The Consultative Committee for Space Data Systems

Recommendation for Space Data System Standards

ORBIT DATA MESSAGES

PROPOSED STANDARD

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STATEMENT OF INTENT

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.

This **Recommended Standard** is issued by, and represents the consensus of, the CCSDS members. Endorsement of this **Recommendation** is entirely voluntary. Endorsement, however, indicates the following understandings:

- o Whenever a member establishes a CCSDS-related **standard**, this **standard** will be in accord with the relevant **Recommended Standard**. Establishing such a **standard** does not preclude other provisions which a member may develop.
- o Whenever a member establishes a CCSDS-related **standard**, that member will provide other CCSDS members with the following information:
  - -- The **standard** itself.
  - -- The anticipated date of initial operational capability.
  - -- The anticipated duration of operational service.
- o Specific service arrangements shall be made via memoranda of agreement. Neither this **Recommended Standard** nor any ensuing **standard** is a substitute for a memorandum of agreement.

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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- Scientific and Technological Research Council of Turkey (TUBITAK)/Turkey.
- Space and Upper Atmosphere Research Commission (SUPARCO)/Pakistan.
- 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.P-2.37	ORBIT DATA MESSAGES, **Proposed Standard**, **Issue 3**	**13 February 2018 DRAFT**	Current issue: – changes from the original issue are documented in ANNEX M
EC 1	Editorial Change 1		Corrects erroneous cross references and table of contents entries; corrects typographical anomaly in annex F; updates informative references to current issues in ANNEX M, Subsection M2
CCSDS 502.0.R-2, Cor. 1	Technical Corrigendum 1		Corrects/clarifies text; updates references [1] and [4] to current issues in 0.
CCSDS 502.0.P-2.37	Orbit Comprehensive Message		Added Orbit Comprehensive Message (OCM)

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1 INTRODUCTION

1.1 PURPOSE AND SCOPE

This Orbit Data Message (ODM) Recommended Standard specifies four 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 Comprehensive Message (OCM). 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.

The Orbit Data Message (ODM) is an international standard published under the auspices of CCSDS and International Standards Organization (ISO) Technical Committee 20, Subcommittee 13, developed jointly and in concert with the ISO TC20/SC14. As such, this CCSDS standard is also properly labeled as ISO 26900.

The recommended Orbit Data Message format is ASCII (reference [3]).

This ODM document describes both ‘Keyword = Value Notation’ (or KVN) as well as Extensible Markup Language (XML, reference [4]) formatted messages. Selection of KVN or XML format should be specified in an ICD.

NOTE – As currently specified, an OPM, OMM, or OEM file is to represent orbit data for a single spacecraft and the OCM 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.

1.2 APPLICABILITY

The rationale behind the design of each orbit data message is described in ANNEX K 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 K2.4.

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 (OCM) 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 M.

1.4 DOCUMENT STRUCTURE

Section 0 provides a brief overview of the CCSDS-recommended Orbit Data Message types, the Orbit Parameter Message (OPM), Orbit Mean-Elements Message (OMM), Orbit Ephemeris Message (OEM) and the Orbit Comprehensive Message (OCM).

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 OCM.

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

Following the principal content of the document, there are a number of annexes, both normative and informative, to guide the ODM user.

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 OCM messages.

1.6 NOMENCLATURE

The following conventions apply for the normative specifications in this Manual:

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.

NOTE – These conventions do not imply constraints on diction in text that is clearly informative in nature.

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.

[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] *United Nations Office of Outer Space Affairs satellite designator/index, searchable at* <http://www.unoosa.org/oosa/osoindex >

[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.

[8] Henry S. Thompson, et al. eds. XML Schema Part 1: Structures. 2nd ed. W3C Recommendation. N.p.: W3C, October 2004.

[9] CCSDS 503.0-P-1.0.4, Tracking Data Message, January 2017.

[10] CCSDS 504.0-P-1.5, Attitude Data Message, October 2017.

2 OVERVIEW

2.1 ORBIT DATA MESSAGE TYPES

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 [L4].

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 COMPREHENSIVE MESSAGE (OCM)

An OCM specifies position and velocity of either a single object or an en masse parent/child deployment scenario stemming from a single object. The OCM aggregates and extends OPM, OEM and OMM content in a single comprehensive 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 area cross-sections for drag, SRP perturbations modeling.
- Optional spacecraft dimensions and orientation information for collision probability estimation
- Optional perturbations model specification;
- Optional maneuver specification (impulsive or finite burn);
- 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 orbit determination data and metrics;
- 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 State Transition Matrix specification;
- Optional Ephemeris Compression (EC) specification via polynomials;

The OCM simultaneously emphasizes flexibility and message conciseness by offering extensive optional content while minimizing mandatory content. The OCM 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 OCM allows the user, in a single message/file, to either embed high-fidelity orbit propagation into an ephemeris time history (akin to the OEM ephemeris), or specify orbital states which can be propagated with supplied perturbations 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 OCM is typically sufficient. If ephemeris information for multiple objects is to be exchanged, then multiple OPM, OMM, OEM or OCM files must be used, with the exception that the OCM 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 [L1].

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 [L1]) 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 Comprehensive Message (OCM) 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 [L1]) 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.

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 mandatory 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	Mandatory
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 drawn from the SANA "Organizations" registry). 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 mandatory or optional.

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

Table 3-2: OPM Metadata

Keyword	Description	Examples of Values	Mandatory
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 UN Office of Outer Space Affairs designator index (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 UN Office of Outer Space Affairs designator index (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 UN Office of Outer Space Affairs designator index or that index 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	Mandatory
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 B, subsection B2 must be documented and conveyed 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 ITRF1993 ITRF1997 ITRF2000 ITRFYYYY (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 B, subsection B1 must be documented and conveyed 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 mandatory 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	Mandatory
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
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 B, subsections B2 and B3)	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

Commented [OD1]: From Fran 12/14/2016: We are conducting some test campaigns in GMV where we have detected a possible inconsistency between the ODM 2.0 and NDM/XML (the XML schemas). Maybe this was already know and recorded, but just in case.
The ODM 2.0 does not consider the epoch for covariance assuming that is should be the same as the state vector (like for the Keplerian elements) what from the technical point of view makes probably sense.
Instead, the NDM/XML reuses the same covariance type for OEM, OPM, and OMM what implies that the epoch is present (optional element) also in OPM and OMM. This may or not be an error to fix but certainly represent a certain inconsistency between the KVN and XML representations that we may want to address. Something similar as what is done for units in the covariance elements (see 505 4.10.2.12) could be enough.
Just an input to maybe consider in the on-going review of the ODM.

Keyword	Description	Units	Mandatory
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
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 B, subsection B2 and B3)	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 [L1] 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 B, subsection B2 and B3.

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 may be provided if necessary. 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 AND SUPPLEMENTARY INFORMATION

Example OPMs and associated supplementary (non-normative) information are provided in Annex E.

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 [L1]) 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 [L3]). 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 Comprehensive Message (OCM) 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 [L1]), 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.

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 mandatory 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	Mandatory
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.	3.0	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 drawn from the SANA "Organizations" registry). 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 mandatory 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 B, subsections B1 and B2.

Table 4-2: OMM Metadata

Keyword	Description	Examples of Values	Mandatory
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 UN Office of Outer Space Affairs designator index (reference [2]), which include Object name and international designator of the participant.	TELKOM 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 UN Office of Outer Space Affairs designator index (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 UN Office of Outer Space Affairs designator index format is not used, the value should be provided in an ICD.	2005-046A 2005-046B 2003-022A	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 B, subsection B2 must be documented and conveyed 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 B, subsection B1 must be documented and conveyed 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 mandatory 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	Mandatory
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

Keyword	Description	Units	Mandatory
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 B, subsections B2 and B3.	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

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 7.5. 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'.

– The value associated with the REF_FRAME keyword shall be 'TEME' (see ANNEX B, subsection B2).

– 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 UN Office of Outer Space Affairs designator index (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 [L3] and [L4])

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 AND SUPPLEMENTARY INFORMATION

Example OMMs and associated supplementary (non-normative) information are provided in Annex F.

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.

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 mandatory 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	Mandatory
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.	3.0	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 drawn from the SANA "Organizations" registry). 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 mandatory 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 B, subsections B1 and B2.

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	Mandatory
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 UN Office of Outer Space Affairs designator index (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 UN Office of Outer Space Affairs designator index (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 UN Office of Outer Space Affairs designator index 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	Mandatory
REF_FRAME	Name of the reference frame in which the ephemeris data are given. Use of values other than those in ANNEX B, subsection B2 must be documented and conveyed 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 ITRF1993 ITRF1997 ITRF2000 ITRFyyyy (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 B, subsection B1 must be documented and conveyed 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	Yes
USEABLE_START_TIME USEABLE_STOP_TIME	Optional start and end of USEABLE time span covered by ephemeris data immediately following this metadata block. To allow for proper interpolation near the ends of the ephemeris data block it may be necessary, depending upon the interpolation method to be used, to utilize these keywords with values within the time span covered by the ephemeris data records as delimited 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	Yes
INTERPOLATION	This keyword may be used to specify the recommended interpolation method for ephemeris data in the immediately following set of ephemeris lines.	Hermite Linear Lagrange	No

Keyword	Description	Examples of Values	Mandatory
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 mandatory; 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.

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: COV_START and COVARIANCE_STOP. The 'COV_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 AND SUPPLEMENTARY INFORMATION

Example OEMs and associated supplementary (non-normative) information are provided in Annex G.

6 ORBIT COMPREHENSIVE MESSAGE (OCM)

6.1 GENERAL

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

6.1.2 The OCM 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.

6.1.3 The units universally used throughout the OCM are meters, kilograms and seconds. This is in contrast to the OPM, OEM and OMM, which use kilometers as the distance measurement.

6.1.4 The OCM 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 OCMs should be decided on a case-by-case basis by the exchange partners and documented in an ICD.

6.1.5 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 Comprehensive Message (OCM). 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 [L8], optional perturbations parameters should be included with this message and the recipient must have a suitably-compatible orbit propagator.

6.1.6 The OCM 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 OCM reflects the dynamic modeling of any users' approach to conservative and non-conservative phenomena.

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

6.2 OCM CONTENT/STRUCTURE

6.2.1 GENERAL

The OCM shall be represented as a combination of the following as shown in Table 6-1. The ordering of these sections is mandatory. The order of occurrence of the OCM sections shall be fixed as shown in table 6-1.

1) one mandatory header;
2) one mandatory metadata section (data about data);
3) optional data section(s), comprised of one or more data constituent types:
   a. one optional space object physical characteristics section
   b. one optional perturbations section
   c. one optional orbit determination data section
   d. one or more optional maneuver data section(s)
   e. one or more optional orbit state time histories
   f. one or more optional covariance time histories
   g. one or more optional State Transition Matrix (STM) time histories
   h. one or more optional Ephemeris Compression (EC) time segments
   i. one optional user-defined section containing data and supplemental comments (explanatory information).

Table 6-1: OCM File Layout and Ordering Specification

Section	Content
Mandatory Header	Header of message
Mandatory Metadata	Metadata (Informational comments recommended but not required.)
Optional Space Object Physical Description	Optional space object physical characteristics, if known.
Optional Perturbations Section	Optional perturbations parameters
Optional Orbit Determination Section	Optional orbit determination data section
Optional Maneuver Section(s)	Optional maneuver specifications for either impulsive or finite burns or acceleration profiles
Optional Orbit Data Section(s)	Optional: One or more orbit state time histories (each consisting of one or more orbit states)
Optional Covariance Data Section(s)	Optional: One or more covariance time histories (each consisting of one or more covariance matrices)
Optional State Transition Matrix Data Section(s)	Optional: One or more state transition matrix time histories (each consisting of one or more state transition matrices)
Optional Ephemeris Compression Data Section(s)	Optional: One or more ephemeris compression sections (each consisting of one or more ephemeris compression segments)
Optional user-defined parameters	Optional: One or more user-defined parameters

6.2.2 OCM HEADER

6.2.2.1 Table 6-2 specifies the keywords for each header item.

6.2.2.2 Only those keywords shown in table 6-2 shall be used in an OCM header.

6.2.2.3 The order of occurrence of these OCM header keywords shall be fixed as shown in table 6-2.

Table 6-2: OCM Header

Keyword	Description	Examples of Values	Mandatory
CCSDS_OCM_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.	3.0	**Yes**
COMMENT	Comments (a contiguous set of one or more comment lines are allowed in the OCM Header only immediately after the OCM 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**

6.2.3 OCM METADATA

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

6.2.3.2 The "OCM Metadata" section is mandatory; "mandatory" in the context of Table 6-3 denotes those keywords which must be included in this section.

6.2.3.3 The OCM shall only contain a single metadata section in the entire scope of the message.

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.

NOTE 2 – While specification of CATALOG_ID, OBJECT_NAME and INTERNATIONAL_DESIGNATOR are each in and of themselves optional, one of these keywords must be supplied.

NOTE 3 – Metadata fields which are relied upon by the subsequent optional OCM message subtypes (orbit state time histories, maneuver data, etc.) are designated as such in the right-hand column of Table 6-3.

6.2.3.4 The order of occurrence of these OCM metadata keywords shall be fixed as shown in table 6-3.

6.2.3.5 The TIME_SYSTEM value must remain fixed within an OCM.

6.2.3.6 Any spacecraft physical characteristics, maneuver, orbit states, covariance and STM values in the OCM data which require time-tagging shall be time-tagged by a relative time value measured with respect to the epoch time specified via the EPOCH_TZERO keyword.

Table 6-3: **OCM Metadata**

Keyword	Description	Default (if any)	Examples of Values	Mandatory	Any OCM sections relying upon this field ?
ORIGINATOR	Creating agency or operator (value should be drawn from the SANA "Organizations" registry). 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	
MESSAGE_ID	ID that uniquely identifies a message from a given originator. The format and content of the message identifier value are at the discretion of the originator.	201113719185 ABC-12_34	OCM 201113719185 ABC-12_34	No	
MESSAGE_CLASSIF	User-defined free-text classification of this OCM		FOUO	No	
EPOCH_TZERO	Epoch to which all OCM relative times are referenced. (For format specification, see 7.5.9.). The time scale of EPOCH_TZERO and relative times are controlled via "TIME_SYSTEM_ABS" and "TIME_SYSTEM_REL" keywords in the metadata section, respectively. Note that times relative to EPOCH_TZERO are double precision and can be negative, zero, or positive values.		2001-11-06T00:00:00	Yes	MNVR, STATES, COVAR STM,
OBJECT_NAME	Free text field containing the spacecraft name for the object.		SPOT, ENVISAT, IRIDIUM, INTELSAT UNKNOWN	No	No
INTERNATIONAL_DESIGNATOR	Free text field containing the full international designator for the object. It is recommended that values have the following 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 object has no international designator, the value UNKNOWN may be used.		2000-052A 1996-068A 2000-053A 1996-008A UNKNOWN	No	No
CATALOG_NAME	Specification of the satellite catalog (or source organization) from which the international designator and catalog ID were obtained. This is a free-text field.	SATCAT	SATCAT, ISON, ESA, COMSPOC, etc.	No	No
CATALOG_ID	Free text field containing the satellite catalog designator for the object.		22444 UNKNOWN	No	No
OBJECT_TYPE	Free text field containing the object type.		PAYLOAD ROCKET BODY UPPER STAGE DEBRIS UNKNOWN OTHER	No	No
DATA_TYPES	Comma-delimited list of data blocks included in this message.		MNVR, ORB, COV, OD, PHYSCHAR, PERTS, STM, EC, ATT, USER	No	No

Commented [DLO2]: More here

Keyword	Description	Default (if any)	Examples of Values	Mandatory	Any OCM sections relying upon this field ?
ORIGINATOR _POC	Free text field containing originator or programmatic Point-of-Contact (PoC) for OCM		Mr. Rodgers	No	No
ORIGINATOR _POSITION	Free text field containing contact position of the originator PoC		Flight Dynamics Mission Design Lead	No	No
ORIGINATOR_PHONE	Free text field containing originator PoC phone number		+49615130312	No	No
ORIGINATOR_ADDRESS	Free text field containing originator PoC address information for OCM creator (suggest email, website, or physical address, etc.)		JOHN.DOE@ SOMEWHERE.NET	No	No
TECH _ORG	Free text field containing name of technical organization for OCM (from SANA ?)		NASA	No	No
TECH _POC	Free text field containing technical Point-of-Contact (PoC) for OCM		Maxwell Smart	No	No
TECH _POSITION	Free text field containing contact position of the technical PoC		Flight Dynamics Mission Design Lead	No	No
TECH _PHONE	Free text field containing technical PoC phone number		+49615130312	No	No
TECH_ADDRESS	Free text field containing technical PoC address information for OCM creator (suggest email, website, or physical address, etc.)		JOHN.DOE@ SOMEWHERE.NET	No	No
START_TIME	Relative time of the earliest of all time tags corresponding to maneuver, orbital state, covariance, and/or STM data. The epoch is specified in timing system “TIME_SYSTEM” (For format specification, see 7.5.9 for absolute time format; relative time is measured in seconds from EPOCH_TZERO)		100.0	No	No
STOP_TIME	Relative time of the end of TOTAL time span covered by ALL maneuver, orbital state, covariance and/or STM data contained in this message. (For format specification, see 7.5.9 for absolute time format; relative time is measured in seconds from EPOCH_TZERO)		1500.0	No	No
TAIMUTC_TZERO	Difference (TAI – UTC) in seconds (i.e. total # leap seconds elapsed since 1958) as modeled by the message originator at epoch “EPOCH_TZERO”.		36 [s]	No	No
TIME_SYSTEM_ABS	Timing system used for the absolute time contained in EPOCH_TZERO. The only allowable entries here are UTC or UT1. **Omission of this non-mandatory field defaults to “UTC”**	**UTC**	UTC UT1	No	MNVR, STATES, COVAR STM, EC
TIME_SYSTEM_REL	Timing system used for all relative time specifications relative to EPOCH_TZERO. **Omission of this non-mandatory field defaults to “UTC”**	**UTC**	UTC TAI	No	MNVR, STATES, COVAR STM, EC
UT1MUTC_TZERO	Difference (UT1 – UTC) in seconds, as modeled by the originator at epoch “EPOCH_TZERO”.		0.357 [s]	No	no
UT1MUTC_RATE_TZERO	Rate-of-change of (UT1 – UTC) in milliseconds per day, as modeled by the originator at epoch “EPOCH_TZERO”		.0001 [ms/day]	No	no

6.2.4 OCM DATA: SPACE OBJECT PHYSICAL CHARACTERISTICS

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

6.2.4.2 Keyword values shall be provided in the units specified in the “Units” column of Table 6-4.

6.2.4.3 The order of occurrence of these OCM Space Objects Physical Characteristics keywords shall be fixed as shown in Table 6-4.

6.2.4.4 The “OCM Data: Space Object Physical Characteristics” section is optional; “mandatory” in the context of Table 6-4 denotes those keywords which must be included in this section if this section is included.

6.2.4.5 Only one space object physical characteristics section shall appear in an OCM.

6.2.4.6 The space object physical characteristics data section in the OCM shall be indicated by two keywords: PHYS_START and PHYS_STOP.

6.2.4.7 Further definition of Space Object Physical Characteristics parameters is provided in ANNEX C.

6.2.4.8 OEB_Q1 = 0.03123

6.2.4.9 OEB_Q2 =

6.2.4.10 OEB_Q3 =

6.2.4.11 OEB_QC =

Table 6-4: OCM Data: Space Object Physical Characteristics

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
PHYS_START	Start of a Space Object Physical Characteristics specification	n/a			Yes
COMMENT	Comments (a contiguous set of one or more comment lines are allowed in the OCM Space Object Physical Characteristics only immediately after the PHYS_START key word; see 7.7 for comment formatting rules).	n/a		COMMENT This is a comment	No
DRAG_AREA	Additional Drag Area (A_D) facing the relative wind vector, not already incorporated into the attitude-dependent “AREA_ALONG_OEB” parameters	m**2		2.5	No
DRAG_COEFF	Drag Coefficient (C_D). If the atmospheric drag coefficient, CD, is set to zero, no atmospheric drag shall be taken into account.	n/a		2.2	No
DRAG_SCALE	Drag scale factor (1.0 represents no scaling). This factor is intended to allow operators to supply the nominal ballistic coefficient components while accommodating ballistic coefficient uncertainties (i.e. 1.06 represents a +6 percent error)	n/a	1.0	1.0	No

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
MASS	S/C Mass at the reference epoch "EPOCH_TZERO"	kg		500	No
OEB_PARENT_FRAME	Name of the reference frame which maps to the Optimally-Encompassing Box (OEB) frame via the Euler sequence OEB_ROLL and OEB_YAW. **Allowable values include all entries contained in ANNEX B, subsections B2 and B3, as well as SC_BODY or a unique ID as documented and conveyed in an ICD**.	n/a	RIC	ITRF1997	No
OEB_PARENT_FRAME_EPOCH	Epoch of the OEB 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 required and not intrinsic to the selected reference frame, omission of this optional field defaults to the time stored in EPOCH_TZERO.**	n/a	**EPOCH_ TZERO**	2001-11-06T11:17:33 2002-204T15:56:23Z	No
OEB_Q1	$q_1 = e_1 * \sin(\theta/2)$, where θ = Euler rotation angle and e_1 = 1st component of Euler rotation axis for the rotation that maps from the OEB_PARENT_FRAME (defined above) to the frame aligned with the optimally-Encompassing Box (defined in ANNEX C). A value of "-999" denotes a tumbling space object.	n/a		0.03123	No
OEB_Q2	$q_2 = e_2 * \sin(\theta/2)$, where θ = Euler rotation angle and e_2 = 2nd component of Euler rotation axis for the rotation that maps from the OEB_PARENT_FRAME (defined above) to the frame aligned with the optimally-Encompassing Box (defined in ANNEX C). A value of "-999" denotes a tumbling space object.	n/a		0.78543	No
OEB_Q3	$q_3 = e_3 * \sin(\theta/2)$, where θ = Euler rotation angle and e_3 = 3rd component of Euler rotation axis for the rotation that maps from the OEB_PARENT_FRAME (defined above) to the frame aligned with the optimally-Encompassing Box (defined in ANNEX C). A value of "-999" denotes a tumbling space object.	n/a		0.39158	No
OEB_QC	$q_c = \cos(\theta/2)$, where θ = Euler axis/angle rotation angle for the rotation that maps from the OEB_PARENT_FRAME (defined above) to the frame aligned with the optimally-Encompassing Box (defined in ANNEX C). q_c shall be made non-negative by convention. A value of "-999" denotes a tumbling space object.	n/a		0.47832	No
OEB_MAX	Maximum physical dimension (along $\hat{X}_{OEB}$) of the Optimally-Encompassing Box (OEB) in meters,	m		1	No
OEB_MED	Medium physical dimension (along $\hat{y}_{OEB}$) of Optimally-Encompassing Box (OEB) normal to OEB_MAX direction	m		0.5	No
OEB_MIN	Minimum physical dimension (along $\hat{z}_{OEB}$) of Optimally-Encompassing Box (OEB) in direction normal to both OEB_MAX and OEB_MED directions	m		0.3	No
AREA_ALONG_OEB_MAX	Cross-sectional area of space object when viewed along max OEB ($\hat{X}_{OEB}$) direction as defined in ANNEX C	m**2		0.15	No
AREA_ALONG_ OEB_MED	Cross-sectional area of space object when viewed along medium OEB ($\hat{y}_{OEB}$) direction as defined in ANNEX C	m**2		0.3	No

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
AREA_ALONG_ OEB_MIN	Cross-sectional area of space object when viewed along minimum OEB ($\hat{Z}_{OEB}$) direction as defined in ANNEX C	m**2		0.5	No
RCS	Effective Radar Cross Section of the object	m**2		1.0	No
SOLAR_RAD_AREA	Additional total Solar Radiation Pressure Area (A_R) facing the Sun, not already incorporated into the attitude-dependent "AREA_ALONG_OEB" parameters (computed from { AREA_ALONG_OEB_MAX $\cos(\theta_1)$ + AREA_ALONG_OEB_MED $\cos(\theta_2)$ + AREA_ALONG_OEB_MIN $\cos(\theta_3)$ } Where θ_i represents the angle between the normal to each MAX/MED/MIN face and the direction to the Sun.	m**2		1.0	No
SOLAR_RAD_COEFF	Solar Radiation Pressure Coefficient (C_R). Note that if the solar radiation coefficient, CR, is set to zero, no solar radiation pressure shall be taken into account.	n/a		1.7	No
SOLAR_RAD_SCALE	Solar Radiation Pressure scale factor (1.0 represents no scaling)	n/a		1.0	No
VM_ABS	Absolute Visual Magnitude "normalized" as discussed in ANNEX E to a 1 AU Sun-to-target distance, a phase angle of 0° and a 40,000 km target-to-sensor distance (equivalent of GEO satellite tracked at 15.6° above local horizon)	n/a		15.0	No
IXX	Moment of Inertia about the X-axis of the spacecraft's primary body frame (e.g. SC_Body_1)	kg*m **2		1000.0	No
IYY	Moment of Inertia about the Y-axis	kg*m **2		800.0	No
I33IZZ	Moment of Inertia about the Z-axis	kg*m **2		400.0	No
I12IXY	Inertia Cross Product of the X & Y axes	kg*m **2		20.0	No
I13IXZ	Inertia Cross Product of the X & Z axes	kg*m **2		40.0	No
I23IYZ	Inertia Cross Product of the Y & Z axes	kg*m **2		60.0	No
PHYS_STOP	End of a Space Object Physical Characteristics specification	n/a			Yes

6.2.5 OCM DATA: PERTURBATIONS SPECIFICATION

6.2.5.1 Table 6-5 provides an overview of the OCM Perturbations Specification section. Only those keywords shown in Table 6-5 shall be used in OCM perturbations specification.

6.2.5.2 Keyword values shall be provided in the units specified in the "Units" column of Table 6-5.

6.2.5.3 The order of occurrence of these OCM Perturbations Specification keywords shall be fixed as shown in Table 6-5.

6.2.5.4 The OCM Perturbations Specification section is optional; “mandatory” in the context of Table 6-5 denotes those keywords which must be included in this section if this section is included.

6.2.5.5 Only one OCM Perturbations Specification section shall appear in an OCM.

6.2.5.6 The OCM Perturbations Specification section shall be delimited by two keywords: PERT_START and PERT_STOP.

Table 6-5: OCM Data: Perturbations Specification

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
PERT_START	Start of the perturbations specification	n/a			Yes
COMMENT	Comments (a contiguous set of one or more comment lines are allowed in the OCM Perturbations Specification only immediately after the PERT_START key word; see 7.7 for comment formatting rules).	n/a		COMMENT This is a comment	No
ATMOSPHERIC_MODEL	Name of atmosphere model. This is a free text field, so if the examples on the right are insufficient, others may be used.	n/a		MSISE90 NRLMSIS00 J70 J71 JRob DTM JB2008 …	No
GRAVITY_MODEL	The name of the geopotential model for central body, followed by the degree and order of the spherical harmonic coefficients applied. Note that specifying a zero value for “order” (i.e. 2 0) denotes zonals ($J_2 \cdots J_D$) only. This is a free text field, so if the examples on the right are insufficient, others may be used.	n/a		EGM-96: 36 36 WGS-84: 8 8 GGM-01: 12 12 TEG-4: 8 2	No
EOP_SOURCE	Source of originator’s Earth orientation parameters. This is a free text field, so if the examples on the right are insufficient, others may be used.	n/a		IERS USNO NGA …	No
EQUATORIAL_RADIUS	Oblate spheroid equatorial radius	km		6378.137	No
GM	Gravitational Coefficient of attracting body (Gravitational Constant x Central Mass)	km**3/ s**2		398600.4	No
INTERP_METHOD_EOP	Used for EOP data	n/a		LINEAR	No
INTERP_METHOD_SPWX	Used for Space Weather data (SOLAR_F10P7, SOLAR_F10P7_MEAN, SOLAR_M10P7, SOLAR_S10P7, SOLAR_Y10P7, GEOMAG_AP, GEOMAG_DST, GEOMAG_KP)	n/a		NONE LINEAR	No
GEOMAG_AP	Planetary 3-hour-range Geomagnetic index Ap at EPOCH_TZERO. The Ap index reports the amplitude of planetary geomagnetic activity for a given day and is translated from the Kp index, which is derived from geo--- magnetic field measurements made at several locations around the world.	nT		21	No
GEOMAG_KP	Planetary 3-hour-range Geomagnetic index Kp at EPOCH_TZERO.	nT		3.2	No

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
GEOMAG_DST	Planetary 1-hour-range Geomagnetic index Dst at EPOCH_TZERO. The Disturbance Storm Time (Dst) index is an indicator of the strength of the storm-time ring current in the inner magnetosphere.	nT		-20	No
N_BODY_PERTURBATIONS	N-body gravitational perturbations used, each separated by a comma. This is a free text field, but values should be consistent with the SANA registry [P-17] list of celestial bodies whenever possible.	n/a		MOON, SUN, JUPITER	No
CENTRAL_BODY_ROTA	Central body angular rotation rate, measured about the major principal axis of the inertia tensor of the central body, relating inertial and central-body-fixed reference frames.	deg/s		4.17807421629e-3	No
OBLATE_FLATTENING	Inverse of the central body's oblate spheroid oblateness for the polar-symmetric oblate central body model.	n/a		298.257223563	No
OCEAN_TIDES_MODEL	Name of ocean tides model (optionally specify order or constituent effects (diurnal, semi-diurnal, etc.)	n/a		DIURNAL SEMI-DIURNAL	No
SOLID_TIDES_MODEL	Name of solid tides model (optionally specify order or constituent effects (diurnal, semi-diurnal, etc.)	n/a		DIURNAL SEMI-DIURNAL	No
PERT_CENTER_NAME	Origin of the perturbations 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, other defined positional references (e.g. Lagrange points) or another spacecraft (in this case the value for 'PERT_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]).	n/a	EARTH	EARTH MOON SOLAR SYSTEM BARYCENTER SUN ISS EROS EARTH_SUN_L2	No
REDUCTION_THEORY	Specification of the reduction theory used for precession and nutation modeling. This is a free text field, so if the examples on the right are insufficient, others may be used.	n/a		IAU1976/FK5 IAU2010 IERS1996	No
DX	Free core nutation and time dependent corrections for the X coordinate of the CIP in the ICRS, at EPOCH_TZERO	arcsec		–0.000 205	No
DY	Free core nutation and time dependent corrections for the Y coordinate of the CIP in the ICRS, at EPOCH_TZERO	arcsec		–0.000 136	No
NUTATION_DEPS	Nutation in obliquity $d\varepsilon$ for 1980 IAU Theory of Nutation model, at EPOCH_TZERO	deg		0.002 031 6	No
NUTATION_DPSI	Nutation in longitude $d\psi$ for 1980 IAU Theory of Nutation model, at EPOCH_TZERO	deg		−0.003 410 8	No
D_NUTATION_DEPS	Correction to Nutation in obliquity δdeps to maintain compatibility with the ICRS.	arcsec		–0.003 875	No
D_NUTATION_DPSI	Correction to Nutation in longitude δdpsi to maintain compatibility with the ICRS.	arcsec		–0.052 195	No
S_PRECNUT	The S parameter provides the position of the Celestial Intermediate Origin (CIO) on the equator of the Celestial Intermediate Pole (CIP) corresponding to the kinematical definition of the [non-rotating origin] in the GCRS when the CIP is moving with respect to the GCRS between the reference epoch and the epoch due to precession and nutation (McCarthy and Petit 2003). (Vallado 2013:214)	arcsec		−0.003 021	No

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
X_PRECNUT	The X-coordinate of the CIP in the ICRS frame, used to locate the GCRF position and velocity vectors [L9]	arcsec		80.531 880	No
Y_PRECNUT	The Y-coordinate of the CIP in the ICRS frame, used to locate the GCRF position and velocity vectors [L9]	arcsec		7.273 921	No
POLAR_MOTION_XP	Polar motion coordinate Xp of the Celestial Intermediate Pole at EPOCH_TZERO	arcsec			No
POLAR_MOTION_YP	Polar motion coordinate Yp of the Celestial Intermediate Pole at EPOCH_TZERO	arcsec			No
ALBEDO	Name of the albedo model	n/a			No
ALBEDO_GRID_SIZE	# of grid points used in the albedo model	n/a			No
SHADOW_MODEL	Shadow modeling for Solar Radiation Pressure; dual cone uses both umbra/penumbra regions. Selected option should be one of “NONE”, “CYLINDRICAL” or “DUAL CONE”	n/a		NONE CYLINDRICAL DUAL CONE	No
SOLAR_F10P7	Solar flux proxy F10.7 at EPOCH_TZERO	Solar Flux Units = 10^4 Jansky = 10^{-22} W/(m^2 *Hz)		120.0	No
SOLAR_F10P7_MEAN	81-day running center-averaged solar flux proxy $\overline{F10.7}$ at EPOCH_TZERO	Solar Flux Units = 10^4 Jansky = 10^{-22} W/(m^2 *Hz)		132.0	No
SOLAR_M10P7	Solar flux daily proxy M10.7 at EPOCH_TZERO, derived from the Mg II core--- o---wing ratio that originated from the NOAA series operational satellites, e.g., NOAA---16,---17,---18, which host the Solar Backscatter Ultraviolet (SBUV) spectrometer	10^{-22} W/(m^2 *Hz)		120.0	No
SOLAR_M10P7_MEAN	Solar flux 81-day running center-averaged proxy M10.7 at EPOCH_TZERO, derived from the Mg II core--- o---wing ratio that originated from the NOAA series operational satellites, e.g., NOAA---16,---17,---18, which host the Solar Backscatter Ultraviolet (SBUV) spectrometer	10^{-22} W/(m^2 *Hz)		120.0	No
SOLAR_S10P7	Solar flux daily index S10.7 at EPOCH_TZERO, the integrated 26–34 nm solar irradiance that is measured by the Solar Extreme Ultraviolet Monitor (SEM) instrument on the NASA/ESA Solar and Heliospheric Observatory (SOHO) research satellite	10^{-22} W/(m^2 *Hz)		120.0	No
SOLAR_S10P7_MEAN	Solar flux 81-day running center-averaged index S10.7 at EPOCH_TZERO, the integrated 26–34 nm solar irradiance that is measured by the Solar Extreme Ultraviolet Monitor (SEM) instrument on the NASA/ESA Solar and Heliospheric Observatory (SOHO) research satellite	10^{-22} W/(m^2 *Hz)		120.0	No

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
SOLAR_Y10P7	Solar flux daily index Y10.7 at EPOCH_TZERO, the composite solar index of the X_{b10} and Lyman-α indices, weighted to represent mostly X_{b10} during solar maximum and to represent mostly Lyman-α during moderate and low solar activity	10^{-22} W/(m^2 *Hz)		120.0	No
SOLAR_Y10P7_MEAN	Solar flux 81-day running center-averaged index Y10.7 at EPOCH_TZERO, the composite solar index of the X_{b10} and Lyman-α indices, weighted to represent mostly X_{b10} during solar maximum and to represent mostly Lyman-α during moderate and low solar activity	10^{-22} W/(m^2 *Hz)		120.0	No
SRP_MODEL	Name of SRP model. This is a free text field, so if the examples on the right are insufficient, others may be used.	n/a		GPS_ROCK BOX_WING CANNONBALL COD …	No
PERT_STOP	End of the perturbations specification	n/a			Yes

6.2.6 OCM DATA: ORBIT DETERMINATION DATA

6.2.6.1 Table 6-6 provides an overview of the OCM orbit determination data section. Only those keywords shown in Table 6-6 shall be used in OCM orbit determination data specification.

6.2.6.2 Keyword values shall be provided in the units specified in the "Units" column of Table 6-6.

6.2.6.3 The order of occurrence of these OCM Orbit Determination Data keywords shall be fixed as shown in Table 6-6.

6.2.6.4 The "OCM Data: Orbit Determination Data" section is optional; "mandatory" in the context of Table 6-6 denotes those keywords which must be included in this section if this section is included.

6.2.6.5 Only one Orbit Determination Data section shall appear in any OCM.

6.2.6.6 Orbit determination data in the OCM shall be indicated by two keywords: OD_START and OD_STOP.

6.2.6.7 All orbit determination event times shall be specified relative to the orbit determination epoch specified via the OD_EPOCH keyword (in SI days, with one day = 86400.0 s) as a double precision number. Event times may be negative, zero or positive, depending upon the definition of the event time (i.e., OD_EPOCH with respect to event time versus event time with respect to OD_EPOCH).

Table 6-6: OCM Data: Orbit Determination Data

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
OD_START	Start of an orbit determination data section	n/a		n/a	Yes
COMMENT	Comments (a contiguous set of one or more comment lines are allowed in the OCM Orbit Determination Data section only immediately after the OD_START key word; see 7.7 for comment formatting rules).	n/a		COMMENT This is a comment	No
OD_ID	Optional identification number for this orbit determination	n/a		OD_20160402	No
OD_PREV_ID	Optional identification number for the previous orbit determination. Note: if this orbit determination is the first one, then OD_PREV_ID should be excluded from this message.	n/a		OD_20160401	No
OD_METHOD	Type of orbit determination method used to produce the orbit estimate. Commonly used methods include Batch Weighted Least Squares (BWLS), the Extended Kalman Filter (EKF).	n/a		BWLS, EKF	Yes
OD_EPOCH	Epoch of the orbit determination solved-for state (See 7.5.9 for formatting rules.) **Where the orbit determination epoch is not supplied, omission of this optional field defaults to EPOCH_TZERO.**	n/a	If not specified, then EPOCH_TZERO is assumed	2001-11-06T11:17:33 2002-204T15:56:23Z	No
DAYS_SINCE_FIRST_OBS	Days (SI day = 86400.0 seconds) elapsed between first accepted observation and OD_EPOCH	d		3.5	No
DAYS_SINCE_LAST_OBS	Days (SI day = 86400.0 seconds) elapsed between last accepted observation and OD_EPOCH	d		1.2	No
RECOMMENDED_OD_SPAN	Number of days (SI day = 86400.0 seconds) of observations recommended for the OD of the object ***(useful only for Batch OD systems)***	d		5.2	No
ACTUAL_OD_SPAN	Actual time span in days (SI day = 86400.0 seconds) used for the OD of the object (NOTE: should equal (DAYS_SINCE_FIRST_OBS - DAYS_SINCE_LAST_OBS)	d		2.3	No
OBS_AVAILABLE	The number of observations available within the actual OD time span	n/a		100	No
OBS_USED	The number of observations accepted within the actual OD time span	n/a		90	No
TRACKS_AVAILABLE	The number of sensor tracks, for the actual time span, that were available for the OD	n/a		33	No
TRACKS_USED	The number of sensor tracks, for the actual time span, that were accepted for the OD	n/a		30	No
MAXIMUM_OBS_GAP	The maximum time between observations in the OD of the object	d		1.0	No
OD_EPOCH_EIGMAJ	Positional error ellipsoid 1σ major eigenvalue at the epoch of the OD	km		.05873	No
OD_ EPOCH_EIGMED	Positional error ellipsoid 1σ medium eigenvalue at the epoch of the OD	km		.0357	No
OD_EPOCH_EIGMIN	Positional error ellipsoid 1σ minor eigenvalue at the epoch of the OD	km		.0215	No
OD_CONFIDENCE	OD confidence metric, which by definition spans 0 to 100%. (useful only for Filter-based OD systems). The OD confidence metric should be defined by ICD.	Percent		95.3	No

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
WEIGHTED_RMS	***(Useful / valid only for Batch OD systems).*** The weighted RMS residual ratio, defined as: $Weighted\ RMS = \sqrt{\frac{\sum_{i=1}^{N} w_i (y_i - \hat{y}_i)^2}{N}}$ Where y_i is the observation measurement at the ith time $\hat{y}_i$ is the current estimate of yi, $w_i = \frac{1}{\sigma_i^2}$ is the weight (sigma) associated with the measurement at the ith time and N is the number of observations. This is a value that can generally identify the quality of the most recent vector update, and is used by the analyst in evaluating the OD process. A value of 1.00 is ideal.	(measurement units)		1.3	No
TRK_MESSAGE_IDS	An alphanumeric free-text string containing a comma-separated list of file name(s) and/or associated identification number(s) of Tracking Data Message (TDM) [9] observations upon which this OD is based.	n/a		TDM_0005.txt	No
DATA_TYPES	Comma-separated list of observation data types utilized in this orbit determination. Although this is a free-text field, it is recommended at a minimum to use data type descriptor(s) as provided in Table 3-5 of the TDM standard [9] (excluding the DATA_START, DATA_STOP, and COMMENT keywords). Orbit determine event times are in double precision days. Additional descriptors/detail is encouraged if the descriptors of Table 3-5 are not sufficiently clear, e.g., could replace ANGLE_1 and ANGLE_2 with RADEC (e.g., from a telescope), AZEL (e.g., from a ground radar), RANGE (whether from radar or laser ranging), etc.	n/a		n/a	No
OD_STOP	End of an orbit determination data section	n/a		n/a	Yes

6.2.7 OCM DATA: MANEUVER SPECIFICATION

6.2.7.1 Table 6-7 provides an overview of the OCM maneuver specification section. Only those keywords shown in Table 6-7 shall be used in the OCM maneuver specification.

6.2.7.2 Keyword values shall be provided in the units specified in the “Units” column of Table 6-7.

6.2.7.3 The order of occurrence of these OCM Maneuver Specification keywords shall be fixed as shown in Table 6-7.

6.2.7.4 The “OCM Data: Maneuver Specification” section is optional; “mandatory” in the context of Table 6-7 denotes those keywords which must be included in this section if this section is included.

6.2.7.5 Maneuver data in the OCM shall be indicated by two keywords: MAN_START and MAN_STOP.

6.2.7.6 Impulsive, thrusting, acceleration and attitude maneuver data in the OCM data shall be time-tagged by a relative time value measured with respect to the epoch time specified via the EPOCH_TZERO keyword.

6.2.7.7 The thrusting and attitude maneuver specifications include the ability to specify duty cycles based on either a reference direction or reference time. As such, specification of the reference direction or reference time is mandatory in the event that the “Phase angle start,” “Phase angle stop” and “Duty cycle ratio” are provided and invoked. Optionally, “Minimum number of repeats” and “Maximum number of repeats” may be specified.

6.2.7.8 For Delta-V-defined maneuvers (MAN_TYPE=DELTAV), each ΔV maneuver within the ΔV time series shall be specified on a single line that contains eight parameters:

1) The **Maneuver Object Number (MON)** that this Delta-V maneuver definition is to be applied to (nominally “0” for the primary or host vehicle)
2) Time “T_Relative” in **seconds**
3) Velocity increment ΔV_X in the selected maneuver reference frame **in m/s**
4) Velocity increment ΔV_y in the selected maneuver reference frame **in m/s**
5) Velocity increment ΔV_z in the selected maneuver reference frame **in m/s**
6) The maneuver duration (0=impulsive; non-zero for Delta-V accumulated over specified time duration, assumed to be centered about the specified maneuver time, in seconds)
7) One-sigma percentage error on ΔV magnitude **in m/s**
8) The mass change **in kg** (where a NEGATIVE VALUE denotes a mass decrement/loss) associated with a ΔV imparted to the host (i.e., MON = 0) or the mass (defined as a POSITIVE VALUE) of the deployed object (if MON ≠ 0)

6.2.7.8.1 NOTE: Unique to MAN_TYPE=DELTAV, t**he** Maneuver Object Number (MON) is defined whereby a non-zero MON invokes a parent/child deployment scenario, with the parent "host" object (MON=0) deploying one or more child space objects by imparting an impulsive ΔV to the deployed object as specified by (ΔV_X, ΔV_Y, ΔV_Z in km/s). The 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) and as directed by the OCM creator, recipients of OCMs using the parent/child deployment capability may need to model/incorporate both the child's 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).

Commented [OD3]: Make impulse be Delta-V throughout

Commented [OD4]: Need to provide an example of how this works.

6.2.7.9 For thrusting (finite burns, MAN_TYPE=THRUST), each thrusting maneuver (or, in the case of low-thrust, long-duration burns, each low-thrust interval) within the maneuver series shall be specified on a single line that contains seventeen parameters. The THRUST option only applies to a single (parent) object. The message creator may indicate a change in thrust conditions over which interpolation should not be performed by providing exactly two adjacent lines containing the same time stamp. The seventeen parameters shall be:

1) Thruster ID (non-negative integer number)
2) Time "T_Relative" at the start of this thrust interval in **seconds**
3) Thrust component Tx measured in the selected maneuver reference frame in **Newtons**
4) Thrust component Ty measured in the selected maneuver reference frame in **Newtons**
5) Thrust component Tz measured in the selected maneuver reference frame in **Newtons**
6) One-sigma percentage error on thrust magnitude
7) Maneuver duration in **seconds** (measured with respect to the START of the specified thrust interval)
8) Thrust vector Euler axis/angle interpolation mode between current and next thrust line (0=OFF and 1=ON)
9) Specific impulse in **seconds**
10) Burn efficiency "η" (e.g. 0.95)
11) Additional mass change (where a negative number denotes a mass decrement/loss) associated with this thrust interval (**kg**)
12) Burn phase angle start (**deg**)
13) Burn phase angle stop (**deg**)
14) Minimum number of "ON" cycles
15) Maximum number of "ON" cycles
16) Duty cycle "ON" duration, initiated at first satisfaction of the burn "on" phase angle range constraint or at completion of a Duty Cycle "OFF" duration (in **seconds)**
17) Duty cycle "OFF" duration, initiated at the completion of a burn "ON" phase angle range constraint (in **seconds)**

Note that a maneuver can be specified as a time history sequence of lines, each containing these seventeen parameters. Note also that thrust interval data may be abutting, overlapping, alternating or even intermingled in the maneuver time history block, to accommodate multiple thrusters simultaneously in operation or to accommodate changes in thrust direction, efficiency, mass change, etc.

6.2.7.10 An acceleration profile (MAN_TYPE=ACCEL) specification allows aggregate modeling of both maneuvers and additional non-conservative perturbations that are not already specified in the "OCM Perturbations Specification" section above. This allows the OCM originator to model and share such maneuver and perturbations information without the OCM recipient needing to do such modeling. The message creator may indicate a change in acceleration over which interpolation should not be performed by providing exactly two adjacent lines containing the same time stamp. The acceleration time series shall be specified on a single line that contains eight parameters:

1) Time "T_Relative" at the start of this acceleration interval in **seconds**
2) Acceleration component A_X in the selected maneuver frame **in m/s**2**
3) Acceleration component A_y in the selected maneuver frame **in m/s**2**
4) Acceleration component A_z in the selected maneuver frame **in m/s**2**
5) One-sigma percentage error on acceleration magnitude
6) Maneuver duration in **seconds** (measured with respect to the START of the specified acceleration interval time)
7) Mass change **in kg** (where a negative number denotes a mass decrement/loss) associated with this acceleration interval
8) Acceleration vector Euler axis/angle interpolation mode between current and next acceleration line (0=OFF and 1=ON)

6.2.7.11 Each maneuver time history data block must begin with keyword MAN_START and end with keyword MAN_STOP.

6.2.7.12 Each of these keywords shall appear on a line by itself.

6.2.7.13 Multiple maneuver data blocks shall only appear in an OCM if all of the following are true:

6.2.7.13.1 They are delimited by separate MAN_START and MAN_STOP keywords;

6.2.7.13.2 Each data block is clearly differentiated from the others by one or more preceding comment(s) or by ICD agreement.

6.2.7.13.3 Each maneuver data block is unique from all other maneuver data blocks in at least one of the following respects:

1) the data basis (PREDICTED, DETERMINED)
2) the maneuver is based upon a unique orbit determination, attitude determination, navigation solution or Monte Carlo simulation;
3) the maneuver type (MAN_TYPE) is unique
4) the reference frame is unique
5) the orbit center is unique
6) the data interval timespan is unique (i.e., has no overlap with any other data interval(s))
7) the thruster ID is different

Table 6-7: OCM Data: Maneuver Specification

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
MAN_START	Start of a maneuver data block specification	n/a			Yes
COMMENT	Comments (a contiguous set of one or more comment lines are allowed in the OCM Maneuver Specification only immediately after the MAN_START key word; see 7.7 for comment formatting rules).	n/a		COMMENT This is a comment	No
MAN_ID	Optional alphanumeric free-text string containing the identification number for this maneuver	n/a		E/W 20160305B	No
MAN_PREV_ID	Optional alphanumeric free-text string containing the identification number for the previous maneuver. Note: if the message is not part of a sequence of maneuver messages or if this maneuver is the first in a sequence of maneuvers, then MAN_PREV_ID should be excluded from this message.	n/a		E/W 20160305A	No
MAN_NEXT_ID	Optional alphanumeric free-text string containing the identification number for the next maneuver. Note: if the message is not part of a sequence of maneuver messages or if this maneuver is the last in a sequence of maneuvers, then MAN_NEXT_ID should be excluded from this message.	n/a		E/W 20160305C	No
MAN_PURPOSE	The user can specify the intention(s) of the maneuver. Multiple maneuver purposes can be provided as a comma-delimited list. While there is no CCSDS-based restriction on the value for this free-text keyword, it is suggested to use: Aerobraking (AEROBRAKE), Attitude adjust (ATT_ADJUST) Collision avoidance (COLA) Disposal (DISPOSAL) Flyby targeting (FLYBY_TARG) Launch & Early Orbit (LEOP) Maneuver cleanup (MNVR_CLEANUP) Mass adjust (MASS_ADJUST) Momentum desaturation (MOM_DESAT) Orbit adjust (ORBIT_ADJUST) Orbit trim (TRIM) Other (OTHER) Period reduction (PER_RED) Pointing Request Message (PRM_ID_xxxx) Relocation (RELOCATION) Science objective (SCI_OBJ) Spin rate adjust (SPIN_RATE_ADJUST) Station-keeping (SK) Trajectory correction (TRAJ_CORR)	n/a		DISPOSAL	No
MAN_WIN_START	Identifies the start of maneuver window that may be different than the maneuver execution start time. This may identify the time at which the satellite is placed into a special maneuver attitude control mode, for example (See 7.5.9 for formatting rules.)	n/a		2001-11-06T11:17:33 2002-204T15:56:23Z	No
MAN_WIN_STOP	Identifies the end of the maneuver window that may be different than the maneuver execution end time. This may identify the end time of any special maneuver attitude control mode, for example (See 7.5.9 for formatting rules.)	n/a		2001-11-06T11:17:33 2002-204T15:56:23Z	No
MAN_BASIS	Basis of this maneuver time history data, selected from “PREDICTED“ or “DETERMINED” for orbit determination-based reconstruction.	**n/a**	**PREDICTED**	DETERMINED PREDICTED	No

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
MAN_PRED_SOURCE	For predicted maneuvers, specifies the source of the orbit and/or attitude state(s) upon which the maneuver is based. While there is no CCSDS-based restriction on the value for this free-text keyword, it is suggested to use ORB_ID, OD_ID, ATT_ID from Indicate that the value for this keyword is recommended to be a value for keywords described in Tables 6-7, 6-9, 6-12 respectively, or a combination thereof.	n/a		OD_5	No
MAN_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, other defined positional references (e.g. Lagrange points) or another spacecraft (in this case the value for 'MAN_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]).	n/a	EARTH	EARTH MOON SOLAR SYSTEM BARYCENTER SUN ISS EROS EARTH_SUN_L2	No
MAN_REF_FRAME	Name of the reference frame in which the maneuver vector direction data is provided, if not intrinsic to the definition of the maneuver data. Use of values other than those in ANNEX B, subsections B2 and B3 must be documented and conveyed in an ICD. The reference frame must be the same for all data elements within a given Maneuver Time History interval.	n/a	TNW	EME2000	No

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
MAN_FRAME_EPOCH	Epoch of the maneuver 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 required and not intrinsic to the selected reference frame, omission of this optional field defaults to EPOCH_TZERO.**	n/a		2001-11-06T11:17:33 2002-204T15:56:23Z	No
MAN_TYPE	Specifies type of maneuver being specified. Select impulsive ΔV (MAN_TYPE = DELTAV) or finite burn thrust (MAN_TYPE = THRUST), acceleration profile (MAN_TYPE = ACCEL) time history or attitude (MAN_TYPE = ATTITUDE) - (see 6.2.6.9, 6.2.6.10, 6.2.6.11 and 6.2.6.12 for details). The maneuver data follows this MAN_TYPE specifier line.	n/a		DELTAV THRUST ACCEL ATTITUDE	Yes
MAN_DUTY_CYCLE_TYPE	Specifies the type of duty cycle type to use for these maneuver time history section: NONE denotes full/continuous thrust; TIME denotes a reference time-based duty cycle; and DIR denotes a reference direction-based duty cycle **Omission of this optional field defaults to NONE**	n/a		NONE TIME DIR	No
MAN_DC_REF_TIME	Specifies the THRUST duty cycle "on" reference time measured in seconds from EPOCH_TZERO. **Omission of this optional field defaults to zero (i.e., at EPOCH_TZERO)**	s		8000.0	No
MAN_DC_REF_DIR	Specifies the THRUST duty cycle "on" reference unit vector direction in the "MAN_REF_FRAME" reference frame	n/a		1.0 0.0 0.0	No
MAN_DC_BODY_TRIGGER_DIR	Specifies the THRUST duty cycle "on" reference unit vector direction in the "MAN_REF_FRAME" reference frame	n/a		1.0 0.0 0.0	No
… < Insert maneuver lines here>	Each maneuver line contains the time tag of the maneuver information measured in seconds from EPOCH_TZERO, followed the corresponding maneuver elements (defined by MAN_TYPE)				Yes
MAN_STOP	End maneuver data block specification	n/a			Yes

Duty cycle on + duration
Duty cycle off + duration

6.2.8 OCM DATA: ORBIT STATE TIME HISTORY

6.2.8.1 Table 6-8 provides an overview of the OCM orbit state time history (“ephemeris”) section. Only those keywords shown in Table 6-8 shall be used in the OCM orbit state time history data specification.

6.2.8.2 Keyword values shall be provided in the units specified in the “Units” column of Table 6-8.

6.2.8.3 The order of occurrence of these orbit state time history keywords shall be fixed as shown in Table 6-8.

6.2.8.4 The orbit state time history section is optional; “mandatory” in the context of Table 6-8 denotes those keywords which must be included in this section if this section is included.

6.2.8.5 Each orbit state time history data block must begin with keyword ORB_START and end with keyword ORB_STOP.

6.2.8.6 Each of these keywords shall appear on a line by itself.

6.2.8.7 Multiple orbit state data blocks shall only appear in an OCM if:

6.2.8.7.1 They are delimited by separate ORB_START and ORB_STOP keywords;

6.2.8.7.2 Each data block is clearly differentiated from the others by one or more precluding comment(s) or by ICD agreement

6.2.8.7.3 Each data block should be unique from all others in at least one of the following respects:

1) the selected orbit state element set (ORB_TYPE) is unique
2) the orbit state time history is based upon a unique orbit determination, attitude determination or navigation solution
3) the reference frame is unique
4) the orbit center is unique
5) the data interval usable timespan is unique (i.e., has no overlap with any other data interval(s))

Commented [DLO5]: Fix this to permit slight overlaps at boundary conditions
Usable start/stop

6.2.8.8 All orbit state values in the OCM data shall be time-tagged by a relative time value measured with respect to the epoch time specified via the EPOCH_TZERO keyword.

6.2.8.9 Each orbit state time history shall be time-ordered to be monotonically increasing, with the exception that the message creator may indicate a change in state over which interpolation should not be performed by providing exactly two consecutive lines containing a duplicate timestamp (e.g. following application of an impulsive maneuver or spacecraft or orbit event). In the case of such a duplicate timestamp, interpolation prior to the duplicate timestamp shall use the first of the two duplicate timestamp orbit states, and interpolation after the duplicate timestamp shall use the second of the two.

6.2.8.10 If the user includes orbit states at key mission event times, it is recommended that those mission event states be annotated as such by a preceding descriptive comment line.

6.2.8.11 Time tags of consecutive orbit states within the ordered sequence may be separated by uniform or non-uniform step size(s).

6.2.8.12 Orbit state time tags may or may not match those of maneuver, covariance and/or state transition matrix time histories.

6.2.8.13 Each line of orbit ephemeris data shall be provided in fixed order as: T_Relative followed by the orbit state as defined in ANNEX B, subsection B4.

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

6.2.8.15 The digits of precision and time steps suitable for interpolation of an orbit ephemeris time history should be chosen according to best practice to avoid positional and interpolation loss of precision [L8].

Table 6-8: OCM Data: Orbit State Time History

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
ORB_START	Start of an orbit state vector or time history section	n/a		n/a	Yes
COMMENT	Comments (a contiguous set of one or more comment lines are allowed in the Orbit State Time History section only immediately after the ORB_START key word; see 7.7 for comment formatting rules).	n/a		COMMENT This is a comment	No
ORB_ID	Optional alphanumeric free-text string containing the identification number for this orbit state time history block	n/a		ORB_20160402_XYZ	No
ORB_N	Number of elements (excluding time) contained in the element set if ORB_TYPE is set to ICD. If ORB_TYPE is not set to ICD, then the number of elements coincides with the selected ORB_TYPE.	n/a	6	8	N
ORB_BASIS	Basis of this Orbit State time history data, selected from “PREDICTED“ or “DETERMINED” for orbit determination-based reconstruction.	n/a	**PREDICTED**	PREDICTED DETERMINED	No
ORB_AVERAGING	Free-text keyword specifying whether provided orbit state/elements are either osculating or mean element definitions. If an alternate single- or double-averaging formulation is used than “MEAN_BROUWER” or “MEAN_KOZAI,” the user may name it or use “OTHER” to denote specification via ICD.	n/a	**OSCULATING**	OSCULATING MEAN_BROUWER MEAN_KOZAI (other…)	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, other defined positional references (e.g. Lagrange points) 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]). Note that since there is no restriction on the value of this keyword, it is valid and may be useful to specify another platform (satellite, airframe, ground vehicle, etc.) as the “orbit center” to permit the specification of relative positional state time history data. In this case, message authors shall clearly communicate to recipients by ICD that propagation of ephemeris vectors or extrapolation of ephemeris start/stop states is not advisable, and that interpolation of state time histories should not be accomplished using classical orbit propagation forces, e.g., gravitational constants, drag.	n/a	EARTH	Earth Moon Solar System Barycenter Sun ISS EROS EaRTH_sun_l2 HOST_SAT	No
ORB_REF_FRAME	Name of the reference frame in which the orbit data is provided, if not intrinsic to the definition of the orbit data. Use of values other than those in ANNEX B, subsection B2 must be documented and conveyed in an ICD. The reference frame must be the same for all data elements within a given Orbit State Time History interval.	n/a	If not intrinsic to selected orbit set, then default is ITRF1997	EME2000	No

Commented [OD6]: Would it make sense to further clarify the definition of each element using something like definition (X,Y,Z, etc when using ORB_N (rather than via an ICD) ?

ORB_FRAME_EPOCH	Epoch of the orbit data reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.9 for formatting rules.)	n/a	If required and not intrinsic to selected reference frame, then default is EPOCH_TZERO	2001-11-06T11:17:33 2002-204T15:56:23Z	No
ORB_TYPE - from SANA Table?	Specifies the orbit element set type; selected from annex B, Table B4; or alternately, "ICD" denotes orbit element set definition sharing via ICD.	n/a	CARTPV	n/a	Yes
… < Insert orbit lines here>	Each orbit time history line contains the time tag of the state measured in seconds from EPOCH_TZERO, followed the corresponding state elements (defined by ORB_TYPE).				Yes
ORB_STOP	End of an orbit state vector or time history section	n/a		n/a	Yes

6.2.9 OCM DATA: ORBIT STATE COVARIANCE TIME HISTORY

6.2.9.1 Table 6-9 provides an overview of the OCM orbit state covariance time history section. Only those keywords shown in Table 6-9 shall be used in OCM orbit state covariance time history data specification.

6.2.9.2 Keyword values shall be provided in the units specified in the “Units” column of Table 6-9.

6.2.9.3 The order of occurrence of these orbit state covariance time history keywords shall be fixed as shown in Table 6-9.

6.2.9.4 The orbit state covariance time history section is optional; “mandatory” in the context of Table 6-9 denotes those keywords which must be included in this section if this section is included.

6.2.9.5 Each orbit state covariance time history data block must begin with keyword COV_START and end with keyword COV_STOP.

6.2.9.6 Each of these keywords shall appear on a line by itself.

6.2.9.7 Multiple orbit state covariance data blocks shall only appear in an OCM if:

6.2.9.7.1 They are delimited by separate COV_START and COV_STOP keywords**;**

6.2.9.7.2 Each data block is clearly differentiated from the others by one or more precluding comment(s) or by ICD agreement

6.2.9.7.3 Each orbit state covariance data block is unique from all others in at least one of the following respects:

1) the selected covariance element set (COV_TYPE) is unique
2) the orbit state covariance time history is based upon a unique orbit determination, attitude determination, navigation solution or Monte Carlo simulation
3) the reference frame is unique
4) the orbit center is unique
5) the data interval timespan is unique (i.e., has no overlap with any other data interval(s))

6.2.9.8 The COV_TYPE keyword value shall be selected from Table B4 or B5.

6.2.9.9 All covariance matrices in the OCM data shall be time-tagged by a relative time value measured with respect to the epoch time specified via the EPOCH_TZERO keyword.

6.2.9.10 Each covariance time history shall be time-ordered to be monotonically increasing, with the exception that the message creator may indicate a change in state over which interpolation should not be performed by providing exactly two consecutive covariance data blocks containing a duplicate timestamp (e.g. following application of an impulsive maneuver or spacecraft or orbit event). In the case of such a duplicate timestamp, interpolation prior to the duplicate timestamp shall use the first of the two duplicate timestamp covariance matrices, and interpolation after the duplicate timestamp shall use the second of the two.

6.2.9.11 If the user includes covariances at key mission event times, it is recommended that those mission event covariances be annotated as such by a preceding descriptive comment line.

6.2.9.12 Time tags of consecutive covariance information within the ordered sequence may be separated by uniform or non-uniform step size(s).

6.2.9.13 Covariance time tags may or may not match those of maneuver, orbit state and/or state transition matrix time histories.

NOTE: Interpolation of covariance matrices at neighboring relative time points shall be done by (1) eigenvalue/vector decomposition; (2) linear (or higher-order) interpolation of neighboring eigenvalues; (3) Euler axis/angle rotation of eigenvectors at intermediate time(s) of interest; and (4) Re-composition of attained eigenvalues and eigenvectors into covariances at time(s) of interest [L16]. Direct interpolation of covariance matrix components can produce invalid (non-positive-semidefinite) covariances.

6.2.9.14 The time of the event associated with each provided covariance matrix shall be specified via the "T = " keyword.

6.2.9.15 The reference frame of the covariance matrix shall be provided via the 'COV_REF_FRAME' keyword.

6.2.9.16 Values in the covariance matrix shall be expressed in the applicable reference frame and shall be presented sequentially from upper left [1,1] to lower right in lower triangular form, row-by-row from left to right. Variance and covariance values shall be expressed in standard double precision as related in 7.5.

6.2.9.17 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 COV_TYPE keyword specification (note that only a single line shall be provided for COV_TYPE = TEIGVAL3EIGVEC3).

6.2.9.18 If COV_TYPE ≠ TEIGVAL3EIGVEC3, then each of the "N" rows of the covariance matrix shall contain from one to "N" 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 "Nth" row has "N" elements).

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

6.2.9.20 The digits of precision and time steps suitable for interpolation of a covariance time history should be chosen according to best practice to avoid covariance and interpolation loss of precision [L8].

Table 6-9: OCM Data: Covariance Time History

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
COV_START	Start of a covariance time history section	n/a		n/a	Yes
COMMENT	Comments (a contiguous set of one or more comment lines are allowed in the OCM Covariance Time History section only immediately after the COV_START key word; see 7.7 for comment formatting rules).	n/a		COMMENT This is a comment	No
COV_BASIS	Basis of this covariance time history data: PREDICTED or EMPIRICAL (for empirically-determined such as overlap analyses) or DETERMINED for orbit determination-based or MONTE_CARLO for Monte Carlo-based simulation estimations. Use of values other than those shown in the **Examples** (shown at right) must be documented and conveyed via an ICD.	n/a	PREDICTED	PREDICTED EMPIRICAL DETERMINED MONTE_CARLO	No
COV_REF_FRAME	Name of the reference frame in which the covariance data is provided. Use of values other than those in ANNEX B, subsections B2 and B3 must be documented and conveyed via an ICD. The reference frame must be the same for all data elements within a given Covariance Time History interval.	n/a	TNW	EME2000	No
COV_ FRAME_EPOCH	Epoch of the covariance data 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 required and not intrinsic to the selected reference frame, omission of this optional field defaults to EPOCH_TZERO.**	n/a	If not specified, then EPOCH_TZERO is assumed	2001-11-06T11:17:33 2002-204T15:56:23Z	No
COV_NNXNN	Number of diagonal elements contained in full covariance if COV_TYPE is set to ICD. **If COV_TYPE is not set to ICD, then the number of diagonal elements shall coincide with the selected COV_TYPE (ANNEX B, subsections B2 and B3)**.	n/a	6	10	No
COV_TYPE	Indicates covariance composition; selected from ANNEX B, subsections B4 and B5) or alternately, "ICD" denotes covariance composition sharing via ICD.	n/a	CARTPV	n/a	Yes
…< Insert covariance data here>	One or more covariance matrices, each delimited by a single line containing the time keyword "**T=YYY**", where "YYY" contains time in seconds relative to EPOCH_TZERO.				Yes
COV_STOP	End of a covariance time history section	n/a		n/a	Yes

6.2.10 OCM DATA: STATE TRANSITION MATRIX TIME HISTORY

6.2.10.1 Table 6-10 provides an overview of the OCM state transition matrix time history section. Only those keywords shown in Table 6-10 shall be used in OCM state transition matrix time history data specification.

6.2.10.2 Keyword values shall be provided in the units specified in the "Units" column of Table 6-10.

6.2.10.3 The order of occurrence of these OCM state transition matrix time history keywords shall be fixed as shown in table 6-10.

6.2.10.4 The OCM state transition matrix time history section is optional; "mandatory" in the context of Table 6-10 denotes those keywords which must be included in this section if this section is included.

6.2.10.5 Each state transition matrix time history data block must begin with keyword STM_START and end with keyword STM_STOP.

6.2.10.6 Each of these keywords shall appear on a line by itself.

6.2.10.7 Multiple **s**tate transition matrix data blocks shall only appear in an OCM if:

6.2.10.7.1 They are delimited by separate STM_START and STM_STOP keywords;

6.2.10.7.2 Each section is clearly differentiated from the others by one or more precluding comment(s) or by ICD agreement

6.2.10.7.3 Each data block is unique from all others in at least one of the following respects:

8) the selected orbit state element set (STM_TYPE) is unique;
9) the state transition matrix time history is based upon a unique orbit determination, attitude determination, navigation solution or Monte Carlo simulation;
10) the reference frame is unique;
11) the orbit center is unique;
12) the state transition matrix timespan is unique.

6.2.10.8 The STM_TYPE keyword value shall be selected from Table B4.

6.2.10.9 All state transition matrices in the OCM data shall be time-tagged by a relative time value measured with respect to the epoch time specified via the EPOCH_TZERO keyword.

6.2.10.10 Each state transition matrix time history shall be time-ordered to be monotonically increasing with no duplicate time points permitted within each time history.

6.2.10.11 No interpolation of the state transition matrix time history shall be undertaken, since the state transition matrix pre- and post-multiplies the state (or covariance) in the mapping process to yield states and covariances that may then be properly interpolated.

6.2.10.12 If the user includes state transition matrices at key mission event times, it is recommended that those mission event state transition matrices be preceded by descriptive comment line(s).

6.2.10.13 Time tags of consecutive state transition matrices within the ordered sequence may be separated by uniform or non-uniform step size(s).

6.2.10.14 State transition matrix time tags may or may not match those of maneuver, orbit state and/or covariance time histories.

6.2.10.15 The time of the event associated with provided state transition matrices must be provided via the "T = " keyword. The reference frame of the state transition matrices, if different from that of the states in the ephemeris, must be provided via the 'STM_FRAME' keyword.

6.2.10.16 Values in each state transition matrix shall be expressed in the applicable reference frame and shall be presented sequentially from upper to lower and row-by-row from left to right. State transition matrix values shall be expressed in standard double precision as discussed in 7.5.

6.2.10.17 Each row of each state transition matrix must be provided on a single line. The order in which data items are given shall be fixed. The elements in each row shall be defined by the STM_TYPE keyword specification. The "N" rows of the state transition matrix shall each contain "N" numbers.

6.2.10.18 At least one space character must be used to separate the items in each state transition matrix data line.

6.2.10.19 The digits of precision and time steps suitable for state transition matrix time history should be chosen to avoid STM propagation loss of precision.

NOTE: State Transition Matrices (STMs) can be very useful in mapping both an initial state, and (separately) differences about that state, to other time(s) of interest. Following the terminology and definitions of reference [L9], pp. 82, 778-780 and 809) allows the analyst to map states, or alternatively state differences, at time t_0 to another time t_i. As noted in reference [L9], these are distinctly different in definition and content from each other. Both types of State Transition Matrices are supported, as specified by the STM_MAP_MODE keyword.

Table 6-10: OCM Data: State Transition Matrix Time History

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
STM_START	Start of a state transition matrix time history section	n/a		n/a	Yes

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
COMMENT	Comments (a contiguous set of one or more comment lines are allowed in the OCM State Transition Matrix Time History section only immediately after the STM_START key word; see 7.7 for comment formatting rules).	n/a		COMMENT This is a comment	No
STM_MAP_MODE	Indicates whether state transition matrix maps: - An initial state to later states (STATE) or - Initial state differences (or uncertainties) to later differences (DIFFERENCES)	n/a	DIFFERENCES	STATE DIFFERENCES	Yes
STM_REF_TIME	Epoch time of the initial state or initial state differences relative to EPOCH_TZERO, to which the state transition matrix is referenced and at which time the STM ≡ the identity matrix	n/a	0.0	0.0	Yes
STM_ORB_STATE	Initial orbit state at STM_REF_TIME from which the state transition mapping is derived and referenced	Deg, km, km/s	(consistent with "STM_TYPE")	2789.6 -280.0 -1746.8 4.73 -2.50 -1.04	No
STM_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, other defined positional references (e.g. Lagrange points) or another spacecraft (in this case the value for 'STM_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]).	n/a	EARTH	EARTH MOON SOLAR SYSTEM BARYCENTER SUN ISS EROS EARTH_SUN_L2	No

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
STM_REF_FRAME	Name of the reference frame in which the state transition matrix data is computed, if not intrinsic to the definition of the state transition matrix data. Use of values other than those in ANNEX B, subsections B2 and B3 must be documented and conveyed via an ICD. The reference frame must be the same for all data elements within a given State Transition Matrix Time History interval. **Where the reference frame is not intrinsic to the selected STM set, omission of this optional field defaults to ICRF2000.**	n/a	**ICRF2000**	EME2000	No
STM_ FRAME_EPOCH	Epoch of the state transition matrix data 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 required and not intrinsic to the selected reference frame, omission of this optional field defaults to EPOCH_TZERO.**	n/a	If not specified, then EPOCH_TZERO is assumed	2001-11-06T11:17:33 2002-204T15:56:23Z	No
STM_N	Dimension "N" of the "N x N" state transition matrix if STM_TYPE is set to ICD. If STM_TYPE is not set to ICD, then the dimension "N" coincides with the number of elements implied by STM_TYPE (ANNEX B, subsection B4 or B5).	n/a	6	6	No
STM_TYPE	Indicates state transition matrix composition; selected from ANNEX B, subsection B4 or B5 or alternately, "ICD" denotes state transition matrix composition definition via ICD.	n/a	CARTPV	CARTPV	Yes
…< Insert STM data here>	One or more state transition matrices, each delimited by a single line containing the time keyword "**T=YYY**", where "YYY" contains time in seconds relative to EPOCH_TZERO.				Yes
STM_STOP	End of a state transition matrix time history section	n/a		n/a	Yes

6.2.11 OCM DATA: EPHEMERIS COMPRESSION REPRESENTATION(S)

6.2.11.1 Ephemeris Compression (EC) techniques are described in Annex K.

6.2.11.2 Table 6-11 provides an overview of the OCM ephemeris compression section. Only those keywords shown in Table 6-11 shall be used in OCM ephemeris compression data specification.

6.2.11.3 Keyword values shall be provided in the units specified in the "Units" column of Table 6-11.

6.2.11.4 The order of occurrence of these OCM Ephemeris Compression Representation keywords shall be fixed as shown in Table 6-11.

6.2.11.5 The "OCM ephemeris compression" section is optional; "mandatory" in the context of Table 6-11 denotes those keywords which must be included in this section if this section is included.

6.2.11.6 Each ephemeris compression representation must begin with keyword EC_START and end with keyword EC_STOP.

6.2.11.7 Each of these keywords shall appear on a line by itself.

6.2.11.8 Multiple ephemeris compression representations shall only appear in an OCM if:

6.2.11.8.1 They are delimited by separate EC_START and EC_STOP keywords**;**

6.2.11.8.2 Each ephemeris compression representation is clearly differentiated from the others by one or more precluding comment(s) or by ICD agreement

6.2.11.8.3 Each ephemeris compression representation is unique from all others in at least one of the following respects:

1) the selected ephemeris compression type (EC_STATE_TYPE) is unique
2) the ephemeris compression representation is based upon a unique orbit determination, attitude determination, navigation solution or Monte Carlo simulation
3) the orbit state is unique (e.g., when the EC represents different mission events as a function of time from launch window open)
4) the specified orbit state element set is unique
5) the reference frame is unique
6) the orbit center is unique
7) the ephemeris compression representation timespan from EC_TSTART to EC_TSTOP is unique (i.e., has no overlap with any other ephemeris compression representation timespans)

6.2.11.9 The EC_STATE_TYPE keyword value shall be selected from Table B4 or B5 (not including "COV_NNXNN").

6.2.11.10 The OCM EC implementation may also be used to accommodate secular orbit perturbations via polynomials governing time. This means that a seventh set of polynomial coefficients may be supplied to yield either an "adjusted" state event time as a function of time, e.g., $t_{event} = EC_{representation}(time\ of\ interest)$. Such an implementation facilitates the use of more simple baseline orbit propagators for "Hybrid" EC application. For this reason, orbit state types (EC_STATE_TYPE) may be also selected from ANNEX B, subsections B4 or B5, where subsection B5 (excepting COV_NNXNN) allows orbit states to be comprised of time in addition to the standard six-element orbit state specification.

6.2.11.11 In the OCM implementation of ephemeris compression, each Chebyshev or Fourier representation's independent time variable shall be "normalized" to a time interval of -1 ≤ t^* ≤ +1 via the following formula [L15], where a denotes the actual start time (i.e. EC_TSTART) of the ephemeris compression representation segment's time interval of validity, b denotes the corresponding actual segment stop time (i.e. EC_TSTOP), t denotes the actual time of interest measured with respect to EPOCH_TZERO and t^* denotes "normalized time":

$$t^* = \frac{2 \cdot t - (a + b)}{(b - a)}$$

6.2.11.12 Where not clear from EC_BASIS_PROP, .

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

6.2.11.14 The digits of precision suitable for ephemeris representation specification should be chosen to avoid EC loss of precision for the recipient's intended use case [L8].

Table 6-11: OCM Data: Ephemeris Compression Time History

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
EC_START	Start of a Ephemeris Compression Time History section	n/a		n/a	Yes
COMMENT	Comments (a contiguous set of one or more comment lines are allowed in the OCM Ephemeris Compression Time History section only immediately after the EC_START key word; see 7.7 for comment formatting rules).	n/a		COMMENT This is a comment	No
EC_TSTART	Start time relative to EPOCH_TZERO of this Ephemeris Compression time interval of applicability	n/a	0.0	0.0	Yes
EC_BASIS_PROP	Specifies the orbit propagator which is to serve as the basis, upon which the EC representation additively corrects. Note that this orbit propagator and underlying force model are not required to match the force model specified in the "OCM Force Model" section above to facilitate rapid EC evaluation in field operational use. Note that while this is a free-text field, the OCM creator must ensure that any/all recipients know how to interpret any specified orbit propagator (and have full access to that orbit propagator) Specifying EC_BASIS_PROP = NONE indicates that the EC representation is not a hybrid method and the returned functional values obtained from the EC representation correspond directly with desired orbit state information, whereas specification (in free text, including specification of any non-standardized force model or geodetic system implementations and where relevant integrator type i.e. RK 4/5 or RK 8/9; Cowell 9) of a message creator/recipient-shared orbit propagator selects a "Hybrid EC representation" approach in the orbit element definition specified by "EC_STATE_TYPE = YYY" (below).	n/a	Defaults to NONE	SGP4 NONE	No
EC_REF_TIME	Epoch time of the initial orbit state relative to EPOCH_TZERO, to which this ephemeris compression interval is referenced, **used only if EC_BASIS_PROP is not set to NONE and the epoch of the orbit state is not implicitly included in the EC_BASIS_PROP propagator's state definition (for example, the orbit epoch is already included in a Two-Line Element set definition)**	n/a	0.0	0.0	This keyword is mandatory if and only if EC_BASIS_PROP is not set to "NONE" and the orbit state does not already contain the state's epoch
EC_ORB_STATE	Specifies in one or more subsequent rows the orbit state elements for employment of a "Hybrid EC representation" approach in the orbit element definition specified by "EC_STATE_TYPE = YYY" (below). The number of state vector rows following the EC_ORB_STATE keyword containing the initial state correspond to the "EC_BASIS_PROP" required state vector format (shared either by ICD agreement or common industry understanding). Note the specification of the initial condition state vector epoch may be included in this common understanding.	(as defined by selected orbit propagator)	n/a	6700.0 0.0 0.0 0.0 0.0 0.839099633	This keyword and state vector data are mandatory if and only if EC_BASIS_PROP is not set to "NONE"

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
EC_ REPRESENT	Specifies the type of EC representation used in the coefficients which immediately follow. The only valid options are: CHEBYSHEV or FOURIER. Specific implementation details of the basis functions and algorithms used shall be clarified by accompanying ICD where necessary.	n/a	CHEBYSHEV	CHEBYSHEV FOURIER	No
EC_STATE_TYPE	Indicates EC representation generated by evaluating EC polynomials or series; selected from ANNEX B, subsection B4 or B5 (excluding "COV_NNXNN").	n/a	EQUIN	EQUIN	No
EC_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, other defined positional references (e.g. Lagrange points) or another spacecraft (in this case the value for 'EC_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]).	n/a	EARTH	EARTH MOON SOLAR SYSTEM BARYCENTER SUN ISS EROS EARTH_SUN_L2	No
EC_REF_FRAME	Name of the reference frame in which the Ephemeris Compression data is computed, if not intrinsic to the EC orbit element definition. Use of values other than those in ANNEX B, subsection B2 must be documented and conveyed via an ICD. The reference frame must be the same for all data elements within a given Ephemeris Compression Time History interval. **Where the reference frame is not intrinsic to the selected EC set, omission of this optional field defaults to EME2000.**	n/a	EME2000	EME2000	No

Commented [OD7]: Comment from reviewer (Jim Woodburn): As the supplied EC data is specific to a particular algorithm, and as the exact implementation of such algorithms is outside the experience of most in the field, I think that algorithm definitions should be explicitly included in the document (along with a simple numerical example). Note that this is different than interpolation where the numerical algorithm is performed on the native data. For EC, specialized data elements are being produced from the native data, without the exact recovery algorithm the end user will not get the correct results.

Keyword	Description	Units	Default (if any)	Examples of Values	Mandatory
EC_ FRAME_EPOCH	Epoch of the Ephemeris Compression 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 <u>required</u> and not intrinsic to the selected reference frame, omission of this optional field defaults to EPOCH_TZERO.**	n/a	If not specified, then EPOCH_ TZERO is assumed	2001-11-06T11:17:33 2002-204T15:56:23Z	No
EC_ REPR_N	Number of terms (coefficients) in the selected EC representation for this segment. Coefficients shall be supplied in columnar fashion, with each subsequent "ith" row corresponding to the next (i.e., "jth" column) orbital element. In the FOURIER representation, the cosine coefficients are supplied for each orbit element, followed (on the same line) by the sine coefficients for each element. As such, EC_ REPR_N always denotes the number of coefficient data rows to follow within this EC data block.	n/a		10	Yes
EC_TSTOP	End time relative to **EPOCH_TZERO** of this Ephemeris Compression time interval of applicability	n/a		86400.0	Yes
<EC data>	Ephemeris compression coefficients, with each subsequent data ith row representing the jth orbital element				Yes
EC_STOP	End of a Ephemeris Compression section	n/a		n/a	Yes

Commented [OD8]: Fix to example to match this text.

Commented [OD9]: Need to fix this. In Fourier series = C1 cos (wt), what is the "w" ?

6.2.12 OCM DATA: USER-DEFINED PARAMETERS

6.2.12.1 A section of User Defined Parameters may be provided if necessary. 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 OCM, should be used as sparingly as possible; their use is not encouraged.

6.2.12.2 If User-Defined Parameters are used, comment(s) are encouraged to help minimize risk of confusion or misinterpretation by message recipients.

6.2.12.3 The "OCM Data: User-Defined Parameters" section is optional; "mandatory" in the context of Table 6-13 denotes those keywords which must be included in this section if this section is included.

6.2.12.4 Table 6-13 provides an overview of the OCM user-defined data section. Only those keywords shown in Table 6-12 shall be used in OCM user-defined data specification.

Table 6-12: OCM Data: User-Defined Parameters

Keyword	Description	Units	Examples of Values	Mandatory
USER_START	Start of a User-defined parameters data block	n/a		Yes
COMMENT	Comments (a contiguous set of one or more comment lines are allowed immediately following the USER_START keyword (See 7.7 for formatting rules.)	n/a	COMMENT This is a comment	No
(USER-DEFINED)	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.	n/a	EARTH_MODEL = WGS-84	No
USER_STOP	End of a User-defined parameters data block	n/a		Yes

6.3 OCM EXAMPLES AND SUPPLEMENTARY INFORMATION

Example OCMs and associated supplementary (non-normative) information are provided in I-19.

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 OCM) shall observe the syntax described in 7.3 through 7.7.

7.3 ODM LINES

7.3.1 Each OPM, OMM, OEM or OCM line shall be one of the following:

– Header line;

– Metadata line;

– Data line;

– Comment line; or

– Blank line.

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

7.3.3 OCM lines may be of arbitrary length. If exchange between the two parties requires a maximum line length, that limit should be negotiated and specified in an ICD.

7.3.4 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.

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

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

7.3.7 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 (I.E., NON-XML) 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 OEM 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.)

7.4.1.3 OEM 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.)

7.4.1.4 For the OCM, all header and metadata elements shall use KVN notation.

7.4.1.5 All OCM KVN keyword-specified lines can contain interspersed blank lines as desired, for example to enhance message clarity and readability.

7.4.1.6 OCM orbit state time history data lines shall not use KVN format; rather, the structure of such OCM orbit state time history data lines shall be comprised of a contiguous set of lines containing time relative to EPOCH_TZERO followed by the parameters corresponding to the selected orbit set (See 6.2.8).

7.4.1.7 OCM covariance matrix epoch and covariance reference frame (if used) shall use KVN format. The OCM covariance data lines shall not use KVN format; rather, the OCM covariance data line has a fixed structure which shall be comprised of a contiguous set of lines containing from one to "N" required fields (a row from the N x N lower triangular form of a square covariance matrix). (See 6.2.9.)

7.4.1.8 OCM state transition matrix data lines shall not use KVN format; rather, OCM state transition matrix data shall be comprised of a contiguous set of lines containing a fixed structure as presented in Sec. 6.2.10.

7.4.1.9 OCM ephemeris compression data lines shall not use KVN format; rather, OCM ephemeris compression data shall be comprised of a contiguous set of lines containing a fixed structure as presented in Sec. 6.2.11.

7.4.2 The keywords 'COMMENT', [wild card]'_START' and [wild card]'_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 mandatory and optional KVN assignments shall be fixed as shown in the tables in sections 3, 4, 5 and 6 that describe the OPM, OMM, OEM and OCM keywords.

7.5 VALUES

7.5.1 A non-empty value field must be specified for each mandatory 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:

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

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 OCM .

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.

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.). Where such epochs occur within one second after leap second introduction, the hh:mm:ss portion of the above time specification shall use the convention XX:XX:60.XXXX.

7.5.10 The time system for CREATION_DATE is UTC; for all other keywords representing times or epochs, the time system is determined by the TIME_SYSTEM metadata keyword.

7.6 UNITS IN THE ORBIT DATA MESSAGES

7.6.1 OPM/OMM/OCM UNITS

7.6.1.1 For documentation purposes and clarity, units may be included as ASCII text after a value in the OPM, OMM and OCM. If units are displayed, they must exactly match the units (including lower/upper case) as specified in tables 3-3, 4-3, 5-3 and 6-4 through 6-12. 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, OCM 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 OCM UNITS

7.6.3.1 In an OCM orbit state data line, units shall be degrees for angular quantities, kilometers for distance quantities and seconds for time quantities. The units shall not be displayed.

7.6.3.2 In an OCM covariance matrix line, units shall be comprised of the requisite combination of degrees for angular quantities, kilometers for distance quantities and seconds for time quantities. The units shall not be displayed.

7.6.3.3 In an OCM state transition matrix data section, units shall be compatible with the corresponding orbit type's requisite combination of degrees for angular quantities, kilometers for distance quantities and seconds for time quantities. The units shall not be displayed.

7.6.3.4 In an OCM ephemeris compression data section, units shall be compatible with the corresponding orbit type's requisite combination of degrees for angular quantities, kilometers for distance quantities and seconds for time quantities. The units shall not be displayed.

7.6.3.5 Units for all other OCM quantities are as specified in section 6.2.

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 OCM, 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, 5 and 6 that describe the OPM, OMM, OEM and OCM 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 ‘COV_START’ keyword). Comment lines must not appear within any block of ephemeris lines or covariance matrix lines.

7.7.9 Comments in the OCM may appear in the OCM Header, Metadata, Space Object Physical Characteristics, Force Model, Maneuver, Orbit State Time History, Covariance Time History, State Transition Matrix Time History, Ephemeris Compression and User-Defined Parameters data sections only at the positions shown in the defining Tables (generally at the top of each section).

7.7.10 Extensive comments in an ODM are recommended in cases where there is insufficient time to negotiate an ICD.

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, OEM and OCM 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, OEM and OCM shall be CCSDS_OPM_VERS, CCSDS_OMM_VERS, CCSDS_OEM_VERS and CCSDS_OCM_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, OEM and OCM version numbers less than 1.0 (e.g., 0.x). Exchange participants should specify in the ICD the specific OPM, OMM, OEM and OCM version numbers they will support. The following version numbers are supported (Blue Book) or have been supported in the past (Silver Book):

Version Keyword	Version Number	Applicable Recommendation
CCSDS_OPM_VERS	1.0	Silver Book 1.0, 09/2004
CCSDS_OPM_VERS	2.0	Silver Book 2.0, 09/2009
CCSDS_OPM_VERS	3.0	Blue Book 3.0 (this document)
CCSDS_OMM_VERS	2.0	Silver Book 2.0, 09/2009
CCSDS_OMM_VERS	3.0	Blue Book 3.0 (this document)
CCSDS_OEM_VERS	1.0	Silver Book 1.0, 09/2004
CCSDS_OEM_VERS	2.0	Silver Book 2.0, 09/2009
CCSDS_OEM_VERS	3.0	Blue Book 3.0 (this document)
CCSDS_OCM_VERS	3.0	Blue Book 3.0 (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 mandatory 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 mandatory 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 mandatory items and some are optional. KVN assignments representing optional items may be omitted.

7.8.2.4 Only those keywords shown in tables 6-2, table 6-3, table 6-4, table 6-5, table 6-6, table 6-7, table 6-8, table 6-9, table 6-10 and table 6-11 shall be used in an OCM. Some keywords represent mandatory items and some are optional. KVN assignments representing optional items may be omitted.

8 CONSTRUCTING AN ODM/XML INSTANCE

8.1 OVERVIEW

This section provides detailed instructions for the user on how to create an XML message based on one of the ASCII-text KVN-formatted messages described in Section 3, Section 4, Section 5 and Section 6.

8.2 XML VERSION

The first line of each instantiation shall specify the XML version, exactly as follows:

```
<?xml version="1.0" encoding="UTF-8"?>
```

8.3 BEGINNING THE INSTANTIATION: ROOT ELEMENT TAG

8.3.1 Each instantiation shall have a 'root element tag' that identifies the message type and other information such as where to find the applicable schema, required attributes, etc.

8.3.2 The root element tag in an ODM/XML instantiation shall be one of those listed in Table 8-1.

Table 8-1: ODM/XML Root Element Tags

Root Element Tag	Message Type
`<opm></opm>`	Orbit Parameter Message
`<omm></omm>`	Orbit Mean Elements Message
`<oem></oem>`	Orbit Ephemeris Message
`<ocm></ocm>`	Orbit Comprehensive Message

8.3.3 The XML Schema Instance namespace attribute must appear in the root element tag of all ODM/XML instantiations, exactly as shown:

```
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
```

If it is desired to validate an instantiation against the CCSDS Web-based schema, the xsi:noNamespaceSchemaLocation attribute must be coded as a single string of non-blank characters, with no line breaks exactly as shown:

```
xsi:noNamespaceSchemaLocation="http://sanaregistry.org/r/ndmxml/ndmxml-
1.0-master.xsd"
```

NOTE – The value associated with the `xsi:noNamespaceSchemaLocation` attribute shown in this document is too long to appear on a single line.

8.3.4 For use in a local operations environment, the schema set may be downloaded from the CCSDS Web site to a local server that meets local requirements for operations robustness.

8.3.5 If a local version is used, the value associated with the xsi:noNamespaceSchemaLocation attribute must be changed to a URL that is accessible to the local server.

8.3.6 Two attributes shall appear in the root element tag of an ODM/XML single message instantiation, specifically, the CCSDS_xxx_VERS keyword that is also part of the standard KVN header, and the Blue Book version number.

8.3.7 The CCSDS_xxx_VERS keyword shall be supplied via the 'id' attribute of the root element tag (xxx = OPM, OMM, OEM, OCM).

8.3.8 The version number of the Blue Book to which the schema applies shall be supplied via the 'version' attribute.

NOTE – The following example root element tag for an OPM instantiation combines all the directions in the preceding several subsections:

```
<?xml version="1.0" encoding="UTF-8"?>
<opm  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
      xsi:noNamespaceSchemaLocation="http://sanaregistry.org/r/ndmxml/ndmxml-
           1.0-master.xsd"
      id="CCSDS_OPM_VERS" version="3.0">
```

8.4 THE STANDARD ODM/XML HEADER SECTION

8.4.1 The ODMs shall share a standard header format, with tags <header> and </header>.

8.4.2 Immediately following the <header> tag the message may have any number of <COMMENT></COMMENT> tag pairs.

8.4.3 The standard ODM header shall contain the <CREATION_DATE> and the <ORIGINATOR> tags.

NOTE – An example `<header>` section is shown immediately below.

```
<header>
   <COMMENT>This is the common ODM/XML header</COMMENT>
   <COMMENT>I can put as many comments here as I want,</COMMENT>
   <COMMENT>including none.</COMMENT>
   <CREATION_DATE>2004-281T17:26:06</CREATION_DATE>
   <ORIGINATOR>AGENCY-X</ORIGINATOR>
</header>
```

8.5 THE ODM BODY SECTION

8.5.1 After coding the `<header>`, the instantiation must include a `<body></body>` tag pair.

8.5.2 Inside the `<body></body>` tag pair must appear at least one `<segment></segment>` tag pair.

8.5.3 Each segment must be made up of one or more `<metadata></metadata>` and `<data></data>` tag pairs.

8.6 THE ODM METADATA SECTION

8.6.1 All ODMs must have a metadata section.

8.6.2 The metadata section shall be set off by the `<metadata></metadata>` tag combination.

8.6.3 Between the `<metadata>` and `</metadata>` tags, the keywords shall be the same as those in the metadata sections in Section 3, Section 4, Section 5 and Section 6, with exceptions as noted in the subsections that discuss creating instantiations of the specific messages.

8.7 THE ODM DATA SECTION

8.7.1 All ODMs must have a data section.

8.7.2 The data section shall follow the metadata section and shall be set off the by the `<data></data>` tag combination.

8.7.3 Between the `<data>` and `</data>` tags, the keywords shall be the same as those in the data sections in Section 3, Section 4, Section 5 and Section 6, with exceptions as noted in the subsections that discuss creating instantiations of the specific messages.

8.8 CREATING AN OPM INSTANTIATION

8.8.1 An OPM instantiation shall be delimited with the `<opm></opm>` root element tags using the standard attributes documented in **8.3**.

8.8.2 The final attributes of the `<opm>` tag shall be 'id' and 'version'.

8.8.3 The 'id' attribute shall be '`id="CCSDS_OPM_VERS"`'.

8.8.4 The 'version' attribute shall be '`version="3.0"`'.

8.8.5 The standard NDM header shall follow the `<opm>` tag (see **8.4**).

8.8.6 The OPM `<body>` shall consist of a single `<segment>`.

8.8.7 The `<segment>` shall consist of a `<metadata>` section and a `<data>` section.

8.8.8 The keywords in the `<metadata>` and `<data>` sections shall be those specified in Section 3. The rules for including any of the keyword tags in the OPM/XML are the same as those specified for the OPM/KVN.

8.8.9 Tags for keywords specified in Section 3 shall be all uppercase.

8.8.10 Several of the OPM/XML keywords may have a unit attribute, if desired by the OPM producer.

8.8.11 In all cases, the units shall match those defined in Section 3.

8.8.12 The following table lists the keyword tags for which units may be specified.

Keyword	Units	Example
X	km	<X units="km">numeric-value</X>
Y	km	<Y units="km">numeric-value</Y>
Z	km	<Z units="km">numeric-value</Z>
X_DOT	km/s	<X_DOT units="km/s">numeric-value</X_DOT>
Y_DOT	km/s	<Y_DOT units="km/s">numeric-value</Y_DOT>
Z_DOT	km/s	<Z_DOT units="km/s">numeric-value</Z_DOT>
SEMI_MAJOR_AXIS	km	<SEMI_MAJOR_AXIS units="km">numeric-value</SEMI_MAJOR_AXIS>
INCLINATION	deg	<INCLINATION units="deg">numeric-value</INCLINATION>
RA_OF_ASC_NODE	deg	<RA_OF_ASC_NODE units="deg">numeric-value</RA_OF_ASC_NODE>
ARG_OF_PERICENTER	deg	<ARG_OF_PERICENTER units="deg">numeric-value</ARG_OF_PERICENTER>
TRUE_ANOMALY	deg	<TRUE_ANOMALY units="deg">numeric-value</TRUE_ANOMALY>
MEAN_ANOMALY	deg	<MEAN_ANOMALY units="deg">numeric-value</MEAN_ANOMALY>
GM	km**3/s**2	<GM units="km**3/s**2">numeric-value</GM>
MASS	kg	<MASS units="kg">numeric-value</MASS>
SOLAR_RAD_AREA	m**2	<SOLAR_RAD_AREA units="m**2">numeric-value</SOLAR_RAD_AREA>
DRAG_AREA	m**2	<DRAG_AREA units="m**2">numeric-value</DRAG_AREA>
CX_X, CY_X, CY_Y, CZ_X, CZ_Y, CZ_Z	km**2	<CX_X units="km**2">numeric-value</CX_X>
CX_DOT_X, CX_DOT_Y, CX_DOT_Z, CY_DOT_X, CY_DOT_Y, CY_DOT_Z, CZ_DOT_X, CZ_DOT_Y,CZ_DOT_Z	km**2/s	<CX_DOT_X units="km**2/s">numeric-value</CX_DOT_X>
CX_DOT_X_DOT, CY_DOT_X_DOT, CY_DOT_Y_DOT, CZ_DOT_X_DOT, CZ_DOT_Y_DOT, CZ_DOT_Z_DOT,	km**2/s**2	<CX_DOT_X_DOT units="km**2/s**2">numeric-value</CX_DOT_X_DOT>
MAN_DURATION	s	<MAN_DURATION units="s">numeric-value</MAN_DURATION>
MAN_DELTA_MASS	kg	<MAN_DELTA_MASS units="kg">numeric-value</MAN_DELTA_MASS>

Keyword	Units	Example
MAN_DV_1	km/s	<MAN_DV_1 units="km/s">numeric-value</MAN_DV_1>
MAN_DV_2	km/s	<MAN_DV_2 units="km/s">numeric-value</MAN_DV_2>
MAN_DV_3	km/s	<MAN_DV_3 units="km/s">numeric-value</MAN_DV_3>

8.8.13 In addition to the OPM keywords specified in Section 3, there are several special tags associated with the OPM body as described in the next few subsections. The information content in the OPM is separated into 'logical blocks'. Special tags in the OPM are used to encapsulate the information in the logical blocks of the OPM.

8.8.14 The ODM/XML tags used to delimit the logical blocks of the OPM shall be drawn from the following table:

OPM Logical Block	Associated ODM/XML OPM Tag
State Vector	<stateVector>
Keplerian Elements	<keplerianElements>
Spacecraft Parameters	<spacecraftParameters>
Covariance Matrix	<covarianceMatrix>
Maneuver Parameters	<maneuverParameters>
User Defined Parameters	<userDefinedParameters>

8.8.15 Between the begin tag and end tag (e.g., between <spacecraftParameters> and </spacecraftParameters>), the user shall place the keywords required by the specific logical block as specified in Section 3.

8.9 CREATING AN OMM INSTANTIATION

8.9.1 An OMM instantiation shall be delimited with the `<omm></omm>` root element tags using the standard attributes documented in **8.3**.

8.9.2 The final attributes of the `<omm>` tag shall be 'id' and 'version'.

8.9.3 The 'id' attribute shall be '`id="CCSDS_OMM_VERS"`'.

8.9.4 The 'version' attribute for the version of the OMM described in Section 4 shall be '`version="3.0"`'.

8.9.5 The standard NDM header shall follow the `<omm>` tag (see **8.4**).

8.9.6 The OMM `<body>` shall consist of a single `<segment>`.

8.9.7 The `<segment>` shall consist of a `<metadata>` section and a `<data>` section.

8.9.8 The keywords in the `<metadata>` and `<data>` sections shall be those specified in Section 4. The rules for including any of the keyword tags in the OMM/XML are the same as those specified for the OMM/KVN in Section 4.

8.9.9 Tags for keywords specified in Section 4 shall be all uppercase.

8.9.10 Several of the OMM/XML keywords may have a unit attribute, if desired by the OMM producer.

8.9.11 In all cases, the units shall match those defined in Section 4.

8.9.12 The following table lists the keyword tags for which units may be specified.

Keyword	Units	Example
SEMI_MAJOR_AXIS	km	<SEMI_MAJOR_AXIS units="km">numeric-value</SEMI_MAJOR_AXIS>
MEAN_MOTION	rev/day	<MEAN_MOTION units="rev/day">numeric-value</MEAN_MOTION>
INCLINATION	deg	<INCLINATION units="deg">numeric-value</INCLINATION>
RA_OF_ASC_NODE	deg	<RA_OF_ASC_NODE units="deg">numeric-value</RA_OF_ASC_NODE>
ARG_OF_PERICENTER	deg	<ARG_OF_PERICENTER units="deg">numeric-value</ARG_OF_PERICENTER>
MEAN_ANOMALY	deg	<MEAN_ANOMALY units="deg">numeric-value</MEAN_ANOMALY>
GM	km**3/s**2	<GM units="km**3/s**2">numeric-value</GM>
MASS	kg	<MASS units="kg">numeric-value</MASS>
SOLAR_RAD_AREA	m**2	<SOLAR_RAD_AREA units="m**2">numeric-value</SOLAR_RAD_AREA>
DRAG_AREA	m**2	<DRAG_AREA units="m**2">numeric-value</DRAG_AREA>
BSTAR	1/ER	<BSTAR units="1/ER">numeric-value</BSTAR>
MEAN_MOTION_DOT	rev/day**2	<MEAN_MOTION_DOT units="rev/day**2">numeric-value</MEAN_MOTION_DOT>

Keyword	Units	Example
MEAN_MOTION_DDOT	rev/day**3	<MEAN_MOTION_DDOT units="rev/day**3">numeric-value</MEAN_MOTION_DDOT>
CX_X, CY_X, CY_Y, CZ_X, CZ_Y, CZ_Z	km**2	<CX_X units="km**2">numeric-value</CX_X>
CX_DOT_X, CX_DOT_Y, CX_DOT_Z, CY_DOT_X, CY_DOT_Y, CY_DOT_Z, CZ_DOT_X, CZ_DOT_Y, CZ_DOT_Z	km**2/s	<CX_DOT_X units="km**2/s">numeric-value</CX_DOT_X>
CX_DOT_X_DOT, CY_DOT_X_DOT, CY_DOT_Y_DOT, CZ_DOT_X_DOT, CZ_DOT_Y_DOT, CZ_DOT_Z_DOT	km**2/s**2	<CX_DOT_X_DOT units="km**2/s**2">numeric-value</CX_DOT_X_DOT>

8.9.13 In addition to the OMM keywords specified in Section 4, there are several special tags associated with the OMM body as described in the next few subsections. The information content in the OMM is separated into constructs described in Section 4 as ‘logical blocks’. Special tags in the OMM are used to encapsulate the information in the logical blocks of the OMM.

8.9.14 The ODM/XML tags used to delimit the logical blocks of the OMM shall be drawn from the following table:

OMM Logical Block	Associated ODM/XML OMM Tag
Mean Keplerian Elements	<meanElements>
Spacecraft Parameters	<spacecraftParameters>
TLE Parameters	<tleParameters>
Covariance Matrix	<covarianceMatrix>
User Defined Parameters	<userDefinedParameters>

8.9.15 Between the begin tag and end tag (e.g., between <spacecraftParameters> and </spacecraftParameters>), the user must place the keywords required by the specific logical block as specified in Section 4.

8.10 CREATING AN OEM INSTANTIATION

8.10.1 An OEM instantiation shall be delimited with the `<oem></oem>` root element tags using the standard attributes documented in 8.3.

8.10.2 The final attributes of the `<oem>` tag shall be 'id' and 'version'.

8.10.3 The 'id' attribute shall be '`id="CCSDS_OEM_VERS"`'.

8.10.4 The 'version' attribute for the version of the OEM described in Section 5 shall be '`version="3.0"`'.

8.10.5 The standard NDM header shall follow the `<oem>` tag (see 8.4).

8.10.6 The OEM `<body>` shall consist of one or more `<segment>` constructs.

8.10.7 Each `<segment>` shall consist of a `<metadata>` section and a `<data>` section.

8.10.8 The keywords in the `<metadata>` and `<data>` sections shall be those specified in Section 5. The rules for including any of the keyword tags in the OEM/XML are the same as those specified for the OEM in Section 5.

8.10.9 Tags for keywords specified in Section 5 shall be all uppercase.

8.10.10 In addition to the OEM keywords specified in Section 5, there are some special tags associated with the OEM body as described in the next subsections.

8.10.11 The `<stateVector>` tag shall encapsulate the keywords associated with one of the ephemeris data lines in the OEM.

8.10.12 In the XML representation of the OEM, the components of the `<stateVector>` ephemeris data line must be represented with keywords (i.e., a tag).

8.10.13 The <stateVector> keywords shall be the same as those defined for the same construct in the OPM.

8.10.14 The ODM/XML tags used within the `<stateVector>` structure shall be drawn from the following table:

OEM Tag	Represents	Example
<EPOCH>	time tag of the state	<EPOCH>2007-09-20T17:41:00</EPOCH>
<X>	x component of position	<X units="km">6678.0</X>
<Y>	y component of position	<Y units="km">0.0</Y>
<Z>	z component of position	<Z units="km">0.0</Z>
<X_DOT>	x component of velocity	<X_DOT units="km/s">0</X_DOT>
<Y_DOT>	y component of velocity	<Y_DOT units="km/s">7.73</Y_DOT>
<Z_DOT>	z component of velocity	<Z_DOT units="km/s">0.0</Z_DOT>
<X_DDOT>	x component of acceleration	<X_DDOT units="km/s**2">0.0</X_DDOT>
<Y_DDOT>	y component of acceleration	<Y_DDOT units="km/s**2">0.50</Y_DDOT>
<Z_DDOT>	z component of acceleration	<Z_DDOT units="km/s**2">0.0</Z_DDOT>

8.10.15 Between the begin tag and end tag (i.e., between `<stateVector>` and `</stateVector>`), the user shall place the values required by the ephemeris data line as specified in Section 5.

8.10.16 Since the state vector structure is shared by the OPM schema and OEM schema, units may optionally appear in the XML version of the OEM ephemeris data line.

8.10.17 The `<covarianceMatrix>` tag shall encapsulate the keywords associated with the covariance matrix lines in the OEM.

8.10.18 In the XML representation of the OEM, the covariance data line must be represented with keywords (i.e., a tag).

8.10.19 The OEM <covarianceMatrix> keywords shall be the same as those defined for the same construct in the OPM and OMM.

NOTE – In the KVN representations of the OEM covariance matrix data lines, keywords are not used. Rather, the components of the covariance matrix data line appear in an order defined in Section 5. Similarly, units are not used in the KVN version of the OEM covariance matrix; however, they are optional in the OPM and OMM.

8.10.20 Since the covariance matrix structure is shared by the OPM, OMM and OEM, units may optionally appear in the XML version of the OEM covariance matrix line.

8.10.21 The OEM/XML tags used within the `<covarianceMatrix>` structure shall be drawn from the following table:

Keyword	Units	Example
CX_X, CY_X, CY_Y, CZ_X, CZ_Y, CZ_Z	km**2	<CX_X units="km**2">numeric-value</CX_X>
CX_DOT_X, CX_DOT_Y, CX_DOT_Z, CY_DOT_X, CY_DOT_Y, CY_DOT_Z, CZ_DOT_X, CZ_DOT_Y, CZ_DOT_Z	km**2/s	<CX_DOT_X units="km**2/s">numeric-value</CX_DOT_X>
CX_DOT_X_DOT, CY_DOT_X_DOT, CY_DOT_Y_DOT, CZ_DOT_X_DOT, CZ_DOT_Y_DOT, CZ_DOT_Z_DOT	km**2/s**2	<CX_DOT_X_DOT units="km**2/s**2">numeric-value</CX_DOT_X_DOT>

8.10.22 Between the begin tag and end tag (i.e., between <covarianceMatrix> and </covarianceMatrix>), the user shall place the values required by the covariance matrix line type as specified in Section 5.

8.11 CREATING AN OCM INSTANTIATION

8.11.1 An OCM instantiation shall be delimited with the `<ocm></ocm>` root element tags using the standard attributes documented in 8.3.

8.11.2 The final attributes of the `<ocm>` tag shall be 'id' and 'version'.

8.11.3 The 'id' attribute shall be '`id="CCSDS_OCM_VERS"`'.

8.11.4 The 'version' attribute for the version of the OCM described in Section 6 shall be '`version="3.0"`'.

8.11.5 The standard NDM header shall follow the `<ocm>` tag (see 8.4).

8.11.6 The OCM `<body>` shall consist of a single <segment> construct.

8.11.7 The <segment> shall consist of a `<metadata>` section and a `<data>` section.

8.11.8 The keywords in the `<metadata>` and `<data>` sections shall be those specified in Section 6. The rules for including any of the keyword tags in the OCM/XML are the same as those specified for the OCM in Section 6.

8.11.9 Tags for keywords specified in Section 6 shall be all uppercase.

8.11.10 In addition to the OCM keywords specified in Section 6, there are some special tags associated with the OCM body as described in the next subsections.

8.11.11 TBD

8.11.12 TBD

8.11.13 TBD

8.11.14 The OCM/XML tags used within the `<tbd>` structure shall be drawn from the following table:

OCM Tag	Represents	Example
`<tbd>`	tbd	`<tbd units="tbd">tbd</tbd>`

8.10.23 Between the begin tag and end tag (e.g., between `<tbd>` and `</tbd>`), the user shall place the values required by the TBD data line as specified in Section 6.

8.10.24 In the XML representation of the OCM, the tbd data line must be represented with keywords (i.e., a tag).

8.10.25 A sample OCM/XML follows:

```
<?xml version="1.0" encoding="UTF-8"?>
<ocm  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
```

```
      xsi:noNamespaceSchemaLocation="http://sanaregistry.org/r/ndmxml/ndmxml-1.0-master.xsd"
      id="CCSDS_OEM_VERS" version="3.0">

   <header>
      <COMMENT>THIS EXAMPLE IS TBD</COMMENT>
      <CREATION_DATE>2017-11-04T17:22:31</CREATION_DATE>
      <ORIGINATOR>NASA</ORIGINATOR>
   </header>
   <body>
      &lt;segment&gt;
         <metadata>
         </metadata>
         <data>
         </data>
      &lt;/segment&gt;
   </body>
</ocm>
```

ANNEX A

IMPLEMENTATION CONFORMANCE

STATEMENT PRO FORMA

(NORMATIVE)

A1 INTRODUCTION

A1.1 OVERVIEW

This annex provides the Implementation Conformance Statement (ICS) Requirements List (RL) for an implementation of the Orbit Data Message (CCSDS 502.0). The ICS for an implementation is generated by completing the RL in accordance with the instructions below. An implementation shall satisfy the mandatory conformance requirements referenced in the RL.

- The RL in this annex is blank. An implementation's completed RL is called the ICS. The ICS states which capabilities and options have been implemented. The following can use the ICS:
  - the implementer, as a checklist to reduce the risk of failure to conform to the standard through oversight;
  - a supplier or potential acquirer of the implementation, as a detailed indication of the capabilities of the implementation, stated relative to the common basis for understanding provided by the standard ICS proforma;
  - a user or potential user of the implementation, as a basis for initially checking the possibility of interworking with another implementation (it should be noted that, while interworking can never be guaranteed, failure to interwork can often be predicted from incompatible ICS lists);
  - a tester, as the basis for selecting appropriate tests against which to assess the claim for conformance of the implementation.

A1.2 ABBREVIATIONS AND CONVENTIONS

The RL consists of information in tabular form. The status of features is indicated using the abbreviations and conventions described below.

Item Column

The item column contains sequential numbers for items in the table.

Feature Column

The feature column contains a brief descriptive name for a feature. It implicitly means “Is this feature supported by the implementation?”

Status Column

The status column uses the following notations:

– M mandatory;

– O optional;

– C conditional;

– X prohibited;

– I out of scope;

– N/A not applicable.

Support Column Symbols

The support column is to be used by the implementer to state whether a feature is supported by entering Y, N, or N/A, indicating:

Y Yes, supported by the implementation.

N No, not supported by the implementation.

N/A Not applicable.

The support column should also be used, when appropriate, to enter values supported for a given capability.

A1.3 INSTRUCTIONS FOR COMPLETING THE RL

An implementer shows the extent of compliance to the Recommended Standard by completing the RL; that is, the state of compliance with all mandatory requirements and the options supported are shown. The resulting completed RL is called an ICS. The implementer shall complete the RL by entering appropriate responses in the support or values supported column, using the notation described in A1.2. If a conditional requirement is inapplicable, N/A should be used. If a mandatory requirement is not satisfied, exception information must be supplied by entering a reference X*i*, where *i* is a unique identifier, to an accompanying rationale for the noncompliance.

A2 ICS PROFORMA FOR ORBIT DATA MESSAGE

A2.1 IDENTIFICATION OF ICS

Date of Statement (DD/MM/YYYY)	
ICS serial number	
System Conformance statement cross-reference	

A2.2 IDENTIFICATION OF IMPLEMENTATION UNDER TEST (IUT)

Implementation name	
Implementation version	
Special Configuration	
Other Information	

A2.3 IDENTIFICATION OF SUPPLIES

Supplier	
Contact Point for Queries	
Implementation Name(s) and Versions	
Other information necessary for full identification, e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)	

A2.4 DOCUMENT VERSIONS

CCSDS 502.0 Document Version	
Have any exceptions been required? (Note: A YES answer means that the implementation does not conform to the Recommended Standard. Non-supported mandatory capabilities are to be identified in the ICS, with an explanation of why the implementation is non-conforming.)	Yes _____ No_____

A2.5 REQUIREMENTS LISTS

[See CCSDS A20.1-Y-1, *CCSDS Implementation Conformance Statements* (Yellow Book, Issue 1, April 2014).]

Item	Feature	Keyword	Reference (Blue book)	Status (M/O/…)	Support

ANNEX B

VALUES FOR TIME_SYSTEM AND FRAME RELATED KEYWORDS

(NORMATIVE)

The values in this annex represent the set of acceptable values for the TIME_SYSTEM, REF_FRAME, OEB_PARENT_FRAME, MAN_REF_FRAME, ORB_REF_FRAME, COV_REF_FRAME and STM_REF_FRAME keywords in the OPM, OMM, OEM and OCM. (For details and description of these time systems, see reference [L1]) If exchange partners wish to use different settings, the settings should be documented in the ICD.

B1 TIME_SYSTEM METADATA KEYWORD

Time System Value	Meaning
BEIDOU	Beidou
GALILEO	Galileo
GLONASS	Glonass
GMST	Greenwich Mean Sidereal Time
GPS	Global Positioning System
MET	Mission Elapsed Time (note)
MRT	Mission Relative Time (note)
NAVIC	Navic
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.

B2 REFERENCE FRAME KEYWORDS

Fixed Reference Frame Value	Meaning
DTRFyyyy	The DTRFyyyy (e.g. DTRF2014) is the ITRS realization considering corrections for non-tidal atmospheric and hydrological loading, as of year “yyyy” (e.g. 2000)
EFG	Earth-Fixed Greenwich (E, F, G) rotating frame
EME2000	Earth Mean Equator and Equinox of J2000
GCRF	Geocentric Celestial Reference Frame
GRC	Greenwich Rotating Coordinates
ICRFyyyy	International Celestial Reference Frame (Barycentric) solution as of year “yyyy” (e.g. 2000)
ITRFyyyy	International Terrestrial (i.e., rotating) Reference Frame solution as of year “yyyy” (e.g. 2000)
MCI	Mars Centered Inertial
MEME	Mean Equator Mean Equinox
MOON_ME	Moon Mean Earth (ME) frame, which has its X axis pointed along the mean direction to the center of the Earth and the Z axis pointing to the mean direction of rotation. The ME frame is typically used to specify the location of objects on the Moon.
MOON_MEIAUE	Moon-Centered, Moon Mean Equator and IAU-Node of Epoch frame as specified in [L11, Fig. 6-2].
MOON_PA	Moon Principal Axis (PA) frame which is defined by the inertial tensor of the Moon. The PA frame is used as the basis for Lunar gravity models, in the numerical integration of the planetary ephemerides, and as the reference for modern moon gravity solutions. Euler angles supplied as part of the JPL DE planetary ephemerides relate the MOON_PA frame to ICRF.
TDR	True of Date, Rotating frame (Realized as ITRF Fixed)
TEME	True Equator Mean Equinox (see below NORAD comment) pseudo-inertial frame
TOD	True of Date (True Equator True Equinox) pseudo-inertial frame
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

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 [L3] or [L4]). 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.

B3 RELATIVE REFERENCE FRAME KEYWORDS

In addition to the above reference frames, maneuver and covariance data can be specified in the following relative frames. Note that for many of these frames (particularly those that are spacecraft hardware-dependent), an ICD will likely be necessary to fully define and convey understanding of these frames.

Note that the orbit-relative local reference frames below are provided in two flavors: inertial and rotating. When transforming velocity terms between inertial and rotating frames, remember to properly incorporate the $(\bar{\boldsymbol{\omega}} \times \overline{\boldsymbol{r}})$ contribution.

Relative Reference Frame Value	Meaning
ACTUATOR_xx	Actuator reference frame (‘xx’ = 00→99): could denote reaction wheels, solar arrays, thrusters, etc.
CSS_xx	Coarse Sun Sensor (‘xx’ = 00→99)
DSS_xx	Digital Sun Sensor (‘xx’ = 00→99)
GYRO_xx	Gyroscope Reference Frame(‘xx’ = 00→99)
INSTRUMENT_xx	Instrument ‘y’ reference frame (‘xx’ = 00→99)

NSW_INERTIAL	A pseudo-inertial "NADIR, Sun, Normal" local orbital coordinate frame instantaneously frozen in inertial space with the x-axis in the NADIR direction, the y-axis as much as possible toward the Sun while still being normal to the x-axis, and the z-axis completing the right-hand set
NSW_ROTATING	A rotating "NADIR, Sun, Normal" local orbital coordinate frame with the x-axis in the NADIR direction, the y-axis as much as possible toward the Sun while still being normal to the x-axis, and the z-axis completing the right-hand set
RTN_INERTIAL	A pseudo-inertial local orbital coordinate frame instantaneously frozen in inertial space with the x, y and z-axis aligned with Radial, Transverse (or in-track), and Normal (also known as RIC, QSW or RSW)
RTN_ROTATING	A rotating local orbital coordinate frame with the x, y and z-axis aligned with Radial, Transverse (or in-track), and Normal (also known as RIC, QSW or RSW)
SC_BODY_xx	Spacecraft Body Frame ('xx' = 00→99); requires clear specification via ICD
SC_BODY_xx	Spacecraft Body Frame of another object ('xx' = 00→99); requires clear specification via ICD
SENSOR_xx	Sensor 'x' reference frame ('xx' = 00→99)
STARTRACKER_xx	Star Tracker Reference Frame ('xx' = 00→99)
TAM_xx	Three Axis Magnetometer Reference Frame ('xx' = 00→99)
TNW_INERTIAL	A pseudo-inertial local orbital coordinate frame instantaneously frozen in inertial space with the x-axis along the Tangential (or velocity) vector, z-axis ("W") along the orbital angular momentum vector ($\bar{\omega} = \bar{r}\ x\ \bar{v}$), and N completing the right handed system (i.e., for a circular orbit "N" points in the Nadir direction and for an eccentric orbit, "N" points as close to Nadir as possible while still being normal to the T-W plane).
TNW_ROTATING	A rotating local orbital coordinate frame with the x-axis along the Tangential (or velocity) vector, z-axis ("W") along the orbital angular momentum vector ($\bar{\omega} = \bar{r}\ x\ \bar{v}$), and N completing the right handed system (i.e., for a circular orbit "N" points in the Nadir direction and for an eccentric orbit, "N" points as close to Nadir as possible while still being normal to the T-W plane).
VNC_INERTIAL	A pseudo-inertial local orbital coordinate frame instantaneously frozen in inertial space with the x-axis along the Velocity (or tangential) vector, y-axis Normal to the orbit

	along the orbital angular momentum vector ($\bar{\omega} = \bar{r}\ x\ \bar{v}$), and z-axis is the "Co-normal" direction completing the right handed system (i.e., for a circular orbit "C" points in the radius vector direction whereas for an eccentric orbit, "C" points as close to radial as possible while still being normal to the V-N plane).
VNC_ROTATING	A rotating local orbital coordinate frame with the x-axis along the Velocity (or tangential) vector, y-axis Normal to the orbit along the orbital angular momentum vector ($\bar{\omega} = \bar{r}\ x\ \bar{v}$), and z-axis is the "Co-normal" direction completing the right handed system (i.e., for a circular orbit "C" points in the radius vector direction whereas for an eccentric orbit, "C" points as close to radial as possible while still being normal to the V-N plane).
ICD	Other relative reference frame, as defined in ICD

B4 ELEMENT SET KEYWORDS

Unique to the Orbit Comprehensive Message (OCM), orbit element states and/or time histories may be specified in the following multiple 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).

Non-inertial reference frames shall not be specified when employing inertial element sets.

Similarly, inertial reference frames shall not be specified when employing non-inertial element sets.

Orbit Element Set Value	Meaning
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)
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)
EQUIN	Equinoctial 7-element set ([ahkλpqf_r] = [a, a_g, a_f, L=$(\Omega + \omega + f_r\, M)$, χ, ψ, $f_r = \pm 1$] as defined in Vallado [L9])
EQUINMOD	Equinoctial 7-element modified set ([pfghkLf_r] = [a(1-e^2), a_f, a_g, χ, ψ, $L = (\Omega + \omega + f_r\, \nu)$, $f_r = \pm 1$] as defined in Vallado [L9])
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)
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

B5 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
COV_NNXNN	Generic NN x NN covariance containing "NN" rows and columns, with "NN" containing a TWO-DIGIT (including leading zero) representation) of the covariance size. Valid examples are: COV_02X02, COV_12X12. The contents of the covariance matrix must be defined in an accompanying ICD
TADBARV	7x7: 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
TCARTP	4x4: Time & Cartesian 3-element position (only) errors (X, Y, Z)
TCARTPV	7x7: Time & Cartesian 6-element position and velocity errors (X, Y, Z, XD, YD, ZD)
TCARTPVA	10x10: Time & Cartesian 9-element position, velocity and acceleration errors (X, Y, Z, XD, YD, ZD, XDD, YDD, ZDD)
TEQUIN	7x7: Time & Equinoctial 6-element set ([ahkλpq] = [a, a_g, a_f, L=$(\Omega + \omega + f_r\ M)$, χ, ψ] as defined in Vallado [L9]) errors
TEQUINMOD	7x7: Time & Equinoctial 6-element modified set ([pfghkL] = [a(1-e^2), a_f, a_g, χ, ψ, $L = (\Omega + \omega + f_r\ \nu)$] per Vallado [L9])

TEIGVAL3EIGVEC3	13-element eigenvalue/eigenvector representation time history corresponding to the 3x3 position covariance time history, with each line containing Time, the three (major, medium and minor) eigenvalues IN DESCENDING ORDER, and the corresponding three eigenvectors matching the major, medium and minor eigenvalues
TKPLR	7x7: Time & Keplerian 6-element classical set ($ aei\Omega\omega\nu $: semi-major axis, eccentricity, inclination, right ascension of the ascending node, argument of perigee, and true anomaly) errors
TKPLRM	7x7: Time & Keplerian 6-element classical set ($ aei\Omega\omega M $: semi-major axis, eccentricity, inclination, right ascension of the ascending node, argument of perigee, and mean anomaly) errors
TLDBARV	7x7: Time & Modified spherical 6-element set ($\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) errors

ANNEX C

TECHNICAL MATERIAL

(INFORMATIVE)

C1 OVERVIEW

8.11.1.1 Definition: an 'observation' is a unique measurement set of a satellite's state from a single sensor configuration at a single time (e.g. azimuth from a single sensor at a single time).

8.11.1.2 Definition: a 'sensor track' is a set of observations within NMINTRK minutes for the same object, observed by the same sensor configuration, where each observation is within a specified number of minutes (which is dependent on the orbit regime of the object) of the other observations in the track (e.g. a set of 10 two-way transponder range measurements from the same sensor using the same transponder on the satellite), where the number of minutes could alternately be defined as the time between start and stop of the measurement "session" or signal modulation that enables metric tracking.

ANNEX D

SATELLITE PHYSICAL CHARACTERISTICS SPECIFICATION

(INFORMATIVE)

D1 OVERVIEW

This annex defines satellite dimensional and orientational parameters of the OCM's satellite physical characteristics specification.

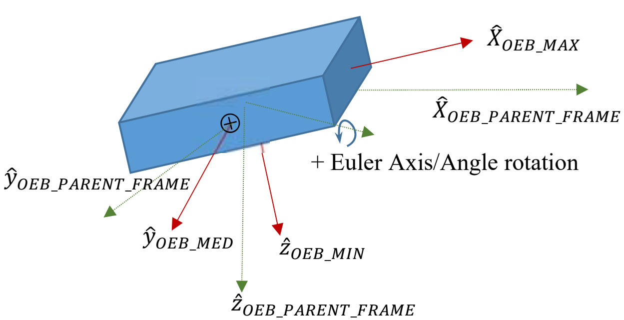
To facilitate improved modeling of space object attitude, hard body collision, and drag and SRP acceleration forces, the OCM allows the specification of an "**Optimally-Encompassing Box**" (**OEB**).

For a box-shaped satellite (e.g., a CubeSat) without appendages, the satellite and its corresponding OEB are one and the same. For a satellite having solar arrays that extend from the spacecraft body structure, the OEB would extend from the main satellite body to encompass the deployed solar arrays as well.

As shown in the figure below, the OEB reference frame axes (depicted in RED) are defined by convention as follows:

- The OEB x-axis is along the **longest** dimension of the OEB ($\hat{X}_{OEB\_MAX}$)
- The OEB y-axis is along the **intermediate** orthonormal dimension ($\hat{y}_{OEB\_MED}$)
- The OEB z-axis is along the **shortest** orthonormal dimension ($\hat{z}_{OEB\_MIN}$).

In the event that the longest orthonormal dimensions are equivalent, the user shall select $\hat{X}_{OEB\_MAX}$ as the direction along one of those longest dimensions and the next as $\hat{y}_{OEB\_MED}$. The OEB z-axis shall be defined as: $\hat{z}_{OEB\_MIN} = \hat{X}_{OEB\_MAX} \times \hat{y}_{OEB\_MAX}$



A fixed orientation of the Optimally-Enclosing Box with respect to the user-specified "OEB_PARENT_FRAME" is defined using an ordered sequence of Euler rotations that map from the user-specified OEB_PARENT_FRAME to the Optimally-Encompassing Box vector directions. The above figure shows the proper definitions and adopted sign conventions for Yaw, Pitch and Roll angles. The resulting transformation sequence is:

$$\begin{bmatrix} \boldsymbol{x} \\ \boldsymbol{y} \\ \boldsymbol{z} \end{bmatrix}_{\mathbf{OEB}} = [\boldsymbol{M}] \begin{bmatrix} \boldsymbol{x} \\ \boldsymbol{y} \\ \boldsymbol{z} \end{bmatrix}_{\boldsymbol{OEB\_PARENT\_FRAME}}$$

Where the frame transformation matrix [M] is a function of the quaternion components

$$[M] = \begin{bmatrix} {q_1}^2 - {q_2}^2 - {q_3}^2 + {q_c}^2 & 2(q_1 q_2 + q_3 q_c) & 2(q_1 q_3 - q_2 q_c) \\ 2(q_1 q_2 - q_3 q_c) & -{q_1}^2 + {q_2}^2 - {q_3}^2 + {q_c}^2 & 2(q_2 q_3 + q_1 q_c) \\ 2(q_1 q_3 + q_2 q_c) & 2(q_2 q_3 - q_1 q_c) & -{q_1}^2 - {q_2}^2 + {q_3}^2 + {q_c}^2 \end{bmatrix}$$

The physical dimensions of the OEB (long, intermediate and short dimensions) are specified via OEB_MAX, OEB_MED and OEB_MIN respectively.

The cross-sectional area as viewed along the OEB x, y and z axes (long, intermediate and short dimension directions) are specified via AREA_ALONG_OEB_MAX, AREA_ALONG_OEB_MED and AREA_ALONG_OEB_MIN, respectively.

ANNEX E

APPARENT-TO-ABSOLUTE VISUAL MAGNITUDE RELATIONSHIP

(INFORMATIVE)

E1 OVERVIEW

This annex presents the relationships to be used to map apparent to absolute visual magnitude for inclusion in an OCM. These equations, based on reference [L12], examine signal magnitude for reflected illumination by a Resident Space Object (RSO) that is exoatmospheric, meaning that its illumination by the Sun is not reduced or impeded by atmospheric transmission losses. The equations do not account for spatial distribution across multiple detectors, which involves characterizing the Point Spread Function of the system.

Definitions:

$\boldsymbol{E_{EntranceAperture}}$	Target's specific entrance aperture radiance [W/m^2]
I_{Sun}	Solar Intensity ≈ $3.088374161 \times 10^{25}$ $[W]$
$d_{SunToTarget}$	Distance from the sun to the target (e.g. 1 AU = $1.4959787066 \times 10^{11}$ m)
E_{Sun}	Exoatmospheric solar irradiance, nominally 1380 $[W/m^2]$ at 1 AU
φ	Phase or Critical Angle to the Sun (CATS) from sun to the sensor, measured at the observed target [rad]
$Phase(\varphi)$	Geometric reflectance function [between 0 and 1]
F	General shadowing term accounting for the penumbra region's influence [unitless ratio between 0 = umbra and 1 = full Sun illumination]
A_{Target}	Effective area of the target $[m^2]$
π	Pi constant
ρ	Reflectance of the target [between 0 (none) and 1 (perfect reflectance)]
I_{Target}	Intensity of reflected energy from target treated as a point source [W]
E_{Target}	Target Irradiance at Sensor without atmos loss [W/m^2]
r_{Target}	Effective radius of the target $[m^2]$
$d_{TargetToSensor}$	Distance from target to sensor $[m]$
$\tau_{Atmosphere}$	Atmospheric transmission [unitless between 0 and 1]
E_0	Ref. Visual Magnitude (Vega) Irradiance [2.77894$\times 10^{-8}$ W/m^2]

Given an optical sensor's measured target entrance aperture radiance:

$VM_{apparent} = -2.5\ \log_{10} \frac{E_{target}}{E_0}$, measured on the visual magnitude scale

$\boldsymbol{E}_{target} = \frac{E_{EntranceAperture}}{\tau_{Atmosphere}(\boldsymbol{\theta})}$ [W/m^2]

or if $VM_{apparent}$ known: $E_{target} = E_0\, 10^{\left[-\frac{VM_{apparent}}{2.5}\right]}$

$$I_{target} = E_{target}\, d^2_{TargetToSensor} \text{ [W]}$$

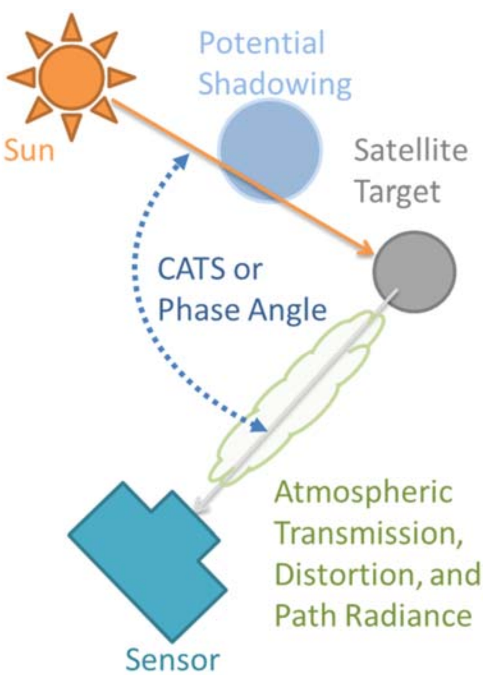
$$E_{Sun} = \frac{I_{Sun}}{d^2_{SunToTarget}} \text{ [W/m}^2\text{]}$$

$$Phase(\varphi) = \frac{\sin\varphi + (\pi - \varphi)\cos\varphi}{\pi}$$

$$\boldsymbol{\rho\, A_{Target}} = \frac{\boldsymbol{\pi\, I_{Target}}}{\boldsymbol{E_{Sun}\, F\;\, Phase(\varphi)}} \text{ [m}^2\text{]}$$

From the above equations, $VM_{absolute}$ "normalized" to a 1 AU Sun-to-target distance, a phase angle of 0° and a 40,000 km target-to-sensor distance (equivalent to a GEO satellite tracked at 15.6° elevation above the optical site's local horizon), is obtained as:

$$VM_{absolute} = -2.5\, \log_{10}\left\{\frac{\left[\boldsymbol{E_{Sun_{1\,AU}}=1380}\, {}^{W}/_{m^2}\right]\left[\boldsymbol{Phase(0\,rad)}=1.0\right]\left[\boldsymbol{\rho\, A_{Target}}\, from\ above,\ \ in\ m^2\right]}{\boldsymbol{\pi}\left[E_0 = 2.77894\times10^{-8}\, {}^{W}/_{m^2}\right]\left[1.6\times10^{15}\, m^2\right]}\right\}$$



ANNEX F

OPM EXAMPLES

(INFORMATIVE)

The following are examples of Orbit Parameter Messages (OPMs).

OPM examples in KVN:

The following figures are examples of OPMs in Keyword Value Notation (KVN) format. The first has only a state; the second has state, Keplerian elements, and maneuvers; the third and fourth include the position/velocity covariance matrix.

Figures Annex Fig. F-1 and Annex Fig. F-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.

Figure Annex Fig. F-3 and Annex Fig. F-4 include unique features of ODM version 2.0, and thus 'CCSDS_OPM_VERS = 2.0' (at a minimum) must be specified.

```
CCSDS_OPM_VERS = 3.0
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      = ITRF1997
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
```

Annex Fig. F-1: Simple OPM file example

```
CCSDS_OPM_VERS    =  3.0

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         =  1998-099A
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]
```

Annex Fig. F-2: OPM file example with optional Keplerian elements and two maneuvers

```
CCSDS_OPM_VERS = 3.0

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      = ITRF1997
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
```

Annex Fig. F-3: OPM file example with covariance matrix

```
CCSDS_OPM_VERS    =  3.0
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         =  1998-099A
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
```

Annex Fig. F-4: OPM file example with optional Keplerian elements, covariance matrix, and a user defined parameter

OPM example in XML:

Annex Fig. F-5 contains an example of an OPM in Extensible Markup Language (XML) format.

```
<?xml version="1.0" encoding="UTF-8"?>
<opm  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
      xsi:noNamespaceSchemaLocation="http://sanaregistry.org/r/ndmxml/ndmxml-1.0-master.xsd"
      id="CCSDS_OPM_VERS" version="3.0">

   <header>
      <COMMENT>THIS EXAMPLE CONFORMS TO FIGURE 3-1 IN 502.0-B-2</COMMENT>
      <CREATION_DATE>2001-11-06T09:23:57</CREATION_DATE>
      <ORIGINATOR>JAXA</ORIGINATOR>
   </header>
   <body>
      &lt;segment&gt;
         <metadata>
            <COMMENT>GEOCENTRIC, CARTESIAN, EARTH FIXED</COMMENT>
            <OBJECT_NAME>GODZILLA 5</OBJECT_NAME>
            <OBJECT_ID>1998-057A</OBJECT_ID>
            <CENTER_NAME>EARTH</CENTER_NAME>
            <REF_FRAME>ITRF1997</REF_FRAME>
            <TIME_SYSTEM>UTC</TIME_SYSTEM>
         </metadata>
         <data>
            <COMMENT>OBJECT_ID:  1998-057A</COMMENT>
            <stateVector>
               <EPOCH>1996-12-18T14:28:15.1172</EPOCH>
               <X>6503.514000</X>
               <Y>1239.647000</Y>
               <Z>-717.490000</Z>
               <X_DOT>-0.873160</X_DOT>
               <Y_DOT>8.740420</Y_DOT>
               <Z_DOT>-4.191076</Z_DOT>
            </stateVector>
            <spacecraftParameters>
               <MASS>3000.000000</MASS>
               <SOLAR_RAD_AREA>18.770000</SOLAR_RAD_AREA>
               <SOLAR_RAD_COEFF>1.000000</SOLAR_RAD_COEFF>
               <DRAG_AREA>18.770000</DRAG_AREA>
               <DRAG_COEFF>2.500000</DRAG_COEFF>
            </spacecraftParameters>
            <covarianceMatrix>
               <COV_REF_FRAME>ITRF1997</COV_REF_FRAME>
               <CX_X>0.316</CX_X>
               <CY_X>0.722</CY_X>
               <CY_Y>0.518</CY_Y>
               <CZ_X>0.202</CZ_X>
               <CZ_Y>0.715</CZ_Y>
               <CZ_Z>0.002</CZ_Z>
               <CX_DOT_X>0.912</CX_DOT_X>
               <CX_DOT_Y>0.306</CX_DOT_Y>
               <CX_DOT_Z>0.276</CX_DOT_Z>
               <CX_DOT_X_DOT>0.797</CX_DOT_X_DOT>
               <CY_DOT_X>0.562</CY_DOT_X>
               <CY_DOT_Y>0.899</CY_DOT_Y>
               <CY_DOT_Z>0.022</CY_DOT_Z>
               <CY_DOT_X_DOT>0.079</CY_DOT_X_DOT>
               <CY_DOT_Y_DOT>0.415</CY_DOT_Y_DOT>
               <CZ_DOT_X>0.245</CZ_DOT_X>
               <CZ_DOT_Y>0.965</CZ_DOT_Y>
               <CZ_DOT_Z>0.950</CZ_DOT_Z>
               <CZ_DOT_X_DOT>0.435</CZ_DOT_X_DOT>
               <CZ_DOT_Y_DOT>0.621</CZ_DOT_Y_DOT>
               <CZ_DOT_Z_DOT>0.991</CZ_DOT_Z_DOT>
            </covarianceMatrix>
         </data>
      &lt;/segment&gt;
   </body>
</opm>
```

Annex Fig. F-5: OPM file example in XML format

ANNEX G

OMM EXAMPLES

(INFORMATIVE)

The following are examples of Orbit Mean-Element Messages (OMMs). All of these examples are based on the TLE shown in Annex Fig. G-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
```

Annex Fig. G-1: Example Two Line Element Set (TLE)

OMM examples in KVN:

The following figures are examples of OMMs in Keyword Value Notation (KVN) format .

```
CCSDS_OMM_VERS = 3.0
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
```

Annex Fig. G-2: OMM file example without covariance matrix

```
CCSDS_OMM_VERS = 3.0
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
```

Annex Fig. G-3: OMM file example with covariance matrix

```
CCSDS_OMM_VERS = 3.0
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
```

Annex Fig. G-4: OMM with units and a user defined parameter

OMM example in XML:

Annex Fig. G-5 contains an example of an OMM in Extensible Markup Language (XML) format.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<omm  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
      xsi:noNamespaceSchemaLocation="http://sanaregistry.org/r/ndmxml/ndmxml-1.0-master.xsd"
      id="CCSDS_OMM_VERS" version="3.0">

   <header>
      <COMMENT>THIS EXAMPLE CONFORMS TO FIGURE 4-3 IN 502.0-B-2</COMMENT>
      <CREATION_DATE>2007-065T16:00:00</CREATION_DATE>
      <ORIGINATOR>NOAA/USA</ORIGINATOR>
   </header>

   <body>
      &lt;segment&gt;
         <metadata>
            <OBJECT_NAME>GOES-9</OBJECT_NAME>
            <OBJECT_ID>1995-025A</OBJECT_ID>
            <CENTER_NAME>EARTH</CENTER_NAME>
            <REF_FRAME>TEME</REF_FRAME>
            <TIME_SYSTEM>UTC</TIME_SYSTEM>
            <MEAN_ELEMENT_THEORY>TLE</MEAN_ELEMENT_THEORY>
         </metadata>

         <data>
            <meanElements>
               <EPOCH>2007-064T10:34:41.4264</EPOCH>
               <MEAN_MOTION>1.00273272</MEAN_MOTION>
               <ECCENTRICITY>0.0005013</ECCENTRICITY>
               <INCLINATION>3.0539</INCLINATION>
               <RA_OF_ASC_NODE>81.7939</RA_OF_ASC_NODE>
               <ARG_OF_PERICENTER>249.2363</ARG_OF_PERICENTER>
               <MEAN_ANOMALY>150.1602</MEAN_ANOMALY>
               <GM>398600.8</GM>
            </meanElements>
            <tleParameters>
               <NORAD_CAT_ID>23581</NORAD_CAT_ID>
               <ELEMENT_SET_NO>0925</ELEMENT_SET_NO>
               <REV_AT_EPOCH>4316</REV_AT_EPOCH>
               <BSTAR>0.0001</BSTAR>
               <MEAN_MOTION_DOT>-0.00000113</MEAN_MOTION_DOT>
               <MEAN_MOTION_DDOT>0.0</MEAN_MOTION_DDOT>
            </tleParameters>
            <covarianceMatrix>
               <COV_REF_FRAME>TEME</COV_REF_FRAME>
               <CX_X>0.316</CX_X>
               <CY_X>0.722</CY_X>
               <CY_Y>0.518</CY_Y>
               <CZ_X>0.202</CZ_X>
               <CZ_Y>0.715</CZ_Y>
               <CZ_Z>0.002</CZ_Z>
               <CX_DOT_X>0.912</CX_DOT_X>
               <CX_DOT_Y>0.306</CX_DOT_Y>
               <CX_DOT_Z>0.276</CX_DOT_Z>
               <CX_DOT_X_DOT>0.797</CX_DOT_X_DOT>
               <CY_DOT_X>0.562</CY_DOT_X>
               <CY_DOT_Y>0.899</CY_DOT_Y>
               <CY_DOT_Z>0.022</CY_DOT_Z>
               <CY_DOT_X_DOT>0.079</CY_DOT_X_DOT>
               <CY_DOT_Y_DOT>0.415</CY_DOT_Y_DOT>
               <CZ_DOT_X>0.245</CZ_DOT_X>
               <CZ_DOT_Y>0.965</CZ_DOT_Y>
               <CZ_DOT_Z>0.950</CZ_DOT_Z>
               <CZ_DOT_X_DOT>0.435</CZ_DOT_X_DOT>
               <CZ_DOT_Y_DOT>0.621</CZ_DOT_Y_DOT>
               <CZ_DOT_Z_DOT>0.991</CZ_DOT_Z_DOT>
            </covarianceMatrix>
         </data>
      &lt;/segment&gt;
   </body>
</omm>
```

Annex Fig. G-5: OMM file example in XML format

ANNEX H

OEM EXAMPLES

(INFORMATIVE)

The following are examples of Orbit Ephemeris Messages (OEMs).

OEM examples in KVN:

The following figures are examples of OEMs in Keyword Value Notation (KVN) format. Annex Fig. H-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). Annex Fig. H-2 and Annex Fig. H-3 contain features unique to the ODM version 2, and thus 'CCSDS_OEM_VERS = 2.0' must be specified. Some ephemeris data lines have been omitted to save space.

```
CCSDS_OEM_VERS = 3.0
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
```

Annex Fig. H-1: Version 1 OEM Compatible Example (No Acceleration, No Covariance)

```
CCSDS_OEM_VERS = 3.0

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
```

Annex Fig. H-2: Version 2 OEM Example with Optional Accelerations

```
CCSDS_OEM_VERS = 3.0
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


COV_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
```

Annex Fig. H-3: Version 2 OEM Example with Optional Covariance Matrices

OEM example in XML:

Annex Fig. H-4 contains an example of an Orbit Ephemeris Message in Extensible Markup Language (XML) format.

```
<?xml version="1.0" encoding="UTF-8"?>
<oem  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
      xsi:noNamespaceSchemaLocation="http://sanaregistry.org/r/ndmxml/ndmxml-1.0-master.xsd"
      id="CCSDS_OEM_VERS" version="3.0">

   <header>
      <COMMENT>THIS EXAMPLE CONFORMS TO FIGURE 5-2 IN 502.0-B-2</COMMENT>
      <COMMENT>OEM WITH OPTIONAL ACCELERATIONS CAN ONLY BE OEM VERSION 2.0</COMMENT>
      <CREATION_DATE>1996-11-04T17:22:31</CREATION_DATE>
      <ORIGINATOR>NASA/JPL</ORIGINATOR>
   </header>
```

```
<body>
   &lt;segment&gt;
      <metadata>
         <OBJECT_NAME>MARS GLOBAL SURVEYOR</OBJECT_NAME>
         <OBJECT_ID>1996-062A</OBJECT_ID>
         <CENTER_NAME>MARS BARYCENTER</CENTER_NAME>
         <REF_FRAME>EME2000</REF_FRAME>
         <TIME_SYSTEM>UTC</TIME_SYSTEM>
         <START_TIME>1996-12-18T12:00:00.331</START_TIME>
         <USEABLE_START_TIME>1996-12-18T12:10:00.331</USEABLE_START_TIME>
         <USEABLE_STOP_TIME>1996-12-28T21:23:00.331</USEABLE_STOP_TIME>
         <STOP_TIME>1996-12-28T21:28:00.331</STOP_TIME>
         <INTERPOLATION>HERMITE</INTERPOLATION>
         <INTERPOLATION_DEGREE>7</INTERPOLATION_DEGREE>
      </metadata>
      <data>
         <COMMENT>Produced by M.R. Sombedody, MSOO NAV/JPL, 1996 OCT 11.  It is</COMMENT>
         <COMMENT>to be used for DSN scheduling purposes only.</COMMENT>
         <stateVector>
            <EPOCH>1996-12-18T12:00:00.331</EPOCH>
            <X>2789.6</X>
            <Y>-280.0</Y>
            <Z>-1746.8</Z>
            <X_DOT>4.73</X_DOT>
            <Y_DOT>-2.50</Y_DOT>
            <Z_DOT>-1.04</Z_DOT>
            <X_DDOT>0.008</X_DDOT>
            <Y_DDOT>0.001</Y_DDOT>
            <Z_DDOT>-0.159</Z_DDOT>
         </stateVector>
         <stateVector>
            <EPOCH>1996-12-18T12:01:00.331</EPOCH>
            <X>2783.4</X>
            <Y>-308.1</Y>
            <Z>-1877.1</Z>
            <X_DOT>5.19</X_DOT>
            <Y_DOT>-2.42</Y_DOT>
            <Z_DOT>-2.00</Z_DOT>
            <X_DDOT>0.008</X_DDOT>
            <Y_DDOT>0.001</Y_DDOT>
            <Z_DDOT>0.001</Z_DDOT>
         </stateVector>
         <stateVector>
            <EPOCH>1996-12-18T12:02:00.331</EPOCH>
            <X>2776.0</X>
            <Y>-336.9</Y>
            <Z>-2008.7</Z>
            <X_DOT>5.64</X_DOT>
            <Y_DOT>-2.34</Y_DOT>
            <Z_DOT>-1.95</Z_DOT>
            <X_DDOT>0.008</X_DDOT>
            <Y_DDOT>0.001</Y_DDOT>
            <Z_DDOT>0.159</Z_DDOT>
         </stateVector>
         <stateVector>
            <EPOCH>1996-12-28T21:28:00.331</EPOCH>
            <X>-3881.0</X>
            <Y>564.0</Y>
            <Z>-682.8</Z>
            <X_DOT>-3.29</X_DOT>
            <Y_DOT>-3.67</Y_DOT>
            <Z_DOT>1.64</Z_DOT>
            <X_DDOT>-0.003</X_DDOT>
            <Y_DDOT>0.000</Y_DDOT>
            <Z_DDOT>0.000</Z_DDOT>
         </stateVector>
         <covarianceMatrix>
            <EPOCH></EPOCH>
            <COV_REF_FRAME>ITRF1997</COV_REF_FRAME>
            <CX_X>0.316</CX_X>
            <CY_X>0.722</CY_X>
```

```
                <CY_Y>0.518</CY_Y>
                <CZ_X>0.202</CZ_X>
                <CZ_Y>0.715</CZ_Y>
                <CZ_Z>0.002</CZ_Z>
                <CX_DOT_X>0.912</CX_DOT_X>
                <CX_DOT_Y>0.306</CX_DOT_Y>
                <CX_DOT_Z>0.276</CX_DOT_Z>
                <CX_DOT_X_DOT>0.797</CX_DOT_X_DOT>
                <CY_DOT_X>0.562</CY_DOT_X>
                <CY_DOT_Y>0.899</CY_DOT_Y>
                <CY_DOT_Z>0.022</CY_DOT_Z>
                <CY_DOT_X_DOT>0.079</CY_DOT_X_DOT>
                <CY_DOT_Y_DOT>0.415</CY_DOT_Y_DOT>
                <CZ_DOT_X>0.245</CZ_DOT_X>
                <CZ_DOT_Y>0.965</CZ_DOT_Y>
                <CZ_DOT_Z>0.950</CZ_DOT_Z>
                <CZ_DOT_X_DOT>0.435</CZ_DOT_X_DOT>
                <CZ_DOT_Y_DOT>0.621</CZ_DOT_Y_DOT>
                <CZ_DOT_Z_DOT>0.991</CZ_DOT_Z_DOT>
             </covarianceMatrix>
          </data>
       &lt;/segment&gt;
    </body>
</oem>
```

Annex Fig. H-4: OEM file example in XML format

ANNEX I

OCM EXAMPLES AND ASSOCIATED SUPPLEMTARY INFORMATION

(INFORMATIVE)

The following are examples of Orbit Comprehensive Messages (OCMs).

OCM examples in KVN:

The following figures are examples of OCMs in Keyword Value Notation (KVN) format. The first has only a time history of orbital states and constitutes a minimal content OCM. The second includes space object characteristics and perturbations 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; the fourth includes a time series of covariance matrices, and the fifth contains a State Transition Matrix and an Ephemeris Compression section.

```
CCSDS_OCM_VERS  = 3.0
CREATION_DATE   = 1998-11-06T09:23:57
ORIGINATOR      = JAXA
MESSAGE_ID      = OCM 201113719185
EPOCH_TZERO     = 1998-12-18T14:28:15.1172
TIME_SYSTEM_ABS = UTC
TIME_SYSTEM_REL = UT1
OBJECT_NAME     = GODZILLA 5

ORB_START
ORB_REF_FRAME   = EME2000
ORB_TYPE        = CARTPV
  0.0 2789.6 -280.0 -1746.8 4.73 -2.50 -1.04
 10.0 2783.4 -308.1 -1877.1 5.19 -2.42 -2.00
 20.0 2776.0 -336.9 -2008.7 5.64 -2.34 -1.95
   < intervening data records omitted here >
500.0 2164.375 1115.811 -688.131 -3.53328 -2.88452 0.88535
ORB_STOP
```

Annex Fig. I-1: Simple/Succinct OCM File example with only Cartesian ephemeris. Here, the t-zero epoch is defined in the UTC system whereas relative time is specified in UT1 seconds with respect to that t-zero epoch

```
CCSDS_OCM_VERS  = 3.0
COMMENT This OCM reflects the latest conditions post-maneuver A67Z
COMMENT This example shows the specification of multiple comment lines
CREATION_DATE         = 1998-11-06T09:23:57

ORIGINATOR            = JAXA
EPOCH_TZERO           = 1998-12-18T14:28:15.1172
OBJECT_NAME           = GODZILLA 5
INTERNATIONAL_DESIGNATOR = 1998-999ZZZ

ORIGINATOR_POC        = R. Rabbit
ORIGINATOR_POSITION   = Flight Dynamics Mission Design Lead
ORIGINATOR_PHONE      = (719)555-1234

TECH_POC              = Mr. Rodgers
TECH_PHONE            = (719)555-1234
TECH_ADDRESS          = email@email.XXX

TAIMUTC_TZERO         = 36      [s]
TIME_SYSTEM_ABS       = UT1
UT2MUTC_TZERO         = .357    [s]
UT1MUTC_RATE_TZERO    = 0.0001  [ms/day]

PHYS_START
COMMENT S/C Physical Characteristics:
MASS                  = 100.0   [kg]
OEB_Q1                = 0.03123
OEB_Q2                = 0.78543
OEB_Q3                = 0.39158
OEB_QC                = 0.47832
OEB_MAX               = 2.0     [m]
OEB_MED               = 1.0     [m]
OEB_MIN               = 0.5     [m]
AREA_ALONG_OEB_MAX    = 0.15    [m**2]
AREA_ALONG_OEB_MED    = 0.3     [m**2]
AREA_ALONG_OEB_MIN    = 0.5     [m**2]
PHYS_STOP

PERT_START
COMMENT Perturbations Specification:
ATMOSPHERIC_MODEL     = NRLMSIS00
GRAVITY_MODEL         = EGM-96: 36D 36O
GM                    = 398600.4415        [km**3/s**2]
KSUBP                 = 12.0
N_BODY_PERTURBATIONS  = MOON, SUN
SOLAR_F10P7           = 105.0
SOLAR_F10P7_MEAN      = 120.0
PERT_STOP

ORB_START
COMMENT           GEOCENTRIC, CARTESIAN, EARTH FIXED
ORB_REF_FRAME         = EFG
ORB_TYPE              = CARTPVA
  0.000000 2789.6 -280.0 -1746.8 4.73 -2.50 -1.04 0.008 0.001 -0.159
ORB_STOP

USER_START
EARTH_MODEL = WGS-84
USER_STOP
```

Annex Fig. I-2: OCM example with space object characteristics and perturbations

```
CCSDS_OCM_VERS   = 3.0
CREATION_DATE    = 1998-11-06T09:23:57

ORIGINATOR       = JAXA
EPOCH_TZERO      = 1998-12-18T14:28:15.1172

OBJECT_NAME      = GODZILLA 5
INTERNATIONAL_DESIGNATOR = 1998-057A
TIME_SYSTEM_ABS = UT1

PHYS_START
COMMENT S/C Physical Characteristics:
DRAG_AREA        = 10.00 [m**2]
DRAG_COEFF       = 2.300
MASS             = 100.0 [kg]
SOLAR_RAD_AREA   = 4.00
SOLAR_RAD_COEFF  = 1.300
PHYS_STOP

PERT_START
COMMENT  Perturbations specification
GM               =  398600.4415        [km**3/s**2]
PERT_STOP

MAN_START
COMMENT          = 100-second in-track burn w/effic η=0.95, Isp=300s, 5% 1-sigma error
MAN_PURPOSE      = SK
MAN_BASIS        = PREDICTED
MAN_REF_FRAME    = RTN
MAN_TYPE         = THRUST
1 500.0 0.0 10.0 0.0 5.0 100.0 1 330.0 0.95 0.0
1 502.0 0.0 10.1 0.0 5.0 100.0 1 330.0 0.95 0.0
1 505.0 0.0 10.2 0.0 5.0 100.0 1 330.0 0.95 0.0
2 503.0 0.0 5.0 0.0 5.0 100.0 1 330.0 0.95 0.0
2 505.0 0.0 5.1 0.0 5.0 100.0 1 330.0 0.95 0.0
2 510.0 0.0 5.2 0.0 5.0 100.0 1 330.0 0.95 0.0
MAN_STOP

ORB_START
ORB_REF_FRAME    = TOD
ORB_FRAME_EPOCH  = 1998-12-18T14:28:15.1172
ORB_TYPE         = CARTPVA
  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
ORB_STOP

ORB_START
ORB_REF_FRAME    = EME2000
ORB_TYPE         = KPLR
  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
ORB_STOP
```

Annex Fig. I-3: OCM example with maneuvers, Cartesian and Keplerian ephemeris

```
CCSDS_OCM_VERS   = 3.0

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

OBJECT_NAME     = GODZILLA 5
INTERNATIONAL_DESIGNATOR = 1998-057A
EPOCH_TZERO     = 1998-12-18T14:28:15.1172
TIME_SYSTEM_ABS = UTC

PERT_START
COMMENT  Perturbations specification
GM              =  398600.4415        [km**3/s**2]
PERT_STOP

PHYS_START
COMMENT S/C Physical Characteristics:
DRAG_AREA       =      10.000         [m**2]
DRAG_COEFF      =       2.300
MASS      =    1913.000         [kg]
SOLAR_RAD_AREA  =      10.000         [m**2]
SOLAR_RAD_COEFF =       1.300
PHYS_STOP

ORB_START
COMMENT           GEOCENTRIC, CARTESIAN, EARTH FIXED
CENTER_NAME = EARTH
ORB_REF_FRAME   = ITRF1997
ORB_FRAME_EPOCH = 1998-12-18T14:28:15.1172
ORB_TYPE        = CARTPVA

  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

ORB_STOP

COV_START
COV_REF_FRAME   = EME2000
COV_TYPE        = ADBARV

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
COV_STOP

COV_START
COV_TYPE        = EFG
T = 10.00
 3.331349e-04
 4.618927e-04  6.782421e-04
-3.070007e-04 -4.221234e-04  3.231931e-04
COV_STOP
```

Annex Fig. I-4: OCM example with Covariance Matrix

```
CCSDS_OCM_VERS   = 3.0
CREATION_DATE    = 1998-11-06T09:23:57

ORIGINATOR       = JAXA

EPOCH_TZERO      = 1998-12-18T14:28:15.1172
OBJECT_NAME      = GODZILLA 5
INTERNATIONAL_DESIGNATOR = 1998-057A

STM_START
COMMENT  HERE IS A STATE TRANSITION MATRIX DATA BLOCK:
STM_MAP_MODE     = STATE
STM_REF_TIME     = 0.0
STM_ORB_STATE    = 2789.6 -280.0 -1746.8 4.73 -2.50 -1.04
STM_ REF_FRAME   = ICRF2000
STM_TYPE         = CARTPV

T = 0.00
1.0 0.0 0.0 0.0 0.0 0.0
0.0 1.0 0.0 0.0 0.0 0.0
0.0 0.0 1.0 0.0 0.0 0.0
0.0 0.0 0.0 1.0 0.0 0.0
0.0 0.0 0.0 0.0 1.0 0.0
0.0 0.0 0.0 0.0 0.0 1.0

   < intervening data records omitted here >

T = 500.00
1.23456 7.89012 3.45678 9.01234 5.67890 1.23456
7.89012 3.45678 9.01234 5.67890 1.23456 7.89012
3.45678 9.01234 5.67890 1.23456 7.89012 3.45678
9.01234 5.67890 1.23456 7.89012 3.45678 9.01234
5.67890 1.23456 7.89012 3.45678 9.01234 5.67890
1.23456 7.89012 3.45678 9.01234 5.67890 1.23456
STM_STOP
```

⋮(continued on next page)

⋮(continued from previous page)

```
EC_START
COMMENT Example for Sentinel-1A
EC_TSTART = 2015-06-24 13:20:15
EC_BASIS_PROP = NONE
EC_REPRESENT = CHEBYSHEV
EC_STATE_TYPE = CARTPV
EC_REF_FRAME = EME2000
EC_REPR_N = 13
EC_TSTOP = 2015-06-24 14:50:15

-1427.27379 -992.935231 -259.080055 -1.55168859 -0.0324542873 0.282507201
 1531.98275  4083.63550  5401.40981 -1.01194099  -0.865149064 -5.66436275
-6537.22949 -4547.32405 -1186.48327 -7.10442242  -0.147333971  1.29297751
-1118.01930 -2990.56052 -3960.61325  0.74581082   0.631928889  4.15935650
 1554.89600  1084.62853  283.552911  1.69694197  0.0350715302 -0.31091336
 136.624563 371.574006    494.058009   -0.0943434893    -0.0789983776     -0.521238339
-121.826977 -85.1330444   -22.2065384   -0.1329049820    -0.00277649391     2.42127115
-7.24338305 -20.3698545   -26.4264343    0.00434911942    0.00408942686     2.72273990
 5.33040980  3.13753783    0.665564591   0.00412366570    0.000167950632   -1.89419109
 0.415228467 0.847421259   0.558023640   0.000406873927   0.0000193010587   2.60040102
-0.278931067    0.0592422076 0.0754482395  0.000401600022 -0.0000270870193 -2.95977200
-0.07087232227 -0.0727105864 0.0630067460 -0.000151477742 -0.0000376453860 -2.42172023
 0.03045597899 -0.0295332128 -0.0198922697 -0.000107917286 0.00000706022903 6.53683710
 0.01288453698 0.0103646323 -0.0146386354 0.0000299287270 0.00000634546237  4.83642551

EC_STOP

EC_START
COMMENT  HERE IS AN EPHEMERIS COMPRESSION DATA BLOCK:
COMMENT  FIRST SET IS EPHEM COMPR COEFS FOR FIRST 200 SEC (SGP4 REFINED BY CHEBYSHEV):
EC_TSTART      = 0.0
EC_BASIS_PROP  = SGP4
EC_REF_TIME    = 0.0
EC_ORB_STATE
6700.0 0.0 0.0 0.0 0.0 0.839099633
EC_REPRESENT   = CHEBYSHEV
EC_STATE_TYPE  = EQUIN
EC_REF_FRAME   = ICRF2000
EC_REPR_N      = 10
1.23456 7.89012 3.45678 9.01234 5.67890 1.23456
   < 4 intervening data records omitted here >
5.67890 1.23456 7.89012 3.45678 9.01234 5.67890
EC_TSTOP       = 200.0
EC_STOP

EC_START
COMMENT  SECOND SET IS FOR REMAINDER OF DAY 1 (PURELY FOURIER DIRECT TO EQUIN):
COMMENT  *** NOTE: COEFFS ARE COSINE (COL 1-6) AND SINE (7-12) ***
EC_TSTART      = 200.0
EC_REPRESENT   = FOURIER
EC_REPR_N      = 20
EC_STATE_TYPE         = EQUIN
EC_REF_FRAME   = ICRF2000
1.234 7.890 3.456 9.012 5.678 1.234 1.234 7.890 3.456 9.012 5.678 1.234
   < 4 intervening data records omitted here >
1.234 7.890 3.456 9.012 5.678 1.234 1.234 7.890 3.456 9.012 5.678 1.234
EC_TSTOP      = 86400.0
EC_STOP
```

⋮(continued on next page)

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```
EC_START
COMMENT          CHEBYSHEV POLYS FOR ORBIT STATES AT DAY 2 (SANS FOURIER CLEANUP):
EC_TSTART      = 86400.0
EC_BASIS_PROP  = NONE
EC_REF_FRAME   = ICRF2000

EC_REPRESENT   = CHEBYSHEV
EC_STATE_TYPE         = EQUIN
EC_REPR_N      = 30
3.45678 9.01234 5.67890 1.23456 7.89012 3.45678
   < 4 intervening data records omitted here >
9.01234 5.67890 1.23456 7.89012 3.45678 9.01234
EC_TSTOP       = 172800.0

EC_STOP
```

Annex Fig. I-5: OCM example with STM (Cartesian position and velocity elements) and Ephemeris Compression (Equinoctial elements)

OCM example in XML:

Annex Fig. I-6 contains an example of an Orbit Comprehensive Message in Extensible Markup Language (XML) format.

OCM XML EXAMPLES HERE

Annex Fig. I-6: OCM file example in XML format

ANNEX J

ABBREVIATIONS AND ACRONYMS

(INFORMATIVE)

ASCII	American Standard Code for Information Interchange
CCSDS	Consultative Committee for Space Data Systems
CIO	Celestial Intermediate Origin
CIP	Celestial Intermediate Pole
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 Electro-technical 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
OEB	Optimally-Encompassing Box
OEM	Orbit Ephemeris Message
OCM	Orbit Comprehensive Message
OMM	Orbit Mean-Elements Message
OPM	Orbit Parameter Message
RTN	Radial, Transverse (along-track) and Normal
S/C	Spacecraft
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 Semi-analytical Method
UTC	Coordinated Universal Time
W3C	World Wide Web Consortium
WGS	World Geodetic System

XML Extensible Markup Language

ANNEX K

RATIONALE FOR ORBIT DATA MESSAGES

(INFORMATIVE)

K1 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.

K2 PRIMARY REQUIREMENTS ACCEPTED BY THE ORBIT DATA MESSAGES

K2.1 PRIMARY REQUIREMENTS

Requirement	OPM?	OMM?	OEM?	OCM?
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

K2.2 HERITAGE REQUIREMENTS

#	Requirement	OPM?	OMM?	OEM?	OCM?
H1	Ephemeris data is reliably convertible into the SPICE SPK (NASA) format (reference [L6]) and IIRV (NASA) format (reference [L7]) 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
H2	Ephemeris data provided for 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

H3	The ODM shall provide a mechanism by which messages may be uniquely identified and clearly annotated. Facilitates discussion between the recipient and the message originator, should that be necessary.	N	N	N	Y
H4	The ODM shall provide a mechanism by which maneuvers may be uniquely identified and clearly annotated. Facilitates discussion between the recipient and the message originator, should that be necessary.	N	N	N	Y
H5	The Recommended Standard is, or includes, an ASCII format.	Y	Y	Y	Y
H6	The Recommended Standard does not require software supplied by other Agencies.	Y	N	Y	Y

K2.3 DESIRABLE CHARACTERISTICS

#	Requirement	OPM?	OMM?	OEM?	OCM?
DC1	The Recommended Standard applies to non-traditional objects, such as landers, rovers, balloons, and natural bodies (asteroids, comets).	Y	N	Y	Y
DC2	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
DC3	The Recommended Standard is extensible with no disruption to existing users/uses.	Y	Y	Y	Y
DC4	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
DC5	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

K2.4 APPLICABILITY OF CRITERIA TO MESSAGE OPTIONS

The selection of one particular message will depend on the optimization criteria in the given application. Section K2.5 compares the three recommended messages in terms of the relevant selection criteria identified by the CCSDS:

K2.5 APPLICABILITY OF THE CRITERIA TO ORBIT DATA MESSAGES

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

K3 INCREASING ORBIT PROPAGATION FIDELITY OF AN OPM OR OMM

Some OPM, OMM and/or OCM users may desire/require a higher fidelity propagation of the state vector or Keplerian elements. A higher fidelity technique may be desired/required to minimize inconsistencies in predictions generated by diverse, often operator-unique propagation schemes. Nominally the OPM and OMM 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 is a stochastic estimation problem; 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 or OMM allows exchange partners to compare the results of their respective orbit propagations.

With additional context information, the OPM and OMM may be used for assessing mutual physical or electromagnetic interference among Earth-orbiting spacecraft, developing collaborative maneuvers, and propagating the orbits of active satellites, inactive man-made objects, and near-Earth debris fragments. The additional information facilitates dynamic modeling of any 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 or OMM is the COMMENT mechanism. Alternatively, the 'USER_DEFINED_' keyword prefix may be used, though this usage is not encouraged.

K4 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 K4.1

K4.1 SERVICES AVAILABLE WITH ORBIT DATA MESSAGES

Service	Definition	Applicable to OPM?	Applicable to OMM?	Applicable to OEM?	Applicable to OCM?
Absolute Orbit Interpretation	State availability at specific times for use in additional computations (geometry, event detection, etc.).	Y	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	Y

ANNEX L

ITEMS FOR AN INTERFACE CONTROL DOCUMENT

(INFORMATIVE)

L1 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, 6.1
3) Whether the ASCII format of the ODM will be KVN or XML.	1.1
4) OPM, OMM, OEM and/or OCM file-naming conventions.	3.1, 4.1, 5.1, 6.1
5) Situations where the OBJECT_ID is not published in the UN OOSA index (reference [2]).	3.2.3, 4.2.3, 5.2.3
6) Detailed description of any user defined parameters used.	3.2.4, 4.2.4, 6.2.12
7) Type of TEME reference frame, if applicable (TEME of Epoch or TEME of Date).	Annex B2
8) 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
9) Specific OPM, OMM OEM and/or OCM version numbers that will be exchanged.	7.8.1
10) Specific information security interoperability provisions that apply between agencies.	Annex N

[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) Exceptions for the REF_FRAME and/or TIME_SYSTEM metadata keywords that are not drawn from annex Annex B2 and B1	Annex B2 and B1
12) 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 B1

ANNEX M

CHANGES IN ODM VERSION 3

(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.

M1 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 UNOOSA index 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) [9] and Attitude Data Messages (ADM) [10] 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 mandatory 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.

M2 CHANGES IN THE DOCUMENT

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 [L1]. 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) [10] and Tracking Data Message (TDM) [9]). 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 Comprehensive Message (OCM) was added.

8. The syntax rules for the OPM, OMM, OEM and the new OCM were consolidated into a common syntax section (see section 0).

9. The rules for processing COMMENT keywords were consolidated into a single section of the document (see section 0).

10. Improved discussion of information security considerations was provided, per Secretariat request (see section 0).

ANNEX N

SECURITY, SANA, AND PATENT CONSIDERATIONS

N1 SECURITY CONSIDERATIONS

N1.1 ANALYSIS OF SECURITY CONSIDERATIONS

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

N1.2 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 analyses, 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.

N1.3 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, (b) unauthorized access to the messages during transmission between exchange partners and (c) modification of the messages between partners. 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.

N1.4 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.

N1.5 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.

N1.6 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.

N1.7 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 Information Technology Security functionaries of exchange participants.

N1.8 CONTROL OF ACCESS TO RESOURCES

Control of access to resources should be managed by the systems upon which originator formatting and recipient processing are performed.

N1.9 AUDITING OF RESOURCE USAGE

Auditing of resource usage should be handled by the management of systems and networks on which this Recommended Standard is implemented.

N1.10 UNAUTHORIZED ACCESS

Unauthorized access to the programs/processes that generate and interpret the messages should be prohibited in order to minimize potential threats and attack scenarios.

N1.11 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 could be specified in an ICD.

N2 SANA CONSIDERATIONS

The following ODM-related items will be registered with the SANA Operator.

– The ODM XML schema (see Section 8).

The following ODM elements should be from the SANA registry:

– ODM originators [Q-17];

– Spacecraft identifiers;

– Timing systems;

– Absolute and relative reference frames;

– Element set and covariance column definitions;

The use of reference XX is a convenient solution of the identification of celestial bodies in absence of a corresponding SANA reference. For spacecraft the common identifiers in the SANA registry shall be preferred.

The registration rule for new entries in the registry is the approval of new requests by the CCSDS Area or Working Group responsible for the maintenance of the ODM at the time of the request. New requests for this registry should be sent to SANA (mailto:info@sanaregistry.org).

N2.1 PATENT CONSIDERATIONS

The recommendations of this document have no patent issues.

ANNEX O

EPHEMERIS COMPRESSION (EC) TECHNIQUES (INFORMATIVE)

Ephemeris Compression (EC) techniques are a "lossy" approach to conveying orbit state time history(ies). EC techniques can dramatically reduce message transmission network bandwidth, CPU, I/O and disk storage requirements (e.g. by three orders of magnitude or more) while still retaining sufficient accuracy for many applications. Initial implementations focused on fitting Cartesian position and velocity [P13] with Chebyshev polynomials. This approach has been successfully used in that manner operationally for many decades.

Recent research [P14] into the application of such a compression technique indicates that best overall EC performance may be obtained by:

1. employing "Hybrid" ephemeris compression by adopting an orbit-based element set definition (such as equinoctial elements) rather than a Cartesian representation;

2. adopting an orbit state and an accompanying sharable and efficient orbit propagator to use as the "basis" for the orbit representation;

3. using either exclusive or combined use of Chebyshev or Fourier representations to best "imitate" the residuals between the "truth" and efficient orbit propagator orbit state time histories captured in any of the reference frame definitions contained in ANNEX B, subsection B2 and orbit element set definitions contained in ANNEX B, subsections B4 or B5; and (4) using one or more consecutively staged ephemeris compression sequences to sequentially absorb the residuals between the adopted/sharable propagator and the precise ephemeris at each stage.

The OCM's ephemeris compression implementation may also be used to specify orbit states at a specific event which vary as a function of time within a specified launch window (as opposed to sequential orbit states as a function of correspondingly-sequential time). As such, each polynomial segment may be used to provide the time and orbit state corresponding to a specific launch event (e.g. Stage 2 ignition). Such an application would therefore typically draw its orbit state types (EC_STATE_TYPE) from ANNEX B, subsection B5 (rather than subsection B4), allowing event time to accompany the standard six-element orbit state specification.

The user may choose to use either polynomial and/or series representations to provide orbit state (or orbit state residual) information at key mission events by having EC_TSTART and EC_TSTOP set to the same value, whereupon those key mission events should be annotated by a preceding descriptive comment line.

Commented [OD10]: Needs clarification

OCM ephemeris compression users are encouraged to employ a blending function to ensure a smooth positional transition between subsequent EC data segments. Defining F_1 as the desired orbit element functional value at actual time t obtained from the ephemeris compression representation of segment #1 and F_2 from segment #2, and t_1 and t_2 as the overlap blending actual (non-normalized) start and stop times, respectively,

$$F(t) = \frac{1}{2} F_1(t) \left\{1 + \cos\left[\left(\frac{t-t_1}{t_2-t_1}\right)\right]\pi\right\} + \frac{1}{2} F_2(t) \left\{1 + \cos\left[\left(\frac{t_2-t}{t_2-t_1}\right)\right]\pi\right\}, t_1 \le t \le t_2$$

Centering the overlap interval on each segment boundary, retaining the definition of "b" (from above) as the actual segment stop time (i.e. EC_TSTOP) and further defining $\Delta = t_2 - t_1$, the blending function becomes:

$$F(t) = \frac{1}{2} F_1(t) \left\{1 - \sin\left[\left(\frac{t-b}{\Delta}\right)\right]\pi\right\} + \frac{1}{2} F_2(t) \left\{1 - \sin\left[\left(\frac{b-t}{\Delta}\right)\right]\pi\right\}, b - \frac{\Delta}{2} \le t \le b + \frac{\Delta}{2}$$

ANNEX P

INFORMATIVE REFERENCES

(INFORMATIVE)

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