEC	International Electrotechnical Commission
IERS	International Earth Rotation and Reference Systems Service
ISO	International Standards Organization
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
KVN	Keyword = Value Notation
NORAD	North American Aerospace Defense Command
OD	Orbit Determination
ODM	Orbit Data Message
OEM	Orbit Ephemeris Message
OPM	Orbit Parameter Message

OMM	Orbit Mean-Elements Message
RTN	Radial, Transverse (along-track) and Normal
SGP4	US Air Force Simplified General Perturbations No. 4
TAI	International Atomic Time
TCB	Barycentric Coordinated Time
TDB	Barycentric Dynamical Time
TEME	True Equator Mean Equinox
TLE	Two Line Element
TOD	True Equator and Equinox of Date
TT or TDT	Terrestrial Dynamical Time
UTC	Coordinated Universal Time
XML	eXtensible Markup Language

ANNEX C

RATIONALE FOR ORBIT DATA MESSAGES

(INFORMATIVE)

C1 OVERVIEW

This annex presents the rationale behind the design of each message. It may help the application engineer to select a suitable message.

A specification of requirements agreed to by all parties is essential to focus design and to ensure the product meets the needs of the Member Agencies and satellite operators. There are many ways of organizing requirements, but the categorization of requirements is not as important as the agreement to a sufficiently comprehensive set. In this section the requirements are organized into three categories:

a) Primary Requirements: These are the most elementary and necessary requirements. They would exist no matter the context in which the CCSDS is operating, i.e., regardless of pre-existing conditions within the CCSDS, its Member Agencies, or other independent users.

b) Heritage Requirements: These are additional requirements that derive from pre-existing Member Agency or other independent user requirements, conditions or needs. Ultimately these carry the same weight as the Primary Requirements. This Recommendation reflects heritage requirements pertaining to some of the panels' home institutions collected during the preparation of the document; it does not speculate on heritage requirements that could arise from other sources. Corrections and/or additions to these requirements are expected during future updates.

c) Desirable Characteristics: These are not requirements, but they are felt to be important or useful features of the Recommendation.

C2 PRIMARY REQUIREMENTS ACCEPTED BY THE ORBIT DATA MESSAGES

Table ~~7~~C-1: Primary Requirements

Requirement	Accepted for OPM?	Accepted for OMM?	Accepted for OEM?
Data must be provided in digital form (computer file).	Y	Y	Y
The file specification must not require of the receiving exchange partner the separate application of, or modeling of, spacecraft dynamics or gravitational force models, or integration or propagation.	N	N	Y
The interface must facilitate the receiver of the message to generate a six-component Cartesian state vector (position and velocity) at any required epoch.	Y	Y	Y
State vector information must be provided in a reference frame that is clearly identified and unambiguous.	Y	Y	Y
Identification of the object and the center(s) of motion must be clearly identified and unambiguous.	Y	Y	Y
Time measurements (time stamps, or epochs) must be provided in a commonly used, clearly specified system.	Y	Y	Y
The time bounds of the ephemeris must be unambiguously specified.	N/A	N/A	Y
The standard must provide for clear specification of units of measure.	Y	Y	Y
Files must be readily ported between, and useable within, 'all' computational environments in use by Member Agencies.	Y	Y	Y
Files must have means of being uniquely identified and clearly annotated. The file name alone is considered insufficient for this purpose.	Y	Y	Y
File name syntax and length must not violate computer constraints for those computing environments in use by Member Agencies.	Y	Y	Y
Information about the uncertainty of the state is provided.	Y	Y	Y

Table ~~7~~C-2: Heritage Requirements

Requirement	Accepted for OPM?	Accepted for OMM?	Accepted for OEM?
Ephemeris data is reliably convertible into the SPICE SPK (NASA) format (ref [F6]) and IIRV (NASA) format (ref [F7]) using a standard, multi-mission, unsupervised pipeline process. A complete ephemeris, not subject to integration or propagation by the customer, must be provided.	N	N	Y
Ephemeris data provided for Deep Space Network (DSN), Ground Network (GN) and Space Network (SN) scheduling or operations (metric predicts) is to be certified by the providing Agency as correct and complete for the intended purpose. The receiving Agency cannot provide evaluation, trajectory propagation or other usability services.	N	N	Y
The standard is, or includes, an ASCII format.	Y	Y	Y
The standard does not require software supplied by other Agencies.	Y	N	Y

Table ~~7~~C-3: Desirable Characteristics

Requirement	Accepted for OPM?	Accepted for OMM?	Accepted for OEM?
The standard applies to non-traditional objects, such as landers, rovers, balloons, and natural bodies (asteroids, comets).	Y	N	Y
The standard allows state vectors to be provided in other than the traditional EME2000 inertial reference frame; one example is the International Astronomical Union (IAU) Mars body-fixed frame. (In such a case, provision or ready availability of supplemental information needed to transform data into a standard frame must be arranged.)	Y	Y	Y
The standard is extensible with no disruption to existing users/uses.	Y	Y	Y
The standard is consistent with, and ideally a part of, ephemeris products and processes used for other space science purposes.	N	Y	N
The standard is as consistent as reasonable with any related CCSDS ephemeris standards used for earth-to-spacecraft or spacecraft-to-spacecraft applications.	Y	Y	Y

C3 APPLICABILITY OF CRITERIA TO MESSAGE OPTIONS

The selection of one particular message will depend on the optimization criteria in the given application. Table C-4~~Table 7-4~~ compares the three recommended messages in terms of the relevant selection criteria identified by the CCSDS:

Table ~~7~~C-4: Applicability of the Criteria to Orbit Data ~~Codes~~Messages

Criteria	Definition	Applicable to OPM?	Applicable to OMM?	Applicable to OEM?
Modeling Fidelity	Permits modeling of any dynamic perturbation to the trajectory.	N	N	Y
Human Readability	Provides easily readable message corresponding to widely used orbit representation.	Y	Y	Y
Remote Body Extensibility	Permits use for assets on remote solar system bodies.	Y	N	Y
Lander/Rover Compatibility	Permits exchange of non-orbit trajectories.	N	N	Y

C4 INCREASING ORBIT PROPAGATION FIDELITY OF AN OPM OR OMM

Some OPM and/or OMM users may desire/require a higher fidelity propagation of the state vector or orbital elements. A higher fidelity technique may be desired/required in order to minimize inconsistencies in predictions generated by diverse, often operator unique propagation schemes. Nominally the OPM and OMM are only engineered for a relatively lower fidelity orbit propagation. However, with the inclusion of additional context information, it is possible for users to provide data that could be used to provide a relatively higher fidelity orbit propagation. For this relatively higher fidelity orbit propagation, a much greater amount of ancillary information regarding spacecraft properties and dynamical models should be provided. Higher fidelity orbit propagations may be useful in special studies such as orbit conjunction studies.

Spacecraft orbit determination and propagation are stochastic estimation problems. Observations are inherently uncertain, and not all of the phenomena that influence satellite motion are clearly discernible. State vectors and orbital elements with their respective covariances are best propagated with models that include the same forces and phenomena that were used for determining the orbit. Including this information in an OPM/OMM allows exchange partners to compare the results of their respective orbit propagations.

With additional context information, the OPM/OMM may be used for assessing mutual physical or electromagnetic interference among Earth orbiting spacecraft, developing collaborative maneuvers, and propagating the orbits of active satellites, inactive man made objects, and near Earth debris fragments. The additional information facilitates dynamic modeling of any users' approach to conservative and non-conservative phenomena.

The primary vehicle for the provision of additional optional ancillary information to be used when propagating an OPM/OMM is the COMMENT mechanism. A number of potential COMMENT statements are included in Annex D.

C4C5 SERVICES RELATED TO THE DIFFERENT ORBIT DATA MESSAGE FORMATS

The different orbit data messages have been distinguished by the self-interpretability of the messages. The different services that can be achieved without special arrangements between users of the CCSDS orbit data messages are listed in Table C-5.

Table 7C-5: Services Available with Orbit Data Messages

Service	Definition	Applicable to OPM?	Applicable to OMM?	Applicable to OEM?
Absolute Orbit Interpretation	State availability at specific times for use in additional computations (geometry, event detection, etc.).	Y	Y	Y
Relative Orbit Interpretation	Trajectory comparison and differencing for events based on the same time source.	Only at time specified at Epoch	Only at time specified at Epoch	Y

ANNEX D

ITEMS FOR AN INTERFACE CONTROL DOCUMENT

(INFORMATIVE)

D1 STANDARD ICD ITEMS

In several places in this document there are references to items which should be specified in an Interface Control Document (ICD) between participants ~~in~~that supplements an exchange of ephemeris data. The ICD should be jointly produced by both participants in a cross-support involving the transfer of ephemeris data. This section compiles those recommendations into a single section. Although the Orbit Data Messages described in this document may at times be used in situations in which participants have not negotiated interface control documents (ICD), ICD's based on the content specified in this Standard should be developed and negotiated whenever possible.

EDITOR'S COMMENT: The greater the amount of material which must be specified via ICD, the lesser the utility/benefit of the ODM (custom programming may be required to tailor software for each ICD).

Item	Section
1. Definition of orbit accuracy requirements pertaining to any particular ODM	1.2~~1.2~~
2. Method of physically exchanging ODMs (transmission)	1.2~~1.2~~, 3.1~~3.1~~, 4.1~~4.1~~, 5.1~~5.1~~
3. Whether the ASCII format of the ODM will be KVN or XML.	2.1~~2.1~~
4. OPM, OMM and/or OEM file naming conventions	3.1~~3.1~~, 4.1~~4.1~~, 5.1~~5.1~~
5. Format on values used for the "ORIGINATOR" keyword	3.2.1~~3.2.1~~, 4.2.1~~4.2.1~~, 5.2.1~~5.2.1~~
6. Situations where the OBJECT_ID is not published in the SPACEWARN Bulletin (reference [2]).	3.2.2~~3.2.2~~, 4.2.2~~4.2.2~~, 5.2.2~~5.2.2~~
7. Type of TEME reference frame, if applicable (TEME of Epoch or TEME of Date).	4.2.2~~4.2.2~~

8. OBJECT_ID and OBJECT_NAME convention if the OEM is used for a planetary ephemeris.	5.2.25.2.2
9. If floating point numbers in extended-single or extended-double precision are to be used, then discussion of implementation specific attributes is required in an ICD between exchange partners.	6.46.4
10. Information which must appear in comments for any given ODM exchange	6.66.6
11. Specific OPM, OMM and/or OEM version numbers that will be exchanged.	6.7.16.7.1
12. Specific information security interoperability provisions that apply between agencies.	7.57.5
13. Exceptions for the REF_FRAME and/or TIME_SYSTEM metadata keywords that are not drawn from Annex A.	ANNEX AANNEX A
14. Interpretation of TIME_SYSTEM specified as MET, MRT or SCLK, if to be exchanged, and how to transform them to a standardized time system. The ICD should specify that elapsed days are to be used for epochs, with year starting at zero.	ANNEX A

D2 THE "CHECKLIST ICD"

The following checklist is provided in order to allow for the exchange of essential information when there is insufficient time to generate an official, documented Interface Control Document. None of the items in this checklist are required, but may be used to convey as much information as possible in an exchange. This checklist may also be used as a guideline for the development of a formal ICD, if so desired. –The basic idea of the "Checklist ICD" is to provide a vehicle that may be used by exchange partners to document sufficient data and metadata to allow comparison of their independent estimates of future states of satellites of interest.

Information about atmospheric models and other elements of analysis that cannot be described precisely enough to allow consumers to reproduce the provider's processes may be included via this vehicle, i.e., in optional comment fields and not in normative requirements. The rationale for making these non-normative includes: (a) investigators often tune or modify "standard" models and there may be many uncontrolled versions, and (b) simply stating the name of a model such as a "Jacchia atmosphere" may not be a sufficient specification, yet there may be no more precise description available.

USAGE NOTE: This checklist should be filled in by an engineer or technician and used as a supplement to one (or more) of the normative messages in this document (OPM, OMM, or OEM). For each attribute, a space is allocated in which the applicable values or text may be provided. The far right column provides usage information. Also, to facilitate use within one of the normative messages, the far left column of the "Checklist ICD" is set up with the "COMMENT" keyword. This allows the user to fill in the checklist and then copy it into one of the ODM files as a comment section. Prior to doing this, the "Usage" field in the far right column should be deleted. Individual COMMENT statements that are not applicable to any given exchange may be deleted. A blank copy of this "Checklist ICD" is available on the CCSDS web site at http://cwe.ccsds.org/moims/docs/MOIMS-NAV/Draft%20Documents/Orbit%20Data%20Messages%20(ODM)/ODM-checklist-icd.doc. Because this checklist is non-normative, it may be extended, reduced, or otherwise tailored to meet the needs of individual exchange partners. This online version is suitable for downloading, editing, and inserting directly into an OPM. Note that this set of COMMENT statements is also suitable for use in situations where an ICD between exchange partners is neither required, desired, nor feasible.

~~Information about atmospheric models and other elements of analysis that cannot be described precisely enough to allow consumers to reproduce the provider's processes may be included via this vehicle, i.e., optional comment fields and not in normative requirements. The rationale for not making these normative includes: (a) investigators often tune or modify "standard" models and there may be many uncontrolled versions, and (b) simply stating the name of a model such as a "Jacchia atmosphere" may not be a sufficient specification, yet there may be no more precise description available.~~

~~The basic idea of the "Checklist ICD" is to provide a vehicle that may be used by exchange partners to document sufficient data and metadata to allow comparison of their independent estimates of future states of satellites of interest.~~

~~NOTE: Because this checklist is non-normative, it may be extended, reduced, or otherwise tailored to meet the needs of individual exchange partners.~~

CHECKLIST INTERFACE CONTROL DOCUMENT

COMMENT	Attribute	Value	Usage
COMMENT	DATE =		Date/time the checklist was filled out
COMMENT	OBJECT ID =		If this list is used as a standalone ICD, this satellite international designator number links the checklist to the applicable normative message. It is not necessary if the checklist is pasted into one of the normative messages.
COMMENT	OBJECT NAME =		If this list is used as a standalone ICD, this item links the checklist to

			the applicable normative message. It is not necessary if the checklist is pasted into one of the normative messages.
COMMENT	GEOPOTENTIAL MODEL =		Gravitational model (e.g. EGM-96, WGS-84/EGM-96, WGS-84, GGM-01, TEG-4)
COMMENT	GEOPOTENTIAL MODEL DEGREE AND ORDER =	____ x ____	
COMMENT	EARTH RADIUS USED =		
COMMENT	EARTH ANGULAR ROTATION USED =		deg/sec
COMMENT	ATMOSPHERIC DRAG MODEL =		Atmospheric models (e.g. MSISE90, NRLMSIS00, J70, J71, JRob, DTM)
COMMENT COMMENT COMMENT COMMENT COMMENT COMMENT COMMENT COMMENT COMMENT COMMENT	THIRD BODY PERTURBATIONS = THIRD BODY PERTURBATIONS = THIRD BODY PERTURBATIONS = THIRD BODY PERTURBATIONS = THIRD BODY PERTURBATIONS = THIRD BODY PERTURBATIONS = THIRD BODY PERTURBATIONS = THIRD BODY PERTURBATIONS = THIRD BODY PERTURBATIONS = THIRD BODY PERTURBATIONS =	Sun Moon Mercury Venus Mars Jupiter Saturn Uranus Neptune Pluto	If this list is printed, circle or otherwise indicate the included accelerations. If this annex is used as a file, or is cut/pasted into an ODM, then the lines for 3rd body perturbations that were not included in the analysis may be removed from the file.
COMMENT	SOLAR PRESSURE MODEL =		
COMMENT	SOLID TIDES MODEL =		
COMMENT	OCEAN TIDES MODEL =		
COMMENT	EARTH ALBEDO =		
COMMENT	EARTH ALBEDO GRID SIZE =		
COMMENT	ATTITUDE =		Note: Attitude state is best supplied by an Attitude Data Message (see Reference [9]). Could supply the applicable APM or AEM file name as the value for this parameter.
COMMENT	EOP EPOCH =		
COMMENT	EOP SOURCE =		e.g., IERS, USNO, NGA
COMMENT	POLAR MOTION X =		in arcseconds
COMMENT	POLAR MOTION Y =		in arcseconds
COMMENT	POLAR ANGLE EPSILON =		in degrees
COMMENT	POLAR MOTION PSI =		in degrees
COMMENT	UT1 CORRECTION =		in seconds
COMMENT	SOLAR F10.7 =		units = 10^4 Jansky
COMMENT	AVERAGE F10.7 =		units = 10^4 Jansky. Time frame should be specified.
COMMENT	INTERPOLATION METHOD =		Used for EOP and Solar Weather data
COMMENT	SHADOW MODEL		Shadow modeling for Solar Radiation Pressure (e.g. NONE, CYLINDRICAL, DUAL CONE); dual cone uses both umbra/penumbra regions
COMMENT	PRECESSION/NUTATION UPDATE INTERVAL =		Update interval for precession nutation values
COMMENT	ORBIT DETERMINATION SCHEME =		e.g. PODS, DSST, RTOD, ODTK, or other widely used orbit estimation technique or tool
COMMENT	INTEGRATION SCHEME =		(e.g. RKF78, GAUSSJACK, ADAMSB, other)
COMMENT	INTEGRATION STEP MODE =		Type of integration (e.g. FIXED,

			RELATIVE ERROR, REGTIME)
COMMENT	INTEGRATOR STEP SIZES =		Step sizes—not used if relative error is selected
COMMENT	INTEGRATOR ERROR CONTROL =		Error control if needed by the integrator (e.g. 1.0 e-15, other)
COMMENT	COVARIANCE SOLVE-FOR =		Repeat this line as many times as is necessary to list the factors included in the orbit determination solution

ANNEX E

CHANGES IN ODM VERSION 2

(INFORMATIVE)

This annex lists the differences between ODM 1.0 and ODM 2.0.

1. A normative annex for primary TIME_SYSTEM and REFERENCE_FRAME keywords was added, replacing non-normative references to the Navigation Green Book (reference [F1]). The CCSDS documents are not allowed to make references to non-normative documents in the normative sections of a document.

2. Annexes were rearranged to conform to CCSDS Guidelines that were inadvertently not followed in the first version of the ODM (specifically, normative annexes are supposed to appear first, prior to the informative annexes).

3. The Orbit Mean-Elements Message (OMM) was added to provide better support for ISO Technical Committee 20, Subcommittee 14 objectives (see Section 4).

4. A 6x6 covariance matrix (lower triangular form) was added to the OPM and OEM to allow producers of these files to provide the uncertainties associated with the state(s).

5. The formats of units allowed in the OPM were changed to make them compliant with the International System (SI) of ~~u~~Units~~ or Non SI units accepted for use with the International System (specifically, degrees of angle)~~. In the Blue Book version 1, the SI conventions were not observed. In ~~most ~~all cases, this was merely a change in case conventions~~ (lower case as opposed to upper case).~~ from upper case to lower case.

6. The option to use the Julian Date in formatting of epochs and other time fields is withdrawn, as this format is described in neither the CCSDS Time Code Formats (Reference [1]) nor the ISO 8601 standard “Data elements and interchange formats — Information interchange — Representation of dates and times”.

7. Optional accelerations were added to the state vectors provided in the OEM format~~.~~ (~~S~~see Section 5).

8. A few changes were made to harmonize the ODM with the other Navigation Data Messages (Attitude Data Messages (ADM) and Tracking Data Message (TDM)). Most of these changes were generated from the CCSDS Agency Review processes of the ADM and TDM.

9. Some restrictions were imposed on the placement of COMMENT statements in order to allow easy conversion of ODM’s from KVN format to XML format or vice versa.

10. In the original ODM Blue Book, several aspects of the CCSDS "Style Guide" were not followed when the ODM was originally published. This version corrects these styling errors.

11. The Annex that describes information to be included in an ICD was significantly revised to suggest additional information that would be worthwhile to exchange. Also, a checklist was added that will allow exchange partners to exchange ODM's when there is no time to negotiate a formal ICD by inserting COMMENT statements into an ODM.

12. The syntax rules for the OPM, OMM and OEM were consolidated into a common syntax section (see Section 6).

13. The rules for processing COMMENT keywords were consolidated into a single section of the document (see Section 6).

14. Improved discussion of information security considerations was provided (see Section 7), per Secretariat request.

15. The requirement to put the OBJECT_ID parameter in SPACEWARN format was changed from a requirement ("shall") to a recommendation ("should") based on current operational uses of the OEM.

16. Maximum line width for all messages changed to 254 to be consistent with the Tracking Data Message (TDM) and Attitude Data Messages (ADM) standards.

17. The possibility of using the OEM to convey a planetary ephemeris is acknowledged.

18. The rules for text value fields were constrained to only all uppercase or all lowercase.

ANNEX F

INFORMATIVE REFERENCES

(INFORMATIVE)

[F1] *Navigation Data—Definitions and Conventions*. Report Concerning Space Data System Standards, CCSDS 500.0-G-2. Green Book. Issue 2. Washington, D.C.: CCSDS, November 2005. [http://www.ccsds.org/green_books.html]

[F2] *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.

[F3] http://celestrak.com/ (reference web site for NORAD Two Line Elements)

[F4] Vallado, David A; Crawford, Paul; Hujsak, Richard; Kelso, T.S.; "Revisiting Spacetrack Report #3", American Institute for Aeronautics and Astronautics, AIAA 2006-6753, http://www.centerforspace.com/downloads/files/pubs/AIAA-2006-6753.pdf

[F5] *Attitude Data Messages*. Draft Recommendation for Space Data System Standards, CCSDS 504.0-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, November 2005.

[F6] SPICE documentation: http://naif.jpl.nasa.gov/naif/documentation.html

[F7] Tracking and Acquisition Handbook for the Spaceflight Tracking and Data Network, NASA document 450-TAH-STDN, October 1994.~~xxx Add HRV reference (see requirements) xxx~~

~~ANNEX G~~

~~QUESTIONS AND DISCUSSION~~

~~(TO BE REMOVED FROM FINAL DOCUMENT)~~

~~G1questions / TO DO~~

~~1. Should we add a keyword for the relevant planetary ephemeris to be used when the OEM is used for predicts generation?~~