The Consultative Committee for Space Data Systems

Recommendation for Space Data System Standards

ORBIT DATA MESSAGES

RECOMMENDED STANDARD

CCSDS 502.0.B-2 and ISO 22644

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The Consultative Committee for Space Data Systems (CCSDS) is an organization officially established by the management of its members. The Committee meets periodically to address data systems problems that are common to all participants, and to formulate sound technical solutions to these problems. Inasmuch as participation in the CCSDS is completely voluntary, the results of Committee actions are termed **Recommended Standards** and are not considered binding on any Agency.

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  - -- The **standard** itself.

  - -- The anticipated date of initial operational capability.

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No later than five years from its date of issuance, this **Recommended Standard** will be reviewed by the CCSDS to determine whether it should: (1) remain in effect without change; (2) be changed to reflect the impact of new technologies, new requirements, or new directions; or (3) be retired or canceled.

In those instances when a new version of a **Recommended Standard** is issued, existing CCSDS-related member standards and implementations are not negated or deemed to be non-CCSDS compatible. It is the responsibility of each member to determine when such standards or implementations are to be modified. Each member is, however, strongly encouraged to direct planning for its new standards and implementations towards the later version of the Recommended Standard.

FOREWORD

This document is a Recommended Standard 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 Recommended Standard is the baseline concept for trajectory representation in data interchange applications that are cross-supported between Agencies of the CCSDS.

This Recommended Standard establishes a common framework and provides a common basis for the interchange of orbit and orbit-relevant 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 Recommended Standard and may incorporate features not addressed by this Recommended Standard.

Through the process of normal evolution, it is expected that expansion, deletion, or modification of this document may occur. This Recommended Standard is therefore subject to CCSDS document management and change control procedures, which are defined in the *Procedures Manual for the Consultative Committee for Space Data Systems*. Current versions of CCSDS documents are maintained at the CCSDS Web site:

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- Swedish Space Corporation (SSC)/Sweden.
- United States Geological Survey (USGS)/USA.

DOCUMENT CONTROL

Document	Title	Date	Status
CCSDS 502.0-B-1	Orbit Data Messages, Issue 1	September 2004	Original issue, superseded
CCSDS 502.0.B-2 and ISO 22644	ORBIT DATA MESSAGES, **Recommended Standard**, **Issue 3**	**November 2015 DRAFT**	Current issue: – changes from the original issue are documented in annex E
EC 1	Editorial Change 1	**Error! Unknown document property name.**	Corrects erroneous cross references and table of contents entries; corrects typographical anomaly in annex B; updates informative references [G1] and [G2] to current issues in annex G.
CCSDS 502.0.B-2 and ISO 22644 Cor. 1	Technical Corrigendum 1	**Error! Unknown document property name.**	Corrects/clarifies text; updates references [1] and [4] to current issues in 1.7.
?	Technical Corrigendum	**Error! Unknown document property name.**	Added Orbit Hybrid Message (OHM)

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1 INTRODUCTION

1.1 PURPOSE AND SCOPE

This Orbit Data Message (ODM) Recommended Standard 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), the Orbit Ephemeris Message (OEM) and the Orbit Hybrid Message (OHM). 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 (currently 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 Recommended Standard 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 APPLICABILITY

The rationale behind the design of each orbit data 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 Recommended Standard 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 C3.

This Recommended Standard 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 Recommended Standards. (See reference [4].)

1.3 RATIONALE

This update to version 2 of the Orbit Data Messages adds a fourth message type (OHM) based on collaboration of the CCSDS Navigation Working Group and the ISO Technical Committee 20, Subcommittee 14, Working Group 3 (ISO TC20/SC14/WG3). A full list of the changes in this document is located in annex E.

1.4 DOCUMENT STRUCTURE

Section 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).

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

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

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

Section 6 provides details about the structure and content of the OHM.

Section 7 discusses the syntax considerations of the set of Orbit Data Messages (OPM, OMM, OEM and OHM).

Section 8 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 ICDs 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 instructions for how to produce a version 2 OPM/OEM that is backwards compatible to version 1 implementations.

ANNEX G provides a listing of informative references.

1.5 DEFINITIONS

For the purposes of this document, the following definitions apply:

a) the word ‘agencies’ may also be construed as meaning ‘satellite operators’ or ‘satellite service providers’;

b) the word ‘participant’ denotes an entity that has the ability to acquire or broadcast navigation messages and/or radio frequencies, for example, a spacecraft, a tracking station, a tracking instrument, or an agency/operator;

c) the notation ‘n/a’ signifies ‘not applicable’;

d) depending on context, the term ‘ODM’ may be used to refer to this document, or may be used to refer collectively to the OPM, OMM, OEM and OHM messages.

1.6 NOMENCLATURE

The following conventions apply throughout this Recommended Standard:

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.

1.7 REFERENCES

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

Cor. 1

[1] *Time Code Formats*. Recommendation for Space Data System Standards, CCSDS 301.0-B-4. Blue Book. Issue 4. Washington, D.C.: CCSDS, November 2010.

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

[3] *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.

[4] *XML Specification for Navigation Data Messages*. Recommendation for Space Data System Standards, CCSDS 505.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, December 2010.

[5] "JPL Solar System Dynamics." Solar System Dynamics Group. <http://ssd.jpl.nasa.gov/>

[6] Paul V. Biron and Ashok Malhotra, eds. *XML Schema Part 2: Datatypes*. 2nd Edition. W3C Recommendation. N.p.: W3C, October 2004. <http://www.w3.org/TR/2001/REC-xmlschema-2-20010502/>

[7] *IEEE Standard for Binary Floating-Point Arithmetic*. IEEE Std 754-1985. New York: IEEE, 1985.

Cor. 1

2 OVERVIEW

2.1 ORBIT DATA MESSAGE TYPES

Four CCSDS-recommended Orbit Data Messages (ODMs) are described in this Recommended Standard: the Orbit Parameter Message (OPM), the Orbit Mean-Elements Message (OMM), the Orbit Ephemeris Message (OEM), and the Orbit Hybrid Message (OHM).

The recommended orbit data messages are ASCII text format (reference [3]). This ODM document describes 'keyword = value notation' formatted messages, while reference [4] describes XML formatted messages (the ICD should specify which of these formats will be exchanged).

NOTE – As currently specified, an OPM, OMM, or OEM file is to represent orbit data for a single spacecraft and the OHM is to represent orbit data for either a single spacecraft or single parent spacecraft of a parent/child spacecraft deployment scenario. It is possible that the architecture may support multiple spacecraft 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 allows for modeling of any number of maneuvers (as both finite and instantaneous events) and simple modeling of solar radiation pressure and atmospheric drag.

The OPM also contains an optional covariance matrix which reflects the uncertainty of the orbit state.

Though primarily intended for use by computers, the attributes of the OPM also make it suitable for applications such as exchanges by email, 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 (TLEs) to accommodate the needs of heritage users (see reference [G4]).

The OMM also contains an optional covariance matrix which reflects the uncertainty of the mean Keplerian elements. This information may be used to determine contact parameters that encompass uncertainties in predicted future states of orbiting objects of interest.

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.

Though primarily intended for use by computers, the attributes of the OMM also make it suitable for applications such as exchanges by email, 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 also contains an optional covariance matrix which reflects the uncertainty of the orbit solution used to generate states in the ephemeris.

2.5 ORBIT HYBRID MESSAGE (OHM)

An OHM specifies position and velocity of either a single object or an en masse parent/child deployment scenario stemming from a single object. The OHM aggregates and extends OPM, OEM and OMM content in a single hybrid message (file) and offers the following additional capabilities:

- Optional Earth Orientation (UT1 and UTC) at a nearby (relevant) reference epoch;
- Optional Leap second specification

- Optional orbit states (specified using one or more of Cartesian and orbit elements and reference frames) for a single or parent object at either a single epoch or as a time history (ephemeris);
- Optional maneuver specification (impulsive or finite burn);
- Optional force model specification;
- Optional covariance matrix of selectable/arbitrary order for a single or parent object at either a single epoch or as a time history (ephemeris) which reflects the uncertainty of the orbit solution or Monte Carlo simulation used to obtain the nominal states in the orbit state(s);
- Optional covariance content options (e.g. Cartesian 3x3, 6x6, 7x7, or any combination of order, reference frame and orbit elements)
- Optional area cross-sections for drag, SRP force modeling.
- Optional spacecraft dimensions and orientation information for collision probability estimation

The OHM simultaneously emphasizes flexibility and message conciseness by offering extensive optional content while minimizing mandatory content. The OHM is well-suited for exchanges that (1) involve automated interaction (e.g., computer-to-computer communication where frequent, fast automated time interpretation and processing is required), and (2) involve regular orbit data transfer for numerous objects (e.g. 200,000) using minimal network bandwidth, disk storage and quantity of files. The OHM allows the user, in a single message/file, to either embed high-fidelity force modeling into an ephemeris time history (akin to the OEM ephemeris), or specify orbital states which can be propagated with supplied force model parameters (akin to OPM content), or both.

2.6 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, whereas a single, self-contained OHM is typically sufficient. If ephemeris information for multiple objects is to be exchanged, then multiple OPM, OMM, OEM or OHM files must be used, with the exception that the OHM supports parent/child deployment scenario specifications in a single message.

2.7 DEFINITIONS

Definitions of time systems, reference frames, planetary models, maneuvers and other fundamental topics related to the interpretation and processing of state vectors and spacecraft ephemerides are provided in reference [G1].

3 ORBIT PARAMETER MESSAGE (OPM)

3.1 GENERAL

3.1.1 Orbit information may be exchanged between two participants by sending a state vector (see reference [G1]) 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) may be included with the message.

3.1.2 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.

3.1.3 If participants wish to exchange mean element information, then the Orbit Mean-Elements Message (OMM) or Orbit Hybrid Message (OHM) should be the selected message type. (See sections 4 and 6.)

3.1.4 The use of the OPM is best applicable under the following conditions:

a) an orbit propagator consistent with the models used to develop the orbit data should be available at the receiver's site;

b) the receiver's modeling of gravitational forces, solar radiation pressure, atmospheric drag, and thrust phases (see reference [G1]) should fulfill accuracy requirements established between the exchange partners.

3.1.5 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.

3.1.6 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 ICD. The method of exchanging OPMs should be decided on a case-by-case basis by the exchange partners and documented in an ICD.

NOTE – Detailed syntax rules for the OPM are specified in section 7.

3.2 OPM CONTENT/STRUCTURE

3.2.1 GENERAL

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).

3.2.2 OPM HEADER

3.2.2.1 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.

3.2.2.2 Only those keywords shown in table 3-1 shall be used in an OPM header.

Table 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 7.7 for formatting rules.)	COMMENT This is a comment	No
CREATION_DATE	File creation date/time in UTC. (For format specification, see 7.5.9)	2001-11-06T11:17:33 2002-204T15:56:23Z	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

3.2.3 OPM METADATA

3.2.3.1 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.

3.2.3.2 Only those keywords shown in table 3-2 shall be used in OPM metadata.

Cor. 1

NOTE – 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 1.7 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 3-2: OPM Metadata

Keyword	Description	Examples of Values	Obligatory
COMMENT	Comments (allowed at the beginning of the OPM Metadata). (See 7.7 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 [2]), 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 [2]). 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 [5]).	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. Use of values other than those in annex A must be documented in an ICD. The reference frame must be the same for all data elements, with the exception of 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

REF_FRAME_EPOCH	Epoch of reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.9 for formatting rules.)	2001-11-06T11:17:33 2002-204T15:56:23Z	No
TIME_SYSTEM	Time system used for state vector, maneuver, and covariance data (also see table 3-3). Use of values other than those in annex A must be documented in an ICD.	UTC, TAI, TT, GPS, TDB, TCB	Yes

3.2.4 OPM DATA

3.2.4.1 Table 3-3 provides an overview of the six logical blocks in the OPM Data section (State Vector, Osculating Keplerian Elements, Spacecraft Parameters, Position/Velocity Covariance Matrix, Maneuver Parameters, and User Defined 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.

3.2.4.2 Only those keywords shown in table 3-3 shall be used in OPM data.

NOTE – Requirements relating to the keywords in table 3-3 appear after the table.

Table 3-3: OPM Data

Keyword	Description	Units	Obligatory
State Vector Components in the Specified Coordinate System			
COMMENT	(See 7.7 for formatting rules.)	n/a	No
EPOCH	Epoch of state vector & optional Keplerian elements. (See 7.5.9 for formatting rules.)	n/a	Yes

Keyword	Description	Units	Obligatory
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 7.7 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 7.7 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
Position/Velocity Covariance Matrix (6x6 Lower Triangular Form. None or all parameters of the matrix must be given. COV_REF_FRAME may be omitted if it is the same as the metadata REF_FRAME.)			
COMMENT	(See 7.7 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

Keyword	Description	Units	Obligatory
CZ_DOT_Z_DOT	Covariance matrix [6,6]	km**2/s**2	No
Maneuver Parameters (Repeat for each maneuver. None or all parameters of this block must be given.)			
COMMENT	(See 7.7 for formatting rules.)	n/a	No
MAN_EPOCH_IGNITION	Epoch of ignition. (See 7.5.9 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
User Defined Parameters (all parameters in this section must be described in an ICD).			
USER_DEFINED_x	User defined parameter, where 'x' is replaced by a variable length user specified character string. Any number of user defined parameters may be included, if necessary to provide essential information that cannot be conveyed in COMMENT statements. Example: USER_DEFINED_EARTH_MODEL = WGS-84	n/a	No

3.2.4.3 All values except Maneuver Parameters in the OPM data are 'at epoch', i.e., the value of the parameter at the time specified in the EPOCH keyword.

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

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

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

3.2.4.7 Parameters for thrust phases may be optionally given for the computation of the trajectory during or after maneuver execution (see reference [G1] 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.

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

3.2.4.9 If the OPM contains a maneuver definition, the Spacecraft Parameters section must be included.

3.2.4.10 Values in the covariance matrix shall be expressed in the applicable reference frame (COV_REF_FRAME keyword if used, or REF_FRAME keyword if not), and 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 7.5. 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.

3.2.4.11 A section of User Defined Parameters is allowed. In principle, this provides flexibility, but also introduces complexity, non-standardization, potential ambiguity, and potential processing errors. Accordingly, if used, the keywords and their meanings must be described in an ICD. User Defined Parameters, if included in an OPM, should be used as sparingly as possible; their use is not encouraged.

3.3 OPM EXAMPLES

Figure 3-1 through figure 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 and 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 a value of 1.0 could be specified for the 'CCSDS_OPM_VERS' keyword. (See annex F.)

Figure 3-3 and figure 3-4 include unique features of ODM version 2.0, and 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

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 3-1: Simple OPM File Example

```
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 3-2: 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

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 =  3.331349476038534e-04
CY_X =  4.618927349220216e-04
CY_Y =  6.782421679971363e-04
CZ_X =  -3.070007847730449e-04
CZ_Y =  -4.221234189514228e-04
CZ_Z =  3.231931992380369e-04
CX_DOT_X =  -3.349365033922630e-07
CX_DOT_Y =  -4.686084221046758e-07
CX_DOT_Z =  2.484949578400095e-07
CX_DOT_X_DOT =  4.296022805587290e-10
CY_DOT_X =  -2.211832501084875e-07
CY_DOT_Y =  -2.864186892102733e-07
CY_DOT_Z =  1.798098699846038e-07
CY_DOT_X_DOT =  2.608899201686016e-10
CY_DOT_Y_DOT =  1.767514756338532e-10
CZ_DOT_X =  -3.041346050686871e-07
CZ_DOT_Y =  -4.989496988610662e-07
CZ_DOT_Z =  3.540310904497689e-07
CZ_DOT_X_DOT =  1.869263192954590e-10
CZ_DOT_Y_DOT =  1.008862586240695e-10
CZ_DOT_Z_DOT =  6.224444338635500e-10
```

Figure 3-3: 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
COV_REF_FRAME = RTN
CX_X =  3.331349476038534e-04
CY_X =  4.618927349220216e-04
CY_Y =  6.782421679971363e-04
CZ_X =  -3.070007847730449e-04
CZ_Y =  -4.221234189514228e-04
CZ_Z =  3.231931992380369e-04
CX_DOT_X =  -3.349365033922630e-07
CX_DOT_Y =  -4.686084221046758e-07
CX_DOT_Z =  2.484949578400095e-07
CX_DOT_X_DOT =  4.296022805587290e-10
CY_DOT_X =  -2.211832501084875e-07
CY_DOT_Y =  -2.864186892102733e-07
CY_DOT_Z =  1.798098699846038e-07
CY_DOT_X_DOT =  2.608899201686016e-10
CY_DOT_Y_DOT =  1.767514756338532e-10
CZ_DOT_X =  -3.041346050686871e-07
CZ_DOT_Y =  -4.989496988610662e-07
CZ_DOT_Z =  3.540310904497689e-07
CZ_DOT_X_DOT =  1.869263192954590e-10
CZ_DOT_Y_DOT =  1.008862586240695e-10
CZ_DOT_Z_DOT =  6.224444338635500e-10
USER_DEFINED_EARTH_MODEL = WGS-84
```

Figure 3-4: OPM File Example with Optional Keplerian Elements, Covariance Matrix, and a User Defined Parameter

4 ORBIT MEAN-ELEMENTS MESSAGE (OMM)

4.1 GENERAL

4.1.1 Orbit information may be exchanged between two participants by sending an orbital state based on mean Keplerian elements (see reference [G1]) 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 to compute the orbit at other desired epochs.

4.1.2 The OMM is intended to allow replication of the data content of an existing TLE in a CCSDS standard format, but the message can also accommodate other implementations of mean elements. All essential fields of the 'de facto standard' 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 [G3]). Programs that convert OMMs 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.

4.1.3 If participants wish to exchange osculating element information, then the Orbit Parameter Message (OPM) or the Orbit Hybrid Message (OHM) should be the selected message type. (See sections 3 and 6.)

4.1.4 The use of the OMM is best applicable under the following conditions:

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

b) the receiver's modeling of gravitational forces, solar radiation pressure, atmospheric drag, etc. (see reference [G1]), should fulfill accuracy requirements established between the exchange partners.

4.1.5 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.

4.1.6 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 ICD. The method of exchanging OMMs should be decided on a case-by-case basis by the exchange partners and documented in an ICD.

NOTE – Detailed syntax rules for the OMM are specified in section 7.

4.2 OMM CONTENT/STRUCTURE

4.2.1 GENERAL

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).

4.2.2 OMM HEADER

4.2.2.1 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.

4.2.2.2 Only those keywords shown in table 4-1 shall be used in an OMM header.

Table 4-1: 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 7.7 for formatting rules.)	COMMENT This is a comment	No
CREATION_DATE	File creation date/time in UTC. (For format specification, see 7.5.9.)	2001-11-06T11:17:33 2002-204T15:56:23Z	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

4.2.3 OMM METADATA

4.2.3.1 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.

4.2.3.2 Only those keywords shown in table 4-2 shall be used in OMM metadata.

NOTE – 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 1.7 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.

Table 4-2: OMM Metadata

Keyword	Description	Examples of Values	Obligatory
COMMENT	Comments (allowed at the beginning of the OMM Metadata). (See 7.7 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 [2]), which include Object name and international designator of the participant.	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 [2]). 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.	2005-046B 2005-046A 2003-022A 2005-044A	Yes
CENTER_NAME	Origin of reference frame. 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 [5]).	EARTH MARS MOON	Yes
REF_FRAME	Name of the reference frame in which the Keplerian element data are given. Use of values other than those in annex A must be documented in an ICD. The reference frame must be the same for all data elements, with the exception of the covariance matrix, for which an applicable different reference frame may be specified.	TEME EME2000	Yes
REF_FRAME_EPOCH	Epoch of reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.9 for formatting rules.)	2001-11-06T11:17:33 2002-204T15:56:23Z	No
TIME_SYSTEM	Time system used for the orbit state and covariance matrix. Use of values other than those in annex A must be documented in an ICD.	UTC	Yes
MEAN_ELEMENT_THEORY	Description of the Mean Element Theory. Indicates the proper method to employ to propagate the state.	SGP4 DSST USM	Yes

4.2.4 OMM DATA

4.2.4.1 Table 4-3 provides an overview of the five logical blocks in the OMM Data section (Mean Keplerian Elements, Spacecraft Parameters, TLE Related Parameters, Position/Velocity Covariance Matrix, and User Defined 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.

4.2.4.2 Only those keywords shown in table 4-3 shall be used in OMM data.

NOTE – Requirements relating to the keywords in table 4-3 appear after the table.

Table 4-3: OMM Data

Keyword	Description	Units	Obligatory
Mean Keplerian Elements in the Specified Reference Frame			
`COMMENT`	(See 7.7 for formatting rules.)	n/a	No
`EPOCH`	Epoch of Mean Keplerian elements. (See 7.5.9 for formatting rules.)	n/a	Yes
`SEMI_MAJOR_AXIS or` `MEAN_MOTION`	Semi-major axis in kilometers (preferred), or, if MEAN_ELEMENT_THEORY = SGP/SGP4, 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)	km**3/s**2	No
Spacecraft Parameters			
`COMMENT`	(See 7.7 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=SGP/SGP4)			
`COMMENT`	(See 7.7 for formatting rules.)	n/a	No
`EPHEMERIS_TYPE`	Default value = 0. (See 4.2.4.7.)	n/a	No
`CLASSIFICATION_TYPE`	Default value = U. (See 4.2.4.7.)	n/a	No
`NORAD_CAT_ID`	NORAD Catalog Number ('Satellite Number') an integer of up to nine digits. This keyword is only required if MEAN_ELEMENT_THEORY=SGP/SGP4.	n/a	No

Cor. 1

Cor. 1

Keyword	Description	Units	Obligatory
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 = SGP/SGP4).	n/a	No
REV_AT_EPOCH	Revolution Number	n/a	No
BSTAR	SGP/SGP4 drag-like coefficient (in units 1/[Earth radii]). Only required if MEAN_ELEMENT_THEORY=SGP/SGP4	1/ER	No
MEAN_MOTION_DOT	First Time Derivative of the Mean Motion (only required if MEAN_ELEMENT_THEORY = SGP)	rev/day**2	No
MEAN_MOTION_DDOT	Second Time Derivative of Mean Motion (only required if MEAN_ELEMENT_THEORY = SGP)	rev/day**3	No
Position/Velocity Covariance Matrix (6x6 Lower Triangular Form. None or all parameters of the matrix must be given. COV_REF_FRAME may be omitted if it is the same as the metadata REF_FRAME.)			
COMMENT	(See 7.7 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
User Defined Parameters (all parameters in this section must be described in an ICD).			
USER_DEFINED_x	User defined parameter, where 'x' is replaced by a variable length user specified character string. Any number of user defined parameters may be included, if necessary to provide essential information that cannot be conveyed in COMMENT statements. Example: USER_DEFINED_EARTH_MODEL = WGS-84	n/a	No

Cor. 1

Cor. 1

Cor. 1

4.2.4.3 All values in the OMM are ‘at epoch’, i.e., the value of the parameter at the time specified in the EPOCH keyword.

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

4.2.4.5 Values in the covariance matrix shall be expressed in the applicable reference frame (COV_REF_FRAME keyword if used, or REF_FRAME keyword if not), and 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 6.4. This logical block of the OMM may be useful for risk assessment and establishing maneuver and mission margins.

4.2.4.6 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’.
- Cor. 1 The value associated with the REF_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 must be used instead of SEMI_MAJOR_AXIS.

4.2.4.7 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. Some sources suggest the coding for the EPHEMERIS_TYPE keyword: 1=SGP, 2=SGP4, 3=SDP4, 4=SGP8, 5=SDP8. Some sources suggest the following coding for the CLASSIFICATION_TYPE keyword: U=unclassified, S=secret. (For further information see references [G3] and [G4].)

4.2.4.8 Maneuvers are not accommodated in the OMM. Users of the OMM who wish to model maneuvers may use several OMM files to describe the orbit at applicable epochs.

4.2.4.9 A section of User Defined Parameters is allowed. In principle, this provides flexibility, but also introduces complexity, non-standardization, potential ambiguity, and potential processing errors. Accordingly, if used, the keywords and their meanings must be described in an ICD. User Defined Parameters, if included in an OMM, should be used as sparingly as possible; their use is not encouraged.

4.3 OMM EXAMPLES

Figure 4-2 and figure 4-3 are examples of OMMs based on the TLE shown in 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 4-1: 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 = SGP/SGP4


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
EPHEMERIS_TYPE    = 0
CLASSIFICATION_TYPE = U
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
```

Cor. 1

Figure 4-2: OMM File Example without Covariance Matrix

Cor. 1

```
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 = SGP/SGP4

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

EPHEMERIS_TYPE    = 0
CLASSIFICATION_TYPE = U
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 =  3.331349476038534e-04
CY_X =  4.618927349220216e-04
CY_Y =  6.782421679971363e-04
CZ_X =  -3.070007847730449e-04
CZ_Y =  -4.221234189514228e-04
CZ_Z =  3.231931992380369e-04
CX_DOT_X =  -3.349365033922630e-07
CX_DOT_Y =  -4.686084221046758e-07
CX_DOT_Z =  2.484949578400095e-07
CX_DOT_X_DOT =  4.296022805587290e-10
CY_DOT_X =  -2.211832501084875e-07
CY_DOT_Y =  -2.864186892102733e-07
CY_DOT_Z =  1.798098699846038e-07
CY_DOT_X_DOT =  2.608899201686016e-10
CY_DOT_Y_DOT =  1.767514756338532e-10
CZ_DOT_X =  -3.041346050686871e-07
CZ_DOT_Y =  -4.989496988610662e-07
CZ_DOT_Z =  3.540310904497689e-07
CZ_DOT_X_DOT =  1.869263192954590e-10
CZ_DOT_Y_DOT =  1.008862586240695e-10
CZ_DOT_Z_DOT =  6.224444338635500e-10
```

Figure 4-3: OMM File Example with 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 = SGP/SGP4


EPOCH             = 2007-064T10:34:41.4264
MEAN_MOTION       = 1.00273272    [rev/day]
ECCENTRICITY      = 0.0005013
INCLINATION       =   3.0539      [deg]
RA_OF_ASC_NODE    =  81.7939      [deg]
ARG_OF_PERICENTER = 249.2363      [deg]
MEAN_ANOMALY      = 150.1602      [deg]
GM                = 398600.8      [km**3/s**2]
EPHEMERIS_TYPE    = 0
CLASSIFICATION_TYPE = U
NORAD_CAT_ID   = 23581
ELEMENT_SET_NO = 0925
REV_AT_EPOCH      = 4316
BSTAR             = 0.0001        [1/ER]
MEAN_MOTION_DOT   = -0.00000113   [rev/day**2]
MEAN_MOTION_DDOT  = 0.0           [rev/day**3]

USER_DEFINED_EARTH_MODEL = WGS-84
```

Cor. 1

Figure 4-4: OMM with Units and a User Defined Parameter

5 ORBIT EPHEMERIS MESSAGE (OEM)

5.1 GENERAL

5.1.1 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.

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

5.1.3 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.

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

NOTE – Detailed syntax rules for the OEM are specified in section 7.

5.2 OEM CONTENT/STRUCTURE

5.2.1 GENERAL

5.2.1.1 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).

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

Table 5-1: 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.)

5.2.2 OEM HEADER

5.2.2.1 The OEM header assignments are shown in table 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.

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

Table 5-2: 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 7.7 for formatting rules.)	COMMENT This is a comment	No
CREATION_DATE	File creation date and time in UTC. (For format specification, see 7.5.9.)	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

5.2.3 OEM METADATA

5.2.3.1 The OEM metadata assignments are shown in table 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.

5.2.3.2 Only those keywords shown in table 5-3 shall be used in OEM metadata.

NOTE – 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 1.7 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.

5.2.3.3 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. 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 5-3: 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 7.7 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 [2]), 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 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 [2]). 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 [2], 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 [5]).	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. Use of values other than those in annex A must be documented in an ICD. The reference frame must be the same for all data elements, with the exception of the covariance matrix, for which an applicable different reference frame may be specified.	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
REF_FRAME_EPOCH	Epoch of reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.9 for formatting rules.)	2001-11-06T11:17:33 2002-204T15:56:23Z	No
TIME_SYSTEM	Time system used for metadata, ephemeris data, and covariance data. Use of values other than those in annex A must be documented in an ICD.	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. (For format specification, see 7.5.9.)	1996-12-18T14:28:15.1172 1996-277T07:22:54	No
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 7.5.9.) 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. The USEABLE_START_TIME time tag at a new block of ephemeris data must be greater than or equal to the USEABLE_STOP_TIME time tag of the previous block.	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. (For format specification, see 7.5.9.)	1996-12-18T14:28:15.1172 1996-277T07:22:54	No
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

Cor. 1

Cor. 1

Cor. 1

Keyword	Description	Examples of Values	Obligatory
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
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

5.2.4 OEM DATA: EPHEMERIS DATA LINES

5.2.4.1 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**.

5.2.4.2 The position and velocity terms shall be obligatory; acceleration terms may be provided.

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

5.2.4.4 Repeated time tags may occur in consecutive ephemeris data blocks if the STOP_TIME of the first ephemeris data block is greater than the START_TIME of the second ephemeris data block. Although the USEABLE_STOP_TIME and USEABLE_START_TIME of the consecutive ephemeris data blocks must not overlap (except for a possibly shared endpoint), the STOP_TIME of the first ephemeris data block may be greater than the START_TIME of the second ephemeris data block if the extra data is required for interpolation purposes. Cor. 1

5.2.4.5 The TIME_SYSTEM value must remain fixed within an OEM.

5.2.4.6 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.

5.2.4.7 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.

5.2.5 OEM DATA: COVARIANCE MATRIX LINES

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

5.2.5.2 If present, the covariance matrix data lines in the OEM are separated from the ephemeris data by means of two new keywords: COVARIANCE_START and COVARIANCE_STOP. The 'COVARIANCE_START' keyword must appear before the first line of the covariance matrix data. The 'COVARIANCE_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.

5.2.5.3 The epoch of the navigation solution related to the covariance matrix must be provided via the 'EPOCH' keyword. The reference frame of the covariance matrix, if different from that of the states in the ephemeris, must be provided via the 'COV_REF_FRAME' keyword.

5.2.5.4 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 elements in each row of covariates shall be defined by the order in the ephemeris data line (i.e., **X, Y, Z**, **X_DOT, Y_DOT, Z_DOT)**. The six rows of the covariance matrix contain from one to six numbers depending on what row of the matrix is being represented (first row has one element, second row has two, continuing in this fashion until the sixth row has six elements).

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

5.2.5.6 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.

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

5.3 OEM EXAMPLES

Figure 5-1, figure 5-2, and figure 5-3 are example OEMs. Some ephemeris data lines have been omitted to save space.

Figure 5-1 is compatible with ODM version 1, and thus could 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 5-2 and figure 5-3 contain features unique to the ODM version 2, and thus '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, 1996NOV 04. 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 5-1: 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 NOV 04. 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 5-2: 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
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


COVARIANCE_START
EPOCH = 1996-12-28T21:29:07.267
COV_REF_FRAME = EME2000
 3.3313494e-04
 4.6189273e-04  6.7824216e-04
-3.0700078e-04 -4.2212341e-04  3.2319319e-04
-3.3493650e-07 -4.6860842e-07  2.4849495e-07  4.2960228e-10
-2.2118325e-07 -2.8641868e-07  1.7980986e-07  2.6088992e-10  1.7675147e-10
-3.0413460e-07 -4.9894969e-07  3.5403109e-07  1.8692631e-10  1.0088625e-10  6.2244443e-10

EPOCH = 1996-12-29T21:00:00
COV_REF_FRAME = EME2000
 3.4424505e-04
 4.5078162e-04  6.8935327e-04
-3.0600067e-04 -4.1101230e-04  3.3420420e-04
-3.2382549e-07 -4.5750731e-07  2.3738384e-07  4.3071339e-10
-2.1007214e-07 -2.7530757e-07  1.6870875e-07  2.5077881e-10  1.8786258e-10
-3.0302350e-07 -4.8783858e-07  3.4302008e-07  1.7581520e-10  1.0077514e-10  6.2244443e-10
COVARIANCE_STOP
```

Figure 5-3: Version 2 OEM Example with Optional Covariance Matrices

6 ORBIT HYBRID MESSAGE (OHM)

6.1 GENERAL

6.1.1 Orbit information may be exchanged between two participants by sending orbit data/content (see reference [G1]) for one or more epochs using an Orbit Hybrid Message (OHM). The OHM aggregates and extends OMM, OPM and OEM content in a single hybrid message. The OHM simultaneously emphasizes flexibility and message conciseness by offering extensive optional standardized content while minimizing mandatory content.

6.1.2 The OHM shall be a plain text file consisting of orbit data for a single space object, or in the case of a parent/child satellite deployment scenario, a single parent object. It shall be easily readable by both humans and computers.

6.1.3 The OHM file-naming scheme should be agreed to on a case-by-case basis between the exchange partners, and should be documented in an ICD. The method of exchanging OHMs should be decided on a case-by-case basis by the exchange partners and documented in an ICD.

NOTE – Detailed syntax rules for the OHM are specified in section 7.

6.1.4 Orbit information may be exchanged between two participants by sending an ephemeris in the form of one or more time series of orbital states (selectable as orbital elements and/or Cartesian vectors providing position and optionally velocity and accelerations) using an Orbit Hybrid Message (OHM). If orbital states are desired at arbitrary time(s) contained within the span of the ephemeris, the message recipient is encouraged to use a suitable interpolation method. For times outside of supplied orbit state time spans or if the step size between orbit states is too large to support interpolation [G8], optional force model parameters should be included with this message and the recipient must have a suitably-compatible orbit propagator.

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

6.1.6 The OHM shall be a plain text file consisting of orbit data for a either a single object, or in the case of a parent/child satellite deployment scenario, a single parent object. It shall be easily readable by both humans and computers.

6.1.7 The OHM file-naming scheme should be agreed to on a case-by-case basis between the participants, typically using an ICD. The method of exchanging OHMs should be decided on a case-by-case basis by the participants and documented in an ICD.

NOTE – Detailed syntax rules for the OHM are specified in section 7.

6.2 OHM CONTENT/STRUCTURE

6.2.1 GENERAL

The OHM shall be represented as a combination of the following as shown in Table 6-1. The ordering of the sections is mandatory; reordering is not permitted.

1) a single header;
2) a single metadata section (data about data);
3) a single, optional space object physical characteristics section
4) a single, optional force model section
5) a single, optional maneuver data section
6) one or more optional orbit state time histories
7) one or more covariance time histories
8) optional user-defined data and supplemental comments (explanatory information).

Table 6-1: OHM File Layout Specifications

Section	Content
Required Header	Header of message
Metadata	Metadata (Informational comments recommended but not required.)
Optional Space Object Physical Description	Optional space object physical characteristics, if known.
Optional Force Model Section	Optional force model parameters…etc. (Appropriate comments are also encouraged.)
Optional Maneuver Section	Optional maneuver specifications for either impulsive or finite burns
Optional Orbit Data Section	Optional: One or more orbit state time histories (each consisting of one or more orbit states)
Optional Covariance Data Section	Optional: One or more covariance time histories (each consisting of one or more covariance matrices)

6.2.2 OHM HEADER

6.2.2.1 Table 6-2 (and all OHM Keyword tables that follow) specifies for each header item:

1) the keyword to be used;
2) a short description of the item;
3) examples of allowed values; and
4) whether the item is obligatory or optional.

6.2.2.2 Only those keywords shown in table 3-1 shall be used in an OHM header.

Table 6-2: OHM Header

Keyword	Description	Examples of Values	Obligatory
CCSDS_OHM_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 OHM Header only immediately after the OHM version number). (See 7.7 for formatting rules.)	COMMENT This is a comment	No
CREATION_DATE	File creation date/time in UTC. (For format specification, see 7.5.9.)	2001-11-06T11:17:33 2002-204T15:56:23Z	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
TECH_POC	Free text field containing Technical PoC information for OHM creator (suggest phone number, email address, website, etc.)	Mr. Rodgers, (719)555-5555, email@email.XXX	No
TZERO_EPOCH	UTC reference epoch of all time-relative time tags used in specification of maneuvers, orbital states and covariance data	2001-11-06T11:17:33	Yes

6.2.3 OHM Metadata

6.2.3.1 Table 6-3 specifies the metadata keywords. Only those keywords shown in table 6-3 shall be used in OHM metadata.

6.2.3.2 The TIME_SYSTEM value must remain fixed within an OHM.

6.2.3.3 Only a single metadata section is permitted.

NOTE – For some keywords (OBJECT_NAME, OBJECT_ID) there are no definitive lists of authorized values maintained by a control authority; the references listed in 1.7 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 6-3: OHM Metadata

Keyword	Description	Examples of Values	Obligatory
COMMENT	Comments (allowed at the beginning of the OHM Metadata). (See 7.7 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 [2]), which include Object name and international designator of the participant. ALTHOUGH NON-OBLIGATORY, INCLUSION OF THIS FIELD IS STRONGLY ENCOURAGED IF AN OBJECT NAME EXISTS.	EUTELSAT W1 MARS PATHFINDER STS 106 NEAR	No
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 [2]). 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. ALTHOUGH NON-OBLIGATORY, INCLUSION OF THIS FIELD IS STRONGLY ENCOURAGED IF THE OBJECT ID (E.G. SPACECRAFT INTERNATIONAL DESIGNATOR EXISTS)	2000-052A 1996-068A 2000-053A 1996-008A	No
START_TIME	Start of TOTAL time span covered by ephemeris data and covariance data immediately following this metadata block. (For format specification, see 7.5.9.)	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. (For format specification, see 7.5.9.)	1996-12-18T14:28:15.1172 1996-277T07:22:54	No
TAIMUTC_TZERO	Difference (TAI – UTC) (i.e. total # leap seconds elapsed since 1958) as modeled by the originator at epoch “TZERO_EPOCH”	36 s	No

TIME_SYSTEM	Time system used for reference frame and reference timing epoch. Use of values other than those in annex A must be documented in an ICD. OMISSION OF THIS NON-OBLIGATORY FIELD DEFAULTS TO “UTC”	UTC, UT1, TAI, TT, GPS, TDB, TCB	No
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 7.5.9.) 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. The USEABLE_START_TIME time tag at a new block of ephemeris data must be greater than or equal to the USEABLE_STOP_TIME time tag of previous block.	1996-12-18T14:28:15.1172 1996-277T07:22:54	No
UT1MUTC_TZERO	Difference (UT1 – UTC) as modeled by the originator at epoch “TZERO_EPOCH”	0.357 s	No
UT1MUTC_RATE_TZERO	Rate-of-change of (UT1 – UTC) as modeled by the originator at epoch “TZERO_EPOCH”	.0001 ms/day	No

6.2.4 OHM Space Object Physical Characteristics Data

6.2.4.1 Table 6-4 gives an overview of the OHM space object physical characteristics section. Only those keywords shown in table 6-4 shall be used in OHM space object physical characteristics data.

6.2.4.2 All spacecraft physical characteristics, maneuver, orbit ephemeris and covariance values in the OHM data are time-tagged by a relative time value measured with respect to the epoch time specified via the TZERO_EPOCH keyword..

6.2.4.3 Only a single space object physical characteristics section is permitted.

Table 6-4: OHM Space Object Physical Characteristics

Keyword	Description	Examples of Values	Obligatory
COMMENT	Comments (allowed at any point throughout the OHM Space Object Physical Characteristics). (See 7.7 for formatting rules.)	COMMENT This is a comment	No
MASS_TZERO	S/C Mass at reference epoch	kg	No
SOLAR_RAD_COEFF	Solar Radiation Pressure Coefficient (CR)	n/a	No
SOLAR_RAD_AREA	Solar Radiation Pressure Area (AR)	m**2	No
DRAG_COEFF	Drag Coefficient (C_D)	n/a	No
DRAG_AREA	Drag Area (AD)	m**2	No
PHYSDIM_MAX	Maximum physical size of space object in meters	1 m	No
PHYSDIM_MED	Largest physical dimension of object in the plane NORMAL to PHYSDIM_MAX	.5 m	No
PHYSDIM_MIN	Physical dimension of object in direction normal to both PHYSDIM_MAX and PHYSDIM_MED directions	.3 m	No
RIC2PHYS_YAW	Yaw angle of the (Yaw/Pitch/Roll ordered sequence) that maps the Radial/Intrack/Crosstrack (RIC) relative frame to the “PHYSDIM” frame (defined above). A value of “-999” denotes a tumbling space object.	30 deg	No
RIC2PHYS_PITCH	Pitch angle of the (Yaw/Pitch/Roll ordered sequence) that maps the Radial/Intrack/Crosstrack (RIC) relative frame to the “PHYSDIM” frame (defined above). A value of “-999” denotes a tumbling space object.	1.7 deg	No
RIC2PHYS_ROLL	Roll angle of the (Yaw/Pitch/Roll ordered sequence) that maps the Radial/Intrack/Crosstrack (RIC) relative frame to the “PHYSDIM” frame (defined above). A value of “-999” denotes a tumbling space object.	-10 deg	No
PHYSDIM_MAX_AREA	Projected cross-sectional area of space object when viewed along maximum physical size direction as defined above	.15 m^2	No
PHYSDIM_MED_AREA	Projected cross-sectional area of space object when viewed along medium physical size direction as defined above	.3 m^2	No
PHYSDIM_MIN_AREA	Projected cross-sectional area of space object when viewed along minimum physical size direction as defined above	.5 m^2	No
TX_FREQ	Transmission frequency of space object (additional frequencies can be accommodated as a “comment” field”)	MHz	No
TX_EIRP	Transmission EIRP	dB	No

6.2.5 OHM Force Model Data

6.2.5.1 Table 6-5 provides an overview of the OHM force model specification section. Only those keywords shown in table 6-5 shall be used in OHM force model specification.

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

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

6.2.5.4 Only a single force model data section is permitted.

Table 6-5: OHM Force Model Specification Data

Keyword	Description	Examples of Values	Obligatory
COMMENT	Comments (allowed at any point throughout the OHM Force Model Specification Data). (See 7.7 for formatting rules.)	COMMENT This is a comment	No
GM	Gravitational Coefficient of attracting body (Gravitational Constant x Central Mass)	398600.4 km**3/s**2	No
GEOPOTENTIAL	Geopotential model	Gravitational model (e.g., EGM-96, WGS-84/EGM-96, WGS-84, GGM-01, TEG-4)	No
GEOPOTENTIAL_NXM	Geopotential degree (# rows) and order (#columns) used	____ x ____ (e.g. 30 x 30)	No
EARTH_RADIUS	Earth equatorial radius used (km)	6378.137	No
EARTH_FLATTENING	Earth oblateness for the polar-symmetric oblate Earth model	1/298.257223563	No
EARTH_ANGULAR_ROTA	Earth angular rotation rate	4.17807421629e-3 deg/sec	No
ATMOSPHERE_MODEL	Name of atmosphere model	Atmospheric models (e.g., MSISE90, NRLMSIS00, J70, J71, JRob, DTM)	No
3RD_BODY_PERTS	Series of TEN binary "switches" specifying which (if any) Solar system bodies were used ("0"=OFF & "1"=ON). A digit is REQUIRED for all TEN bodies. For example, "1100000000" uses Sun and Moon 3rd-body perturbations, but no other ones. (1) Sun (2) Moon (3) Mercury (4) Venus (5) Mars (6) Jupiter (7) Saturn (8) Uranus (9) Neptune (10) Pluto	1100000000	No
SRP_MODEL	Name of SRP model		No
SOLID_TIDES_MODEL	Name of solid tides model (optionally specify order or constituent effects (diurnal, semi-diurnal, etc)		No
OCEAN_TIDES_MODEL	Name of ocean tides model (optionally specify order or constituent effects (diurnal, semi-diurnal, etc)		No
EARTH_ALBEDO			No
EARTH_ALBEDO_GRID_SIZE			No
EOP_SOURCE	Source of originator's Earth orientation parameters	e.g., IERS, USNO, NGA	No
NUTA_CORR_DEPS	Nutation correction to obliquity $d\varepsilon$	degrees	No
NUTA_CORR_DPSI	Nutation correction to longitude $d\psi$	degrees	No
POLAR_MOTION_XP	Polar motion coordinate Xp of the Celestial Intermediate Pole	arcsec	No
POLAR_MOTION_YP	Polar motion coordinate Yp of the Celestial Intermediate Pole	arcsec	No
SOLAR_F10P7	Solar flux proxy F10.7	units = 10^4 Jansky	No

SOLAR_F10P7_81DAY_AVG	81-day averaged solar flux proxy $\overline{F10.7}$	units = 10^4 Jansky	No
ASUBP	Geomagnetic index Ap		No
INTERP_METHOD_EOP		Used for EOP data	No
INTERP_METHOD_SPWX		Used for Space Weather data (Solar, geomagnetic, etc)	No
SHADOW_MODEL		Shadow modeling for Solar Radiation Pressure (e.g., NONE, CYLINDRICAL, DUAL CONE); dual cone uses both umbra/penumbra regions	No

nutation corrections to the obliquity and longitude (deps, and dpsi).

6.2.6 OHM Maneuver Data

6.2.6.1 Table 6-6 provides an overview of the OHM maneuver specification section. Only those keywords shown in table 6-6 shall be used in OHM maneuver specification.

6.2.6.2 Impulsive and finite burn maneuver data in the OHM data are time-tagged by a relative time value measured with respect to the epoch time specified via the TZERO_EPOCH keyword.

6.2.6.3 For impulsive maneuvers, each ΔV maneuver within the ΔV time series shall be specified on a single line that contains 8 parameters: time "T_Relative" in seconds, ΔV components measured in the selected maneuver reference frame (ΔV_X, ΔV_Y, ΔV_Z in km/s), the maneuver duration (assumed to be centered about the specified maneuver time, in seconds), a maneuver status flag (0=predictive, 1=post-event reconstruction), the maneuver object number (MON) that this maneuver is to be applied to (nominally "0" for the primary or host vehicle) and either the mass decrement (i.e. a negative number) associated with that ΔV (if MON = 0) or the mass of the deployed object (if MON ≠ 0).

6.2.6.4 A non-zero MON invokes a parent/child deployment scenario, whereby the parent "host" object (MON=0) deploys one or more child space objects. In this case, MON shall be a positive number starting at "1" and incrementing through all deployed objects until "N" objects have separated. Where appropriate (e.g. with spring deployment mechanisms), recipients of OHMs using the parent/child deployment capability should incorporate both the deployment ΔV as well as the retrograde ΔV imparted to the host (as a ratio of the host and deployed object relative masses such that momentum is conserved).

6.2.6.5 For finite burns, each finite burn maneuver (or, in the case of low-thrust, long-duration burns, each maneuver segment) within the finite burn time series shall be specified on a single line that contains 9 parameters: time "T_Relative" in seconds, Thrust components measured in the selected maneuver reference frame (T_X, T_Y and T_Z, in Newtons), specific impulse in seconds, burn efficiency "η" (e.g. 0.95), maneuver duration (measured with respect to the START of the specified finite burn time, in seconds), thrust vector Euler axis/angle interpolation mode between current and next thrust line (0=OFF and 1=ON) and maneuver status flag (0=predictive, 1=post-event reconstruction).

6.2.6.6 An acceleration profile allows aggregate modeling of both maneuvers and additional non-conservative forces that the OHM originator can model without the OHM recipient needing to. The acceleration time series shall be specified on a single line that contains 6 parameters: time "T_Relative" in seconds, acceleration components measured in the selected maneuver reference frame (A_X, A_Y and A_Z, in m/s**2), acceleration vector Euler axis/angle interpolation mode between current and next acceleration line (0=OFF and 1=ON) and acceleration profile status flag (0=predictive, 1=post-event reconstruction)..

6.2.6.7 Only a single maneuver time history is permitted.

Table 6-6: OHM Maneuver Specification

Keyword	Description	Examples of Values	Obligatory
COMMENT	Comments (allowed at any point throughout the OHM Maneuver Specification section). (See 7.7 for formatting rules.)	COMMENT This is a comment	No
MNVR	Begin maneuver specification. Select impulsive ΔV (MNVR = DV), finite burn (MNVR = FINITE) or acceleration profile (MNVR = ACCEL) time history (see 6.2.6.3, 6.2.6.4 and 6.2.6.5 for details)	n/a	No
MNVR_REF_FRAME	Coordinate system for maneuver vector direction(s) (reference frame value must be selected from annex A)	n/a	No
MNVR_STOP	End finite burn time history	n/a	No

6.2.7 OHM Orbit State Time History Data

6.2.7.1 Table 6-7 provides an overview of the OHM orbit ephemeris section. Only those keywords shown in table 6-7 shall be used in OHM orbit ephemeris data specification.

6.2.7.2 One or more Orbit State Time Histories may be represented in this section. However, multiple representations shall only be used if .

6.2.7.3 All orbit state values in the OHM data are time-tagged by a relative time value measured with respect to the epoch time specified via the TZERO_EPOCH keyword.

6.2.7.4 Orbit states shall be time-ordered to be monotonically increasing, with the exception that a single duplicate time point is permitted to indicate a change in state (e.g. following application of an impulsive maneuver). In the case of a duplicate time point, interpolation prior to the duplicate point shall use the first of the two orbit states, and interpolation after the duplicate point shall use the second of the two. It is strongly recommended that the user include orbit states at key events and annotate such events with a preceding descriptive comment line. There is no requirement for the time sequence to have uniform step size.

6.2.7.5 Each set of orbit ephemeris data, including the time tag, must be provided on a single line. The order in which data items are given shall be fixed: **T_Relative** followed by the orbit state as defined in Annex A.

6.2.7.6 At least one space character must be used to separate the items in each orbit ephemeris data line.

6.2.7.7 The digits of precision and time steps suitable for interpolation of an orbit ephemeris time history shall be chosen according to best practice to avoid positional and interpolation loss of precision [G8].

Table 6-7: OHM Orbit State Time History Data

Keyword	Description	Examples of Values	Obligatory
ORBEPH	Start of an orbit ephemeris section; indicate ORBEPH composition via "ORBEPH = YYY" where YYY is selected from annex A.	n/a	No
COMMENT	Comments (allowed at any point throughout the OHM Orbit State Time History section). (See 7.7 for formatting rules.)	COMMENT This is a comment	No
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 [5]). OMISSION OF THIS NON-OBLIGATORY FIELD DEFAULTS TO "EARTH'	EARTH EARTH BARYCENTER MOON SOLAR SYSTEM BARYCENTER SUN JUPITER BARYCENTER STS 106 EROS	No
REF_FRAME	Name of the reference frame in which the state vector and optional Keplerian element data are given. Use of values other than those in annex A must be documented in an ICD. The reference frame must be the same for all data elements, with the exception of the maneuvers and covariance matrix, for which applicable different reference frames may be specified. WHERE THE REFERENCE FRAME IS NOT INTRINSIC TO THE SELECTED ORBITAL SET AND NOT SUPPLIED (FOR THIS NON-OBLIGATORY FIELD), THE REF_FRAME SHALL DEFAULT TO ITRF-97.	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)	No
REF_FRAME_EPOCH	Epoch of reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.9 for formatting rules.) WHERE THE REFERENCE FRAME EPOCH IS NOT INTRINSIC TO THE SELECTED REFERENCE FRAME BUT NOT SUPPLIED (FOR THIS NON-OBLIGATORY FIELD), THE REF_FRAME_EPOCH SHALL DEFAULT TO THE TZERO_EPOCH VALUE.	2001-11-06T11:17:33 2002-204T15:56:23Z	No
ORBEPH_STOP	End of an orbit ephemeris section	n/a	No

6.2.8 OHM Covariance Data

6.2.8.1 Table 6-8 provides an overview of the OHM covariance section. This may represent one or more Orbit State Covariance Time Histories. Only those keywords shown in table 6-8 shall be used in OHM covariance data specification.

6.2.8.2 All covariance matrices in the OHM data are time-tagged by a relative time value measured with respect to the epoch time specified via the TZERO_EPOCH keyword.

6.2.8.3 Covariance matrices shall be time-ordered to be monotonically increasing, with the exception that a single duplicate time point is permitted to indicate a change in state (e.g. following application of an impulsive maneuver). In the case of a duplicate time point, interpolation prior to the duplicate point shall use the first of the two covariance matrices, and interpolation after the duplicate point shall use the second of the two.

6.2.8.4 If the user includes covariances at key events, it is recommended that those events be annotated by a preceding descriptive comment line.

6.2.8.5 There is no requirement for the covariance time sequence to have uniform step size, nor is there a requirement for the covariance matrix time points to match those of the orbit state time history.

6.2.8.6 The covariance matrix time history data lines in the OHM must be indicated by means of two new keywords: COVARIANCE_START and COVARIANCE_STOP. The 'COVARIANCE_START' keyword must appear before the first line of the covariance matrix data. The 'COVARIANCE_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.

6.2.8.7 The epoch of the event associated with provided covariance matrices must be provided via the 'EPOCH' keyword. The reference frame of the covariance matrix, if different from that of the states in the ephemeris, must be provided via the 'COV_REF_FRAME' keyword.

6.2.8.8 Each row of the lower triangular covariance matrix must be provided on a single line. The order in which data items are given shall be fixed. The elements in each row of covariates shall be defined by the COVAR . The six rows of the covariance matrix contain from one to six numbers depending on what row of the matrix is being represented (first row has one element, second row has two, continuing in this fashion until the sixth row has six elements).

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

6.2.8.10 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 OHM may also contain propagated covariances, not just individual covariances associated with navigation solutions.

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

6.2.8.12 The digits of precision and time steps suitable for interpolation of a covariance time history shall be chosen according to best practice to avoid covariance and interpolation loss of precision [G8].

6.2.8.13 Values in the covariance matrix shall be expressed in the applicable reference frame (COV_REF_FRAME keyword if used, or REF_FRAME keyword if not), and 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 7.5. This logical block of the OHM 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.

Table 6-8: OHM Covariance Data

Keyword	Description	Examples of Values	Obligatory
COVAR	Start of a covariance time history section; indicate COVAR composition via "COVAR = YYY" where YYY is selected from annex A.	n/a	No
COMMENT	Comments (allowed at any point throughout the OHM Covariance Time History section). (See 7.7 for formatting rules.)	COMMENT This is a comment	No
REF_FRAME	Name of the reference frame in which the covariance data is provided. Use of values other than those in annex A must be documented in an ICD. The reference frame must be the same for all data elements, with the exception of the maneuvers and covariance matrix, for which applicable different reference frames may be specified. WHERE THE REFERENCE FRAME IS NOT INTRINSIC TO THE SELECTED ORBITAL SET BUT NOT SUPPLIED (FOR THIS NON-OBLIGATORY FIELD), THE REF_FRAME_EPOCH SHALL DEFAULT TO ITRF-97.	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)	No
REF_FRAME_EPOCH	Epoch of reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.9 for formatting rules.) WHERE THE REFERENCE FRAME EPOCH IS NOT INTRINSIC TO THE SELECTED REFERENCE FRAME BUT NOT SUPPLIED (FOR THIS NON-OBLIGATORY FIELD), THE REF_FRAME_EPOCH SHALL DEFAULT TO THE TZERO_EPOCH VALUE.	2001-11-06T11:17:33 2002-204T15:56:23Z	No
COVAR_STOP	End of a covariance time history section	n/a	No

6.2.9 OHM User-Defined Parameter Data

6.2.9.1 A section of User Defined Parameters is allowed. In principle, this provides flexibility, but also introduces complexity, non-standardization, potential ambiguity, and potential processing errors. Accordingly, if used, the keywords and their meanings must be described in an ICD. User Defined Parameters, if included in an OHM, should be used as sparingly as possible; their use is not encouraged.

6.2.9.2 Table 6-9 provides an overview of the OHM user-defined data section. Only those keywords shown in table 6-9 shall be used in OHM user-defined data specification.

Table 6-8: OHM User-Defined Data

Keyword	Description	Examples of Values	Obligatory
COMMENT	Comments (allowed at any point throughout the OHM Orbit State Time History section). (See 7.7 for formatting rules.)	COMMENT This is a comment	No
USER_DEFINED_x	User defined parameter, where 'x' is replaced by a variable length user specified character string. Any number of user defined parameters may be included, if necessary to provide essential information that cannot be conveyed in COMMENT statements. Example: USER_DEFINED_EARTH_MODEL = WGS-84	n/a	No

6.3 OHM EXAMPLES

Figure 6-1 through figure 6-4 are examples of Orbit Hybrid Messages. The first has only a time history of orbital states; the second includes space object characteristics and force model specifications; the third includes a time series of maneuvers, a time history of Cartesian position and velocity orbit states, followed by a time history of Keplerian elements; and the fourth includes a time series of covariance matrices.

```
CCSDS_OHM_VERS  = 2.0
CREATION_DATE   = 1998-11-06T09:23:57
ORIGINATOR      = JAXA
OBJECT_NAME     = GODZILLA 5
TZERO_EPOCH     = 1998-12-18T14:28:15.1172

ORBEPH          = CARTPV
REF_FRAME       = EME2000
  0.000000 2789.6 -280.0 -1746.8 4.73 -2.50 -1.04
 10.000000 2783.4 -308.1 -1877.1 5.19 -2.42 -2.00
 20.000000 2776.0 -336.9 -2008.7 5.64 -2.34 -1.95
   < intervening data records omitted here >
500.000000 2164.375 1115.811 -688.131 -3.53328 -2.88452 0.88535
ORBEPH_STOP
```

Figure 6-1: Simple/Succinct OHM File example with only Cartesian ephemeris

```
CCSDS_OHM_VERS  = 2.0

CREATION_DATE         = 1998-11-06T09:23:57
ORIGINATOR            = JAXA
TECH_POC              = Mr. Rodgers, (719)555-5555, email@email.XXX
TZERO_EPOCH           = 1998-12-18T14:28:15.1172

OBJECT_NAME           = GODZILLA 5
OBJECT_ID             = 1998-057A
TIME_SYSTEM           = UTC
TAIMUTC_TZERO         = 36      [s]
UT1MUTC_RATE_TZERO    = 0.0001  [ms/day]
UT2MUTC_TZERO         = .357    [s]

COMMENT S/C Physical Characteristics:
MASS_TZERO            = 100.0   [kg]
PHYSDIM_MAX           = 2.0     [m]
PHYSDIM_MED           = 1.0     [m]
PHYSDIM_MIN           = 0.5     [m]
RIC2PHYS_YAW          = 30.0    [deg]
RIC2PHYS_PITCH        = 1.7     [deg]
RIC2PHYS_ROLL         = -10.0   [deg]
PHYSDIM_MAX_AREA      = 0.15    [m**2]
PHYSDIM_MED_AREA      = 0.3     [m**2]
PHYSDIM_MIN_AREA      = 0.5     [m**2]

COMMENT Force Model Specification:
GM                    = 398600.4415        [km**3/s**2]
GEOPOTENTIAL          = WGS-84
GEOPOTENTIAL_NXM      = 20X20
ATMOSPHERE_MODEL      = NRLMSIS00
3RD_BODY_PERTS        = 1100000000
SOLAR_F10P7           = 105.0
SOLAR_F10P7_81DAY_AVG = 120.0
ASUBP                 = 12.0

COMMENT           GEOCENTRIC, CARTESIAN, EARTH FIXED

ORBEPH                = CARTPVA
REF_FRAME             = EFG
  0.000000 2789.6 -280.0 -1746.8 4.73 -2.50 -1.04 0.008 0.001 -0.159
ORBEPH_STOP
```

Figure 6-2: OHM example with space object characteristics and force model

```
CCSDS_OHM_VERS   = 2.0

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

OBJECT_NAME      = GODZILLA 5
OBJECT_ID        = 1998-057A
TZERO_EPOCH      = 1998-12-18T14:28:15.1172
TIME_SYSTEM      = UTC

COMMENT S/C Physical Characteristics:
MASS_TZERO       = 100.0 [kg]
SOLAR_RAD_COEFF  = 1.300
DRAG_AREA        = 10.00 [m**2]
DRAG_COEFF       = 2.300

COMMENT  Force Model parameters
GM               =  398600.4415        [km**3/s**2]

COMMENT          = Perform 100-second finite burn
MNVR             = FINITE
MNVR_REF_FRAME   = RTN
500.0 0.0 10.0 0.0 330.0 0.95 100.0
MNVR_STOP

ORBEPH           = CARTPVA
REF_FRAME        = ITRF-97
REF_FRAME_EPOCH  = 1998-12-18T14:28:15.1172

  0.000000 2789.6 -280.0 -1746.8 4.73 -2.50 -1.04 0.008 0.001 -0.159
 10.000000 2783.4 -308.1 -1877.1 5.19 -2.42 -2.00 0.008 0.001 0.001
 20.000000 2776.0 -336.9 -2008.7 5.64 -2.34 -1.95 0.008 0.001 0.159
   < intervening data records omitted here >
500.000000 2164.375 1115.811 -688.131 -3.53328 -2.88452 0.88535

ORBEPH_STOP

ORBEPH           = KPLR
REF_FRAME        = ITRF-97

  0.000000 6600.0 .03 28.5 50.0 30.0 10.0
 10.000000 6600.0 .03 28.5 50.0 30.0 10.1
 20.000000 6600.0 .03 28.5 50.0 30.0 10.2
   < intervening data records omitted here >
500.000000 6600.0 .03 28.5 50.0 30.0 35.0

ORBEPH_STOP
```

Figure 6-3: OHM example with maneuvers, Cartesian and Keplerian ephemeris

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

OBJECT_NAME     = GODZILLA 5
OBJECT_ID       = 1998-057A
TZERO_EPOCH     = 1998-12-18T14:28:15.1172
TIME_SYSTEM     = UTC

COMMENT  Force Model parameters
GM              =  398600.4415        [km**3/s**2]

COMMENT S/C Physical Characteristics:
MASS_TZERO      =    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           GEOCENTRIC, CARTESIAN, EARTH FIXED

ORBEPH          = CARTPVA
CENTER_NAME     = EARTH
REF_FRAME       = ITRF-97
REF_FRAME_EPOCH = 1998-12-18T14:28:15.1172

  0.000000 2789.6 -280.0 -1746.8 4.73 -2.50 -1.04 0.008 0.001 -0.159
 10.000000 2783.4 -308.1 -1877.1 5.19 -2.42 -2.00 0.008 0.001 0.001
 20.000000 2776.0 -336.9 -2008.7 5.64 -2.34 -1.95 0.008 0.001 0.159
   < intervening data records omitted here >
500.000000 2164.375 1115.811 -688.131 -3.53328 -2.88452 0.88535

ORBEPH_STOP

COVAR           = ADBARV
REF_FRAME       = EME2000

T = 10.00
 3.331349e-04
 4.618927e-04  6.782421e-04
-3.070007e-04 -4.221234e-04  3.231931e-04
-3.349365e-07 -4.686084e-07  2.484949e-07  4.296022e-10
-2.211832e-07 -2.864186e-07  1.798098e-07  2.608899e-10  1.767514e-10
-3.041346e-07 -4.989496e-07  3.540310e-07  1.869263e-10  1.008862e-10  6.224444e-10

   < intervening data records omitted here >

T = 500.00
3.442450e-04
 4.507816e-04  6.893532e-04
-3.060006e-04 -4.110123e-04  3.342042e-04
-3.238254e-07 -4.575073e-07  2.373838e-07  4.307133e-10
-2.100721e-07 -2.753075e-07  1.687087e-07  2.507788e-10  1.878625e-10
-3.030235e-07 -4.878385e-07  3.430200e-07  1.758152e-10  1.007751e-10  6.224444e-10
COVARIANCE_STOP

COVAR           = EFG
T = 10.00
 3.331349e-04
 4.618927e-04  6.782421e-04
-3.070007e-04 -4.221234e-04  3.231931e-04
COVARIANCE_STOP
```

Figure 6-4: OHM example with Covariance Matrix

7 ORBIT DATA MESSAGE SYNTAX

7.1 OVERVIEW

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

7.2 GENERAL

The Orbit Data Messages (OPM, OMM, OEM or OHM) shall observe the syntax described in 7.2 through 7.7.

7.3 ODM LINES

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

– Header line;

– Metadata line;

– Data line; or

– Blank line.

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

7.3.3 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.

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

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

7.3.6 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.

7.4 KEYWORD = VALUE NOTATION AND ORDER OF ASSIGNMENT STATEMENTS

7.4.1 For the OPM and OMM, all header, metadata, and data lines shall use ‘keyword = value’ notation, abbreviated as KVN.

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

7.4.1.2 For the OHM, all header and metadata elements shall use KVN notation.

7.4.1.3 OHM orbit ephemeris data lines shall not use KVN format; rather, the structure of such OHM ephemeris data line (time relative to TZERO_EPOCH and the parameters corresponding to the selected orbit set.

7.4.1.4 OHM covariance matrix epoch and covariance reference frame (if used) shall use KVN format. The OEM covariance data lines shall not use KVN format; rather, the OEM covariance data line has a fixed structure containing from one to six required fields (a row from the 6x6 lower triangular form covariance matrix). (See 5.2.5.)

7.4.1.5 OHM ephemeris data lines shall not use KVN format; rather, the OEM ephemeris data line has a fixed structure containing seven required fields (epoch time, three position components, three velocity components), and three optional acceleration components. (See 5.2.4.)

7.4.1.6 OHM covariance matrix epoch and covariance reference frame (if used) shall use KVN format. The OEM covariance data lines shall not use KVN format; rather, the OEM covariance data line has a fixed structure containing from one to six required fields (a row from the 6x6 lower triangular form covariance matrix). (See 5.2.5.)

7.4.2 The keywords 'COMMENT', 'META_START', 'META_STOP', 'COVARIANCE_START', and 'COVARIANCE_STOP' are exceptions to the KVN syntax assignment.

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

7.4.4 Keywords must be uppercase and must not contain blanks.

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

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

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

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

7.5 VALUES

7.5.1 A non-empty value field must be specified for each obligatory keyword.

7.5.2 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., $-2^{31} <= x <= 2^{31}-1$).

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

7.5.4 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 one digit shall appear before and after a decimal point. The number of digits shall be 16 or fewer.

Commented [OD1]: What's the reason for this requirement ?

7.5.5 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:

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

b) 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.

c) 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 zero shall be assumed (essentially yielding a fixed point value).

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

e) 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', 'decimal', and 'double', respectively (reference [6]). The specifications for floating point values conform to the IEEE double precision type (references [6] and [7]). Floating point numbers in IEEE extended-single or IEEE extended-double precision may be represented, but do require an ICD between exchange partners because of their implementation-specific attributes (reference [7]). The special values 'NaN', '-Inf', '+Inf', and '-0' are not supported in the ODM.

7.5.6 Text value fields must be constructed using only all uppercase or all lowercase.

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

7.5.8 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 contiguous blanks shall be equivalent to a single blank.

7.5.9 In value fields that represent an absolute 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, up to the maximum allowed for a fixed point number. All fields shall have leading zeros. (See reference [1], ASCII Time Code A or B.)

7.5.10 There are eight 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 REF_FRAME_EPOCH, START_TIME, USEABLE_START_TIME, USEABLE_STOP_TIME, STOP_TIME shall be as determined by the TIME_SYSTEM metadata keyword.

Cor. 1

7.6 UNITS IN THE ORBIT DATA MESSAGES

7.6.1 OPM/OMM UNITS

7.6.1.1 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 and 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).

7.6.1.2 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.

7.6.2 OEM UNITS

7.6.2.1 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.

7.6.2.2 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 two velocity components. The units shall not be displayed.

7.6.3 OHM UNITS

7.6.3.1 In an OHM 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.

7.6.3.2 In an OHM 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 two velocity components. The units shall not be displayed.

7.7 COMMENTS IN THE ORBIT DATA MESSAGES

7.7.1 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.

7.7.2 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.

7.7.3 For the OPM, OMM, OEM and OHM, comment lines shall be optional.

7.7.4 All comment lines shall begin with the '`COMMENT`' keyword followed by at least 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.

7.7.5 Placement of comments shall be as specified in the tables in sections 3, 4, and 5 that describe the OPM, OMM, OEM and OHM keywords.

7.7.6 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.

NOTE – The logical blocks in the OPM Data section are indicated in table 3-3.

7.7.7 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.

NOTE – The logical blocks in the OMM Data section are indicated in table 4-3.

7.7.8 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_START' keyword). Comment lines must not appear within any block of ephemeris lines or covariance matrix lines.

7.7.9 Comments in the OHM may appear in the OHM Header immediately after the 'CCSDS_OHM_VERS' keyword, at the very beginning of the OHM Metadata section (after the 'META_START' keyword), at the beginning of the OHM Ephemeris Data Section, and at the beginning of the OHM Covariance Data section (after the 'COVARIANCE_START' keyword). Comment lines must not appear within any block of ephemeris lines or covariance matrix lines.

7.7.10 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.)

7.7.11 The following comments should be provided:

a) 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.
```

b) 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.
```

c) 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).

7.8 ORBIT DATA MESSAGE KEYWORDS

7.8.1 VERSION KEYWORDS

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 Recommendation
CCSDS_OPM_VERS	1.0	Silver Book 1.0, 09/2004
CCSDS_OPM_VERS	2.0	Blue Book 2.0 (this document)
CCSDS_OMM_VERS	2.0	Blue Book 2.0 (this document)
CCSDS_OEM_VERS	1.0	Silver Book 1.0, 09/2004
CCSDS_OEM_VERS	2.0	Blue Book 2.0 (this document)

7.8.2 GENERAL KEYWORDS

7.8.2.1 Only those keywords shown in table 3-1, table 3-2, and 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 omitted.

7.8.2.2 Only those keywords shown in table 4-1, table 4-2, and 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 omitted.

7.8.2.3 Only those keywords shown in table 5-2 and 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 omitted.

8 SECURITY

8.1 OVERVIEW

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

8.2 SECURITY CONCERNS RELATED TO THIS RECOMMENDED STANDARD

8.2.1 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.

8.2.2 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.

8.2.3 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.

8.2.4 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.

8.2.5 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.

8.2.6 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.

8.3 POTENTIAL THREATS AND ATTACK SCENARIOS

Potential threats or attack scenarios include, but are not limited to, (a) unauthorized access to the programs/processes that generate and interpret the messages, and (b) unauthorized access to the messages during transmission between exchange partners. Unauthorized access to the programs/processes that generate and interpret the messages should be prohibited. Protection from unauthorized access during transmission 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. It is strongly recommended that potential threats or attack scenarios applicable to the systems and networks on which this Recommended Standard is implemented be addressed by the management of those systems and networks.

8.4 CONSEQUENCES OF NOT APPLYING SECURITY TO THE TECHNOLOGY

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. Because these messages are used in preparing pointing and frequency predicts used during spacecraft commanding, and may also be used in collision avoidance studies, the consequences of not applying security to the systems and networks on which this Recommended Standard is implemented could include compromise or loss of the mission if malicious tampering of a particularly severe nature occurs.

8.5 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

Cor. 1

VALUES FOR TIME_SYSTEM AND FRAME RELATED KEYWORDS

(NORMATIVE)

Cor. 1

The values in this annex represent the set of acceptable values for the TIME_SYSTEM, REF_FRAME, MAN_REF_FRAME, and COV_REF_FRAME keywords in the OPM, OMM, and OEM. (For details and description of these time systems, see reference [G1].) If exchange partners wish to use different settings, the settings 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 (note)
MJD1	Modified Julian Date based on Universal Time (UT1), defined as elapsed UT1 days and fractions since 0h on 17 Nov 1858 UT1
MJDTT	Modified Julian Date based on Terrestrial Time (TT), defined as elapsed TT days and fractions since 0h on 17 Nov 1858 TT
MRT	Mission Relative Time (note)
SCLK	Spacecraft Clock (receiver) (requires rules for interpretation in ICD)
TAI	International Atomic Time
TCB	Barycentric Coordinate Time
TDB	Barycentric Dynamical Time
TCG	Geocentric Coordinate Time
TT	Terrestrial Time
UT1	Universal Time
UTC	Coordinated Universal Time
ICD	Other timing system, as defined in ICD

If MET or MRT is 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. The time format should only utilize three digit days from the MET or MRT epoch, not months and days of the months.

A2 REF_FRAME KEYWORD

Absolute Reference 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 (Barycentric)
ITRFYYYY	International Terrestrial Reference Frame solution as of year "YYYY" (e.g. 2000)
ITRF-93	International Terrestrial Reference Frame 1993
ITRF-97	International Terrestrial Reference Frame 1997
MCI	Mars Centered Inertial
MEME	Mean Equator Mean Equinox
TDR	True of Date, Rotating (Realized as ITRF Fixed)
TEME	True Equator Mean Equinox (see below NORAD comment)
TOD	True of Date (True Equator True Equinox)
UVW	Launch go-inertial reference frame, with U in local horizon plane along inertial launch azimuth (downrange), W along the geodetic vertical and V completing the set (cross-range). In typical use the go-inertial epoch should be specified in an accompanying comment field.
ICD	Other reference frame, as defined in ICD

Cor. 1

Cor. 1

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 OMMs based on NORAD Two Line Element sets, and in no other circumstances. There are subtle differences between TEME of Epoch and TEME of Date (see reference [G3] or [G4]). 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.

A3 MAN_REF_FRAME AND COV_REF_FRAME KEYWORDS

In addition to the above reference frames, maneuver and covariance data can be specified in the following (three) relative frames:

Cor. 1

Relative Reference Frame Value	Meaning
RIC	'Radial, In-track, Cross-track"
RSW	Another name for 'Radial, Transverse, Normal'
RTN	Radial, Transverse, Normal
TNW	A local orbital coordinate frame that has the x-axis along the velocity vector, W along the orbital angular momentum vector, and N completes the right handed system.
ICD	Other relative reference frame, as defined in ICD

Cor. 1

A4 ORBEPH KEYWORDS

Orbit element states and/or time histories (ephemerides) may be specified in the following element sets.

Orbit elements shall be interpreted as osculating elements unless pre-coordinated between the message originator and recipient to contain mean elements (e.g. singly- or doubly-averaged elements based upon Kozai, Brouwer or other theories).

Note that non-inertial reference frames cannot be used with inertial element sets and such use is not allowed.

Orbit Element Set Value	**Meaning**
CARTP	Cartesian 3-element position (only) orbit state (X, Y, Z)
CARTPV	Cartesian 6-element position and velocity orbit state (X, Y, Z, XD, YD, ZD)
CARTPVA	Cartesian 9-element position, velocity and acceleration orbit state (X, Y, Z, XD, YD, ZD, XDD, YDD, ZDD)
EFG	Earth-Fixed Greenwich 6-element (E, F, G, ED, FD, GD)
KPLR	Keplerian 6-element classical set ($aei\Omega\omega\nu$: semi-major axis, eccentricity, inclination, right ascension of the ascending node, argument of perigee and true anomaly)
KPLRM	Keplerian 6-element classical set ($aei\Omega\omega M$: semi-major axis, eccentricity, inclination, right ascension of the ascending node, argument of perigee and mean anomaly)
ADBARV	Spherical 6-element set ($\alpha\delta\beta$Arv: right ascension +E°, declination +N°, inertial flight path angle measured from the radial direction to inertial velocity direction (e.g. 90° for circular orbit), inertial azimuth angle, measured from local North to projection of inertial velocity in local horizontal plane, radius magnitude and velocity magnitude)
EQUIN	Equinoctial 7-element set ([ahkλpqf_r] = [a, a_g, a_f, L=$(\Omega + \omega + f_r\, M)$, χ, ψ, $f_r = \pm1$] as defined in Vallado [G4])
EQUINMOD	Equinoctial 7-element modified set ([pfghkLf_r] = [a(1-e^2), a_f, a_g, χ, ψ, $L = (\Omega + \omega + f_r\, \nu)$, $f_r = \pm1$] as defined in Vallado [G4])
LDBARV	Modified spherical 6-element set ($\lambda\delta\beta$Arv: Earth longitude +E°, declination +N°, inertial flight path angle measured from the radial

	direction to inertial velocity direction (e.g. 90° for circular orbit), inertial azimuth angle, measured from local North to projection of inertial velocity in local horizontal plane, radius magnitude and velocity magnitude)
ICD	Other element set definition, as defined in ICD

A5 ADDITIONAL COVARIANCE SET KEYWORDS

In addition to the above orbit element sets, covariance data can be specified in the following orbit sets:

Orbit Element Set Value	Meaning
TCARTP	Time & Cartesian 3-element position (only) errors (X, Y, Z)
TCARTPV	Time & Cartesian 6-element position and velocity errors (X, Y, Z, XD, YD, ZD)
TCARTPVA	Time & Cartesian 9-element position, velocity and acceleration errors (X, Y, Z, XD, YD, ZD, XDD, YDD, ZDD)
TKPLR	Time & Keplerian 6-element classical set ($aei\Omega\omega\nu$: semi-major axis, eccentricity, inclination, right ascension of the ascending node, argument of perigee and true anomaly) errors
TKPLRM	Time & Keplerian 6-element classical set ($aei\Omega\omega M$: semi-major axis, eccentricity, inclination, right ascension of the ascending node, argument of perigee and mean anomaly) errors
TADBARV	Time & Spherical 6-element set ($\alpha\delta\beta$Arv: right ascension +E°, declination +N°, inertial flight path angle measured from the radial direction to inertial velocity direction (e.g. 90° for circular orbit), inertial azimuth angle, measured from local North to projection of inertial velocity in local horizontal plane, radius magnitude and velocity magnitude) errors
TEQUIN	Time & Equinoctial 7-element set ([ahkλpqf_r] = [a, a_g, a_f, L=($\Omega + \omega + f_r M$), χ, ψ, f_r = ±1] as defined in Vallado [G9]) errors
TEQUINMOD	Time & Equinoctial 7-element modified set ([pfghkLf_r] = [a(1-e^2), a_f, a_g, χ, ψ, $L = (\Omega + \omega + f_r \nu)$, f_r = ±1] per Vallado [G9])
TLDBARV	Time & Modified spherical 6-element set (λ$\delta\beta$Arv: Earth longitude +E°, declination +N°, inertial flight path angle measured from the radial direction to inertial velocity direction (e.g. 90° for circular orbit), inertial azimuth angle, measured from local North to projection of inertial velocity in local horizontal plane, radius magnitude and velocity magnitude) errors

COVAR3X3	Generic 3x3 covariance as defined in COMMENTS or ICD
COVAR4X4	Generic 4x4 covariance as defined in COMMENTS or ICD
COVAR5X5	Generic 5x5 covariance as defined in COMMENTS or ICD
COVAR6X6	Generic 6x6 covariance as defined in COMMENTS or ICD
COVAR7X7	Generic 7x7 covariance as defined in COMMENTS or ICD
COVAR8X8	Generic 8x8 covariance as defined in COMMENTS or ICD
COVAR9X9	Generic 9x9 covariance as defined in COMMENTS or ICD
COVAR10X10	Generic 10x10 covariance as defined in COMMENTS or ICD
COVAR11X11	Generic 11x11 covariance as defined in COMMENTS or ICD
COVAR12X12	Generic 12x12 covariance as defined in COMMENTS or ICD

ANNEX B

ABBREVIATIONS AND ACRONYMS

(INFORMATIVE)

ASCII	American Standard Code for Information Interchange
CCSDS	Consultative Committee for Space Data Systems
DSST	Draper Semi-Analytic Satellite Theory
ECI	Earth Centered Inertial
EGM	Earth Gravitational Model, Earth Geopotential Model
EME2000	Earth Mean Equator and Equinox of J2000 (Julian Date 2000)
EOP	Earth Orientation Parameters
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
IIRV	Improved Inter-Range Vector
ISO	International Standards Organization
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
GRC	Greenwich Rotating Coordinate Frame
KVN	Keyword = Value Notation
NORAD	North American Aerospace Defense Command

OD	Orbit Determination
ODM	Orbit Data Message
OEM	Orbit Ephemeris Message
OHM	Orbit Hybrid Message
OMM	Orbit Mean-Elements Message
OPM	Orbit Parameter Message
RTN	Radial, Transverse (along-track) and Normal
SGP4	US Air Force Simplified General Perturbations No. 4
SPK	Satellite, Planetary Kernel
TAI	International Atomic Time
TCB	Barycentric Coordinate Time
TCG	Geocentric Coordinate Time
TDB	Barycentric Dynamical Time
TDR	True of Date Rotating
TDT	Terrestrial Dynamical Time (see also 'TT')
TEME	True Equator Mean Equinox
TLE	Two Line Element
TOD	True Equator and Equinox of Date
TT	Terrestrial Dynamical Time (see also 'TDT')
USM	Universal Semianalytical Method
UTC	Coordinated Universal Time
W3C	World Wide Web Consortium
WGS	World Geodetic System
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 Recommended Standard reflects heritage requirements pertaining to some of the CCSDS Areas' 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 Recommended Standard.

C2 PRIMARY REQUIREMENTS ACCEPTED BY THE ORBIT DATA MESSAGES

Table C-1: Primary Requirements

Requirement	OPM?	OMM?	OEM?	OHM?
Data must be provided in digital form (computer file).	Y	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	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	Y
State vector information must be provided in a reference frame that is clearly identified and unambiguous.	Y	Y	Y	Y
Identification of the object and the center(s) of motion must be clearly identified and unambiguous.	Y	Y	Y	Y
Time measurements (time stamps, or epochs) must be provided in a commonly used, clearly specified system.	Y	Y	Y	Y
The time bounds of the ephemeris must be unambiguously specified.	N/A	N/A	Y	Y
The Recommended Standard must provide for clear specification of units of measure.	Y	Y	Y	Y
Files must be readily ported between, and useable within, 'all' computational environments in use by Member Agencies.	Y	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	Y
File name syntax and length must not violate computer constraints for those computing environments in use by Member Agencies.	Y	Y	Y	Y
A means to convey information about the uncertainty of the state shall be provided.	Y	Y	Y	Y

Table C-2: Heritage Requirements

Requirement	OPM?	OMM?	OEM?	OHM?
Ephemeris data is reliably convertible into the SPICE SPK (NASA) format (reference [G6]) and IIRV (NASA) format (reference [G7]) 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	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	Y
The Recommended Standard is, or includes, an ASCII format.	Y	Y	Y	Y
The Recommended Standard does not require software supplied by other Agencies.	Y	N	Y	Y

Table C-3: Desirable Characteristics

Requirement	OPM?	OMM?	OEM?	OHM?
The Recommended Standard applies to non-traditional objects, such as landers, rovers, balloons, and natural bodies (asteroids, comets).	Y	N	Y	Y
The Recommended 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	Y
The Recommended Standard is extensible with no disruption to existing users/uses.	Y	Y	Y	Y
The Recommended Standard is consistent with, and ideally a part of, ephemeris products and processes used for other space science purposes.	N	Y	N	Y
The Recommended Standard is as consistent as reasonable with any related CCSDS ephemeris Recommended Standards used for earth-to-spacecraft or spacecraft-to-spacecraft applications.	Y	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 compares the three recommended messages in terms of the relevant selection criteria identified by the CCSDS:

Table C-4: Applicability of the Criteria to Orbit Data 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, OMM and/or OHM users may desire/require a higher fidelity propagation of the state vector or Keplerian 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, OMM and OHM are engineered only for low- to medium-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 Keplerian 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/OHM 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 user's 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/OHM is the COMMENT mechanism. A number of potential COMMENT statements are included in annex D. Alternatively, the 'USER_DEFINED_' keyword prefix may be used, though this usage is not encouraged.

C5 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 C-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 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 annex 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), ICDs based on the content specified in this Recommended Standard should be developed and negotiated whenever possible.[1]

Item	Section
1) Definition of orbit accuracy requirements pertaining to any particular ODM.	1.2
2) Method of physically exchanging ODMs (transmission).	1.2, 3.1, 4.1, 5.1
3) Whether the ASCII format of the ODM will be KVN or XML.	2.1
4) OPM, OMM and/or OEM file-naming conventions.	3.1, 4.1, 5.1
5) Format on values used for the 'ORIGINATOR' keyword.	3.2.2, 4.2.2, 5.2.2
6) Situations where the OBJECT_ID is not published in the SPACEWARN Bulletin (reference [2]).	3.2.3, 4.2.3, 5.2.3
7) Detailed description of any user defined parameters used.	3.2.4, 4.2.4
8) Type of TEME reference frame, if applicable (TEME of Epoch or TEME of Date).	4.2.3
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.	7.5
10) Information which must appear in comments for any given ODM exchange.	7.7

[1] 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
11) Specific OPM, OMM and/or OEM version numbers that will be exchanged.	7.8.1
12) Specific information security interoperability provisions that apply between agencies.	8
13) Exceptions for the REF_FRAME and/or TIME_SYSTEM metadata keywords that are not drawn from annex A.	annex 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. Individual COMMENT statements that are not applicable to any given exchange may be deleted. A blank Microsoft Word copy of this 'Checklist ICD' is available on the CCSDS web site at:

http://public.ccsds.org/publications/archive/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. This set of COMMENT statements is also suitable for use in situations where an ICD between exchange partners is neither required, desired, nor feasible. An alternative to the use of this set of COMMENT statements is the User Defined Parameters capability; however, User Defined Parameters should only be used sparingly. For a list this extensive the User Defined Parameters feature should not be used.

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 a CCSDS Attitude Data Message (see reference [G5]). 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 ANGLE 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. The differences are divided into those which affect the content of one or more of the orbit data messages, and those which only affect the document.

E1 CHANGES IN THE MESSAGES

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

2. The 6x6 covariance matrix (lower triangular form) included in the initial version of the OMM was added to the OPM and OEM to allow producers of these files to provide the uncertainties associated with the state(s).

3. 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'.

4. Optional accelerations were added to the state vectors provided in the OEM format (see section 5).

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

6. 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.

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

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

9. The fields in the 'Spacecraft Parameters' block of the OPM were changed from obligatory to optional parameters.

10. The block of optional User Defined Parameters included in the initial version of the OMM is added to the OPM.

11. The REF_FRAME_EPOCH is added to accommodate cases when the reference frame epoch is not intrinsic to the definition of the reference frame.

12. The relationship between successive blocks of ephemeris data was clarified such that the repetition of time tags is relative to the USEABLE_STOP_TIME and USEABLE_START_TIME instead of the STOP_TIME and START_TIME.

Cor. 1

E2 CHANGES IN THE DOCUMENT

Cor. 1

1. A normative annex for primary TIME_SYSTEM and reference frame related keywords was added, replacing non-normative references to the Navigation Green Book (reference [G1]). The CCSDS documents are not allowed to make normative references to non-normative documents.

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 formats of units allowed in the OPM were changed to make them compliant with the International System (SI) of Units. In the Blue Book version 1, the SI conventions were not observed. In all cases, this was merely a change in case conventions from upper case to lower case.

4. 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.

5. 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.

6. 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 ODMs when there is no time to negotiate a formal ICD by inserting COMMENT statements into an ODM.

7. The new Orbit Hybrid Message (OHM) was added.

8. The syntax rules for the OPM, OMM, OEM and the new OHM were consolidated into a common syntax section (see section 8).

9. The rules for processing COMMENT keywords were consolidated into a single section of the document (see section 8).

10. Improved discussion of information security considerations was provided, per Secretariat request (see section 8).

ANNEX F

CREATING A VERSION 1.0 COMPLIANT OPM/OEM

(INFORMATIVE)

This annex describes the actions that the user should perform in order to create an OPM or OEM that is compatible with implementations of the ODM version 1.0 Blue Book. Note: there is no version 1.0 compatible OMM; that message type first appears in the ODM version 2.0. Examples of version 1.0 compatible OPM and OEM messages are shown in the body of the document.

F1 ODM VERSION 1.0 COMPATIBLE OPM

For various reasons, the user may wish to create an OPM that is compatible with the ODM Version 1. In this case, the user must observe the following requirements:

– If the software implementation of the exchange partner will not accept a version 2.0 OPM, the value associated with the CCSDS_OPM_VERS keyword must be '1.0'.

– If the software implementation of the exchange partner will accept either version 1.0 or 2.0 OPMs, the value associated with the CCSDS_OPM_VERS keyword may be either '1.0' or '2.0'.

– The OPM line length must not exceed 80 characters (including end of line markers).

– The user must ***not*** code the REF_FRAME_EPOCH metadata keyword.

– The user must code the Spacecraft Parameters logical block.

– The user must ***not*** code the Covariance Matrix logical block.

– The user must ***not*** code the User Defined Parameters logical block.

– If units are desired in the version 1.0 compatible OPM, it may be that an exchange partner's software requires units in upper case characters as they were shown in the Version 1.0 OPM. While it seems unlikely that the case of the units in an OPM would be checked, the user should be aware of this potential issue.

NOTE – OPM Version 2.0 commenting rules are backward compatible to OPM Version 1.0.

F2 ODM VERSION 1.0 COMPATIBLE OEM

For various reasons, the user may wish to create an OEM that is compatible with the ODM Version 1. In this case, the user must observe the following requirements:

– If the software implementation of the exchange partner will not accept a version 2.0 OEM, the value associated with the CCSDS_OEM_VERS keyword must be '1.0'.

- If the software implementation of the exchange partner will accept either version 1.0 or 2.0 OEMs, the value associated with the CCSDS_OEM_VERS keyword may be either '1.0' or '2.0'.
- The user must ***not*** code the REF_FRAME_EPOCH metadata keyword.
- The user must ***not*** code the acceleration components in the OEM Data Lines.
- The user must ***not*** code the Covariance Matrix logical block.
- The user must ensure that ephemeris data time tags do not overlap except at the STOP_TIME/START_TIME boundary.

Cor. 1

NOTE – OEM Version 2.0 commenting rules are backward compatible to OEM Version 1.0.

ANNEX G

INFORMATIVE REFERENCES

(INFORMATIVE)

[G1] *Navigation Data—Definitions and Conventions*. Report Concerning Space Data System Standards, CCSDS 500.0-G-3. Green Book. Issue 3. Washington, D.C.: CCSDS, May 2010.

[G2] *Organization and Processes for the Consultative Committee for Space Data Systems*. CCSDS A02.1-Y-3. Yellow Book. Issue 3. Washington, D.C.: CCSDS, July 2011.

[G3] "CelesTrak." Center for Space Standards & Innovation (CSSI). <http://celestrak.com/>

[G4] David A. Vallado, et al. "Revisiting Spacetrack Report #3." In *Proceedings of the AIAA/AAS Astrodynamics Specialist Conference and Exhibit* (21–24 August 2006, Keystone, Colorado). AIAA 2006-6753. Reston, Virginia: AIAA, 2006. <http://www.centerforspace.com/downloads/files/pubs/AIAA-2006-6753.pdf>

[G5] *Attitude Data Messages*. Recommendation for Space Data System Standards, CCSDS 504.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, May 2008.

[G6] "Documentation." *SPICE: NASA's Solar System Exploration Ancillary Information System*. Navigation and Ancillary Information Facility (NAIF). <http://naif.jpl.nasa.gov/naif/documentation.html>

[G7] *Ground Network Tracking and Acquisition Data Handbook*. 453-HNDK-GN. Greenbelt, Maryland: Goddard Space Flight Center, May 2007.

[G8] D.L. Oltrogge et al, "Ephemeris Requirements for Space Situational Awareness," AAS 11-151, February 2011.

[G9] David A. Vallado, et al. *Fundamentals of Astrodynamics and Applications, 4th Ed*., Microcosm Press and Springer, ISBN 978-1881883180.