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Space data and information transfer systems — Orbit data message

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National foreword

This British Standard is the UK implementation of ISO 26900:2024. It supersedes BS ISO 26900:2012, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee ACE/68, Space systems and operations.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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Space data and information transfer systems — Orbit data messages

Systèmes de transfert des informations et données spatiales — Messages pour données d'orbites

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Foreword

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This document was prepared by the Consultative Committee for Space Data Systems (CCSDS) (as CCSDS 502.0-B-3, Apil 2023) and drafted in accordance with its editorial rules. It was assigned to Technical Committee ISO/TC 20, *Aircraft and space vehicles,* Subcommittee SC 14, *Space systems and operations* and adopted under the “fast-track procedure”.

This second edition cancels and replaces the first edition (ISO 26900:2012), which has been technically revised.

The main changes compared to the previous edition are as follows:

— Changes in the messages:

  — The OCM was added to provide better support for ISO Technical Committee 20, Subcommittee 14 objectives (see section 6).

  — MESSAGE_ID was added to the OPM, OMM, and OEM to provide better satisfaction of requirement P10 (identification and annotation of messages).

  — EPHEMERIS_TYPE was updated in the OMM to reflect currently used numbering scheme.

  — BSTAR and MEAN_MOTION_DDOT fields are paired with BTERM and AGOM parameters to support the SGP and SGP4 propagators as well as the new SGP4-XP propagator, respectively.

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— Changes in the document:

  — A new CCSDS repository for normative keyword values for navigation messages has been created at the SANA Registry, accessible on the Internet at: https://sanaregistry.org/r/navigation_standard_normative_annexes/. (See annex B for details on the affected keywords and links to the content.)

  — Several annexes were added. Some are required by CCSDS rule changes, and some are for the provision of supplementary material.

  — Examples for OPM, OMM, and OEM that formerly appeared in sections 3, 4, and 5, respectively, have been moved to an informative annex.

  — The 'Checklist ICD' that was added in ODM Version 2 has been discontinued. This Checklist ICD, intended to convey information that the OPM, OEM, and OMM did not address, such as third-body perturbations, solar pressure model, solid tides, ocean tides, Earth albedo, and polar motion, has now been replaced by the material that can be specified in the Orbit Comprehensive Message.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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1 INTRODUCTION

1.1 PURPOSE AND SCOPE

This Orbit Data Messages (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 (primarily Earth, Moon, and Mars at present);

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 in which these requirements do not capture the needs of the participating agencies and satellite operators, another mechanism may be selected.

The ODM Recommended Standard 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 [4]).

This ODM document describes both ‘Keyword = Value Notation’ (KVN) as well as Extensible Markup Language (XML) (reference [5]) formatted messages. Selection of KVN or XML format should be mutually agreed between message exchange partners.

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.

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1.2 APPLICABILITY

The Orbit Data Message family of standardized orbit messages is applicable to all phases of the spacecraft and launch vehicle life cycle. The rationale behind the design of each orbit data message is described in annex E 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 mutually agreed upon between message exchange partners (or specified via COMMENT sections in the message itself). Applicability information specific to each orbit data message format appears in sections 3, 4, 5, and 6, as well as in annex subsections E2.4 and E2.5.

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 mutually agreed between message exchange partners.

Description of the message formats based on the use of XML is detailed in section 8.

1.3 RATIONALE

This update to version 2 of the Orbit Data Messages adds a fourth message type, the 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 in annex J.

1.4 DOCUMENT STRUCTURE

Section 2 provides a brief overview of the CCSDS-recommended Orbit Data Message types, the OPM, OMM, OEM, and 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).

Section 8 provides details on the XML instantiations of the OPM, OMM, OEM, and OCM.

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

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1.5 CONVENTIONS AND DEFINITIONS

1.5.1 NOTATION

1.5.1.1 Unit Notations

The following conventions for unit notations apply throughout this Recommended Standard, with message-specific guidance provided in 7.7. Units are drawn from the International System of Units (SI); units are either SI base units, SI derived units, or units outside the SI that are accepted for use with the SI (reference [1]). Except as noted, the units used within this document are as follows:

- d: days, 86400 SI seconds;
- kg: kilograms;
- km: kilometers;
- m: meters;
- n/a: (units are not applicable);
- %: percent;
- s: SI seconds;
- SFU: Solar Flux Units, equivalent to 10^{-22} W/(m**2*Hz);
- W: watts.

1.5.1.2 General

The following notational conventions are used in this document:

a) multiplication of units is denoted with a single asterisk '*' (e.g., 'kg*s');

b) exponents of units are denoted with a double asterisk '**' (e.g., m^2 = m**2);

c) square roots of units are denoted by the same exponent notation of a double asterisk '**' (e.g., $\sqrt{km}$ = km**0.5);

d) division of units is denoted with a single forward slash '/' (e.g., m/s);

e) the usual order of operations ordering applies (e.g., exponents before multiplication).

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1.5.2 NOMENCLATURE

1.5.2.1 Normative Text

The following conventions apply for the normative specifications in this Recommended Standard:

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

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

c) the word ‘may’ implies an optional specification;

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

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

1.5.2.2 Informative Text

In the normative sections of this document, informative text is set off from the normative specifications either in notes or under one of the following subsection headings:

– Overview;

– Background;

– Rationale;

– Discussion.

1.5.3 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 can 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;

e) 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);

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f) a 'sensor track' is a set of observations within a specified number of 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), and 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.

1.6 REFERENCES

The following publications contain provisions which, through reference in this text, constitute provisions of this document. At the time of publication, the editions indicated were valid. All publications are subject to revision, and users of this document are encouraged to investigate the possibility of applying the most recent editions of the publications indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS publications.

[1] *The International System of Units (SI)*. 8th ed., 2006; updated in 2014. Sèvres, France: BIPM, 2006.

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

[3] "Online Index of Objects Launched into Outer Space." United Nations Office for Outer Space Affairs (UNOOSA). https://www.unoosa.org/oosa/osoindex/.

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

[5] *XML Specification for Navigation Data Messages*. Issue 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 505.0-B-3. Washington, D.C.: CCSDS, May 2023.

[6] Paul V. Biron and Ashok Malhotra, eds. *XML Schema Part 2: Datatypes*. 2nd ed. W3C Recommendation.

[7] *IEEE Standard for Floating-Point Arithmetic*. 3rd ed. IEEE Std 754-2019. New York: IEEE, 2019.

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

[9] *Tracking Data Message*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 503.0-B-2. Washington, D.C.: CCSDS, June 2020.

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

[11] "CCSDS Navigation Standards Normative Annexes." Space Assigned Numbers Authority. https://sanaregistry.org/r/navigation_standard_normative_annexes.

[12] *Re-entry Data Message*. Issue 1. Recommendation for (Blue Book), CCSDS 508.1-B-1. Washington, D.C.: CCSDS, November 2019.

[13] *Pointing Request Message*. Issue 1. Recommendation for (Blue Book), CCSDS 509.0-B-1. Washington, D.C.: CCSDS, February 2018.

[14] *Conjunction Data Message*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 508.0-B-1. Washington, D.C.: CCSDS, June 2013.

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2 OVERVIEW

2.1 ORBIT PARAMETER MESSAGE

An OPM specifies the position and velocity of a single object at a specified epoch. Optionally, osculating Keplerian elements may be provided. It should be noted that a sequence of OPMs for either a single object or for multiple objects can be aggregated into a single Navigation Data Message (NDM) XML file as described in 8.12 and shown in annex G. 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.

The OPM also contains an optional 6x6 position/velocity covariance matrix that reflects the uncertainty of the orbit state and may be used in the propagation process to estimate future uncertainties.

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

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

2.2 ORBIT MEAN-ELEMENTS MESSAGE

The OMM contains the orbital characteristics of a single object at a specified epoch, expressed in mean Keplerian elements: mean motion, eccentricity, inclination, right ascension of ascending node, argument of perigee, and mean anomaly. These are adequate for providing the initial mean state of analytical and semi-analytical orbit models. In addition, the OMM contains values for parameters that facilitate the modeling of non-conservative forces for various mean element theories.

It may be noted that a sequence of OMMs for either a single object or for multiple objects can be aggregated into a single NDM XML file as described in 8.12 and shown in annex G. The OMM 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 may be used to generate canonical NORAD Two Line Element (TLE) sets to accommodate the needs of heritage users (see annex H, reference [H3]).

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The OMM also contains an optional covariance matrix that 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 in which the message is to be frequently interpreted by humans.

2.3 ORBIT EPHEMERIS MESSAGE

An OEM specifies the position and velocity of a single object at multiple epochs contained within a specified time range. It should be noted that a sequence of OEMs for either a single object or for multiple objects can be aggregated into a single NDM XML file as described in 8.12 and shown in annex G. The OEM is suited to exchanges that (1) involve automated interaction (e.g., computer-to-computer communication when 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 that reflects the uncertainty of the orbit solution used to generate states in the ephemeris.

2.4 ORBIT COMPREHENSIVE MESSAGE

An OCM specifies position and velocity of either a single object or an en masse parent/child deployment scenario stemming from a single object. It should be noted that a sequence of OCMs for either a single object or for multiple objects can be aggregated into a single NDM XML file as described in 8.12 and shown in annex G.

The OCM aggregates and extends OPM, OEM, and OMM content in a single comprehensive hybrid message (file) and includes the following additional capabilities:

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

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- Optional area cross-sections for drag, Solar Radiation Pressure (SRP) perturbations modeling;
- Optional spacecraft dimensions and orientation information for collision probability estimation;
- 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 covariance matrix of selectable/arbitrary order for a single or parent object at either a single epoch or as a time history (ephemeris) that reflects the uncertainty of the orbit solution or 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 maneuver specification (impulsive or finite burn);
- Optional perturbations model specification;
- Optional orbit determination data and metrics.

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 when 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 that can be propagated with supplied perturbations model parameters (akin to OPM content), or both.

2.5 EXCHANGE OF MULTIPLE MESSAGES

For a given object, multiple OPM, OMM, or OEM messages may be provided in a message exchange session to achieve ephemeris fidelity requirements, whereas a single, self-contained OCM may be 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.

2.6 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 [H1].

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3 ORBIT PARAMETER MESSAGE

3.1 GENERAL

3.1.1 Orbit information may be exchanged between two participants by sending a state vector (see reference [H1]) for a specified epoch using an 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 the 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 OMM or 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 [H1]) 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.

NOTE – A sequence of OPMs for either a single object or for multiple objects can be aggregated into a single NDM XML file as described in 8.12 and shown in annex G.

3.1.6 The OPM file-naming scheme should be mutually agreed between message exchange partners.

3.1.7 The method of exchanging OPMs should be mutually agreed between message exchange partners.

NOTES

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

2 Example OPMs and associated supplementary (non-normative) information are provided in annex G.

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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 (M), Optional (O), or Conditional (C). Conditional indicates that the item is mandatory if specified conditions are met (e.g., providing *all* covariance matrix elements if *any* are provided).

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

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Table 3-1: OPM Header

Keyword	Description	Examples of Values	M/O/C
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.	3.0	M
COMMENT	Comments (allowed in the OPM Header only immediately after the OPM version number). (See 7.8 for formatting rules.)	This is a comment	O
CLASSIFICATION	User-defined free-text message classification/caveats of this OPM. It is recommended that selected values be pre-coordinated between exchanging entities by mutual agreement.	SBU 'Operator-proprietary data; secondary distribution not permitted'	O
CREATION_DATE	File creation date/time in UTC. (For format specification, see 7.5.10.)	2001-11-06T11:17:33 2002-204T15:56:23Z	M
ORIGINATOR	Creating agency or operator. Select from the accepted set of values indicated in annex B, subsection B1 from the 'Abbreviation' column (when present), or the 'Name' column when an Abbreviation column is not populated. If desired organization is not listed there, follow procedures to request that originator be added to SANA registry.	CNES, ESOC, GSFC, GSOC, JPL, JAXA, INTELSAT, USAF, INMARSAT	M
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.	OPM 201113719185 ABC-12_34	O

3.2.3 OPM METADATA

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 (M), Optional (O), or Conditional (C). Conditional indicates that the item is mandatory if specified conditions are met (e.g., providing *all* covariance matrix elements if *any* are provided).

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

NOTE – For some keywords (OBJECT_NAME, OBJECT_ID) there are no definitive lists of authorized values maintained by a control authority; references [3] and [11] and the organizations provided on the SANA Registry (annex B, subsection B1) are the best known sources for authorized values to date. (For the TIME_SYSTEM keyword, see annex B, subsection B3, for guidance and a link to the approved set of values.)

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Table 3-2: OPM Metadata

Keyword	Description	Examples of Values	M/O/C
COMMENT	Comments (allowed at the beginning of the OPM Metadata). (See 7.8 for formatting rules.)	This is a comment	O
OBJECT_NAME	Spacecraft name for which orbit state data is provided. While there is no CCSDS-based restriction on the value for this keyword, it is recommended to use names from the UN Office of Outer Space Affairs designator index (reference [3], which include Object name and international designator of the participant). If OBJECT_NAME is not listed in reference [3] or the content is either unknown or cannot be disclosed, the value should be set to UNKNOWN.	EUTELSAT W1 MARS PATHFINDER STS 106 NEAR UNKNOWN	M
OBJECT_ID	Object identifier of the object for which orbit state data is provided. While there is no CCSDS-based restriction on the value for this keyword, it is recommended to use the international spacecraft designator as published in the UN Office of Outer Space Affairs designator index (reference [3]). 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. If the asset is not listed in reference [3], the UN Office of Outer Space Affairs designator index format is not used, or the content is either unknown or cannot be disclosed, the value should be set to UNKNOWN.	2000-052A 1996-068A 2000-053A 1996-008A UNKNOWN	M
CENTER_NAME	**Origin of the OPM reference frame**, which shall be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter. Natural bodies shall be selected from the accepted set of values indicated in annex B, subsection B2.	EARTH EARTH BARYCENTER MOON SOLAR SYSTEM BARYCENTER SUN JUPITER BARYCENTER STS 106 EROS	M
REF_FRAME	Reference frame in which the state vector and optional Keplerian element data are given. Use of values other than those in 3.2.3.3 should be documented in an ICD.	ICRF ITRF2000 EME2000 TEME	M
REF_FRAME_EPOCH	Epoch of reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.10 for formatting rules.)	2001-11-06T11:17:33 2002-204T15:56:23Z	C
TIME_SYSTEM	Time system used for state vector, maneuver, and covariance data. Use of values other than those in 3.2.3.2 should be documented in an ICD.	UTC, TAI, TT, GPS, TDB, TCB	M

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3.2.3.2 Values for the TIME_SYSTEM keyword should be selected from the following set:

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

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.

3.2.3.3 Values for the REF_FRAME keyword should be selected from the following set:

REF_FRAME Value	Meaning
EME2000	Earth Mean Equator and Equinox of J2000
GCRF	Geocentric Celestial Reference Frame
GRC	Greenwich Rotating Coordinates
ICRF	International Celestial Reference Frame
ITRF2000	International Terrestrial Reference Frame 2000
ITRF-93	International Terrestrial Reference Frame 1993
ITRF-97	International Terrestrial Reference Frame 1997
MCI	Mars Centered Inertial
TDR	True of Date, Rotating
TEME	True Equator Mean Equinox (only used in OMMs)
TOD	True of Date

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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 (M), Optional (O), or Conditional (C). An 'M' denotes mandatory keywords that must be included in this section if that particular data section is included. Conditional indicates that the item is mandatory if specified conditions are met (e.g., providing all covariance matrix elements if any are provided).

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	M/O/C
State Vector Components in the Specified Coordinate System			
COMMENT	(see 7.8 for formatting rules)		O
EPOCH	Epoch of state vector & optional Keplerian elements (see 7.5.10 for formatting rules)		M
X	Position vector X-component	km	M
Y	Position vector Y-component	km	M
Z	Position vector Z-component	km	M
X_DOT	Velocity vector X-component	km/s	M
Y_DOT	Velocity vector Y-component	km/s	M
Z_DOT	Velocity vector Z-component	km/s	M
Osculating Keplerian Elements in the Specified Reference Frame (none or all parameters of this block must be given)			
COMMENT	(see 7.8 for formatting rules)		O
SEMI_MAJOR_AXIS	Semi-major axis	km	C
ECCENTRICITY	Eccentricity		C
INCLINATION	Inclination	deg	C
RA_OF_ASC_NODE	Right ascension of ascending node	deg	C
ARG_OF_PERICENTER	Argument of pericenter	deg	C
TRUE_ANOMALY or MEAN_ANOMALY	True anomaly or mean anomaly	deg	C
GM	Gravitational Coefficient (Gravitational Constant × Central Mass)	km**3/s**2	C
Spacecraft Parameters (if maneuver is specified, then mass must be provided)			
COMMENT	(see 7.8 for formatting rules)		O

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Keyword	Description	Units	M/O/C
MASS	Spacecraft mass	kg	C
SOLAR_RAD_AREA	Solar Radiation Pressure Area (A_R)	m**2	O
SOLAR_RAD_COEFF	Solar Radiation Pressure Coefficient (C_R)		O
DRAG_AREA	Drag Area (A_D)	m**2	O
DRAG_COEFF	Drag Coefficient (C_D)		O
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 REF_FRAME.)			
COMMENT	(see 7.8 for formatting rules)		O
COV_REF_FRAME	Reference frame in which the covariance data are given. Select from the accepted set of values indicated in 3.2.4.11.		C
CX_X	Covariance matrix [1,1]	km**2	C
CY_X	Covariance matrix [2,1]	km**2	C
CY_Y	Covariance matrix [2,2]	km**2	C
CZ_X	Covariance matrix [3,1]	km**2	C
CZ_Y	Covariance matrix [3,2]	km**2	C
CZ_Z	Covariance matrix [3,3]	km**2	C
CX_DOT_X	Covariance matrix [4,1]	km**2/s	C
CX_DOT_Y	Covariance matrix [4,2]	km**2/s	C
CX_DOT_Z	Covariance matrix [4,3]	km**2/s	C
CX_DOT_X_DOT	Covariance matrix [4,4]	km**2/s**2	C
CY_DOT_X	Covariance matrix [5,1]	km**2/s	C
CY_DOT_Y	Covariance matrix [5,2]	km**2/s	C
CY_DOT_Z	Covariance matrix [5,3]	km**2/s	C
CY_DOT_X_DOT	Covariance matrix [5,4]	km**2/s**2	C
CY_DOT_Y_DOT	Covariance matrix [5,5]	km**2/s**2	C
CZ_DOT_X	Covariance matrix [6,1]	km**2/s	C
CZ_DOT_Y	Covariance matrix [6,2]	km**2/s	C
CZ_DOT_Z	Covariance matrix [6,3]	km**2/s	C
CZ_DOT_X_DOT	Covariance matrix [6,4]	km**2/s**2	C
CZ_DOT_Y_DOT	Covariance matrix [6,5]	km**2/s**2	C
CZ_DOT_Z_DOT	Covariance matrix [6,6]	km**2/s**2	C
Maneuver Parameters (Repeat for each maneuver)			
COMMENT	(see 7.8 for formatting rules)		O
MAN_EPOCH_IGNITION	Epoch of ignition (see 7.5.10 for formatting rules)		O
MAN_DURATION	Maneuver duration (If = 0, impulsive maneuver)	s	O
MAN_DELTA_MASS	Mass change during maneuver (value is < 0)	kg	O
MAN_REF_FRAME	Reference frame in which the velocity increment vector data are given. The user must select from the accepted set of values indicated in 3.2.4.11.		O
MAN_DV_1	1st component of the velocity increment	km/s	O
MAN_DV_2	2nd component of the velocity increment	km/s	O
MAN_DV_3	3rd component of the velocity increment	km/s	O

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Keyword	Description	Units	M/O/C
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		O

3.2.4.3 All values except Maneuver Parameters in the OPM data are 'at epoch', that is, 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 considered.

NOTE – It is recommended that C_R and solar radiation pressure area be provided for GEO spacecraft.

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

NOTE – It is recommended that C_D and drag area be provided for LEO spacecraft.

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 [H1] 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.

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, then the Conditional elements of the Spacecraft Parameters section (designated with a 'C') must be included.

3.2.4.10 Values in the covariance matrix shall be expressed in the applicable reference frame (COV_REF_FRAME keyword) 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.

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3.2.4.11 Values for the MAN_REF_FRAME and COV_REF_FRAME keyword may be selected from the following set:

Reference Frame Value	Meaning
RSW	Another name for 'Radial, Transverse, Normal'
RTN	Radial, Transverse, Normal
TNW	A local orbital coordinate frame that has the x-axis along the velocity vector, W along the orbital angular momentum vector, and N completing the right-handed system

3.2.4.12 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, should be used as sparingly as possible; their use is not encouraged.

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4 ORBIT MEAN-ELEMENTS MESSAGE

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 [H1]) for a specified epoch using an OMM. The message recipient must use appropriate orbit propagator algorithms 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 [H2]). 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 OPM or the 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 [H1]), 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.

NOTE – A sequence of OMMs for either a single object or for multiple objects can be aggregated into a single NDM XML file as described in 8.12 and shown in annex G.

4.1.6 The OMM file-naming scheme should be mutually agreed upon between message exchange partners.

4.1.7 The method of exchanging OMMs should be mutually agreed upon between message exchange partners.

NOTES

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

2 Example OMMs and associated supplementary (non-normative) information are provided in annex G.

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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 (M), Optional (O), or Conditional (C). An 'M' denotes mandatory keywords that must be included in this section if that data section is included. Conditional indicates that the item is mandatory if specified conditions are met (e.g., providing all covariance matrix elements if any are provided).

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

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Table 4-1: OMM Header

Keyword	Description	Examples of Values	M/O/C
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	M
COMMENT	Comments (allowed in the OMM Header only immediately after the OMM version number). (See 7.8 for formatting rules.)	This is a comment	O
CLASSIFICATION	User-defined free-text message classification/caveats of this OMM. It is recommended that selected values be pre-coordinated between exchanging entities by mutual agreement.	SBU 'Operator-proprietary data; secondary distribution not permitted'	O
CREATION_DATE	File creation date/time in UTC. (For format specification, see 7.5.10.)	2001-11-06T11:17:33 2002-204T15:56:23Z	M
ORIGINATOR	Creating agency or operator. Select from the accepted set of values indicated in annex B, subsection B1 from the 'Abbreviation' column (when present), or the 'Name' column when an Abbreviation column is not populated. If desired organization is not listed there, follow procedures to request that originator be added to SANA registry.	CNES, ESOC, GSFC, GSOC, JPL, JAXA, INTELSAT, USAF, INMARSAT	M
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.	OMM 201113719185 ABC-12_34	O

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 (M), Optional (O), or Conditional (C). Conditional indicates that the item is mandatory if specified conditions are met (e.g., providing *all* covariance matrix elements if *any* are provided).

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

NOTE – For some keywords (OBJECT_NAME and OBJECT_ID), there are no definitive lists of authorized values maintained by a control authority; references [3] and [11] and the organizations provided on the SANA Registry (annex B, subsection B1) are the best known sources for authorized values to date.

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Table 4-2: OMM Metadata

Keyword	Description	Examples of Values	M/O/C
COMMENT	Comments (allowed at the beginning of the OMM Metadata). (See 7.8 for formatting rules.)	This is a comment	O
OBJECT_NAME	Spacecraft name for which mean element orbit state data is provided. While there is no CCSDS-based restriction on the value for this keyword, it is recommended to use names from the UN Office of Outer Space Affairs designator index (reference [3], which include Object name and international designator of the participant). If OBJECT_NAME is not listed in reference [3] or the content is either unknown or cannot be disclosed, the value should be set to UNKNOWN.	TelKom 2 Spaceway 2 INMARSAT 4-F2 UNKNOWN	M
OBJECT_ID	Object identifier of the object for which mean element orbit state data is provided. While there is no CCSDS-based restriction on the value for this keyword, it is recommended to use the international spacecraft designator as published in the UN Office of Outer Space Affairs designator index (reference [3]). 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. If the asset is not listed in reference [3], the UN Office of Outer Space Affairs designator index format is not used, or the content is either unknown or cannot be disclosed, the value should be set to UNKNOWN.	2005-046A 2005-046B 2003-022A UNKNOWN	M
CENTER_NAME	Origin of the OMM reference frame, which shall be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter. Natural bodies shall be selected from the accepted set of values indicated in annex B, subsection B2.	EARTH MARS MOON	M
REF_FRAME	Reference frame in which the Keplerian element data are given. Use of values other than those in 3.2.3.3 should be documented in an ICD. NOTE – NORAD Two Line Element Sets and corresponding Simplified General Perturbations (SGP) orbit propagator ephemeris outputs are explicitly defined to be in the True Equator Mean Equinox of Date (TEME of Date) reference frame. Therefore, TEME of date shall be used for OMMs based on NORAD Two Line Element sets, rather than the almost imperceptibly different TEME of Epoch (see reference [H2] or [H3] for further details).	ICRF ITRF2000 EME2000 TEME	M

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Keyword	Description	Examples of Values	M/O/C
REF_FRAME_EPOCH	Epoch of reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.10 for formatting rules.)	2001-11-06T11:17:33 2002-204T15:56:23Z	C
TIME_SYSTEM	Time system used for Keplerian elements and covariance data. Use of values other than those in 3.2.3.2 should be documented in an ICD.	UTC	M
MEAN_ELEMENT_THEORY	Description of the Mean Element Theory. Indicates the proper method to employ to propagate the state.	SGP SGP4 SGP4-XP DSST USM	M

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; and

d) whether the item is Mandatory (M), Optional (O), or Conditional (C). Conditional indicates that the item is mandatory if specified conditions are met (e.g., providing *all* covariance matrix elements if *any* are provided).

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	M/O/C
Mean Keplerian Elements in the Specified Reference Frame			
COMMENT	(see 7.8 for formatting rules)		O
EPOCH	Epoch of Mean Keplerian elements (see 7.5.10 for formatting rules)		M
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	M
ECCENTRICITY	Eccentricity		M
INCLINATION	Inclination	deg	M
RA_OF_ASC_NODE	Right ascension of ascending node	deg	M
ARG_OF_PERICENTER	Argument of pericenter	deg	M
MEAN_ANOMALY	Mean anomaly	deg	M

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Keyword	Description	Units	M/O/C
GM	Gravitational Coefficient (Gravitational Constant × Central Mass)	km**3/s**2	O
Spacecraft Parameters			
COMMENT	(see 7.8 for formatting rules.)		O
MASS	Spacecraft Mass	kg	O
SOLAR_RAD_AREA	Solar Radiation Pressure Area (A_R)	m**2	O
SOLAR_RAD_COEFF	Solar Radiation Pressure Coefficient (C_R)		O
DRAG_AREA	Drag Area (A_D)	m**2	O
DRAG_COEFF	Drag Coefficient (C_D)		O
TLE Related Parameters (This section is only required if MEAN_ELEMENT_THEORY=SGP/SGP4)			
COMMENT	(see 7.8 for formatting rules.)		O
EPHEMERIS_TYPE	Default value = 0. (See 4.2.4.7.)		O
CLASSIFICATION_TYPE	Default value = U. (See 4.2.4.7.)		O
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.		O
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).		O
REV_AT_EPOCH	Revolution Number		O
BSTAR or BTERM	Drag-like ballistic coefficient, required for SGP4 and SGP4-XP mean element models: MEAN_ELEMENT_THEORY= SGP4 (BSTAR = drag parameter for SGP4). MEAN_ELEMENT_THEORY= SGP4-XP (BTERM ballistic coefficient $C_D A/m$, where C_D = drag coefficient, A = average cross-sectional area, m = mass. Example values for BTERM = 0.02 (rocket body), 0.0015 (payload); average value spanning 20,00 catalog objects = 0.0286.	BSTAR: 1/[Earth radii] BTERM: m^2/kg	C
MEAN_MOTION_DOT	First Time Derivative of the Mean Motion (i.e., a drag term, required when MEAN_ELEMENT_THEORY = SGP or PPT3). (See 4.2.4.7 for important details).	rev/day**2	C
MEAN_MOTION_DDOT or AGOM	MEAN_ELEMENT_THEORY= SGP or PPT3: Second Time Derivative of Mean Motion (i.e., a drag term). (See 4.2.4.7 for important details). MEAN_ELEMENT_THEORY= SGP4-XP: Solar radiation pressure coefficient $A\gamma/m$, where γ = reflectivity, A = average cross-sectional area, m = mass. Example values AGOM = 0.01 (rocket body) and 0.001 (payload); average value spanning 20,00 catalog objects = 0.0143 m2/kg.	MEAN_MOTION_DDOT: rev/day**3 AGOM: m^2/kg	C
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 REF_FRAME.)			
COMMENT	(see 7.8 for formatting rules.)		O
COV_REF_FRAME	Reference frame in which the covariance data are given. Select from the accepted set of values indicated in 3.2.4.11.		C
CX_X	Covariance matrix [1,1]	km**2	C
CY_X	Covariance matrix [2,1]	km**2	C

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Keyword	Description	Units	M/O/C
CY_Y	Covariance matrix [2,2]	km**2	C
CZ_X	Covariance matrix [3,1]	km**2	C
CZ_Y	Covariance matrix [3,2]	km**2	C
CZ_Z	Covariance matrix [3,3]	km**2	C
CX_DOT_X	Covariance matrix [4,1]	km**2/s	C
CX_DOT_Y	Covariance matrix [4,2]	km**2/s	C
CX_DOT_Z	Covariance matrix [4,3]	km**2/s	C
CX_DOT_X_DOT	Covariance matrix [4,4]	km**2/s**2	C
CY_DOT_X	Covariance matrix [5,1]	km**2/s	C
CY_DOT_Y	Covariance matrix [5,2]	km**2/s	C
CY_DOT_Z	Covariance matrix [5,3]	km**2/s	C
CY_DOT_X_DOT	Covariance matrix [5,4]	km**2/s**2	C
CY_DOT_Y_DOT	Covariance matrix [5,5]	km**2/s**2	C
CZ_DOT_X	Covariance matrix [6,1]	km**2/s	C
CZ_DOT_Y	Covariance matrix [6,2]	km**2/s	C
CZ_DOT_Z	Covariance matrix [6,3]	km**2/s	C
CZ_DOT_X_DOT	Covariance matrix [6,4]	km**2/s**2	C
CZ_DOT_Y_DOT	Covariance matrix [6,5]	km**2/s**2	C
CZ_DOT_Z_DOT	Covariance matrix [6,6]	km**2/s**2	C
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		O

4.2.4.3 All values in the OMM are 'at epoch', that is, 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'.

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– 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 [3]).

– 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 several considerations that apply with respect to precision of angle representation, use of certain fields by the propagator, reference frame, etc. Some sources suggest the following coding for the CLASSIFICATION_TYPE keyword: U=unclassified, S=secret. Some sources suggest the coding for the EPHEMERIS_TYPE keyword as follows:

0 = SGP
2 = SGP4
3 = PPT3
4 = SGP4-XP
6 = Special Perturbations

NOTES

1 References [H2] and [H3] can be consulted for additional information.

2 If the source of MEAN_MOTION_DOT and MEAN_MOTION_DDOT is a TLE or if these values are intended to be used as a TLE, then these values need to be divided by 2 and 6 respectively to reflect the SGP theory Taylor Series expansion terms.

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 NORAD Two Line Element Sets are implicitly in a TEME of Date 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 references [H2] and [H3]). The effect is very small relative to TLE accuracy. The preferred option is TEME of Date. Users should specify in the ICD if their assumption is TEME of Epoch.

4.2.4.10 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, should be used as sparingly as possible; their use is not encouraged.

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5 ORBIT EPHEMERIS MESSAGE

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 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.

NOTE – A sequence of OEMs for either a single object or for multiple objects can be aggregated into a single NDM XML file as described in 8.12 and shown in annex G.

5.1.4 The OEM file-naming scheme should be mutually agreed between message exchange partners.

5.1.5 The method of exchanging OEMs should be mutually agreed between message exchange partners.

NOTES

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

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

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).

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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 (M), Optional (O), or Conditional (C). An 'M' denotes mandatory keywords that must be included in this section *if* that particular data section is included. Conditional indicates that the item is mandatory if specified conditions are met (e.g., providing all covariance matrix elements if any are provided).

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

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Table 5-2: OEM Header

Keyword	Description	Examples of Values	M/O/C
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	M
COMMENT	Comments (allowed in the OEM Header only immediately after the OEM version number). (See 7.8 for formatting rules.)	COMMENT This is a comment	O
CLASSIFICATION	User-defined free-text message classification/caveats of this OEM. It is recommended that selected values be pre-coordinated between exchanging entities by mutual agreement.	SBU 'Operator-proprietary data; secondary distribution not permitted'	O
CREATION_DATE	File creation date and time in UTC. (For format specification, see 7.5.10.)	2001-11-06T11:17:33 2002-204T15:56:23	M
ORIGINATOR	Creating agency or operator. Select from the accepted set of values indicated in annex B, subsection B1 from the 'Abbreviation' column (when present), or the 'Name' column when an Abbreviation column is not populated. If desired organization is not listed there, follow procedures to request that originator be added to SANA registry.	CNES, ESOC, GSFC, GSOC, JPL, JAXA, INTELSAT, USAF, INMARSAT	M
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.	OEM 201113719185 ABC-12_34	O

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 (M), Optional (O), or Conditional (C). Conditional indicates that the item is mandatory if specified conditions are met (e.g., providing *all* covariance matrix elements if *any* are provided).

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

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NOTE – For some keywords (OBJECT_NAME and OBJECT_ID) there are no definitive lists of authorized values maintained by a control authority; references [3] and [11] and the organizations provided on the SANA Registry (annex B, subsection B1) are the best known sources for authorized values to date. (For the TIME_SYSTEM keyword, see annex B, subsection B3, for guidance and a link to the approved set of values.)

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	M/O/C
`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	M
`COMMENT`	Comments allowed only immediately after the META_START keyword. (See 7.8 for formatting rules.)	COMMENT This is a comment.	O

`OBJECT_NAME`	Spacecraft name for which ephemeris data is provided. While there is no CCSDS-based restriction on the value for this keyword, it is recommended to use names from the UN Office of Outer Space Affairs designator index (reference [3], which include Object name and international designator of the participant). If OBJECT_NAME is not listed in reference [3] or the content is either unknown or cannot be disclosed, the value should be set to UNKNOWN.	`EUTELSAT W1`
		`MARS PATHFINDER`
		`STS 106`
		`NEAR`
		`UNKNOWN`
			M

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Keyword	Description	Examples of Values	M/O/C
OBJECT_ID	Object identifier of the object for which ephemeris data is provided. While there is no CCSDS-based restriction on the value for this keyword, it is recommended to use the international spacecraft designator as published in the UN Office of Outer Space Affairs designator index (reference [3]). 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. If the asset is not listed in reference [3], the UN Office of Outer Space Affairs designator index format is not used, or the content is either unknown or cannot be disclosed, the value should be set to UNKNOWN.	2000-052A 1996-068A 2000-053A 1996-008A UNKNOWN	M
CENTER_NAME	Origin of the OEM 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 reference frame center (such as a spacecraft, formation flying reference 'chief' spacecraft, etc.). Natural bodies shall be selected from the accepted set of values indicated in annex B, subsection B2. For spacecraft, it is recommended to use either the OBJECT_ID or international designator of the participant as catalogued in the UN Office of Outer Space Affairs designator index (reference [3]).	EARTH EARTH BARYCENTER MOON SOLAR SYSTEM BARYCENTER SUN JUPITER BARYCENTER STS 106 EROS	M
REF_FRAME	Reference frame in which the ephemeris data are given. Use of values other than those in 3.2.3.3 should be documented in an ICD.	ICRF ITRF2000 EME2000 TEME	M
REF_FRAME_EPOCH	Epoch of reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.10 for formatting rules.)	2001-11-06T11:17:33 2002-204T15:56:23Z	C
TIME_SYSTEM	Time system used for ephemeris and covariance data. Use of values other than those in 3.2.3.2 should be documented in an ICD.	UTC, TAI, TT, GPS, TDB, TCB	M
START_TIME	Start of TOTAL time span covered by ephemeris data and covariance data immediately following this metadata block. (For format specification, see 7.5.10.)	1996-12-18T14:28:15.1172 1996-277T07:22:54	M

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Keyword	Description	Examples of Values	M/O/C
USEABLE_START_TIME	Start time of USEABLE time span covered by ephemeris data immediately following this metadata block. (For format specification, see 7.5.10.) This optional keyword allows the message creator to introduce fictitious (but numerically smooth) data nodes prior to the actual data time history to support interpolation methods requiring more than two nodes (e.g., pure higher-order Lagrange interpolation methods). The use of this keyword and introduction of fictitious node points are optional and may not be necessary.	1996-12-18T14:28:15.1172 1996-277T07:22:54	O
USEABLE_STOP_TIME	Stop time of USEABLE time span covered by ephemeris data immediately following this metadata block. (For format specification, see 7.5.10.) This optional keyword allows the message creator to introduce fictitious (but numerically smooth) data nodes following the actual data time history to support interpolation methods requiring more than two nodes (e.g., pure higher-order Lagrange interpolation methods). The use of this keyword and introduction of fictitious node points are optional and may not be necessary.	1996-12-18T14:28:15.1172 1996-277T07:22:54	O
STOP_TIME	End of TOTAL time span covered by ephemeris data and covariance data immediately following this metadata block. (For format specification, see 7.5.10.)	1996-12-18T14:28:15.1172 1996-277T07:22:54	M
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	O
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	C
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	M

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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 enough 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 mandatory keywords as specified in table 5-4: ‘COVARIANCE_START’ and ‘COVARIANCE_STOP’. The COVARIANCE_START keyword must appear before the first line of the covariance matrix data. The COVARIANCE_STOP keyword must appear after the last line of covariance data. Each of these keywords shall appear on a line by itself with no time tags or values.

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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 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.

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.

Table 5-4: OEM Covariance Keywords

Keyword	Description	Examples of Values	M/O/C
COVARIANCE_START	This keyword is used to delineate the start of a covariance data block within the message.	n/a	M
EPOCH	Epoch of covariance matrix. (See 7.5.10 for formatting rules.)	2019-12-28T21:29:07.267	C
COV_REF_FRAME	Reference frame in which the covariance data are given. Select from the accepted set of values indicated in 3.2.3.3 or 3.2.4.11.	EME2000	C
COVARIANCE_STOP	This keyword is used to delineate the end of a covariance data block within the message.	n/a	M

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6 ORBIT COMPREHENSIVE MESSAGE

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 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.

NOTE – A sequence of OCMs for either a single object or for multiple objects can be aggregated into a single NDM XML file as described in 8.12 and shown in annex G.

6.1.3 Orbit information may be exchanged between two or more 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 OCM. If orbital states are desired at arbitrary time(s) contained within the span of the provided orbit or covariance time histories, the message recipient must use a suitable interpolation method. For times outside of supplied orbit or covariance state time spans or if the step size between time points is too large to support interpolation (reference [H6]), optional perturbations parameters should be included in this message to allow the message recipient to use a suitably compatible orbit and covariance propagator.

6.1.4 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.

6.1.5 The OCM file-naming scheme should be mutually agreed between message exchange partners.

6.1.6 The method of exchanging OCMs should be mutually agreed between message exchange partners.

NOTES

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

2 Example OCMs and associated supplementary (non-normative) information are provided in annex G.

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6.2 OCM STRUCTURE AND OVERARCHING REQUIREMENTS

6.2.1 GENERAL STRUCTURE

6.2.1.1 The OCM shall be represented as the combination of the following **mandatory (M)** and **optional (O)** data blocks, which (where provided) shall be ordered as listed in table 6-1.

6.2.1.2 Within the tables of each OCM section, each keyword is labeled as being Mandatory (M), Optional (O), or Conditional (C). **An 'M' denotes mandatory keywords that must be included in this section *if* this data section is included.** Keywords that have a pre-defined (default) value are listed as 'O' (optional), because if the keyword is not provided, then that default value as defined in the corresponding table shall be used in OCM processing. **A 'C' denotes keywords that are mandatory if this data block is included and certain conditions are met**, as specified in the keyword description.

NOTE – One can observe in table 6-1 that the OCM fully supports what might be considered as a 'degenerate' case, where the message is constructed without any data blocks. This was an intentional choice, given that the many metadata elements the OCM can accommodate are very useful (e.g., to convey phonebook information, link disparate messages together, and convey timing source information).

6.2.1.3 In some cases, default values have been provided for mandatory 'M' and conditional 'C' content. Where such defaults exist and those default values match what the message creator intends, the message creator is not required to explicitly provide those mandatory or conditional keywords in that particular data block, and the default values shall implicitly be adopted by the message recipient.

6.2.1.4 No defaults are supplied for Optional 'O' content. If an optional keyword/tag is not supplied by the message creator, then no value is intended and shall be treated simply as 'null' (not set), and no value shall be assumed or used in OCM processing.

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Table 6-1: OCM File Layout and Ordering Specification

	Section		Content	Status M/O
	OCM Header		A single header of the message	M
	OCM Metadata		A single metadata section (data about data)	M
Data	orbit data 1	data description	One or more orbit state time histories (consisting of one or more orbit states)	O
		data lines		
	⋮			
	orbit data n_{orbit}	data description		
		data lines		
	physical properties		A single space object physical characteristics section	O
	covariance data 1	data description	One or more covariance time histories (each consisting of one or more covariance matrices)	O
		data lines		
	⋮			
	covariance data $n_{covariance}$	data description		
		data lines		
	maneuver data 1	data description	One or more maneuver specifications for either impulsive or finite burns or acceleration profiles	O
		data lines		
	⋮			
	maneuver data $n_{maneuver}$	data description		
		data lines		
	perturbations parameters		A single perturbations parameters section (required if an orbit determination section is provided)	C
	orbit determination		A single orbit determination data section	O
	user-defined parameters		A single user-defined parameters section containing data and supplemental comments (explanatory information)	O

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6.2.2 GENERAL REQUIREMENTS

The following requirements apply to all OCM sections and content:

6.2.2.1 The order of occurrence of OCM keywords shall be fixed as listed in the keyword value tables in the OCM section descriptions.

6.2.2.2 If the message creator does not have a value for a mandatory keyword, a value of 'UNKNOWN' may be used.

6.2.2.3 All time-tags may be specified by either a (signed) double precision relative time (e.g., 20157.26) measured in SI seconds with respect to the specified epoch time (EPOCH_TZERO) or as an absolute time (e.g., 2018-11-13T11:13:20.5Z in CCSDS Time String A or B format, as specified in 7.5.10).

6.2.2.4 Duplicate time tags shall not be used in any given OCM data block.

6.2.2.5 Within an OCM data block, all time-tags must adhere to either relative time or absolute time for the entirety of that data block. Relative and absolute time shall not be used within the same data block.

6.2.2.6 Time tags of information within ordered sequences of OCM sections may be separated by uniform or non-uniform step size(s).

6.2.2.7 Time tags of one OCM section may or may not match those of another OCM section.

6.2.3 OCM HEADER

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

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

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

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