

Recommendation for Space Data System Standards

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| ORBIT DATA MESSAGES |

Proposed Standard

PINK BOOK

May 2021 DRAFT

AUTHORITY

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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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Questions relating to the contents or status of this document should be addressed to the CCSDS Secretariat at the address indicated on page i.

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# INTRODUCTION

## 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:

1. pre-flight planning for tracking or navigation support;
2. scheduling tracking support;
3. carrying out tracking operations (sometimes called metric predicts);
4. performing orbit comparisons;
5. carrying out navigation operations such as orbit propagation and orbit reconstruction;
6. assessing mutual physical and electromagnetic interference among satellites orbiting the same celestial body (primarily Earth, Moon, and Mars at present);
7. performing orbit conjunction (collision avoidance) studies; and
8. 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 Messages (ODM) 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’ (or 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.

## 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 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 E2.4 and 0.

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 Extensible Markup Language (XML) is detailed in Section 8.

## 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 in ANNEX J.

## 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).

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.

## Conventions and DEFINITIONS

### notation

#### Unit Notations

The following conventions for unit notations apply throughout this Recommended Standard, with message-specific guidance provided in Section 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;

#### General

The following notational conventions are used in this document:

1. multiplication of units is denoted with a single asterisk ‘\*’ (e.g., ‘kg\*s’);
2. exponents of units are denoted with a double asterisk ‘\*\*’ (e.g., m2 = m\*\*2);
3. square roots of units are denoted by the same exponent notation of a double asterisk ‘\*\*’ (e.g., = km\*\*0.5);
4. division of units is denoted with a single forward slash ‘/’ (e.g., m/s).
5. The usual order of operations ordering applies (e.g., exponents before multiplication).

### 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.

### definitions

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

1. the word ‘agencies’ may also be construed as meaning ‘satellite operators’ or ‘satellite service providers’;
2. 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;
3. the notation ‘n/a’ signifies ‘not applicable’;
4. 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.
5. 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).
6. 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), 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.

## 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] *The International System of Units (SI)*. 9th ed. Sèvres, France: BIPM, 2019.

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

[3] *United Nations Office of Outer Space Affairs satellite designator/index, searchable at* <http://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*. Recommendation for Space Data System Standards, CCSDS 505.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, December 2010.

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

[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. < <https://www.w3.org/TR/xmlschema-2/> >

[9] CCSDS 503.0-B-2, Tracking Data Message, June 2020.

[10] CCSDS 504.0-B-1, Attitude Data Message, May 2008.

[11] SANA Navigation Working Group Registry: <https://sanaregistry.org/r/navigation_standard_normative_annexes>

[12] CCSDS 508.1-B-1, Reentry Data Message, November 2019.

[13] CCSDS 509.0-B-1, Pointing Request Message, February 2018.

[14] CCSDS 508.0-B-1, Conjunction Data Message, June 2013.

# Overview

## 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. Note 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 Section 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 which 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 where the message is to be frequently interpreted by humans.

## Orbit MEAN-ELEMENTS Message (OMM)

An OMM specifies the orbital characteristics of a single object at a specified epoch, expressed in mean Keplerian elements. Note that a sequence of OMMs for either a single object or for multiple objects can be aggregated into a single Navigation Data Message (NDM) XML file as described in Section 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 Sets (TLEs) to accommodate the needs of heritage users (see ANNEX H, Reference [H-3]).

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.

## orbit Ephemeris Message (OEM)

An OEM specifies the position and velocity of a single object at multiple epochs contained within a specified time range. Note that a sequence of OEMs for either a single object or for multiple objects can be aggregated into a single Navigation Data Message (NDM) XML file as described in Section 8.12 and shown in ANNEX G. 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.

## 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. Note that a sequence of OCMs for either a single object or for multiple objects can be aggregated into a single Navigation Data Message (NDM) XML file as described in Section 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;
* Optional area cross-sections for drag, 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) which 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 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.

## 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.

## 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 ANNEX H, Reference [H-1].

# ORBIT PARAMETER MESSAGE (OPM)

## General

Orbit information may be exchanged between two participants by sending a state vector (see ANNEX H, Reference [H-1]) 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.

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.

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.)

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

1. an orbit propagator consistent with the models used to develop the orbit data should be available at the receiver’s site.
2. the receiver’s modeling of gravitational forces, solar radiation pressure, atmospheric drag, and thrust phases (see ANNEX H, Reference [H-1]) should fulfill accuracy requirements established between the exchange partners.

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 Navigation Data Message (NDM) XML file as described in Section 8.12 and shown in ANNEX G.

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

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

NOTE 1 – Detailed syntax rules for the OPM are specified in Section 7.

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

## OPM content/STRUCTURE

### General

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

1. a header;
2. metadata (data about data);
3. data; and
4. optional comments (explanatory information).

### OPM Header

Table 3‑1 specifies for each header item:

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

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** | **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 Section 7.8 for formatting rules.) | This is a comment | O |
| CREATION\_DATE | File creation date/time in UTC. (For format specification, see Section 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, Section 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 |

### OPM Metadata

Table 3‑2 specifies for each metadata item:

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

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, Section B1) are the best known sources for authorized values to date. For the TIME\_SYSTEM keyword, see ANNEX B, Section B3, for guidance and a link to the approved set of values.

Table 3‑2 : OPM Metadata

|  |  |  |  |
| --- | --- | --- | --- |
| **Keyword** | **Description** | **Examples of Values** | **M/O/C** |
| COMMENT | Comments (allowed at the beginning of the OPM Metadata). (See Section 7.8 for formatting rules.) | This is a comment | O |
| OBJECT\_NAME | Spacecraft name for which the orbit state 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). Where OBJECT\_NAME is not known 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 the orbit state is provided. There is no CCSDS-based restriction on the value for this keyword, but values should be 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 letter for the identification of the part brought into space by the launch.  In cases where the asset is not listed in Reference [3], the UN Office of Outer Space Affairs designator index format is not used, or the content 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, Section B2. | Earth  Earth Barycenter  Moon  Solar System Barycenter  Sun  Jupiter Barycenter  STS 106  EROS | M |

|  |  |  |  |
| --- | --- | --- | --- |
| **Keyword** | **Description** | **Examples of Values** | **M/O/C** |
| REF\_FRAME | Reference frame in which the state vector and optional Keplerian element data are given. Use of values other than those in Section 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 Section 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 Section 3.2.3.2 should be documented in an ICD. | UTC, TAI, TT, GPS, TDB, TCB | M |

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.

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 |

### OPM Data

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:

1. the keyword to be used;
2. a short description of the item;
3. the units to be used;
4. 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).

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 Section 7.8 for formatting rules.) |  | O |
| EPOCH | Epoch of state vector & optional Keplerian elements. (See Section 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 Section 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 x Central Mass) | km\*\*3/s\*\*2 | C |
| Spacecraft Parameters (if maneuver is specified, then mass must be provided) | | | |
| COMMENT | (see Section 7.8 for formatting rules.) |  | O |
| MASS | Spacecraft mass | kg | C |
| SOLAR\_RAD\_AREA | Solar Radiation Pressure Area (AR) | m\*\*2 | O |
| SOLAR\_RAD\_COEFF | Solar Radiation Pressure Coefficient (CR) |  | O |
| DRAG\_AREA | Drag Area (AD) | m\*\*2 | O |
| DRAG\_COEFF | Drag Coefficient (CD). |  | 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 Section 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 Section 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 Section 7.8 for formatting rules.) |  | O |
| MAN\_EPOCH\_IGNITION | Epoch of ignition. (See Section 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. Select from the accepted set of values indicated in Section 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 |
| 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 |

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.

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.

If the solar radiation coefficient, CR, is set to zero, no solar radiation pressure shall be considered.

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

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

NOTE - It is recommended that CD and drag area be provided for LEO spacecraft.

Parameters for thrust phases may be optionally given for the computation of the trajectory during or after maneuver execution (see ANNEX H, Reference [H-1] 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.

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.

If the OPM contains a maneuver definition, then the Conditional elements of the Spacecraft Parameters section (designated with a “C”) must be included.

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.

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 completes the right-handed system. |

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.

# ORBIT MEAN-ELEMENTS MESSAGE (OMM)

## General

Orbit information may be exchanged between two participants by sending an orbital state based on mean Keplerian elements (see ANNEX H, Reference [H-1]) for a specified epoch using an Orbit Mean-Elements Message (OMM). The message recipient must use appropriate orbit propagator algorithms to correctly propagate the OMM state to compute the orbit at other desired epochs.

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 ANNEX H, Reference [H-2]). 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.

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.)

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

1. an orbit propagator consistent with the models used to develop the orbit data should be run at the receiver’s site;
2. the receiver’s modeling of gravitational forces, solar radiation pressure, atmospheric drag, etc. (see ANNEX H, Reference [H-1]), should fulfill accuracy requirements established between the exchange partners.

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 Navigation Data Message (NDM) XML file as described in Section 8.12 and shown in ANNEX G.

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

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

NOTE 1 – Detailed syntax rules for the OMM are specified in Section 7.

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

## OMM content/STRUCTURE

### General

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

1. a header;
2. metadata (data about data);
3. data; and
4. optional comments (explanatory information).

### OMM Header

Table 4‑1 specifies for each header item:

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

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** | **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 Section 7.8 for formatting rules.) | This is a comment | O |
| CREATION\_DATE | File creation date/time in UTC (for format specification, see Section 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, Section 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 |

### OMM Metadata

Table 4‑2 specifies for each metadata item:

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

Only those keywords shown in Table 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, Section B1) are the best known sources for authorized values to date.

Table 4‑2 : OMM Metadata

| **Keyword** | **Description** | **Examples of Values** | **M/O/C** |
| --- | --- | --- | --- |
| COMMENT | Comments (allowed at the beginning of the OMM Metadata). (See Section 7.8 for formatting rules.) | This is a comment | O |
| 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 [3]), which include Object name and international designator of the participant. In cases where OBJECT\_NAME is not known 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 the orbit state is provided. There is no CCSDS-based restriction on the value for this keyword, but values should be 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.  In cases where the asset is not listed in reference [3], the UN Office of Outer Space Affairs designator index format is not used, or the content 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, Section B2. | EARTH  MARS  MOON | M |
| REF\_FRAME | Reference frame in which the Keplerian element data are given. Use of values other than those in Section 3.2.3.3 should be documented in an ICD.  Note: NORAD Two Line Element Sets and corresponding 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 ANNEX H, Reference [H-2] or [H-3] for further details). | ICRF  ITRF2000  EME2000  TEME | M |
| REF\_FRAME\_EPOCH | Epoch of reference frame, if not intrinsic to the definition of the reference frame. (See Section 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 Section 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. | SGP4  DSST  USM | M |

### 

### OMM Data

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:

1. the keyword to be used;
2. a short description of the item;
3. the units to be used;
4. 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).

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 Section 7.8 for formatting rules.) |  | O |
| EPOCH | Epoch of Mean Keplerian elements. (See Section 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 |
| GM | Gravitational Coefficient (Gravitational Constant x Central Mass) | km\*\*3/s\*\*2 | O |
| Spacecraft Parameters | | | |
| COMMENT | (see Section 7.8 for formatting rules.) |  | O |
| MASS | Spacecraft Mass | kg | O |
| SOLAR\_RAD\_AREA | Solar Radiation Pressure Area (AR) | m\*\*2 | O |
| SOLAR\_RAD\_COEFF | Solar Radiation Pressure Coefficient (CR) |  | O |
| DRAG\_AREA | Drag Area (AD) | m\*\*2 | O |
| DRAG\_COEFF | Drag Coefficient (CD) |  | O |
| TLE Related Parameters (This section is only required if MEAN\_ELEMENT\_THEORY=SGP/SGP4) | | | |
| COMMENT | (see Section 7.8 for formatting rules.) |  | O |
| EPHEMERIS\_TYPE | Default value = 0. (See Section 4.2.4.7.) |  | O |
| CLASSIFICATION\_TYPE | Default value = U. (See Section 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 | SGP/SGP4 drag-like coefficient (in units 1/[Earth radii]). Only required if MEAN\_ELEMENT\_THEORY=SGP/SGP4 | 1/ER | O |
| MEAN\_MOTION\_DOT | First Time Derivative of the Mean Motion (only required if MEAN\_ELEMENT\_THEORY = SGP). (See Section 4.2.4.7 for important details). | rev/day\*\*2 | O |
| MEAN\_MOTION\_DDOT | Second Time Derivative of Mean Motion (only required if MEAN\_ELEMENT\_THEORY = SGP). (See Section 4.2.4.7 for important details). | rev/day\*\*3 | 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 the REF\_FRAME.) | | | |
| COMMENT | (see Section 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 Section 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 |
| 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 |

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

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.

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 Section 7.5. This logical block of the OMM may be useful for risk assessment and establishing maneuver and mission margins.

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’.
* 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.

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 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 ANNEX H, Reference [H-2] and [H-3]).

NOTE: If the origin 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 must be divided by 2 and 6 respectively to reflect the SGP theory Taylor Series expansion terms.

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.

NORAD Two Line Element Sets are implicitly in a True Equator Mean Equinox (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 Reference [H-2] and [H-3]). 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.

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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.

# ORBIT EPHEMERIS MESSAGE (oeM)

## General

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

The OEM may be used for assessing mutual physical or electromagnetic interference among Earth-orbiting spacecraft, developing collaborative maneuvers, and 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.

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 Navigation Data Message (NDM) XML file as described in Section 8.12 and shown in ANNEX G.

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

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

NOTE 1 – Detailed syntax rules for the OEM are specified in Section 7.

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

## OEM CONTENT/STRUCTURE

### General

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

1. a header;
2. metadata (data about data);
3. ephemeris data;
4. optional covariance matrix data; and
5. optional comments (explanatory information).

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.) |

### OEM Header

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

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

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** | **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 Section 7.8 for formatting rules.) | COMMENT This is a comment | O |
| CREATION\_DATE | File creation date and time in UTC. (For format specification, see Section 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, Section 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 |

### OEM Metadata

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

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

Only those keywords shown in Table 5‑3 shall be used in OEM 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, Section B1) are the best known sources for authorized values to date. For the TIME\_SYSTEM keyword, see ANNEX B, Section B3, for guidance and a link to the approved set of values.

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 Section 7.8 for formatting rules.) | COMMENT This is a comment. | O |
| 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 [3]), which include Object name and international designator of the participant. In cases where OBJECT\_NAME is not known 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 the ephemeris is provided. There is no CCSDS-based restriction on the value for this keyword, but values should be 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.  In cases where the asset is not listed in Reference [3], the UN Office of Outer Space Affairs designator index format is not used, or the content 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, Section 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 Section 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 Section 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 Section 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 Section 7.5.10.) | 1996-12-18T14:28:15.1172  1996-277T07:22:54 | M |
| USEABLE\_START\_TIME | Start time of USEABLE time span covered by ephemeris data immediately following this metadata block. For format specification, see Section 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 Section 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 Section 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 |

### oem data: Ephemeris Data Lines

Each set of ephemeris data, including the time tag, must be provided on a single line. The order in which data items are given shall be fixed: **Epoch**, **X, Y, Z**, **X\_DOT, Y\_DOT, Z\_DOT, X\_DDOT, Y\_DDOT, Z\_DDOT**.

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

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

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.

The TIME\_SYSTEM value must remain fixed within an OEM.

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.

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.

### oem data: COVARIANCE MATRIX Lines

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

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.

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.

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 Section 7.5.

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

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.

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

Table ‑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 Section 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 Sections 3.2.3.2 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 |

# Orbit Comprehensive Message (OCM)

## General description

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.

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 Navigation Data Message (NDM) XML file as described in Section 8.12 and shown in ANNEX G.

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 Orbit Comprehensive Message (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 (ANNEX H, Reference [H-6]), optional perturbations parameters should be included in this message to allow the message recipient to use a suitably-compatible orbit and covariance propagator.

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.

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

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

NOTE 1 – Detailed syntax rules for the OCM are specified in Section 7.

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

## OCM STRUCTURE and Overarching requirements

### General structure

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.

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).

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.

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.

Table ‑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 norbit | 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 ncovariance | 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 nmaneuver | 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 |

### General Requirements

The following requirements apply to all OCM sections and content:

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

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

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 Section 7.5.10).

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

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.

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

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

### OCM Header

Table 6‑2 specifies the keywords for each header item.

Only those keywords shown in Table 6‑2 shall be used in an OCM header.

The order of occurrence of these OCM header keywords shall be fixed as shown in Table 6‑2.

Table ‑2 : OCM Header

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Keyword** | **Description** | | **Examples of Values** | | **M/O/C** | |
| 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 | | M | |
| COMMENT | Comments (a contiguous set of one or more comment lines may be provided in the OCM Header only immediately after the OCM version number). (See Section 7.8 for formatting rules). | | This is a comment | | O | |
| CREATION\_DATE | File creation date/time in UTC. (For format specification, see Section 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, Section 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 | | Free-text field containing an ID that uniquely identifies a message from this message originator. The format and content of the message identifier value are at the discretion of the originator. | | OCM 201113719185  ABC-12\_34 | | O |

### OCM Metadata

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

The metadata section must begin with keyword META\_START and end with keyword META\_STOP.

At most, only one metadata section shall appear in the entire scope of an OCM.

The order of occurrence of these OCM metadata keywords shall be fixed as shown in Table 6‑3.

NOTE 1 – For some keywords (OBJECT\_NAME, OBJECT\_DESIGNATOR) 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, Section B1) are the best known sources for authorized values to date.

NOTE 2: While OBJECT\_NAME, OBJECT\_DESIGNATOR, and INTERNATIONAL\_DESIGNATOR are individually optional, it is recommended that at least one of these three keywords be supplied.

Table ‑3 : OCM Metadata

| **Keyword** | **Description** | **Units** | **Default (if any)** | | **Examples of Values** | **M/O/C** |
| --- | --- | --- | --- | --- | --- | --- |
| META\_START | Start of the metadata section. |  |  |  | | M |
| COMMENT | Comments (a contiguous set of one or more comment lines may be provided in the OCM Metadata section; see Section 7.8 for comment formatting rules). |  |  | | This is a comment | O |
| CLASSIFICATION | User-defined free-text message classification/caveats of this OCM. It is recommended that selected values be pre-coordinated between exchanging entities by mutual agreement. |  |  | | SBU  “Operator-proprietary data; secondary distribution not permitted” | O |
| OBJECT\_NAME | Free-text field containing the name of the object. There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from either the UN Office of Outer Space Affairs designator index (Reference [3], which include Object name and international designator of the participant), the spacecraft operator, or a State Actor or commercial Space Situational Awareness (SSA) provider maintaining the “CATALOG\_NAME” space catalog. If the object name is not known (uncorrelated object), “UNKNOWN” may be used (or this keyword omitted). |  |  | | SPOT-7  ENVISAT  IRIDIUM NEXT-8  INTELSAT G-15  UNKNOWN | O |
| INTERNATIONAL\_DESIGNATOR | Free-text field containing an international designator for the object as assigned by the UN Committee on Space Research (COSPAR). Such designator values have the following COSPAR 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.  NOTE – The international designator was typically specified by “OBJECT\_ID” in the OPM, OMM, and OEM. |  |  | | 2000-052A  1996-068A  2000-053A  1996-008A  UNKNOWN | O |
| CATALOG\_NAME | Free-text field containing the satellite catalog source (or source agency or operator, value to be drawn from the ‘Abbreviation’ column of the SANA Organizations registry at <https://www.sanaregistry.org/r/organizations>) from which “OBJECT\_DESIGNATOR” was obtained. |  |  | | CSPOC  RFSA  ESA  COMSPOC | O |
| OBJECT\_DESIGNATOR | Free-text field specification of the unique satellite identification designator for the object, as reflected in the catalog whose name is “CATALOG\_NAME”. If the ID is not known (uncorrelated object), “UNKNOWN” may be used (or this keyword omitted). |  |  | | 22444  18SPCS 18571  2147483648\_04ae[…]d84c  UNKNOWN | O |
| ALTERNATE\_NAMES | Free-text comma-delimited field containing alternate name(s) of this space object, including assigned names used by spacecraft operator, State Actors, commercial SSA providers and/or media. |  |  | | SV08, IN8 | O |
| ORIGINATOR\_POC | Free-text field containing originator or programmatic Point-of-Contact (PoC) for OCM. |  |  | | Mr. Rodgers | O |
| ORIGINATOR\_POSITION | Free-text field containing contact position of the originator PoC. |  |  | | Flight Dynamics  Mission Design Lead | O |
| ORIGINATOR\_PHONE | Free-text field containing originator PoC phone number. |  |  | | +12345678901 | O |
| ORIGINATOR\_EMAIL | Free-text field containing originator PoC email address. |  |  | | JOHN.DOE@ SOMEWHERE.ORG | O |
| ORIGINATOR\_ADDRESS | Free-text field containing originator’s physical address information for OCM creator (suggest comma-delimited address lines). |  |  | | 5040 Spaceflight Ave., Cocoa Beach, FL, USA, 12345 | O |
| TECH\_ORG | Free-text field containing the creating agency or operator (value should be drawn from the ‘Abbreviation’ column of the SANA Organizations registry at <https://www.sanaregistry.org/r/organizations> ). |  |  | | NASA | O |
| TECH\_POC | Free-text field containing technical Point-of-Contact (PoC) for OCM. |  |  | | Maxwell Smart | O |
| TECH\_POSITION | Free-text field containing contact position of the technical PoC. |  |  | | Flight Dynamics  Mission Design Lead | O |
| TECH\_PHONE | Free-text field containing technical PoC phone number. |  |  | | +49615130312 | O |
| TECH\_EMAIL | Free-text field containing technical PoC email address. |  |  | | JOHN.DOE@ SOMEWHERE.ORG | O |
| TECH\_ADDRESS | Free-text field containing technical PoC physical address information for OCM creator (suggest comma-delimited address lines). |  |  | | 5040 Spaceflight Ave., Cocoa Beach, FL, USA, 12345 | O |
| PREVIOUS\_MESSAGE\_ID | Free-text field containing an ID that uniquely identifies the previous message from this message originator for this space object. The format and content of the message identifier value are at the discretion of the originator.  NOTE – One may provide the previous message ID without supplying the “PREVIOUS\_MESSAGE\_EPOCH” keyword, and vice versa. |  |  | | OCM 201113719184  ABC-12\_33 | O |
| NEXT\_MESSAGE\_ID | Free-text field containing an ID that uniquely identifies the next message from this message originator for this space object. The format and content of the message identifier value are at the discretion of the originator.  NOTE – One may provide the next message ID without supplying the “NEXT\_MESSAGE\_EPOCH” keyword, and vice versa. |  |  | | OCM 201113719186  ABC-12\_35 | O |
| ADM\_MSG\_LINK | Free-text field containing a unique identifier of Attitude Data Message (ADM) [10] that are linked (relevant) to this Orbit Data Message. |  |  | | ADM\_MSG\_35132.txt  ADM\_ID\_0572 | O |
| CDM\_MSG\_LINK | Free-text field containing a unique identifier of Conjunction Data Message (CDM) [14] that are linked (relevant) to this Orbit Data Message. |  |  | | CDM\_MSG\_35132.txt  CDM\_ID\_8257 | O |
| PRM\_MSG\_LINK | Free-text field containing a unique identifier of Pointing Request Message (PRM) [13] that are linked (relevant) to this Orbit Data Message. |  |  | | PRM\_MSG\_35132.txt  PRM\_ID\_6897 | O |
| RDM\_MSG\_LINK | Free-text field containing a unique identifier of Reentry Data Message (RDM) [12] that are linked (relevant) to this Orbit Data Message. |  |  | | RDM\_MSG\_35132.txt  RDM\_ID\_1839 | O |
| TDM\_MSG\_LINK | 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. |  |  | | TDM\_MSG\_37.txt  TDM\_835, TDM\_836 | O |
| OPERATOR | Free-text field containing the operator of the space object. |  |  | | INTELSAT | O |
| OWNER | Free-text field containing the owner of the space object. |  |  | | SIRIUS | O |
| COUNTRY | Free-text field containing the name of the country, country code, or country abbreviation where the space object owner is based. |  |  | | US  SPAIN | O |
| CONSTELLATION | Free-text field containing the name of the constellation to which this space object belongs. |  |  | | SPIRE | O |
| OBJECT\_TYPE | Specification of the type of object. Select from the accepted set of values indicated in ANNEX B, Section B11. |  |  | | PAYLOAD  ROCKET BODY  DEBRIS  UNKNOWN  OTHER | O |
| TIME\_SYSTEM | Time system for all absolute time stamps in this OCM including EPOCH\_TZERO. Select from the accepted set of values indicated in ANNEX B, Section B3. This field is used by all OCM data blocks.  If the spacecraft clock (SCLK) timescale is selected, then “EPOCH\_TZERO” shall be interpreted as the spacecraft clock epoch and both SCLK\_OFFSET\_AT\_EPOCH and SCLK\_SEC\_PER\_SI\_SEC shall be supplied. |  | UTC | | UTC | M |
| EPOCH\_TZERO | Default epoch to which all relative times are referenced in data blocks (for format specification, see Section 7.5.10). The time scale of EPOCH\_TZERO is controlled via the “TIME\_SYSTEM” keyword, with the exception that for the spacecraft clock (SCLK) timescale, EPOCH\_TZERO shall be interpreted as being in the UTC timescale. This field is used by all OCM data blocks. |  |  | | 2001-11-06T11:17:33 | M |
| OPS\_STATUS | Specification of the operational status of the space object. Select from the accepted set of values indicated in ANNEX B, Section B12. |  |  | | OPERATIONAL | O |
| ORBIT\_CATEGORY | Specification of the type of orbit. Select from the accepted set of values indicated in ANNEX B, Section B14. |  |  | | GEO  LEO | O |
| OCM\_DATA\_ELEMENTS | Comma-delimited list of elements of information data blocks included in this message. The order shall be the same as the order of the data blocks in the message. Values shall be confined to the following list: ORB, PHYS, COV, MAN, PERT, OD, USER.  If the OCM contains multiple ORB, COV or MAN data blocks (as allowed by Table 6.1), the corresponding ORB, COV or MAN entry shall be duplicated to match. |  |  | | ORB, ORB, PHYS, COV, MAN, MAN, PERT, OD, USER | O |
| SCLK\_OFFSET\_AT\_EPOCH | Defines the number of spacecraft clock counts existing at EPOCH\_TZERO. This is only used if the spacecraft clock (SCLK) timescale is employed by the user. | s | 0.0 | | -5000.0 | C |
| SCLK\_SEC\_PER\_SI\_SEC | Defines the current number of clock seconds occurring during one SI second. Note that this clock rate may vary with time and is the current approximate value. This is only used if the spacecraft clock (SCLK) timescale is employed by the user. | s | 1.0 | | 2.5 | C |
| PREVIOUS\_MESSAGE\_EPOCH | Creation epoch of the previous message from this originator for this space object. For format specification, see Section 7.5.10.  NOTE – One may provide the previous message epoch without supplying the PREVIOUS\_MESSAGE\_ID, and vice versa. |  |  | | 2001-11-06T11:17:33 | O |
| NEXT\_MESSAGE\_EPOCH | Anticipated (or actual) epoch of the next message from this originator for this space object. For format specification, see Section 7.5.10.  NOTE – One may provide the next message epoch without supplying the NEXT\_MESSAGE\_ID, and vice versa. |  |  | | 2001-11-07T11:17:33 | O |
| START\_TIME | Time of the earliest data contained in the OCM, specified as either a relative or absolute time tag. |  |  | | 0.0  2001-11-06T00:00:00 | O |
| STOP\_TIME | Time of the latest data contained in the OCM, specified as either a relative or absolute time tag. |  |  | | 86400.0  2001-11-08T00:00:00 | O |
| TIME\_SPAN | Span of time that the OCM covers, measured in days. TIME\_SPAN is defined as (STOP\_TIME-START\_TIME), measured in days, irrespective of whether START\_TIME or STOP\_TIME are provided by the message creator. | d |  | | 20.0 | O |
| TAIMUTC\_AT\_TZERO | Difference (TAI – UTC) in seconds (i.e., total number of leap seconds elapsed since 1958) as modeled by the message originator at epoch “EPOCH\_TZERO”. | s |  | | 36 | O |
| NEXT\_LEAP\_EPOCH | Epoch of next leap second, specified as an absolute time tag. |  |  | | 2016-12-31T23:59:60 | O |
| NEXT\_LEAP\_TAIMUTC | Difference (TAI – UTC) in seconds (i.e., total number of leap seconds elapsed since 1958) incorporated by the message originator at epoch “NEXT\_LEAP\_EPOCH”. This keyword should be provided if NEXT\_LEAP\_EPOCH is supplied. | s |  | | 37 | C |
| UT1MUTC\_AT\_TZERO | Difference (UT1 – UTC) in seconds, as modeled by the originator at epoch “EPOCH\_TZERO”. | s |  | | 0.357 | O |
| EOP\_SOURCE | Free-text field specifying the source and version of the message originator’s Earth Orientation Parameters (EOP) used in the creation of this message, including leap seconds, TAI-UT1, etc. |  |  | | CELESTRAK\_20201028 | O |
| INTERP\_METHOD\_EOP | Free-text field specifying the method used to select or interpolate sequential EOP data. |  |  | | PRECEDING\_VALUE  NEAREST\_NEIGHBOR  LINEAR  LAGRANGE\_ORDER\_5 | O |
| CELESTIAL\_SOURCE | Free-text field specifying the source and version of the message originator’s celestial body (e.g., Sun/Earth/Planetary) ephemeris data used in the creation of this message. |  |  | | JPL\_DE\_FILES | O |
| META\_STOP | End of the metadata section. |  |  | |  | M |

### OCM Data: Trajectory state Time History

Table 6‑4 provides an overview of the OCM trajectory state time history (“ephemeris”) section. Only those keywords shown in Table 6‑4 shall be used in the OCM trajectory state time history data specification.

Each trajectory state time history data block must begin with keyword TRAJ\_START and end with keyword TRAJ\_STOP.

Multiple trajectory state data blocks shall appear in an OCM only if they are delimited by separate TRAJ\_START and TRAJ\_STOP keywords

#### Each trajectory state time history data block should differ from all others in at least one of the following respects:

1. the selected element set (TRAJ\_TYPE)
2. the orbit basis, i.e., the orbit determination, navigation solution, or simulation (TRAJ\_BASIS\_ID)
3. the reference frame is unique (TRAJ\_REF\_FRAME)
4. the orbit center is unique (CENTER\_NAME)
5. the data interval timespan is unique (i.e., has no overlap with any other data interval(s))

Where multiple trajectory state time history data blocks are provided for the same TRAJ\_BASIS and TRAJ\_BASIS\_ID, the top-most depiction shall be adopted as the true or master depiction.

Each trajectory state time history shall be time-ordered to be monotonically increasing.

Positionally-discontinuous trajectory states (i.e., separated by a gap in the trajectory state time history data across which interpolation should not be performed) shall be represented by separate trajectory state time history data blocks.

Velocity-discontinuous trajectory states (i.e., by introduction of an impulsive maneuver) shall be represented by separate trajectory state time history data blocks.

All trajectory state time history blocks must contain enough data records to allow the recommended interpolation method to be carried out consistently throughout the time span.

If the user includes trajectory states at key mission events or times, it may be useful to provide times, names, and significance for such mission events in the descriptive comment line(s) immediately following the TRAJ\_START keyword.

Each line of orbit ephemeris data shall be provided in fixed order beginning with an absolute or relative time tag, followed by the corresponding trajectory state elements as defined by TRAJ\_TYPE (see SANA registry [11] and ANNEX B, Section B7).

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

The number of significant figures 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 [ANNEX H, Reference H-6].

If a trajectory state time history section is included in the message, a corresponding perturbations section should be included as well to specify the perturbations incorporated in these trajectory states.

The CENTER\_NAME shall be used to specify the origin of the reference frame that the trajectory state time history is specified in. The specified center may either be a natural, gravitationally attracting body such as is provided in ANNEX B, Section B2, or it may be a non-gravitationally attracting origin to allow relative positional time histories. If a non-gravitationally attracting origin is selected, however, then the specified TRAJ\_TYPE shall be confined to Cartesian or spherical coordinates, where the reference frame may be rotating or inertially fixed.

Table ‑4 : OCM Data: Trajectory State Time History

| **Keyword** | | **Description** | | **Units** | | **Default (if any)** | | **Examples of Values** | | **M/O/C** | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| TRAJ\_START | | Start of a trajectory state vector or time history section. | |  | |  | | n/a | | M | |
| COMMENT | | Comments (a contiguous set of one or more comment lines may be provided in the Trajectory State Time History section only immediately after the TRAJ\_START keyword; see Section 7.8 for comment formatting rules). | |  | |  | | This is a comment | | O | |
| TRAJ\_ID | | Free-text field containing the identification number for this trajectory state time history block. | |  | |  | | TRAJ\_20160402\_XYZ | | O | |
| TRAJ\_PREV\_ID | | Free-text field containing the identification number for the previous trajectory state time history, contained either within this message, or presented in a previous OCM.  NOTE – if this message is not part of a sequence of orbit time histories or if this trajectory state time history is the first in a sequence of orbit time histories, then TRAJ\_PREV\_ID should be excluded from this message. | |  | |  | | ORB20160305a | | O | |
| TRAJ\_NEXT\_ID | | Free-text field containing the identification number for the next trajectory state time history, contained either within this message, or presented in a future OCM.  NOTE – if this message is not part of a sequence of orbit time histories or if this trajectory state time history is the last in a sequence of orbit time histories, then TRAJ\_NEXT\_ID should be excluded from this message. | |  | |  | | ORB20160305C | | O | |
| TRAJ\_BASIS | | Basis of this trajectory state time history data, this is free-text field with the following suggested values:   1. “PREDICTED”. 2. “DETERMINED” when estimated from observation-based determination, reconstruction, and/or calibration. For definitive OD performed onboard whose solutions have been telemetered to the ground for inclusion in an OCM, the TRAJ\_BASIS shall be DETERMINED. 3. “TELEMETRY” when the trajectory states are read directly from telemetry, e.g., based on inertial navigation systems or GNSS data. 4. “SIMULATED” for generic simulations, future mission design studies, and optimization studies. 5. “OTHER” for other bases of this data. | |  | |  | | PREDICTED | | O | |
| TRAJ\_BASIS\_ID | | Free-text field containing the identification number for the telemetry dataset, orbit determination, navigation solution, or simulation upon which this trajectory state time history block is based. Where a matching orbit determination block accompanies this trajectory state time history, the TRAJ\_BASIS\_ID should match the corresponding OD\_ID (see Table 6‑11). | |  | |  | | OD\_5910 | | O | |
| INTERPOLATION | | This keyword may be used to specify the recommended interpolation method for ephemeris data in the immediately following set of ephemeris lines. PROPAGATE indicates that orbit propagation is the preferred method to obtain states at intermediate times, via either a midpoint-switching or endpoint switching approach. | |  | |  | | HERMITE  LINEAR LAGRANGE PROPAGATE | | 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 provided if the ‘INTERPOLATION’ keyword is used and set to anything other than PROPAGATE. | |  | | 3 | | 5  1 | | C | |
| ORB\_AVERAGING | | Specifies whether the provided trajectory state/elements are based upon either osculating or mean elements, and if so, which mean element definition is employed. The intent of this field is to allow the user to correctly interpret how to use the provided orbit elements and know how to use them operationally.  Values should be selected from the accepted set indicated in ANNEX B, Section B13. If an alternate single- or double-averaging formulation is used other than provided, the user may name as mutually agreed by message exchange participants. | |  | | OSCULATING | | OSCULATING  BROUWER  KOZAI  (other…) | | M | |
| PROPAGATOR | | Free-text field containing the name of the orbit propagator used to create this trajectory state time history. | |  | |  | | HPOP  SP  SGP4 | | O | |
| CENTER\_NAME | | Origin of the orbit 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, Section B2.  For spacecraft, it is recommended to use either the “OBJECT\_NAME” or “INTERNATIONAL\_DESIGNATOR” of the participant as catalogued in the UN Office of Outer Space Affairs designator index (Reference [3]). Alternately, the “OBJECT\_DESIGNATOR” may be used.  For other reference frame origins, this field is a free-text descriptor which may draw upon other naming conventions and sources. | |  | | EARTH | | EARTH  MOON  SOLAR SYSTEM BARYCENTER  SUN  ISS  EROS  EARTH\_SUN\_L2  EGLIN | | M | |
| TRAJ\_REF\_FRAME | | Reference frame of the trajectory state time history. Select from the accepted set of values indicated in ANNEX B, Section B4. | |  | | ICRF3 | | J2000 | | M | |
| TRAJ\_FRAME\_EPOCH | | Epoch of the orbit data reference frame, if not intrinsic to the definition of the reference frame. See 7.5.10 for formatting rules. | |  | | EPOCH\_TZERO | | 2001-11-06T11:17:33  2002-204T15:56:23Z | | C | |
| USEABLE\_START\_TIME | | Start time of USEABLE time span covered by ephemeris data immediately following this metadata block. For format specification, see Section 7.5.10.  NOTE 1 –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.  NOTE 2 – If this keyword is not supplied, then all data shall be assumed to be valid. | |  | |  | | 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 Section 7.5.10.  NOTE 1 –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.  NOTE 2 – If this keyword is not supplied, then all data shall be assumed to be valid. | |  | |  | | 1996-12-18T14:28:15.1172  1996-277T07:22:54 | | O | |
| ORB\_REVNUM | | The integer orbit revolution number associated with first trajectory state in this trajectory state time history block.  NOTE – The first ascending node crossing that occurs AFTER launch or deployment is designated to be the beginning of orbit revolution number = one (“1”). | | |  | |  | | 1500  30007 | | O | |
| ORB\_REVNUM\_BASIS | | Specifies the message creator’s basis for their orbit revolution counter, with   * ”0” designates that the first launch or deployment trajectory state corresponds to a revolution number of 0.XXXX, where XXXX represents the fraction of an orbit revolution measured from the equatorial plane and orbit revolution 1.0 begins at the very next (subsequent) ascending node passage; * “1” designates that the first launch or deployment trajectory state corresponds to a revolution number of 1.XXXX, and orbit revolution 2.0 begins at the very next ascending node passage.   This keyword shall be provided if ORB\_REVNUM is specified. | |  | | 0 | | 0  1 | | C | |
| TRAJ\_TYPE | | Specifies the trajectory state type; selected per ANNEX B, Section B7. | |  | | CARTPV | | CARTP | | M | |
| TRAJ\_UNITS | | A comma-delimited set of SI unit designations for each element of the trajectory state time history **following the trajectory state time tag** solely for informational purposes, provided as an free-text field enclosed in square brackets. When provided, each trajectory state element shall have a corresponding units entry, with non-dimensional values (such as orbit eccentricity) denoted by “n/a”.  **NOTE – The listing of units via the TRAJ\_UNITS keyword does not override the mandatory units specified for the selected TRAJ\_TYPE** (links to the relevant SANA registries provided in ANNEX B, Section B7). | |  | |  | | [km,km,km,km/s,km/s,km/s]  [km,n/a,deg, deg, deg, deg] | | O | |
| … < Insert trajectory state time history here > | | Trajectory state time history line(s) shall be formatted as specified in 6.2.4.11, containing time and orbit elements formatted as specified in 7.4.1.5 and corresponding to the selected TRAJ\_TYPE in the SANA Orbital Elements registry (ANNEX B, Section B7). Units are as specified in this registry. | |  | |  | |  | | M | |
| TRAJ\_STOP | | End of an trajectory state vector or time history section. | |  | |  | | n/a | | M | |

### OCM DATA: Space Object Physical Characteristics

Table 6‑5 gives an overview of the OCM space object physical characteristics section. Only those keywords shown in Table 6‑5 shall be used in OCM space object physical characteristics data.

At most, only one space object physical characteristics section shall appear in an OCM.

The space object physical characteristics data section in the OCM shall be indicated by two keywords: PHYS\_START and PHYS\_STOP.

The Space Object Optimally Encompassing Box (OEB) parameters are defined in further detail in Informative ANNEX F, Section F1.

Modeling of cross-sectional area and the contributions of relevant parameters (DRAG\_CONST\_AREA, SRP\_CONST\_AREA, AREA\_ALONG\_OEB\_MAX, AREA\_ALONG\_OEB\_INT, and AREA\_ALONG\_OEB\_MIN) to total cross-sectional area is provided in Informative ANNEX F, Section F1.

Table 6‑5 : OCM Data: Space Object Physical Characteristics

| **Keyword** | **Description** | **Units** | **Default (if any)** | **Examples of Values** | **M/O/C** |
| --- | --- | --- | --- | --- | --- |
| PHYS\_START | Start of a Space Object Physical Characteristics section |  |  |  | M |
| COMMENT | Comments (a contiguous set of one or more comment lines may be provided in the OCM Space Object Physical Characteristics only immediately after the PHYS\_START keyword; see Section 7.8 for comment formatting rules). |  |  | This is a comment | O |
| MANUFACTURER | Free-text field containing the satellite manufacturer name. |  |  | BOEING | O |
| BUS\_MODEL | Free-text field containing the satellite manufacturer’s spacecraft bus model name. |  |  | 702 | O |
| DOCKED\_WITH | Free-text field containing a comma-separated list of other space objects that this object is docked to. |  |  | ISS | O |
| DRAG\_CONST\_AREA | Attitude-independent drag cross-sectional area (AD) facing the relative wind vector, not already incorporated into the attitude-dependent “AREA\_ALONG\_OEB” parameters. | m\*\*2 |  | 2.5 | O |
| DRAG\_COEFF\_NOM | Nominal drag Coefficient (). If the atmospheric drag coefficient, CD, is set to zero, no atmospheric drag shall be considered. |  |  | 2.2 | O |
| DRAG\_UNCERTAINTY | Drag coefficient one sigma (1σ) percent uncertainty, where the actual range of drag coefficients to within 1σ shall be obtained from This factor is intended to allow operators to supply the nominal ballistic coefficient components while accommodating ballistic coefficient uncertainties. | % |  | 10.0 | O |
| INITIAL\_WET\_MASS | Space object total mass at beginning of life. | kg |  | 500 | O |
| WET\_MASS | Space object total mass (including propellent, i.e., “wet mass”) at the current reference epoch “EPOCH\_TZERO”. | kg |  | 472.3 | O |
| DRY\_MASS | Space object dry mass (without propellant). | kg |  | 300 | O |
| OEB\_PARENT\_FRAME | Parent reference frame which maps to the Optimally Enclosing Box (OEB) frame via the quaternion-based transformation defined in ANNEX F, Section F1. Select from the accepted set of values indicated in ANNEX B, Sections B4 and B5.  This keyword shall be provided if OEB\_Q1,2,3,4 are specified. |  | RSW\_ROTATING | ITRF1997 | C |
| OEB\_PARENT\_FRAME\_EPOCH | Epoch of the OEB parent frame, if OEB\_PARENT\_FRAME is provided and its epoch is not intrinsic to the definition of the reference frame. (See Section 7.5.10 for formatting rules.). |  | EPOCH\_TZERO | 2001-11-06T11:17:33  2002-204T15:56:23Z | C |
| OEB\_Q1 | q1 = e1 \* sin(φ/2), where per ANNEX H, Reference [H-1],  φ = Euler rotation angle and e1 = 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 (OEB) (defined in ANNEX F, Section F1). A value of “-999” denotes a tumbling space object. |  |  | -0.575131822 | O |
| OEB\_Q2 | q2 = e2 \* sin(φ/2), where per ANNEX H, Reference [H-1],  φ = Euler rotation angle and e2 = 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 F, Section F1). A value of “-999” denotes a tumbling space object. |  |  | -0.280510532 | O |
| OEB\_Q3 | q3 = e3 \* sin(φ/2), where per ANNEX H, Reference [H-1],  φ = Euler rotation angle and e3 = 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 F, Section F1). A value of “-999” denotes a tumbling space object. |  |  | -0.195634856 | O |
| OEB\_QC | qc = cos(φ/2), where per ANNEX H, Reference [H-1], φ = the Euler rotation angle for the rotation that maps from the OEB\_PARENT\_FRAME (defined above) to the frame aligned with the Optimally Encompassing Box (ANNEX F, Section F1). qc shall be made non-negative by convention. A value of “-999” denotes a tumbling space object. |  |  | 0.743144825 | O |
| OEB\_MAX | Maximum physical dimension (along )of the Optimally Encompassing Box (OEB). | m |  | 1 | O |
| OEB\_INT | Intermediate physical dimension (along ) of Optimally Encompassing Box (OEB) normal to OEB\_MAX direction. | m |  | 0.5 | O |
| OEB\_MIN | Minimum physical dimension (along ) of Optimally Encompassing Box (OEB) in direction normal to both OEB\_MAX and OEB\_INT directions. | m |  | 0.3 | O |
| AREA\_ALONG\_OEB\_MAX | Attitude-dependent cross-sectional area of space object (not already included in DRAG\_CONST\_AREA and SRP\_CONST\_AREA) when viewed along max OEB () direction as defined in ANNEX F. | m\*\*2 |  | 0.15 | O |
| AREA\_ALONG\_OEB\_INT | Attitude-dependent cross-sectional area of space object (not already included in DRAG\_CONST\_AREA and SRP\_CONST\_AREA) when viewed along intermediate OEB () direction as defined in ANNEX F. | m\*\*2 |  | 0.3 | O |
| AREA\_ALONG\_OEB\_MIN | Attitude-dependent cross-sectional area of space object (not already included in DRAG\_CONST\_AREA and SRP\_CONST\_AREA) when viewed along minimum OEB () direction as defined in ANNEX F. | m\*\*2 |  | 0.5 | O |
| AREA\_MIN\_FOR\_PC | Minimum cross-sectional area for collision probability estimation purposes. | m\*\*2 |  | 1.0 | O |
| AREA\_MAX\_FOR\_PC | Maximum cross-sectional area for collision probability estimation purposes. | m\*\*2 |  | 1.0 | O |
| AREA\_TYP\_FOR\_PC | Typical (50th percentile) cross-sectional area sampled over all space object orientations for collision probability estimation purposes. | m\*\*2 |  | 1.0 | O |
| RCS | Typical (50th percentile) effective Radar Cross Section of the space object sampled over all possible viewing angles. | m\*\*2 |  | 1.25 | O |
| RCS\_MIN | Minimum Radar Cross Section observed for this object. | m\*\*2 |  | 1.1 | O |
| RCS\_MAX | Maximum Radar Cross Section observed for this object. | m\*\*2 |  | 2.5 | O |
| SRP\_CONST\_AREA | Attitude-independent solar radiation pressure cross-sectional area (AR) facing the Sun, not already incorporated into the attitude-dependent “AREA\_ALONG\_OEB” parameters (computed from  { AREA\_ALONG\_OEB\_MAX  AREA\_ALONG\_OEB\_INT  AREA\_ALONG\_OEB\_MIN }  Where represents the angle between the normal to each MAX/INT/MIN face and the direction to the Sun. | m\*\*2 |  | 1.0 | O |
| SOLAR\_RAD\_COEFF | Nominal Solar Radiation Pressure Coefficient ().  NOTE – If the solar radiation coefficient, CR, is set to zero, no solar radiation pressure shall be considered. |  |  | 1.7 | O |
| SOLAR\_RAD\_UNCERTAINTY | Solar Radiation Pressure one sigma (1σ) percent uncertainty, where the actual range of SRP coefficients to within 1σ shall be obtained from This factor is intended to allow operators to supply the nominal ballistic coefficient components while accommodating ballistic coefficient uncertainties. | % |  | 1.0 | O |
| VM\_ABSOLUTE | Typical (50th percentile) absolute Visual Magnitude of the space object sampled over all possible viewing angles and “normalized” as specified in Informative ANNEX F, Section F2 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). |  |  | 15.0 | O |
| VM\_APPARENT\_MIN | Minimum apparent Visual Magnitude observed for this space object. |  |  | 19.0 | O |
| VM\_APPARENT | Typical (50th percentile) apparent Visual Magnitude observed for this space object. |  |  | 15.0 | O |
| VM\_APPARENT\_MAX | Maximum apparent Visual Magnitude observed for this space object.  NOTE – The “MAX” value represents the brightest observation, which associates with a lower Vmag . |  |  | 16.0 | O |
| REFLECTANCE | Typical (50th percentile) coefficient of REFLECTANCE of the space object over all possible viewing angles, ranging from 0 (none) to 1 (perfect reflectance). |  |  | 0.7 | O |
| ATT\_CONTROL\_MODE | Free-text specification of primary mode of attitude control for the space object. Suggested examples include:   * THREE\_AXIS * SPIN * DUAL\_SPIN * TUMBLING * GRAVITY\_GRADIENT |  |  | SPIN | O |
| ATT\_ACTUATOR\_TYPE | Free-text specification of type of actuator for attitude control. Suggested examples include:   * ATT\_THRUSTERS * ACTIVE\_MAG\_TORQUE * PASSIVE\_MAG\_TORQUE * REACTION\_WHEELS * MOMENTUM\_WHEELS * CONTROL\_MOMENT\_GYROSCOPE * NONE * OTHER |  |  | ATT\_THRUSTERS | O |
| ATT\_KNOWLEDGE | Accuracy of attitude knowledge. | deg |  | 0.3 | O |
| ATT\_CONTROL | Accuracy of attitude control system (ACS) to maintain attitude, assuming attitude knowledge was perfect (i.e., deadbands). | deg |  | 2.0 | O |
| ATT\_POINTING | Overall accuracy of spacecraft to maintain attitude, including attitude knowledge errors and ACS operation. | deg |  | 2.3 | O |
| AVG\_MANEUVER\_FREQ | Average maneuver frequency, measured in the number of orbit- or attitude-adjust maneuvers per year. | #/yr |  | 20.0 | O |
| MAX\_THRUST | Maximum composite thrust the spacecraft can accomplish in any single body-fixed direction. | N |  | 1.0 | O |
| DV\_BOL | Total ΔV capability of the spacecraft at beginning of life. | km/s |  | 1.0 | O |
| DV\_REMAINING | Total ΔV remaining for the spacecraft. | km/s |  | 0.2 | O |
| IXX | Moment of Inertia about the X-axis of the space object’s primary body frame (e.g. SC\_Body\_1) – see ANNEX H, Reference [H-1]. | kg\*m\*\*2 |  | 1000.0 | O |
| IYY | Moment of Inertia about the Y-axis. | kg\*m\*\*2 |  | 800.0 | O |
| IZZ | Moment of Inertia about the Z-axis. | kg\*m\*\*2 |  | 400.0 | O |
| IXY | Inertia Cross Product of the X & Y axes. | kg\*m\*\*2 |  | 20.0 | O |
| IXZ | Inertia Cross Product of the X & Z axes. | kg\*m\*\*2 |  | 40.0 | O |
| IYZ | Inertia Cross Product of the Y & Z axes. | kg\*m\*\*2 |  | 60.0 | O |
| PHYS\_STOP | End of the Space Object Physical Characteristics section. |  |  |  | M |

### OCM Data: Covariance Time History

Table 6‑6 provides an overview of the OCM covariance time history section. Only those keywords shown in Table 6‑6 shall be used in the OCM covariance time history data specification.

Each covariance time history data block must begin with keyword COV\_START and end with keyword COV\_STOP.

Multiple trajectory state covariance data blocks shall appear in an OCM only if they are delimited by separate COV\_START and COV\_STOP keywords

#### Each covariance time history data block should differ from all others in at least one of the following respects:

1. the selected element set (COV\_TYPE)
2. the orbit basis (COV\_BASIS)
3. the orbit determination, navigation solution, or simulation (COV\_BASIS\_ID)
4. the reference frame is unique (COV\_REF\_FRAME)
5. the data interval timespan is unique (i.e., has no overlap with any other data interval(s))

Where multiple covariance time history data blocks are provided for the same COV\_BASIS and COV\_BASIS\_ID, the top-most depiction shall be adopted as the true or master depiction.

Each covariance time history shall be time-ordered to be monotonically increasing.

Discontinuous covariance time segments shall be represented by separate covariance time history data blocks.

If the user includes trajectory state covariances at key mission events or times, it may be useful to provide times, names, and significance for such mission events in descriptive comment line(s) immediately following the COV\_START keyword.

Values in the trajectory state covariance matrix shall be expressed in the applicable reference frame specified via the COV\_REF\_FRAME keyword.

If a covariance time history section is included in the message, a corresponding perturbations section should be included as well to specify the perturbations incorporated in these covariances.

##### Each covariance time history line shall begin with either a relative or absolute time tag corresponding to the specified covariance matrix.

For all covariance representations, the covariance time tag and covariance matrix elements (or dispersions and eigenvectors, in the case of COV\_TYPE= SIG3EIGVEC3 or TSIG3EIGVEC3) **shall all be presented on a single line**.

##### The composition of the covariance matrix shall be commensurate with the specified COV\_TYPE value.

##### Directly following the time tag specification on the same line as the time tag, all elements of the “NxN” covariance shall be presented in row wise fashion.

##### On each covariance line, the ordering of the covariance values shall be governed by the “COV\_ORDERING” keyword. Acceptable values (illustrated with a 3x3 matrix example) are:

###### LTM: Lower Triangular Matrix (LTM) beginning with element [1,1], followed by [2,1], [2,2], [3,1], [3,2] and so on, until all of the LTM entries have been provided as shown and ordered in Figure 6‑1.

Figure 6‑1: LTM covariance element ordering following time tag.

###### UTM: Upper Triangular Matrix (UTM) beginning with element [1,1], followed by [1,2], [1,3], [2,2], [2,3] and so on, until all of the UTM entries have been provided as shown and ordered in Figure 6‑2.

Figure 6‑2: UTM covariance element ordering following time tag.

###### FULL: The full, symmetric covariance matrix, beginning with element [1,1], followed by [1,2], [1,3], [2,1], [2,2], [2,3], [3,1], [3,2] [3,3] and so on, until all covariance entries (there are entries in total) have been provided as shown and ordered in Figure 6‑3.

Figure 6‑3: Full covariance element ordering following time tag.

###### LTMWCC: Lower Triangular Matrix conflated with cross-correlation terms, where correlation is obtained by dividing the covariance of the two variables by the product of their standard deviations. This combined matrix shall be provided beginning with covariance element [1,1], followed by correlationxy, correlationxz, covariance [2,1], [2,2], correlationyz, and covariance [3,1], [3,2] [3,3] and so on, until all covariance entries (there are entries in total) have been provided as shown and ordered in Figure 6‑4.

Figure 6‑4: LTM covariance/correlation element ordering following time tag.

###### UTMWCC: Upper Triangular Matrix conflated with cross-correlation terms, provided beginning with covariance element [1,1], followed by [1,2] and [1,3], then correlationxy, covariance [2,2], and [2,3], then correlationxz, correlationyz, and covariance [3,3] and so on, until all covariance entries (there are entries in total) have been provided as shown and ordered in Figure 6‑5.

Figure 6‑5: UTM covariance/correlation element ordering following time tag.

##### At least one space character must be used to separate the items in each covariance matrix data line as related in Section 7.4.1.6.

Variance and covariance values shall be expressed in floating point or scientific notation as related in Section 7.5. The number of significant figures and time steps suitable for interpolation of a covariance time history should be chosen according to best practice to avoid covariance interpolation loss of precision ANNEX H, References [H-6] and [H-13]).

NOTE – It is strongly recommended that covariance matrix time history interpolation be done by either (1) using orbit-dynamics-aware numerical methods as provided in [H-9]; or (2) eigenvalue/vector decomposition, linear (or higher-order) interpolation of neighboring eigenvalues; Euler axis/angle rotation of eigenvectors at intermediate time(s) of interest; and re-composition of attained eigenvalues and eigenvectors into covariances at time(s) of interest (see ANNEX F, Section F5 and ANNEX H, References [H-10, H-11, and H-12]). Direct interpolation of covariance matrix components or failure to incorporate enough significant figures on the interpolated covariance elements can produce invalid (non-positive-semidefinite) covariances.

Table ‑6 : OCM Data: Covariance Time History

| **Keyword** | **Description** | **Units** | **Default (if any)** | **Examples of Values** | **M/O/C** |
| --- | --- | --- | --- | --- | --- |
| COV\_START | Start of a covariance time history section. |  |  | n/a | M |
| COMMENT | Comments (a contiguous set of one or more comment lines may be provided in the OCM covariance time history section only immediately after the COV\_START keyword; see Section 7.8 for comment formatting rules). |  |  | This is a comment | O |
| COV\_ID | Free-text field containing the identification number for this covariance time history block. |  |  | COV\_20160402\_XYZ | O |
| COV\_PREV\_ID | Free-text field containing the identification number for the previous covariance time history, contained either within this message, or presented in a previous OCM.  NOTE – If this message is not part of a sequence of covariance time histories or if this covariance time history is the first in a sequence of covariance time histories, then COV\_PREV\_ID should be excluded from this message. |  |  | COV\_20160305a | O |
| COV\_NEXT\_ID | Free-text field containing the identification number for the next covariance time history, contained either within this message, or presented in a future OCM.  NOTE – if this message is not part of a sequence of covariance time histories or if this covariance time history is the last in a sequence of covariance time histories, then COV\_NEXT\_ID should be excluded from this message. |  |  | COV\_20160305C | O |
| COV\_BASIS | Basis of this covariance time history data. This is free-  text field with the following suggested values:   1. “PREDICTED” 2. “DETERMINED” when estimated from observation-based orbit determination reconstruction and/or calibration. For definitive OD performed onboard whose solutions have been telemetered to the ground for inclusion in an OCM, the COV\_BASIS shall be considered to be DETERMINED. 3. EMPIRICAL (for empirically-determined such as overlap analyses) 4. SIMULATED for simulation-based (including Monte Carlo) estimations, future mission design studies, and optimization studies. 5. “OTHER” for other bases of this data |  |  | PREDICTED  EMPIRICAL  DETERMINED  SIMULATED  OTHER | O |
| COV\_BASIS\_ID | Free-text field containing the identification number for the orbit determination, navigation solution, or simulation upon which this covariance time history block is based. Where a matching orbit determination block accompanies this covariance time history, the COV\_BASIS\_ID should match the corresponding OD\_ID (see Table 6‑11). |  |  | OD\_5910 | O |
| COV\_REF\_FRAME | Reference frame of the covariance time history. Select from the accepted set of values indicated in ANNEX B, Section B4 and B5. |  | TNW\_INERTIAL | J2000 | M |
| COV\_FRAME\_EPOCH | Epoch of the covariance data reference frame, if not intrinsic to the definition of the reference frame. See 7.5.10 for formatting rules. |  | EPOCH\_TZERO | 2001-11-06T11:17:33  2002-204T15:56:23Z | C |
| COV\_SCALE\_MIN | Minimum scale factor to apply to this covariance data to achieve realism. |  |  | 0.5 | O |
| COV\_SCALE\_MAX | Maximum scale factor to apply to this covariance data to achieve realism. |  |  | 5.0 | O |
| COV\_CONFIDENCE | A measure of the confidence in the covariance errors matching reality, as characterized via a Wald test, a Chi-squared test, the log of likelihood, or a numerical representation per mutual agreement. | % |  | 50 | O |
| COV\_TYPE | Indicates covariance composition. Select from ANNEX B, Sections B7 and B8. |  | CARTPV | CARTP  CARTPV  ADBARV | M |
| COV\_ORDERING | Indicates covariance ordering as being either Lower Triangular Matrix (LTM), Upper Triangular Matrix (UTM), Full covariance, LTM covariance with cross-correlation information provided in upper triangle off-diagonal terms (LTMWCC), or UTM covariance with cross-correlation information provided in lower triangle off-diagonal terms (UTMWCC) |  | LTM | LTM  UTM  FULL  LTMWCC  UTMWCC | M |
| COV\_UNITS | A comma-delimited set of SI unit designations for each element of the covariance time history following the covariance time tag, solely for informational purposes, provided as a free-text field enclosed in square brackets. When provided, these units designations shall correspond to the units of the standard deviations (or square roots) of each of the covariance matrix diagonal elements (or variances), respectively, and all diagonal elements shall have a corresponding units entry, with non-dimensional values (such as dispersion in orbit eccentricity) denoted by “n/a”.  **NOTE – The listing of units via the COV\_UNITS keyword does not override the mandatory units specified for the selected COV\_TYPE** (links to the relevant SANA registries provided in ANNEX B, Section B7 and B8). |  |  | [km,km,km,km/s,km/s,km/s] | O |
| …< Insert covariance data here> | Covariance time history line(s) shall be formatted as specified in Sections 6.2.6.10.1 through 6.2.6.12 and Section 7.4.1.6 and corresponding to the selected time and covariance elements by COV\_TYPE. |  |  |  | M |
| COV\_STOP | End of a covariance time history section. |  |  | n/a | M |

### OCM Data: Maneuver specification

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 time history data specification.

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

Maneuver data in the OCM shall be indicated by two keywords: MAN\_START and MAN\_STOP.

Multiple maneuver data blocks shall appear in an OCM only when delimited by separate MAN\_START and MAN\_STOP keywords.

#### The time intervals of multiple maneuver data blocks may be separated in time, abut, or overlap.

#### NOTE – This is done to accommodate multiple maneuver reference frames, multiple thrusters in simultaneous operation, deployments during thrusting phases, multiple basis definitions (MAN\_BASIS), etc.

#### Each maneuver data block shall be assigned a maneuver device ID (MAN\_DEVICE\_ID) value, which specifies the unique thruster (or other propulsive device) used in this maneuver sequence time history data block.

#### Except for the special values “ALL” and “DEPLOY”, MAN\_DEVICE\_ID is a free-text field which allows the user to identify which specific thruster or other propulsive device performed this maneuver time history.

#### A MAN\_DEVICE\_ID value of “ALL” shall be used to indicate that this maneuver sequence represents an aggregation of thrust, acceleration, and/or velocity increments imparted by any/all thrusters utilized in the maneuver which are not attributed to a single specific propulsive device.

#### A MAN\_DEVICE\_ID value of “DEPLOY” shall be used to indicate that this maneuver data block represents ONLY maneuvers caused by a series of one or more deployments from this host vehicle.

#### Multiple maneuver data blocks may invoke the same maneuver device ID (MAN\_DEVICE\_ID) value.

All specified maneuver constituents having a common MAN\_ID, MAN\_BASIS and MAN\_REF\_FRAME shall be added together to obtain the total composite maneuver description.

#### Each maneuver data block should differ from all other maneuver data blocks in at least one of the following respects:

1. the maneuver device ID (MAN\_DEVICE\_ID) is unique;
2. the maneuver device ID is the same, but the “ON” time intervals are unique and do not overlap with any other data interval(s) for this maneuver device ID (e.g., during multiple interleaved duty cycle “ON” firings);
3. the maneuver basis (MAN\_BASIS) is unique;
4. the reference frame is unique (MAN\_REF\_FRAME);
5. the maneuver is based upon a unique orbit determination, navigation solution, or simulation (e.g., MAN\_BASIS\_ID);
6. the data interval timespan is unique (i.e., has no overlap).

If the only difference between multiple maneuver time history data blocks is the selected maneuver composition (MAN\_COMPOSITION) or reference frame (MAN\_REF\_FRAME), the top-most depiction (i.e., the time history occurring first in the OCM) shall be adopted as the official depiction, and those subsequent data blocks shall be treated as containing informational derivative depictions.

The MAN\_COMPOSITION keyword shall specify the individual maneuver time history elements to follow the maneuver time tag.

The MAN\_COMPOSITION keyword shall contain a comma-separated list of values taken from either Table 6‑8 **or** Table 6‑9 (i.e., keywords unique to Table 6‑8 or Table 6‑9 shall not be commingled within a single maneuver data block).

The values contained in the MAN\_COMPOSITION keyword shall appear in the order fixed in either Table 6‑8 or Table 6‑9.

##### Maneuver time history lines shall be confined to only one spacecraft object.

Only one of the time tag types (TIME\_ABSOLUTE or TIME\_RELATIVE) shall be selected as the first element of the MAN\_COMPOSITION specification sequence.

#### Within a single maneuver time history line, acceleration, impulsive ΔV, and thrust parameters shall not be additive, but rather shall be interpreted as alternate representations of the same underlying propulsive phenomenology.

#### Time tag(s) on each maneuver line shall represent the start of the maneuver, with the exception that impulsive ΔV entries in the propulsive representation (Table 6‑8) shall be interpreted as occurring at a time tag of Tstart + ½ (MAN\_DURA).

NOTE – While one could artificially make Tstart and the impulsive maneuver time be the same value by setting MAN\_DURA equal to zero, the actual duration of the maneuver is typically nonzero and providing it if/when known facilitates improved modeling and maneuver reconstruction.

##### When invoked, interpolation of acceleration (ACC\_INTERP=ON) and/or thrust vectors (THR\_INTERP=ON) shall be done using a suitable interpolation scheme such as the Euler axis/angle formulation discussed in Informative ANNEX F, Section F5.

##### Thrust and acceleration levels for any propulsive device shall be presumed to be “OFF” until explicitly turned “ON” by setting one or more thrust or acceleration components to a non-zero value.

##### Thrust and acceleration shall be set back to “OFF” after the maneuver duration has elapsed [ Tstart + MAN\_DURA]. Thrusters may also be turned “OFF” by setting all thrust and acceleration components to zero.

##### If thrust is continuous (not affected by a duty cycle), then none of the duty cycle keywords (DC\_XXXX) are required.

##### If thrust is not continuous (DC\_TYPE ≠ CONTINUOUS), thruster duty cycles shall be triggered either by a reference direction or a reference time.

##### NOTE – This duty cycle specification imposes cut-outs of non-thrust periods onto the thrust (finite burn) parameters to reflect the periods of duty cycle inactivity.

##### If the value of the DC\_TYPE keyword is TIME, then the following duty cycle parameters shall be present: DC\_WIN\_OPEN, DC\_WIN\_CLOSE, DC\_EXEC\_START, DC\_EXEC\_STOP, DC\_REF\_TIME, DC\_TIME\_PULSE\_DURATION, and DC\_TIME\_PULSE\_PERIOD.

##### If the value of the DC\_TYPE keyword is TIME\_AND\_ANGLE, then the following duty cycle parameters shall be present: DC\_WIN\_OPEN, DC\_WIN\_CLOSE, DC\_EXEC\_START, DC\_EXEC\_STOP, DC\_REF\_TIME, DC\_TIME\_PULSE\_DURATION, and DC\_TIME\_PULSE\_PERIOD, DC\_REF\_DIR, DC\_BODY\_FRAME, DC\_BODY\_TRIGGER, DC\_PA\_START\_ANGLE, and DC\_PA\_STOP\_ANGLE

##### DC\_MIN\_CYCLES and DC\_MAX\_CYCLES may be specified to constrain the number of duty cycles performed in either TIME or TIME\_AND\_ANGLE mode. These parameters may override the duty cycle maneuver stop time (DC\_EXEC\_STOP).

##### NOTE 1 – Relationships between such duty cycle parameters are described in Informative ANNEX F, Section F3.

NOTE 2 – The effects of using a pulse width modulation thruster controller can be accommodated by applying a reduced constant thrust level or by invoking the duty cycle parameters, or a combination thereof (being careful to avoid double-booking of thruster degradations).

Table ‑7 : OCM Data: Maneuver Specification

| **Keyword** | **Description** | **Units** | **Default (if any)** | **Examples of Values** | **M/O/C** |
| --- | --- | --- | --- | --- | --- |
| MAN\_START | Start of a maneuver time history section. |  |  |  | M |
| COMMENT | Comments (a contiguous set of one or more comment lines may be provided in the OCM Maneuver Specification only immediately after the MAN\_START keyword; see Section 7.8 for comment formatting rules). |  |  | This is a comment | O |
| MAN\_ID | Free-text field containing the unique maneuver identification number for this maneuver. All supplied maneuver “constituents” within the same MAN\_BASIS and MAN\_REF\_FRAME categories shall be added together to represent the total composite maneuver description. |  |  | E\_W\_20160305B  stage2 | M |
| MAN\_PREV\_ID | Free-text field containing the identification number of the previous maneuver for this MAN\_BASIS, contained either within this message, or presented in a previous OCM. If this 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. |  |  | E\_W\_20160305a | O |
| MAN\_NEXT\_ID | Free-text field containing the identification number of the next maneuver for this MAN\_BASIS, contained either within this message, or presented in a future OCM. If this 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. |  |  | E\_W\_20160305C | O |
| MAN\_BASIS | Basis of this maneuver time history data, which shall be selected from one of the following values:   1. “CANDIDATE” for a proposed operational or a hypothetical (i.e., mission design and optimization studies) future maneuver 2. “PLANNED” for a currently planned future maneuver. 3. “ANTICIPATED” for a non-cooperative future maneuver that is anticipated (i.e., likely) to occur (e.g., based upon patterns-of-life analysis). 4. “TELEMETRY” when the maneuver is determined directly from telemetry, e.g., based on inertial navigation systems or accelerometers. 5. “DETERMINED” when a past maneuver is estimated from observation-based orbit determination reconstruction and/or calibration. 6. “SIMULATED” for generic maneuver simulations, future mission design studies, and optimization studies. 7. “OTHER” for other bases of this data. |  |  | TELEMETRY  CANDIDATE | O |
| MAN\_BASIS\_ID | Free-text field containing the identification number for the orbit determination, navigation solution, or simulation upon which this maneuver time history block is based. Where a matching orbit determination block accompanies this maneuver time history, the MAN\_BASIS\_ID should match the corresponding OD\_ID (see Table 6‑11). |  |  | OD\_20181122A | O |
| MAN\_DEVICE\_ID | Free-text field containing the maneuver device identifier used for this maneuver. “ALL” indicates that this maneuver represents the summed acceleration, velocity increment, or thrust imparted by any/all thrusters utilized in the maneuver. |  |  | THR\_02  DEPLOYMENT  ALL | M |
| MAN\_PREV\_EPOCH | Identifies the completion time of the previous maneuver for this MAN\_BASIS. |  |  | 50.0  2001-11-06T11:17:33  2002-204T15:56:23Z | O |
| MAN\_NEXT\_EPOCH | Identifies the start time of the next maneuver for this MAN\_BASIS. |  |  | 50.0  2001-11-06T11:17:33  2002-204T15:56:23Z | O |
| MAN\_PURPOSE | A free-text field used to specify the intention(s) of the maneuver. Multiple maneuver purposes can be provided as a comma-delimited list, and could include:  Aerobraking (AEROBRAKE),  Attitude adjust (ATTITUDE)  Collision avoidance (COLA)  Deployment (DEPLOY)  Disposal (DISPOSAL)  Gravity assist flyby (GRAV\_ASSIST\_FROM\_XXXX, where XXXX=body center name, e.g., SANA Registry [11])  Inclination adjustment (INCLINATION)  Launch & Early Orbit (LEOP)  Maneuver cleanup (MNVR\_CLEANUP)  Mass adjust (MASS\_ADJUST)  Momentum desaturation (DESAT)  Orbit adjust (ORBIT)  Orbit trim (TRIM)  Other (OTHER)  Period adjustment (PERIOD)  Pointing Request Message (PRM\_ID\_xxxx)  Relocation (RELOCATION)  Science objective (SCI\_OBJ)  Spin rate adjust (SPIN\_RATE)  Station-keeping (SK)  Trajectory correction (TRAJ\_CORR) |  |  | DISPOSAL | O |
| MAN\_PRED\_SOURCE | For future 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 consider using TRAJ\_ID and OD\_ID keywords as described in Tables 6-4 and 6-11 respectively, or a combination thereof. |  |  | OD\_5 | O |
| MAN\_REF\_FRAME | Reference frame in which all maneuver vector direction data is provided in this maneuver data block. Select from the accepted set of values indicated in ANNEX B, Sections B4 and B5. The reference frame must be the same for all data elements within a given maneuver time history block. |  | TNW\_INERTIAL | J2000 | M |
| MAN\_FRAME\_EPOCH | Epoch of the maneuver data 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 |
| GRAV\_ASSIST\_NAME | Origin of maneuver gravitational assist body, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter. See ANNEX B, Section B2, for acceptable GRAV\_ASSIST\_NAME values (and the procedure to propose new values). |  |  | Earth  Moon  EROS  JUPITER | O |
| DC\_TYPE | Duty cycle type to use for this maneuver time history section:   * CONTINUOUS denotes full/continuous thrust <default>; * TIME denotes a time-based duty cycle driven by time past a reference time and the duty cycle ON and OFF durations; * TIME\_AND\_ANGLE denotes a duty cycle driven by the phasing/clocking of a space object body frame “trigger” direction past a reference direction. |  | CONTINUOUS | CONTINUOUS  TIME  TIME\_and\_ANGLE | M |
| DC\_WIN\_OPEN | Start time of the duty cycle-based maneuver window that occurs on or prior to the actual maneuver execution start time. For example, this may identify the time at which the satellite is first placed into a special duty-cycle-based maneuver mode.  This keyword shall be set if DC\_TYPE “CONTINUOUS”. |  |  | 50.0  2001-11-06T11:17:33  2002-204T15:56:23Z | C |
| DC\_WIN\_CLOSE | End time of the duty cycle-based maneuver window that occurs on or after the actual maneuver execution end time. For example, this may identify the time at which the satellite is taken out of a special duty-cycle-based maneuver mode.  This keyword shall be set if DC\_TYPE “CONTINUOUS”. |  |  | 100.0  2001-11-07T51:17:33  2002-204T15:58:03Z | C |
| DC\_MIN\_CYCLES | Minimum number of “ON” duty cycles (may override DC\_EXEC\_STOP). This value is optional even if DC\_TYPE “CONTINUOUS”. |  |  | 5 | O |
| DC\_MAX\_CYCLES | Maximum number of “ON” duty cycles (may override DC\_EXEC\_STOP). This value is optional even if DC\_TYPE “CONTINUOUS”. |  |  | 200 | O |
| DC\_EXEC\_START | Start time of the initial duty cycle-based maneuver sequence execution. DC\_EXEC\_START is defined to occur on or prior to the first maneuver “ON” portion within the duty cycle sequence. DC\_EXEC\_START must occur coincident with or after DC\_WIN\_OPEN.  This keyword shall be set if DC\_TYPE “CONTINUOUS”. |  |  | 50.0  2001-11-06T11:17:33  2002-204T15:56:23Z | C |
| DC\_EXEC\_STOP | End time of the final duty cycle-based maneuver sequence execution. DC\_EXEC\_ STOP typically occurs on or after the end of the final maneuver “ON” portion within the duty cycle sequence. DC\_EXEC\_STOP occurs prior to or coincident with DC\_WIN\_CLOSE.  This keyword shall be set if DC\_TYPE “CONTINUOUS”. |  |  | 100.0  2001-11-07T51:17:33  2002-204T15:58:03Z | C |
| DC\_REF\_TIME | Reference time for the THRUST duty cycle, specified as either time in seconds (relative to EPOCH\_TZERO), or as an absolute “<epoch>” (see Section 7.5.10 for formatting rules).  NOTE – Depending upon EPOCH\_TZERO, DC\_REF\_TIME relative times may be negative.  This keyword shall be set if DC\_TYPE “CONTINUOUS”. |  |  | 8000.0  2001-11-06T11:17:33 | C |
| DC\_TIME\_PULSE\_DURATION | Thruster pulse “ON” duration, initiated at first satisfaction of the burn “ON” time constraint or upon completion of the previous DC\_TIME\_PULSE\_PERIOD cycle.  This keyword shall be set if DC\_TYPE “CONTINUOUS”. | s |  | 10.0 | C |
| DC\_TIME\_PULSE\_PERIOD | Elapsed time between the start of one pulse and the start of the next. Must be greater than or equal to DC\_TIME\_PULSE\_DURATION.  This keyword shall be set if DC\_TYPE “CONTINUOUS”. | s |  | 200.0 | C |
| DC\_REF\_DIR | For phase angle thruster duty cycles (DC\_TYPE=TIME\_AND\_ANGLE), specifies the reference vector direction in the “MAN\_REF\_FRAME” reference frame at which, when mapped into the space object’s spin plane (normal to the spin axis) the duty cycle is triggered (see DC\_PA\_START\_ANGLE for phasing).  This (**tripartite**, or three-element vector**)** value shall be provided if DC\_TYPE = “TIME\_AND\_ANGLE”.  This reference direction does NOT represent the duty cycle midpoint. |  |  | 1.0 0.0 0.0 | C |
| DC\_BODY\_FRAME | For phase angle thruster duty cycles (DC\_TYPE=TIME\_AND\_ANGLE), specifies the body reference frame in which DC\_BODY\_TRIGGER will be specified. Select from the accepted set of values indicated in ANNEX B, Section B6. This keyword shall be set if DC\_TYPE = “TIME\_AND\_ANGLE”. |  |  | SC\_BODY\_1  SENSOR\_3 | C |
| DC\_BODY\_TRIGGER | For phase angle thruster duty cycles (DC\_TYPE=TIME\_AND\_ANGLE), specifies the body frame reference vector direction in the “DC\_BODY\_FRAME” reference frame at which, when its projection onto the spin plane crosses the corresponding projection of DC\_REF\_DIR onto the spin plane, this angle-based duty cycle is initiated (see DC\_PA\_START\_ANGLE for phasing).  This tripartite value shall be provided if DC\_TYPE = “TIME\_AND\_ANGLE”. |  |  | 0.707 0.0 0.707 | C |
| DC\_PA\_START\_ANGLE | For phase angle thruster duty cycles (DC\_TYPE=TIME\_AND\_ANGLE), specifies the phase angle offset of thruster pulse start, measured with respect to the occurrence of a DC\_BODY\_TRIGGER crossing of the DC\_REF\_DIR direction when both are projected into the spin plane (normal to the body spin axis). This phase angle offset can be positive or negative to allow the duty cycle to begin prior to the next crossing of the DC\_REF\_DIR. As this angular direction is to be used in a modulo sense, there is no requirement for the magnitude of the phase angle offset to be less than 360 degrees.  This keyword shall be set if DC\_TYPE = “TIME\_AND\_ANGLE”. | deg |  | 25.0 | C |
| DC\_PA\_STOP\_ANGLE | For phase angle thruster duty cycles (DC\_TYPE=TIME\_AND\_ANGLE), specifies the phase angle of thruster pulse stop, measured with respect to the DC\_BODY\_TRIGGER crossing of the DC\_REF\_DIR direction when both are projected into the spin plane. This phase angle offset can be positive or negative to allow the duty cycle to end after to the next crossing of the DC\_REF\_DIR. As this angular direction is to be used in a modulo sense, there is no requirement for the magnitude of the phase angle offset to be less than 360 degrees.  This keyword shall be set if DC\_TYPE = “TIME\_AND\_ANGLE”. | deg |  | 35.0 | C |
| MAN\_COMPOSITION | The comma-delimited ordered set of maneuver elements of information contained on every maneuver time history line, with values selected from Table 6‑8. Within this maneuver data section, the maneuver composition shall include only one TIME specification (TIME\_ABSOLUTE or TIME\_RELATIVE). |  |  | TIME\_RELATIVE, THR\_X, THR\_Y, THR\_Z, THR\_ISP, THR\_EFFIC, DELTA\_MASS, DV\_X, DV\_Y, DV\_Z, DV\_MAG\_SIGMA | M |
| MAN\_UNITS | A comma-delimited set of SI unit designations for each and every element of the maneuver time history following the maneuver time tag(s), solely for informational purposes, provided as an free-text field enclosed in square brackets. When MAN\_UNITS is provided, all elements of MAN\_COMPOSITION must have a corresponding units entry; percentages shall be denoted by “%” and control switches, non-dimensional values and text strings shall be labelled as “n/a”.  **NOTE – The listing of units via the MAN\_UNITS keyword does not override the mandatory units for the selected MAN\_COMPOSITION, as specified in Table 6‑8 or Table 6‑9.** |  |  | [N,N,N,s,%,kg,m/s,m/s,m/s, %,n/a] | O |
| … < Insert maneuver data here> | <Maneuver time history data, content, and units shall be provided, formatted as specified in Section 7.4.1.7 and corresponding to the selected as specified by MAN\_COMPOSITION.> |  |  |  | M |
| MAN\_STOP | End of a maneuver time history section. |  |  |  | M |

##### Maneuver elements of information shall be drawn from Table 6‑8 or Table 6‑9.

NOTE – Each set of data has practical benefits when applied to maneuver scenarios:

##### Specification of a time history of acceleration parameters ACC\_X, ACC\_Y, and ACC\_Z allows the OCM originator to portray and share the net effects of maneuvers without the OCM recipient needing to do complex finite burn modeling.

* Specification of ΔV parameters allows simplified modeling assuming impulsive (instantaneous velocity change) maneuvers.

##### Specification of thrust parameters provides a finite burn capability. In the case of low-thrust and/or long-duration burns, sequential low-thrust interval maneuver lines may be used to reflect the evolution of the low-thrust maneuver thrust parameters.

Table ‑8 : OCM Data: Selectable propulsive (i.e., non-deployment) maneuver fields in the maneuver time history data

| **Keyword** | **Description** | **Units** | **Examples of Values** |
| --- | --- | --- | --- |
| TIME\_ABSOLUTE | Absolute epoch time as formatted in Section 7.5.10. | n/a | 2018-11-13T11:13:20.5Z |
| TIME\_RELATIVE | Relative epoch time measured in SI seconds with respect to the epoch time specified via the EPOCH\_TZERO keyword. | s | 20157.26 |
| MAN\_DURA | The maneuver duration associated with this impulsive ΔV, thrust, and/or acceleration-imparted event. | s | 200.0 |
| DELTA\_MASS | Mass change (where a negative number denotes a mass decrement/loss to the host) associated with this portion (“time slice”) of the maneuver. For “thrust” specification, this mass change shall include the mass change prescribed by the rocket equation. | kg | -5.0 |
| ACC\_X | Acceleration component AX in the selected maneuver frame. | km/s\*\*2 | 0.000734092785 |
| ACC\_Y | Acceleration component AY in the selected maneuver frame. | km/s\*\*2 | 0.000189779834 |
| ACC\_Z | Acceleration component AZ in the selected maneuver frame. | km/s\*\*2 | 0.0000794872502 |
| ACC\_INTERP | Acceleration vector Euler axis/angle interpolation mode between current and next acceleration line. | n/a | OFF  ON |
| ACC\_MAG\_SIGMA | One-sigma percent error on acceleration magnitude. | % | 1.0 |
| ACC\_DIR\_SIGMA | One-sigma angular off-nominal acceleration vector direction. | deg | 5.0 |
| DV\_X | Velocity increment ΔVX in the selected maneuver reference frame. The actual ΔV should be impulsively applied at a time of <time tag> + ½ (MAN\_DURA). | km/s | 0.025 |
| DV\_Y | Velocity increment ΔVY in the selected maneuver reference frame. The actual ΔV should be impulsively applied at a time of <time tag> + ½ (MAN\_DURA). | km/s | 0.0015 |
| DV\_Z | Velocity increment ΔVZ in the selected maneuver reference frame. The actual ΔV should be impulsively applied at a time of <time tag> + ½ (MAN\_DURA). | km/s | 0.00029 |
| DV\_MAG\_SIGMA | One-sigma percent error on ΔV magnitude. | % | 2.0 |
| DV\_DIR\_SIGMA | One-sigma angular off-nominal ΔV vector direction. | deg | 5.0 |
| THR\_X | Thrust component TX measured in the selected maneuver reference frame. | N | 1.0 |
| THR\_Y | Thrust component TY measured in the selected maneuver reference frame. | N | 2.0 |
| THR\_Z | Thrust component TZ measured in the selected maneuver reference frame. | N | 3.0 |
| THR\_EFFIC | Thrust efficiency “η,” typically ranging between 0.0 and 1.0, that must be applied to the nominal thrust X, Y, and Z constituents to obtain the net resultant thrust applied to the vehicle. | n/a | 0.95 |
| THR\_INTERP | Thrust vector Euler axis/angle interpolation mode between current and next thrust line; values shall be selected as either “OFF” or “ON”. | n/a | OFF  ON |
| THR\_ISP | Thrust specific impulse. | s | 330.0 |
| THR\_MAG\_SIGMA | One-sigma percent error on thrust magnitude. | % | 2.0 |
| THR\_DIR\_SIGMA | One-sigma angular off-nominal thrust vector direction. | deg | 5.0 |

Table ‑9 : OCM Data: Selectable deployment fields in the maneuver time history data

| **Keyword** | | **Description** | | **Units** | | **Examples of Values** | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| TIME\_ABSOLUTE | | Absolute epoch time as formatted in Section 7.5.10. | | n/a | | 2018-11-13T11:13:20.5Z | |
| TIME\_RELATIVE | | Relative epoch time measured in SI seconds with respect to the epoch time specified via the EPOCH\_TZERO keyword. | | s | | 20157.26 | |
| DEPLOY\_ID | | Free-text identifier of the resulting “child” object deployed from this host at this time tag. Setting DEPLOY\_ID to zero (value = 0) indicates that a deployment did not occur. | | n/a | | CubeSat\_001 | |
| DEPLOY\_DV\_X | | Velocity increment ΔVX of the deployed “child” object measured in the selected maneuver reference frame, applied instantaneously at the time tag of deployment. | | km/s | | 0.0001 | |
| DEPLOY\_DV\_Y | | Velocity increment ΔVY of the deployed “child” object measured in the selected maneuver reference frame, applied instantaneously at the time tag of deployment. | | km/s | | 0.00003 | |
| DEPLOY\_DV\_Z | | Velocity increment ΔVZ of the deployed “child” object measured in the selected maneuver reference frame, applied instantaneously at the time tag of deployment. | | km/s | | 0.00002 | |
| DEPLOY\_MASS | | Decrement in host mass as a result of deployment (shall be ≤ 0.0). | | kg | | -1.0 | |
| DEPLOY\_DV\_SIGMA | | One-sigma percent error on deployment ΔV magnitude. | | % | | 5.0 | |
| DEPLOY\_DIR\_SIGMA | | One-sigma angular off-nominal deployment vector direction. | | deg | | 5.0 | |
| DEPLOY\_DV\_RATIO | | Ratio of child-to-host ΔV vectors, such that:  NOTE – As an opposite ΔV is typically imparted to the host during deployment, this number is typically less than or equal to zero. This ratio allows the user to specify how much ΔV is imparted to the host vehicle. This is usually not -1.0 (i.e. an equal-and-opposite imparted velocity), to account for the mass fraction between the child and the host as well as any rotational torque acted on the host as a result of deployment direction centerline offsets as compared to the host’s center of gravity. | | n/a | | -0.05 | |
| DEPLOY\_DV\_CDA | | Typical (50th percentile) product of drag coefficient (Cd) times cross-sectional area for the deployed “child” object. | | m\*\*2 | | 0.022 | |

### OCM Data: PERTURBATIONS Specification

Table 6‑10 provides an overview of the OCM Perturbations Specification section. Only those keywords shown in Table 6‑10 shall be used in an OCM perturbations specification.

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

The OCM Perturbations Specification section shall be delimited by two keywords: PERT\_START and PERT\_STOP.

Table ‑10 : OCM Data: Perturbations Specification

| **Keyword** | **Description** | **Units** | **Default (if any)** | **Examples of Values** | **M/O/C** |
| --- | --- | --- | --- | --- | --- |
| PERT\_START | Start of the perturbations data section. |  |  |  | M |
| COMMENT | Comments (a contiguous set of one or more comment lines may be provided in the OCM Perturbations Specification only immediately after the PERT\_START keyword; see Section 7.8 for comment formatting rules). |  |  | This is a comment | O |
| ATMOSPHERIC\_MODEL | Name of atmosphere model, which shall be selected from the accepted set of values indicated in ANNEX B, Section B9. |  |  | MSISE90  NRLMSIS00  J70  J71  JROBERTS  DTM  JB2008 | O |
| GRAVITY\_MODEL | The gravity model (selected from the accepted set of gravity model names indicated in ANNEX B, Section B10), followed by the degree (D) and order (O) of the applied spherical harmonic coefficients used in the simulation.  NOTE – Specifying a zero value for “order” (e.g., 2D 0O) denotes zonals (J2 … JD) |  |  | EGM-96: 36D 36O  WGS-84: 8D 0O  GGM-01: 36D 36O  TEG-4: 36D 36O | O |
| EQUATORIAL\_RADIUS | Oblate spheroid equatorial radius of the central body used in the message, if different from the gravity model. | km |  | 6378.137 | O |
| GM | Gravitational coefficient of attracting body (Gravitational Constant x Central Mass), if different from the gravity model. | km\*\*3/s\*\*2 |  | 3.986004e5 | O |
| N\_BODY\_PERTURBATIONS | One OR MORE (N-body) gravitational perturbations bodies used. Values, listed serially in comma-delimited fashion, denote a natural solar or extra-solar system body (stars, planets, asteroids, comets, and natural satellites).  NOTE – Only those entries (or those procedurally added to the CENTER\_NAME content as specified in ANNEX B) that are denoted as an “Attracting Body” in ANNEX B, Section B2 are acceptable values. |  |  | MOON, SUN, JUPITER | O |
| CENTRAL\_BODY\_ROTATION | 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.  NOTE – The rotation axis may be slightly offset from the inertial frame Z-axis definition. | deg/s |  | 4.17807421629e-3 | O |
| OBLATE\_FLATTENING | Central body’s oblate spheroid oblateness for the polar-symmetric oblate central body model (e.g., for the Earth, it is approximately 1.0/298.257223563). |  |  | 0.00335281066475 | O |
| OCEAN\_TIDES\_MODEL | Name of ocean tides model (optionally specify order or constituent effects, diurnal, semi-diurnal, etc.). This is a free-text field, so if the examples on the right are insufficient, others may be used. |  |  | DIURNAL  SEMI-DIURNAL | O |
| SOLID\_TIDES\_MODEL | Name of solid tides model (optionally specify order or constituent effects, diurnal, semi-diurnal, etc.). |  |  | DIURNAL  SEMI-DIURNAL | O |
| 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. |  |  | IAU1976/FK5  IAU2010  IERS1996 | O |
| ALBEDO\_MODEL | Name of the albedo model. |  |  | STK | O |
| ALBEDO\_GRID\_SIZE | Number of grid points used in the albedo model. |  |  | 100 | O |
| SHADOW\_MODEL | Shadow model used for Solar Radiation Pressure; dual cone uses both umbra/penumbra regions. Selected option should be one of “NONE”, “CYLINDRICAL”, “CONE”, or “DUAL CONE”. |  |  | NONE  CYLINDRICAL  CONE  DUAL CONE | O |
| SHADOW\_BODIES | Comma-separated list of planetary bodies for which SRP shadowing is modeled, selected from ANNEX B for CENTER\_NAME values. |  |  | EARTH  MOON | O |
| 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. |  |  | GPS\_ROCK  BOX\_WING  CANNONBALL  COD | O |
| SW\_DATA\_SOURCE | Free-text field specifying the source and version of the Space Weather data used in the creation of this message. Multiple space weather sources can be specified in a comma-delimited fashion. |  |  | CELESTRAK | O |
| SW\_DATA\_EPOCH | Epoch of the Space Weather data. |  |  | 2001-11-08T00:00:00 | O |
| SW\_INTERP\_METHOD | Free-text field specifying the method used to select or interpolate any and all sequential space weather data (Kp, ap,Dst,F10.7, M10.7, S10.7, Y10.7, etc.). While not constrained to specific entries, it is anticipated that the utilized method would match methods detailed in numerical analysis textbooks. |  |  | PRECEDING\_VALUE  NEAREST\_NEIGHBOR  LINEAR  LAGRANGE\_ORDER\_5 | O |
| FIXED\_GEOMAG\_KP | A fixed (time invariant) value of the planetary geomagnetic index Kp used to override the normal time varying Kp values (e.g., obtained from SW\_DATA\_SOURCE).  NOTE – The use of Kp or Ap would depend on the selected ATMOSPHERIC\_MODEL. | nT |  | 3.2 | O |
| FIXED\_GEOMAG\_AP | A fixed (time invariant) value of the geomagnetic index ap used to override the normal time-varying ap values (e.g., obtained from SW\_DATA\_SOURCE).  NOTE – The use of Kp or Ap would depend on the selected ATMOSPHERIC\_MODEL. | nT |  | 21 | O |
| FIXED\_GEOMAG\_DST | A fixed (time invariant) value of the planetary geomagnetic index Dst used to override the normal time varying daily Dst values (e.g., obtained from SW\_DATA\_SOURCE). | nT |  | -20 | O |
| FIXED\_F10P7 | A fixed (time invariant) value of the solar flux units (SFU) daily proxy F10.7 used to override the normal time varying daily F10.7 values (e.g., obtained from SW\_DATA\_SOURCE). | SFU |  | 120.0 | O |
| FIXED\_F10P7\_MEAN | A fixed (time invariant) value of the solar flux proxy F10.7 used to override the normal time varying averaged F10.7 values (e.g., obtained from SW\_DATA\_SOURCE). | SFU |  | 132.0 | O |
| FIXED\_M10P7 | A fixed (time invariant) value of the solar flux daily proxy M10.7 used to override the normal time varying daily M10.7 values (e.g., obtained from SW\_DATA\_SOURCE). | SFU |  | 120.0 | O |
| FIXED\_M10P7\_MEAN | A fixed (time invariant) value of the solar flux proxy M10.7 used to override the normal time varying averaged M10.7 values (e.g., obtained from SW\_DATA\_SOURCE). | SFU |  | 120.0 | O |
| FIXED\_S10P7 | A fixed (time invariant) value of the solar flux proxy S10.7 used to override the normal time varying daily S10.7 values (e.g., obtained from SW\_DATA\_SOURCE). | SFU |  | 120.0 | O |
| FIXED\_S10P7\_MEAN | A fixed (time invariant) value of the solar flux proxy S10.7 used to override the normal time varying averaged S10.7 values (e.g., obtained from SW\_DATA\_SOURCE). | SFU |  | 120.0 | O |
| FIXED\_Y10P7 | A fixed (time invariant) value of the solar flux proxy Y10.7 used to override the normal time varying daily Y10.7 values (e.g., obtained from SW\_DATA\_SOURCE). | SFU |  | 120.0 | O |
| FIXED\_Y10P7\_MEAN | A fixed (time invariant) value of the solar flux proxy Y10.7 used to override the normal time varying averaged Y10.7 values (e.g., obtained from SW\_DATA\_SOURCE). | SFU |  | 120.0 | O |
| PERT\_STOP | End of the perturbations section. |  |  |  | M |

### OCM Data: Orbit DETERMINATION Data

Table 6‑11 provides an overview of the OCM orbit determination data section. Only those keywords shown in Table 6‑11 shall be used in an OCM orbit determination data specification.

At most, only one Orbit Determination Data section shall appear in an OCM.

Orbit determination data in the OCM shall be indicated by two keywords: OD\_START and OD\_STOP.

The values of the DAYS\_SINCE\_FIRST\_OBS, and DAYS\_SINCE\_LAST\_OBS keywords shall be specified as relative time, in days, to the value of the OD\_EPOCH keyword.

If an orbit determination parameters section is included in the message, a corresponding perturbations section shall be included as well to specify the perturbations incorporated in the orbit determination.

Where these orbit determination settings match those used to generate an OCM orbit, covariance, and/or maneuver time history, the OD\_ID should match the TRAJ\_BASIS\_ID, COV\_BASIS\_ID, and/or MAN\_BASIS\_ID keyword values respectively.

Table ‑11 : OCM Data: Orbit Determination Data

| **Keyword** | **Description** | **Units** | **Default (if any)** | **Examples of Values** | **M/O/C** |
| --- | --- | --- | --- | --- | --- |
| OD\_START | Start of the orbit determination data section. |  |  | n/a | M |
| COMMENT | Comments (a contiguous set of one or more comment lines may be provided in the OCM Orbit Determination Data section only immediately after the OD\_START keyword; see Section 7.8 for comment formatting rules). |  |  | This is a comment | O |
| OD\_ID | Identification number for this orbit determination. |  |  | OD\_20160402 | M |
| OD\_PREV\_ID | Optional identification number for the previous orbit determination.  NOTE – If this orbit determination is the first one performed on this object, then OD\_PREV\_ID should be excluded from this message. |  |  | OD\_20160401 | O |
| OD\_METHOD | Type of orbit determination method used to produce the orbit estimate. While this is a free-text field, it is suggested that it be comprised of the method, followed by a colon delimiter and the actual OD tool used to estimate the orbit (e.g., BAHN, ODIN, ODTK).  NOTE – Commonly used methods include Batch Weighted Least Squares (BWLS), Extended Kalman Filter (EKF), Sequential Filter (SF), Square Root Information Filter (SRIF), Sequential Simultaneous Estimation Method (SSEM). |  |  | BWLS: BAHN  BWLS: ODIN  SF: ODTK | M |
| OD\_EPOCH | Relative or absolute time tag of the orbit determination solved-for state in the selected OCM time system specified by the TIME\_SYSTEM keyword**.** |  |  | 2001-11-06T11:17:33  27854.239 | M |
| DAYS\_SINCE\_FIRST\_OBS | Days elapsed between first accepted observation and OD\_EPOCH.  NOTE – may be positive or negative. | d |  | 3.5 | O |
| DAYS\_SINCE\_LAST\_OBS | Days elapsed between last accepted observation and OD\_EPOCH.  NOTE – may be positive or negative. | d |  | 1.2 | O |
| RECOMMENDED\_OD\_SPAN | Number of days of observations recommended for the OD of the object ***(useful only for Batch OD systems).*** | d |  | 5.2 | O |
| ACTUAL\_OD\_SPAN | Actual time span in days used for the OD of the object.  NOTE – should equal (DAYS\_SINCE\_FIRST\_OBS - DAYS\_SINCE\_LAST\_OBS). | d |  | 2.3 | O |
| OBS\_AVAILABLE | The number of observations available within the actual OD time span. |  |  | 100 | O |
| OBS\_USED | The number of observations accepted within the actual OD time span. |  |  | 90 | O |
| TRACKS\_AVAILABLE | The number of sensor tracks available for the OD within the actual time span (see definition of “tracks”, Section 1.5.3). |  |  | 33 | O |
| TRACKS\_USED | The number of sensor tracks accepted for the OD within the actual time span (see definition of “tracks”, Section 1.5.3). |  |  | 30 | O |
| MAXIMUM\_OBS\_GAP | The maximum time between observations in the OD of the object. | d |  | 1.0 | O |
| OD\_EPOCH\_EIGMAJ | Positional error ellipsoid 1𝜎 major eigenvalue at the epoch of the OD. | m |  | 58.73 | O |
| OD\_EPOCH\_EIGMED | Positional error ellipsoid 1𝜎 intermediate eigenvalue at the epoch of the OD. | m |  | 35.7 | O |
| OD\_EPOCH\_EIGMIN | Positional error ellipsoid 1𝜎 minor eigenvalue at the epoch of the OD. | m |  | 21.5 | O |
| OD\_MAX\_PRED\_EIGMAJ | The resulting maximum **predicted** major eigenvalue of the 1𝜎 positional error ellipsoid over the entire TIME\_SPAN of the OCM, stemming from this OD. | m |  | 21.5 | O |
| OD\_MIN\_PRED\_EIGMIN | The resulting minimum **predicted** minor eigenvalue of the 1𝜎 positional error ellipsoid over the entire TIME\_SPAN of the OCM, stemming from this OD. | m |  | 21.5 | O |
| OD\_CONFIDENCE | OD confidence metric, which spans 0 to 100% (useful only for Filter-based OD systems). The OD confidence metric shall be as mutually defined by message exchange participants. | % |  | 95.3 | O |
| GDOP | Generalized Dilution Of Precision for this orbit determination, based on the observability grammian as defined in ANNEX H, References [H-15] and [H-16] and expressed in Informative ANNEX F, Section F4. GDOP provides a rating metric of the observability of the element set from the OD. Alternate GDOP formations may be used as mutually defined by message exchange participants. |  |  | .857 | O |
| SOLVE\_N | The number of solve-for states in the orbit determination. |  |  | 6 | O |
| SOLVE\_STATES | Free-text comma-delimited description of the state elements solved for in the orbit determination. |  |  | POS[3], VEL[3] | O |
| CONSIDER\_N | The number of consider parameters used in the orbit determination. |  |  | 2 | O |
| CONSIDER\_PARAMS | Free-text comma-delimited description of the consider parameters used in the orbit determination. |  |  | DRAG, SRP | O |
| SEDR | The Specific Energy Dissipation Rate, which is the amount of energy being removed from the object’s orbit by the non-conservative forces. This value is an average calculated during the OD. (See ANNEX F, Section F7 for definition.) | W/kg |  | 4.54570E-05 | O |
| SENSORS\_N | The number of sensors used in the orbit determination. |  |  | 3 | O |
| SENSORS | Free-text comma-delimited description of the sensors used in the orbit determination. |  |  | EGLIN, FYLINGDALES | O |
| WEIGHTED\_RMS | ***(Useful / valid only for Batch OD systems).***  The weighted RMS residual ratio, defined as:  Where yi is the ith observation measurement  is the current estimate of yi,  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 | O |
| 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). 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. |  |  | ANGLE\_1, ANGLE\_2 | O |
| OD\_STOP | End of the orbit determination data section. |  |  | n/a | M |

### OCM Data: User-Defined Parameters

A single 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.

At most, only one User-Defined Parameters section shall appear in an OCM.

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

Table ‑12 : OCM Data: User-Defined Parameters

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Keyword** | **Description** | **Units** | **Examples of Values** | **M/O/C** |
| USER\_START | Start of the User-Defined Parameters data block. |  |  | M |
| COMMENT | Comments (a contiguous set of one or more comment lines may be provided immediately following the USER\_START keyword (see Section 7.8 for formatting rules.)). |  | This is a comment | O |
| 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 |  | USER\_DEFINED\_EARTH\_MODEL = WGS-84 | M |
| USER\_STOP | End of the User-Defined Parameters data block. |  |  | M |

# ORBIT DATA MESSAGE SYNTAX

## Overview

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

## GENERAL

The Orbit Data Messages (OPM, OMM, OEM, and OCM) shall observe the syntax described in 7.3 through 7.8.

## ODM Lines

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

* Header line;
* Metadata line;
* Data line;
* Comment line; or
* Blank line.

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

OCM lines may be of arbitrary length. If exchange between the two parties requires a maximum line length, that limit should be mutually agreed between message exchange partners.

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

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

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

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

## Orbit Data Messages in “keyword = value notation” (i.e., non-XML) and order of assignment statements

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

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

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 Section 5.2.4.)

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 Section 5.2.5.)

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

OCM trajectory state time history data lines shall not use KVN format; rather, the structure of such OCM trajectory state time history data shall be comprised of a contiguous set of lines, with the values on each line separated by at least one white space character, and those values consisting of the time tag followed by the parameters corresponding to the selected orbit set (see TRAJ\_TYPE, Section 6.2.4).

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, OCM covariance time history data shall be comprised of a contiguous set of lines, with the values on each line separated by at least one white space character, and those values consisting of the time tag followed by the covariance matrix corresponding to the selected covariance type (see COV\_TYPE, Section 6.2.6, particularly Sections 6.2.6.10 through 6.2.6.12).

OCM maneuver data lines shall not use KVN format; rather, OCM maneuver data shall be comprised of a contiguous set of lines, the values on each line separated by at least one white space character, and with those values consisting of the specified maneuver parameters (see MAN\_COMPOSITION, Section 6.2.7.11).

The keywords ‘COMMENT’, \*‘\_START’ and \*‘\_STOP’ are exceptions to the KVN syntax assignment.

Only a single ‘keyword = value’ assignment shall be made on a line.

Keywords must be uppercase and must not contain blanks.

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

Any white space immediately preceding or following the ‘equals’ sign shall not be significant.

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

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.

## Values

A non-empty value field must be assigned to each mandatory keyword except for \*‘\_START’ and \*‘\_STOP’ keyword values.

Comments and free-text value fields may be in any case (or mix of case) desired by the user.

Apart from comments and free-text fields, normative text value fields shall be constructed using only exclusively all uppercase or exclusively all lowercase.

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

-2,147,483,648 ≤ x ≤ +2,147,483,647 (i.e., -231 ≤ x ≤ 231-1).

NOTE – The commas in the range of values above are thousands separators and are used only for readability. They should not appear in an actual message.

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.

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

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

1. The sign may be ‘+’ or ‘-’. If the sign is omitted, ‘+’ shall be assumed.
2. The mantissa must be a string of no more than 16 decimal digits with a decimal point (‘.’) in the second position of the ASCII string, separating the integer portion of the mantissa from the fractional part of the mantissa.
3. The character used to denote exponentiation shall be ‘E’ or ‘e’. If the character indicating the exponent and the following exponent are omitted, an exponent value of zero shall be assumed (essentially yielding a fixed-point value).
4. The exponent must be an integer and may have either a ‘+’ or ‘-’ sign (if the sign is omitted, then ‘+’ shall be assumed).
5. The maximum positive floating-point value is approximately 1.798E+308, with 16 significant decimal digits precision. The minimum positive floating-point value is approximately 4.94E-324, with 16 significant decimal digits precision.

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

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.

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 [2], ASCII Time Code A or B.).

NOTE – During a leap second introduction, the value of the two-digit integer seconds (ss) field shall be ‘60’ as specified in Reference [2].

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.

## OCM Vector Data Type

Several OCM keywords may be set to values containing more than one number. Examples include DC\_REF\_DIR and DC\_BODY\_TRIGGER. Such vectors shall be space-delimited and provided serially on a single line following the equals “=” sign, adhering to the requirements for “numeric values” provided in the previous sections.

## Units IN THE ORBIT DATA MESSAGES

### OPM/OMM Units

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

1. there must be at least one blank character between the value and the units text;
2. the units must be enclosed within square brackets (e.g., ‘[km]’);
3. combinations of units shall adhere to requirements listed in Section 1.5.

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]’ shall not appear in an OPM or OMM.

### OEM Units

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.

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.

### OCM Units

#### Apart from trajectory state, covariance and maneuver data lines, units of OCM keyword values shall correspond to the normative “Units” column of the accompanying Keyword Value Tables (i.e., Table 6‑3 through Table 6‑12) for each section definition.

#### NOTE – The units used throughout the OCM are generally a combination of kilometers for distance and seconds for time (e.g., km/s for velocity, km/s\*\*2 for acceleration, and so forth). Mass is in kilograms, and force is in Newtons.

#### The units of orbit time state history data lines, where present, shall adhere to the specified units for trajectory states as provided in the SANA Registry [11] for Orbital Elements (ANNEX B, Section B7).

#### The units of covariance time history data lines, where present, shall adhere to the specified units for covariance data as provided in the SANA Registry [11] for Orbital Elements (ANNEX B, Section B7) and Additional Covariance Representations (ANNEX B, Section B8).

#### The units of maneuver time history data lines, where present, shall adhere to the specified units for maneuver lines as provided in Table 6‑8 and Table 6‑9.

For OCM keywords used to convey multipartite trajectory state, covariance, or maneuver data lines, units may accompany these data lines via the TRAJ\_UNITS, COV\_UNITS, and MAN\_UNITS keywords, respectively. Units shall not be displayed in OCM trajectory state, covariance, or maneuver data lines themselves.

For OCM keywords that are not used to convey multipartite trajectory state, covariance, or maneuver data lines, units may be included as ASCII text after a value in the OCM for documentation purposes and clarity only. If units are displayed, then:

1. there must be at least one blank character between the value and the units text;
2. the units must be enclosed within square brackets (e.g., ‘[m]’);
3. combinations of units shall adhere to requirements listed in Section 1.5.

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) and no units displayed.

## COMMENTS IN THE ORBIT DATA MESSAGES

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 further specifications and information into comments. Static information should be separately shared and/or mutually agreed between message exchange partners outside of the ODM.

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.

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

Comment text may be in any case (or mix of case) desired by the user.

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.

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.

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.

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.

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.

Comments may appear in all logical blocks of the OCM, but only at the positions shown in the defining Tables (generally at the top of each section, following the \*\_START section delimiting keyword).

Extensive comments in an ODM are recommended in cases where that content is germane to the message and changes from message to message.

The following comments should be provided:

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

COMMENT Source: File created by JPL Multi-Mission Navigation Team as part

COMMENT of Launch Operations Readiness Test held on 20 April 2001.

1. 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.

1. 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, considering 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).

## ORBIT DATA MESSAGE KEYWORDS

### 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). The specific OPM, OMM, OEM, and OCM version numbers to be used should be mutually agreed between message exchange partners. 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, 11/2009 |
| CCSDS\_OPM\_VERS | 3.0 | Blue Book 3.0 (this document) |
| CCSDS\_OMM\_VERS | 2.0 | Silver Book 2.0, 11/2009 |
| 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, 11/2009 |
| CCSDS\_OEM\_VERS | 3.0 | Blue Book 3.0 (this document) |
| CCSDS\_OCM\_VERS | 3.0 | Blue Book 3.0 (this document) |

### GENERAL KEYWORDS

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.

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.

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.

Only those keywords shown in tables Table 6‑3, Table 6‑4, Table 6‑5, Table 6‑6, Table 6‑7, Table 6‑8, Table 6‑9, Table 6‑10, Table 6‑11, and Table 6‑12 shall be used in an OCM. Some keywords represent mandatory items, and some are optional. KVN assignments representing optional items may be omitted.

## Validation and Ingest of KVN content via Regular Expressions (or “Regex”)

### Benefits of using Regular Expressions with the ODM

#### Unlike the schema validation feature native to XML versions of this message as described in Section 8, the KVN version of this message does not natively support such validations of KVN content. To accomplish validation and ingest of KVN versions of the ODM, the use of Regular Expressions (referred to as “Regex”) is strongly encouraged where possible. Most programming languages support the Regex feature, and Regex offers a detailed and rigorous way to ensure proper validation, interpretation and conformance to Orbit Data Message content.

### Sample Regular Expressions for CCSDS Messages

To facilitate the use of Regular Expressions when processing CCSDS Navigation Messages, Informative ANNEX F, Section F6 provides sample Regex patterns to rigorously match a variety of common KVN sequences.

# constructing an ODM/XML instance

## Overview

This section provides detailed instructions for the user on how to create an Extensible Markup Language message (XML, Reference [5]) based on one of the KVN-formatted messages described in Section 3, Section 4, Section 5, and Section 6. This section applies only to the XML representation of ODMs.

Overall information on using XML for Navigation Data Messages is provided in [5]. The ODM/XML schemas are available on the SANA Web site. SANA is the registrar for the protocol registries created under CCSDS. The ODM/XML schemas explicitly define the permitted data elements and values acceptable for the XML versions of the ODMs. The location of the ODM/XML schemas is:

OPM: https://sanaregistry.org/files/ndmxml\_unqualified/ndmxml-3.0.0-opm-3.0.xsd

OMM: https://sanaregistry.org/files/ndmxml\_unqualified/ndmxml-3.0.0-omm-3.0.xsd

OEM: https://sanaregistry.org/files/ndmxml\_unqualified/ndmxml-3.0.0-oem-3.0.xsd

OCM: https://sanaregistry.org/files/ndmxml\_unqualified/ndmxml-3.0.0-ocm-3.0.xsd

Figure 8‑1 illustrates the basic structure of an ODM/XML instance. Defined structural elements are the header and body. The body then consists of one or more segments depending on the message type (one for the OPM, OMM, and OCM; one or more for the OEM). Each segment consists of a <metadata>/<data> pair. In an OEM, which could have more than one segment, the metadata/data pair is repeated in each segment.

|  |
| --- |
| <header>  </header>  <body>  <segment>  <metadata>  </metadata>  <data>  </data>  </segment>  </body> |

**Figure 8‑1: ODM/XML Basic Structure**

ODM/XML tags for keywords defined in in Section 3, Section 4, Section 5, and Section 6 appear just as in the KVN, i.e., all capital letters. Tags related to the XML message structure (i.e., that do not correspond directly to a KVN keyword) appear in ‘lowerCamelCase’ (e.g., <header>, <segment>, <metadata>, <stateVector>, <covarianceMatrix>, etc.).

## XML VERSION

This section describes the Extensible Markup Language (or XML) version of the Orbit Data Message. The first line of each XML instantiation shall specify the XML version:

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

This line must appear on the first line of each instantiation, exactly as shown.

## BEGINNING THE INSTANTIATION: ROOT ELEMENT TAG

* + 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.
    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 |

* + 1. 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=<https://sanaregistry.org/r/ndmxml_unqualified/ndmxml-3.0.0-master-3.0.xsd>

and

xsi:noNamespaceSchemaLocation=<https://sanaregistry.org/r/ndmxml_qualified/ndmxml-3.0.0-master-3.0.xsd>

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

* + 1. For use in a local operations environment, the schema set may be downloaded from the SANA website to a local server that meets local requirements for operations robustness.
    2. 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.
    3. 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. The final attributes of the root element tag shall be 'id' and 'version'.
    4. The CCSDS\_xxx\_VERS keyword shall be supplied via the ‘id’ attribute of the root element tag. The id’ attribute shall be 'id="CCSDS\_xxx\_VERS"', where xxx = OPM, OMM, OEM, or OCM.
    5. The version number of the Blue Book to which the schema applies shall be supplied via the ‘version’ attribute. The ‘version’ attribute shall be 'version="3.0"'.

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

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

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

xsi:noNamespaceSchemaLocation="https://sanaregistry.org/r/ndmxml\_unqualified/ndmxml-3.0.0-master-3.0.xsd"

id="CCSDS\_OPM\_VERS" version="3.0">

and

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

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

xsi:noNamespaceSchemaLocation="https://sanaregistry.org/r/ndmxml\_qualified/ndmxml-3.0.0-master-3.0.xsd"

id="CCSDS\_OPM\_VERS" version="3.0">

## The STANDARD ODM/XML Header SECTION

* + 1. The ODMs shall share a standard header section, with tags <header> and </header>.
    2. Immediately following the <header> tag the message may have any number of <COMMENT> elements.
    3. The standard ODM header shall contain the <CREATION\_DATE> and the <ORIGINATOR> elements.
    4. The standard ODM header may contain the <MESSAGE\_ID> element.

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>

<MESSAGE\_ID>XYZ123-2019</MESSAGE\_ID>

</header>

## The ODM/XML BODY section

* + 1. After coding the <header>, the instantiation must include a <body> section.
    2. Inside the <body> section must appear at least one <segment> section.
    3. Each segment must be made up of one or more <metadata> and <data> sections, depending on the specific message type.

## The ODM/XML metadata section

* + 1. All ODMs must have a metadata section.
    2. The metadata section shall be delimited by the <metadata> element.
    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 possible exceptions as noted in the sections below that discuss creating instantiations of the specific messages.

## The ODM/XML data section

* + 1. All ODMs must have a data section.
    2. The data section shall follow the metadata section and shall be delimited by the <data> element.
    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 possible exceptions as noted in the Sections that discuss creating instantiations of the specific messages.

## CREATING AN OPM INSTANTIATION

* + 1. An OPM instantiation shall be delimited with the <opm></opm> root element tags using the standard attributes documented in Section 8.3.
    2. The final attributes of the <opm> tag shall be ‘id’ and ‘version’.
    3. The ‘id’ attribute shall be ‘id="CCSDS\_OPM\_VERS"’.
    4. The ‘version’ attribute shall be ‘version="3.0"’.
    5. The standard NDM header shall follow the <opm> tag (see Section 0).
    6. The OPM <body> shall consist of a single <segment>.
    7. The <segment> shall consist of a <metadata> section and a <data> section.
    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.
    9. Tags for keywords specified in Section 3 shall be all uppercase.
    10. Several of the OPM/XML keywords may have the units attribute.
    11. In all cases, the units shall match those defined in the tables in Section 3.
    12. Table 8‑2 lists examples of the use of units in the OPM/XML.

Table 8‑2 : Examples of units in OPM/XML

| **Keyword** | **Units** | **Example** |
| --- | --- | --- |
| INCLINATION | deg | <INCLINATION units="deg">numeric-value</INCLINATION> |
| MASS | kg | <MASS units="kg">numeric-value</MASS> |
| X | km | <X units="km">numeric-value</X> |
| CX\_X | km\*\*2 | <CX\_X units="km\*\*2">numeric-value</CX\_X> |
| CX\_DOT\_X | km\*\*2/s | <CX\_DOT\_X units="km\*\*2/s">numeric-value</CX\_DOT\_X> |
| CX\_DOT\_X\_DOT, | km\*\*2/s\*\*2 | <CX\_DOT\_X\_DOT units="km\*\*2/s\*\*2">numeric-value</CX\_DOT\_X\_DOT> |
| GM | km\*\*3/s\*\*2 | <GM units="km\*\*3/s\*\*2">numeric-value</GM> |
| X\_DOT | km/s | <X\_DOT units="km/s">numeric-value</X\_DOT> |
| MAN\_DV\_1 | km/s | <MAN\_DV\_1 units="km/s">numeric-value</MAN\_DV\_1> |
| SOLAR\_RAD\_AREA | m\*\*2 | <SOLAR\_RAD\_AREA units="m\*\*2">numeric-value</SOLAR\_RAD\_AREA> |
| MAN\_DURATION | s | <MAN\_DURATION units="s">numeric-value</MAN\_DURATION> |

* + 1. 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 Sections. 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.
    2. The OPM/XML tags used to delimit the logical blocks of the OPM shall be drawn from Table 8‑3.

Table 8‑3 : OPM/XML tag delimiters

|  |  |
| --- | --- |
| **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> |

* + 1. Between the begin tag and end tag (i.e., between <spacecraftParameters> and </spacecraftParameters>), the user shall place the keywords required by the Spacecraft Parameters logical block as specified in Table 3‑3 of Section 3.

## CREATING AN OMM INSTANTIATION

* + 1. An OMM instantiation shall be delimited with the <omm></omm> root element tags using the standard attributes documented in Section 8.3.
    2. The final attributes of the <omm> tag shall be ‘id’ and ‘version’.
    3. The ‘id’ attribute shall be ‘id="CCSDS\_OMM\_VERS"’.
    4. The ‘version’ attribute for the version of the OMM described in Section 4 shall be ‘version="3.0"’.
    5. The standard NDM header shall follow the <omm> tag (see Section 0).
    6. The OMM <body> shall consist of a single <segment>.
    7. The <segment> shall consist of a <metadata> section and a <data> section.
    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.
    9. Tags for keywords specified in Section 4 shall be all uppercase.
    10. Several of the OMM/XML keywords may have the unit attribute.
    11. In all cases, the units shall match those defined in the tables in Section 4.
    12. Table 8‑4 lists examples of the use of units in the OMM/XML.

Table 8‑4 : Examples of units in OMM/XML

| **Keyword** | **Units** | **Example** |
| --- | --- | --- |
| BSTAR | 1/ER | <BSTAR units="1/ER">numeric-value</BSTAR> |
| INCLINATION | deg | <INCLINATION units="deg">numeric-value</INCLINATION> |
| MASS | kg | <MASS units="kg">numeric-value</MASS> |
| SEMI\_MAJOR\_AXIS | km | <SEMI\_MAJOR\_AXIS units="km">numeric-value</SEMI\_MAJOR\_AXIS> |
| CX\_X | km\*\*2 | <CX\_X units="km\*\*2">numeric-value</CX\_X> |
| CX\_DOT\_X | km\*\*2/s | <CX\_DOT\_X units="km\*\*2/s">numeric-value</CX\_DOT\_X> |
| CX\_DOT\_X\_DOT | km\*\*2/s\*\*2 | <CX\_DOT\_X\_DOT units="km\*\*2/s\*\*2">numeric-value</CX\_DOT\_X\_DOT> |
| GM | km\*\*3/s\*\*2 | <GM units="km\*\*3/s\*\*2">numeric-value</GM> |
| SOLAR\_RAD\_AREA | m\*\*2 | <SOLAR\_RAD\_AREA units="m\*\*2">numeric-value</SOLAR\_RAD\_AREA> |
| MEAN\_MOTION | rev/day | <MEAN\_MOTION units="rev/day">numeric-value</MEAN\_MOTION> |
| MEAN\_MOTION\_DOT | rev/day\*\*2 | <MEAN\_MOTION\_DOT units="rev/day\*\*2">numeric-value</MEAN\_MOTION\_DOT> |

* + 1. 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 sections. 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.
    2. The OMM/XML tags used to delimit the logical blocks of the OMM shall be drawn from Table 8‑5:

Table 8‑5 : OMM/XML tag delimiters

|  |  |
| --- | --- |
| **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> |

* + 1. Between the begin tag and end tag (i.e., between <spacecraftParameters> and </spacecraftParameters>), the user must place the keywords required by the Spacecraft Parameters logical block as specified in Table 4‑3 of Section 4.

## CREATING AN OEM INSTANTIATION

* + 1. An OEM instantiation shall be delimited with the <oem></oem> root element tags using the standard attributes documented in Section 8.3.
    2. The final attributes of the <oem> tag shall be ‘id’ and ‘version’.
    3. The ‘id’ attribute shall be ‘id="CCSDS\_OEM\_VERS"’.
    4. The ‘version’ attribute for the version of the OEM described in Section 5 shall be ‘version="3.0"’.
    5. The standard NDM header shall follow the <oem> tag (see Section 0).
    6. The OEM <body> shall consist of one or more <segment> constructs.
    7. Each <segment> shall consist of a <metadata> section and a <data> section.
    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/KVN in Section 5.
    9. Tags for keywords specified in Section 5 shall be all uppercase.
    10. Several of the OEM/XML keywords may have the unit attribute.
    11. In all cases, the units shall match those defined in Section 5.
    12. 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 sections.
    13. The <stateVector> tag shall encapsulate the keywords associated with one of the ephemeris data lines in the OEM.
    14. In the XML representation of the OEM, the components of the <stateVector> ephemeris data line must be represented with keywords (i.e., a tag).
    15. The <stateVector> keywords shall be the same as those defined for the same construct in the OPM.
    16. The OEM/XML tags used within the <stateVector> structure shall be drawn from Table 8‑6.

Table 8‑6 : Examples of units in OEM/XML

|  |  |  |
| --- | --- | --- |
| **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> |

* + 1. 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.
    2. 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.
    3. The <covarianceMatrix> tag shall encapsulate the keywords associated with the covariance matrix lines in the OEM.
    4. In the XML representation of the OEM, the covariance data line must be represented with keywords (i.e., a tag).
    5. 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.

* + 1. 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.
    2. The OEM/XML tags used within the <covarianceMatrix> structure shall be drawn from Table 8‑7.

Table 8‑7 : OEM/XML tag delimiters

| **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> |

* + 1. 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 5.2.5.4 and Table 5‑4 of Section 5.

## CREATING AN OCM INSTANTIATION

* + 1. An OCM instantiation shall be delimited with the <ocm></ocm> root element tags using the standard attributes documented in 8.3.
    2. The final attributes of the <ocm> tag shall be ‘id’ and ‘version’.
    3. The ‘id’ attribute shall be ‘id="CCSDS\_OCM\_VERS"’.
    4. The ‘version’ attribute for the version of the OCM described in Section 6 shall be ‘version="3.0"’.
    5. The standard NDM header shall follow the <ocm> tag (see Section 0).
    6. The OCM <body> shall consist of a single <segment> construct.
    7. The <segment> shall consist of a <metadata> section and a <data> section.
    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.
    9. Tags for keywords specified in Section 6 shall be all uppercase.
    10. Several of the OCM/XML keywords may have the unit attribute.
    11. In all cases, the units shall match those defined in the SANA Registry (detailed in ANNEX B) and tables in Section 6, including orbit, covariance and maneuver data units as specified by TRAJ\_UNITS, COV\_UNITS, and MAN\_UNITS, respectively.
    12. Table 8‑8 lists examples of the use of units in the OCM/XML.

Table 8‑8 : Examples of units in OCM/XML

| **Keyword** | **Units** | **Example** |
| --- | --- | --- |
| ACTUAL\_OD\_SPAN | d | <ACTUAL\_OD\_SPAN units="d">numeric-value</ACTUAL\_OD\_SPAN> |
| DC\_PA\_START\_ANGLE | deg | <DC\_PA\_START\_ANGLE units="deg">numeric-value</DC\_PA\_START\_ANGLE> |
| CENTRAL\_BODY\_ROTATION | deg/s | <CENTRAL\_BODY\_ROTATION units="deg/s">numeric-value</CENTRAL\_BODY\_ROTATION> |
| WET\_MASS | kg | <MASS units="kg">numeric-value</WET\_MASS> |
| IXX | kg\*m\*\*2 | <IXX units="kg\*m\*\*2">numeric-value</IXX> |
| EQUATORIAL\_RADIUS | km | <EQUATORIAL\_RADIUS units="km">numeric-value</EQUATORIAL\_RADIUS> |
| GM | km\*\*3/s\*\*2 | <GM units="km\*\*3/s\*\*2">numeric-value</GM> |
| DV\_BOL | km/s | <DV\_BOL units="km/s">numeric-value</DV\_BOL> |
| OEB\_MAX | m | <OEB\_MAX units="m">numeric-value</OEB\_MAX> |
| DRAG\_CONST\_AREA | m\*\*2 | <DRAG\_CONST\_AREA units="m\*\*2">numeric-value</DRAG\_CONST\_AREA> |
| MAX\_THRUST | N | <MAX\_THRUST units="N">numeric-value</MAX\_THRUST> |
| FIXED\_GEOMAG\_KP | nT | <FIXED\_GEOMAG\_KP units="nT">numeric-value</FIXED\_GEOMAG\_KP> |
| UT1MUTC\_AT\_TZERO | s | <UT1MUTC\_AT\_TZERO units="s">numeric-value</UT1MUTC\_AT\_TZERO> |
| FIXED\_F10P7 | SFU | <FIXED\_F10P7 units="SFU">numeric-value</FIXED\_F10P7> |
| DRAG\_UNCERTAINTY | % | <DRAG\_UNCERTAINTY units="%">numeric-value</DRAG\_UNCERTAINTY> |

* + 1. In addition to the OCM keywords specified in Section 6, there are some special tags associated with the OCM body as listed in Table 8‑9 described in the next sections.

Table 8‑9 : OCM/XML tag delimiters

|  |  |  |
| --- | --- | --- |
| OCM Logical Block | ODM/XML OCM Section Tags | Data Line Tag |
| Trajectory Data | <traj> | <trajLine> |
| Space Object Physical Characteristics | <phys> | N/A |
| Covariance Data | <covar> | <covLine> |
| Maneuver Data | <man> | <manLine> |
| Perturbations Parameters | <pert> | N/A |
| Orbit Determination Data | <od> | N/A |
| User-Defined Parameters | <userDef> | N/A |

* + 1. Between the begin tag and end tag (e.g., between <traj> and </traj>), the user must place the keywords required by the specific OCM section as specified in e.g., Table 6‑4 of Section 6.
    2. The data type of the <trajLine>, <covLine>, and <manLine> elements is "xsd:string", i.e., there is no validation of the contents and the line must be parsed by the OCM recipient to access the individual components of the trajectory, covariance, or maneuver data line.
    3. The number of individual components in the multipartite <trajLine> shall be determined by the number of components in the value for the TRAJ\_TYPE keyword, plus one for the timetag.
    4. The number of individual components in the single multipartite <covLine> shall be 13 if COV\_TYPE=SIG3EIGVEC3 is selected, or 14 if COV\_TYPE=TSIG3EIGVEC3 is selected. Otherwise, if "N" is the dimension of the covariance matrix, then the number of individual components in the single multipartite <covLine> shall either be 1 + (N\*\*2+N)/2 corresponding to the Lower or Upper Triangular Matrix formats plus one for the timetag, or 1 + N\*\*2 for the Full Matrix format plus one for the timetag.
    5. The number of individual components in the multipartite <manLine> shall be determined by the number of comma-separated values in the MAN\_COMPOSITION keyword, plus one for the timetag.

## CREATING A combined INSTANTIATION

An ODM user may create an XML instance that incorporates any number of messages from Sections 3 through 6 of this document in a logical suite called an ‘NDM (Navigation Data Message) Combined Instantiation’. Such combined instantiations may be useful for some situations, for example:

* A maneuver scenario where both "no burn" ephemeris and "with burn" ephemeris are combined in a single message.
* A constellation scenario where states (OPM, OMM) and/or ephemeris data (OEM, OCM) for all the spacecraft in the constellation are combined in a single XML message.
* A full OEM or OCM ephemeris with detail on important states reflected in some number of OPMs. The OEM/OCM and the multiple OPMs can be conveniently conveyed in a single NDM.

An NDM combined instantiation shall be delimited with the <ndm></ndm> root element tags instead of one of the individual message tags described in Section 8.3.2.

The standard attributes documented in 8.3 shall be used with the <ndm> tag, with the exception that neither ‘id’ nor ‘version’ attributes are associated with the <ndm> tag.

In the NDM combined instantiation, the only attributes that shall appear on the constituent message tags (i.e., the tags listed in 8.3.2) are the ‘id’ and ‘version’ attributes.

Between the <ndm></ndm> tags, the desired messages described in Sections8.8 through 8.11 may be combined as needed to meet user requirements.

Any combination of constituent ODM types may be used in an NDM combined instantiation.

**Figure 8‑2** and Figure 8‑3illustrate the basic structure of an NDM combined instantiation. All detail has been removed from **Figure 8‑1** to contrast the single message ODM with an NDM combined instantiation. As shown in Figure 8‑2, in an NDM combined instantiation the individual message tags still have the ‘id’ and ‘version’ attributes, but the namespace attributes and schema location attributes are associated with the <ndm> root element.

|  |  |
| --- | --- |
| **Single Message OPM** | **NDM Combined Instantiation** |
| <opm>  <header>  </header>  <body>  </body>  </opm> | <ndm>  <opm>  <header>  </header>  <body>  </body>  </opm>  .  .  .  <opm>  <header>  </header>  <body>  </body>  </opm>  </ndm> |

Figure 8‑2: Comparison of Single Message OPM with NDM Combined Instantiation

The OPMs shown in Figure 8‑2 may be replaced with any number of OMM, OEM, or OCM messages in any combination as needed to meet user requirements, as shown in Figure 8‑3 below.

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

<ndm xmlns: xsi:noNamespaceSchemaLocation=<https://sanaregistry.org/r/ndmxml_unqualified/ndmxml-3.0.0-master-3.0.xsd>>

<COMMENT>This figure combines multiple ODM/XML messages into a single message</COMMENT>

<COMMENT>Message detail is deleted in order to focus on the message structure</COMMENT>

<COMMENT>Note use of "<ndm>" root element, and ODM/version attributes</COMMENT>

<opm id="CCSDS\_OPM\_VERS" version="3.0">

<header>

</header>

<body>

</body>

</opm>

<oem id="CCSDS\_OEM\_VERS" version="3.0">

<header>

</header>

<body>

</body>

</oem>

<opm id="CCSDS\_OPM\_VERS" version="3.0">

<header>

</header>

<body>

</body>

</opm>

<omm id="CCSDS\_OMM\_VERS" version="3.0">

<header>

</header>

<body>

</body>

</omm>

<ocm id="CCSDS\_OCM\_VERS" version="3.0">

<header>

</header>

<body>

</body>

</ocm>

</ndm>

Figure 8‑3: NDM Combined Instantiation Showing Mix of ODMs and Use of Attributes

NOTE – See Fig. G‑21 for a full example of a use case combining multiple ODMs in a single XML message. For instructions on creating a combined instantiation that incorporates ODM/XML messages combined with other navigation related messages, see Reference [5].

## SPECIAL SYNTAX RULES FOR ODM/XML

Most of the KVN syntax rules apply for ODM/XML instantiations of an ODM, however, there are a few variations described in this section that shall be observed.

Each mandatory XML tag must be present and contain a valid value.

Integer values shall follow the conventions of the integer data type per Reference [6]. Additional restrictions on the allowable range of values permitted for any integer data element may also be defined in the ODM/XML Schema.

NOTE: Examples of such restrictions may include a defined range (e.g., 0 - 100, 1 - 10, etc.), a set of enumerated values (e.g., 0,1,2,4,8), a pre-defined specific variation such as positiveInteger, or a user-defined data type variation.

Non-integer numeric values may be expressed in either fixed-point or floating-point notation. Numeric values shall follow the conventions of the double data type per Reference [6]. Additional restrictions on the allowable range of values permitted for any numeric data element may also be defined in the ODM/XML Schema.

NOTE: Examples of such restrictions may include a defined range (e.g., 0.0-100.0, etc.), or a user-defined data type variation.

Text values shall follow the conventions of the string data type per Reference [6]. Additional restrictions on the allowable range or values permitted for any data element may also be defined in the ODM/XML Schema.

NOTE: Examples of such restrictions may include a set of enumerated values (e.g., ‘YES’/‘NO’) or other user-defined data type variation.

The units in the ODM/XML shall be the same units used in the KVN-formatted ODM described in Section 7.7, or as mandated in the SANA registry per ANNEX B. XML attributes shall be used to explicitly define the units or other important information associated with the given data element. See the tables in this section for the OPM, OMM, OEM, and OCM for examples of coding units in ODM/XML instantiations.

Comments must be displayed as values between the <COMMENT> and </COMMENT> tags.

1. IMPLEMENTATION CONFORMANCE  
     
    STATEMENT (ICS) PRO FORMA  
     
   (NORMATIVE)
   1. INTRODUCTION
      1. OVERVIEW

This annex provides the Implementation Conformance Statement (ICS) Requirements List (RL) for an implementation of the Orbit Data Messages (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.
    1. 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.

* + 1. 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.

* 1. ICS PROFORMA FOR Orbit DATA MESSAGES
     1. Identification of ICS

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

* + 1. Identification of Implementation Under Test (IUT )

|  |  |
| --- | --- |
| Implementation name |  |
| Implementation version |  |
| Special Configuration |  |
| Other Information |  |

* + 1. 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) |  |

* + 1. Document versions

|  |  |
| --- | --- |
| CCSDS 502.0 Document Version | 3 |
| 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\_\_\_\_\_ |

* + 1. Requirements lists

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

* + 1. ORBIT PARAMETER MESSAGE Requirements list

Note to Tom Gannett: these sections should probably be A2.5.1 etc. (Annex level three) but the line type is not defined and I'm not confident I know how to do that.

Note 2 to Tom Gannett: Would it be okay to highlight in BLUE or otherwise denote (with a bolder row-wise border) the separate data blocks as I’ve done below?

| Item | Feature | Keyword | Reference | Status M/O/C | Support |
| --- | --- | --- | --- | --- | --- |
| 1 | OPM Header | N/A | Table 3-1 | M |  |
| 2 | OPM Version | CCSDS\_OPM\_VERS | Table 3-1 | M |  |
| 3 | Comment | COMMENT | Table 3-1 | O |  |
| 4 | Message creation date and time | CREATION\_DATE | Table 3-1 | M |  |
| 5 | Message originator | ORIGINATOR | Table 3-1 | M |  |
| 6 | Unique message identifier | MESSAGE\_ID | Table 3-1 | O |  |
| 7 | OPM Metadata | N/A | Table 3-2 | M |  |
| 8 | Comment | COMMENT | Table 3-2 | O |  |
| 9 | Name of space object | OBJECT\_NAME | Table 3-2 | M |  |
| 10 | Identifier of space object | OBJECT\_ID | Table 3-2 | M |  |
| 11 | Orbit center | CENTER\_NAME | Table 3-2 | M |  |
| 12 | Reference frame | REF\_FRAME | Table 3-2 | M |  |
| 13 | Epoch of reference frame | REF\_FRAME\_EPOCH | Table 3-2 | C |  |
| 14 | Time system applicable to data | TIME\_SYSTEM | Table 3-2 | M |  |
| 15 | OPM Data | N/A | Table 3-3 | M |  |
| 16 | State Vector logical block | N/A | Table 3-3 | M |  |
| 17 | Comment | COMMENT | Table 3-3 | O |  |
| 18 | Epoch of the state vector | EPOCH | Table 3-3 | M |  |
| 19 | X component of position | X | Table 3-3 | M |  |
| 20 | Y component of position | Y | Table 3-3 | M |  |
| 21 | Z component of position | Z | Table 3-3 | M |  |
| 22 | X component of velocity | X\_DOT | Table 3-3 | M |  |
| 23 | Y component of velocity | Y\_DOT | Table 3-3 | M |  |
| 24 | Z component of velocity | Z\_DOT | Table 3-3 | M |  |
| 25 | Keplerian Elements logical block | N/A | Table 3-3 | O |  |
| 26 | Comment | COMMENT | Table 3-3 | O |  |
| 27 | Semi-major axis of orbit | SEMI\_MAJOR\_AXIS | Table 3-3 | C |  |
| 28 | Eccentricity of orbit | ECCENTRICITY | Table 3-3 | C |  |
| 29 | Inclination of orbit | INCLINATION | Table 3-3 | C |  |
| 30 | Right ascension of ascending node of orbit | RA\_OF\_ASC\_NODE | Table 3-3 | C |  |
| 31 | Argument of pericenter of orbit | ARG\_OF\_PERICENTER | Table 3-3 | C |  |
| 32 | True or mean anomaly of orbit | TRUE\_ANOMALY or MEAN\_ANOMALY | Table 3-3 | C |  |
| 33 | Gravitational coefficient of the central body | GM | Table 3-3 | C |  |
| 34 | Spacecraft Parameters logical block | N/A | Table 3-3 | O |  |
| 35 | Comment | COMMENT | Table 3-3 | O |  |
| 36 | Mass of the spacecraft | MASS | Table 3-3 | C |  |
| 37 | Solar radiation area of the spacecraft | SOLAR\_RAD\_AREA | Table 3-3 | C |  |
| 38 | Solar radiation coefficient of the spacecraft | SOLAR\_RAD\_COEFF | Table 3-3 | C |  |
| 39 | Drag area of the spacecraft | DRAG\_AREA | Table 3-3 | C |  |
| 40 | Drag coefficient of the spacecraft | DRAG\_COEFF | Table 3-3 | C |  |
| 41 | Position/velocity Covariance Matrix logical block | N/A | Table 3-3 | O |  |
| 42 | Comment | COMMENT | Table 3-3 | O |  |
| 43 | Cov reference frame | COV\_REF\_FRAME | Table 3-3 | C |  |
| 44 | Covariance matrix [1,1] | CX\_X | Table 3-3 | C |  |
| 45 | Covariance matrix [2,1] | CY\_X | Table 3-3 | C |  |
| 46 | Covariance matrix [2,2] | CY\_Y | Table 3-3 | C |  |
| 47 | Covariance matrix [3,1] | CZ\_X | Table 3-3 | C |  |
| 48 | Covariance matrix [3,2] | CZ\_Y | Table 3-3 | C |  |
| 49 | Covariance matrix [3,3] | CZ\_Z | Table 3-3 | C |  |
| 50 | Covariance matrix [4,1] | CX\_DOT\_X | Table 3-3 | C |  |
| 51 | Covariance matrix [4,2] | CX\_DOT\_Y | Table 3-3 | C |  |
| 52 | Covariance matrix [4,3] | CX\_DOT\_Z | Table 3-3 | C |  |
| 53 | Covariance matrix [4,4] | CX\_DOT\_X\_DOT | Table 3-3 | C |  |
| 54 | Covariance matrix [5,1] | CY\_DOT\_X | Table 3-3 | C |  |
| 55 | Covariance matrix [5,2] | CY\_DOT\_Y | Table 3-3 | C |  |
| 56 | Covariance matrix [5,3] | CY\_DOT\_Z | Table 3-3 | C |  |
| 57 | Covariance matrix [5,4] | CY\_DOT\_X\_DOT | Table 3-3 | C |  |
| 58 | Covariance matrix [5,5] | CY\_DOT\_Y\_DOT | Table 3-3 | C |  |
| 59 | Covariance matrix [6,1] | CZ\_DOT\_X | Table 3-3 | C |  |
| 60 | Covariance matrix [6,2] | CZ\_DOT\_Y | Table 3-3 | C |  |
| 61 | Covariance matrix [6,3] | CZ\_DOT\_Z | Table 3-3 | C |  |
| 62 | Covariance matrix [6,4] | CZ\_DOT\_X\_DOT | Table 3-3 | C |  |
| 63 | Covariance matrix [6,5] | CZ\_DOT\_Y\_DOT | Table 3-3 | C |  |
| 64 | Covariance matrix [6,6] | CZ\_DOT\_Z\_DOT | Table 3-3 | C |  |
| 65 | Maneuver Parameters logical block | N/A | Table 3-3 | O |  |
| 66 | Comment | COMMENT | Table 3-3 | O |  |
| 67 | Time of maneuver start | MAN\_EPOCH\_IGNITION | Table 3-3 | O |  |
| 68 | Duration of maneuver | MAN\_DURATION | Table 3-3 | O |  |
| 69 | Change of mass due to maneuver | MAN\_DELTA\_MASS | Table 3-3 | O |  |
| 70 | Relevant reference frame for maneuver | MAN\_REF\_FRAME | Table 3-3 | O |  |
| 71 | 1st component of velocity change | MAN\_DV\_1 | Table 3-3 | O |  |
| 72 | 2nd component of velocity change | MAN\_DV\_2 | Table 3-3 | O |  |
| 73 | 3rd component of velocity change | MAN\_DV\_3 | Table 3-3 | O |  |
| 74 | User-Defined Parameters logical block | N/A | Table 3-3 | O |  |
| 75 | As defined by user, "essential information that cannot be conveyed in COMMENT statements" | USER\_DEFINED\_x | Table 3-3 | O |  |

* + 1. ORBIT MEAN ELEMENTS MESSAGE Requirements list

| Item | Feature | Keyword | Reference | Status M/O/C | Support |
| --- | --- | --- | --- | --- | --- |
| 1 | OMM Header | N/A | Table 4-1 | M |  |
| 2 | OMM Version | CCSDS\_OMM\_VERS | Table 4-1 | M |  |
| 3 | Comment | COMMENT | Table 4-1 | O |  |
| 4 | Message creation date and time | CREATION\_DATE | Table 4-1 | M |  |
| 5 | Message originator | ORIGINATOR | Table 4-1 | M |  |
| 6 | Unique message identifier | MESSAGE\_ID | Table 4-1 | O |  |
| 7 | OMM Metadata | N/A | Table 4-2 | M |  |
| 8 | Comment | COMMENT | Table 4-2 | O |  |
| 9 | Name of space object | OBJECT\_NAME | Table 4-2 | M |  |
| 10 | Identifier of space object | OBJECT\_ID | Table 4-2 | M |  |
| 11 | Orbit center | CENTER\_NAME | Table 4-2 | M |  |
| 12 | Reference frame | REF\_FRAME | Table 4-2 | M |  |
| 13 | Epoch of reference frame | REF\_FRAME\_EPOCH | Table 4-2 | C |  |
| 14 | Time system applicable to data | TIME\_SYSTEM | Table 4-2 | M |  |
| 15 | Mean element set theory of data | MEAN\_ELEMENT\_THEORY | Table 4-2 | M |  |
| 16 | OMM Data | N/A | Table 4-3 | M |  |
| 17 | Mean Keplerian elements logical block | N/A | Table 4-3 | M |  |
| 18 | Comment | COMMENT | Table 4-3 | O |  |
| 19 | Epoch of the orbital elements | EPOCH | Table 4-3 | M |  |
| 20 | Semi-major axis or mean motion | SEMI\_MAJOR\_AXIS or MEAN\_MOTION | Table 4-3 | M |  |
| 21 | Eccentricity | ECCENTRICITY | Table 4-3 | M |  |
| 22 | Inclination | INCLINATION | Table 4-3 | M |  |
| 23 | Right ascension of ascending node | RA\_OF\_ASC\_NODE | Table 4-3 | M |  |
| 24 | Argument of pericenter | ARG\_OF\_PERICENTER | Table 4-3 | M |  |
| 25 | Mean anomaly | MEAN\_ANOMALY | Table 4-3 | M |  |
| 26 | Gravitational Coefficient | GM | Table 4-3 | O |  |
| 27 | Spacecraft Parameters logical block | N/A | Table 4-3 | O |  |
| 28 | Comment | COMMENT | Table 4-3 | O |  |
| 29 | Spacecraft Mass | MASS | Table 4-3 | O |  |
| 30 | Solar Radiation Pressure Area | SOLAR\_RAD\_AREA | Table 4-3 | O |  |
| 31 | Solar Radiation Pressure Coefficient | SOLAR\_RAD\_COEFF | Table 4-3 | O |  |
| 32 | Drag Area | DRAG\_AREA | Table 4-3 | O |  |
| 33 | Drag Coefficient | DRAG\_COEFF | Table 4-3 | O |  |
| 34 | TLE logical block | N/A | Table 4-3 | O |  |
| 35 | Comment | COMMENT | Table 4-3 | O |  |
| 36 | Ephemeris Type | EPHEMERIS\_TYPE | Table 4-3 | O |  |
| 37 | Classification Type | CLASSIFICATION\_TYPE | Table 4-3 | O |  |
| 38 | NORAD Catalog Number | NORAD\_CAT\_ID | Table 4-3 | O |  |
| 39 | Element set number | ELEMENT\_SET\_NO | Table 4-3 | O |  |
| 40 | Revolution Number | REV\_AT\_EPOCH | Table 4-3 | O |  |
| 41 | SGP/SGP4 drag-like coefficient | BSTAR | Table 4-3 | O |  |
| 42 | First Time Derivative of the Mean Motion | MEAN\_MOTION\_DOT | Table 4-3 | O |  |
| 43 | Second Time Derivative of Mean Motion | MEAN\_MOTION\_DDOT | Table 4-3 | O |  |
| 44 | Pos/Vel/Cov logical block |  | Table 4-3 | O |  |
| 45 | Comment | COMMENT | Table 4-3 | O |  |
| 46 | Cov reference frame | COV\_REF\_FRAME | Table 4-3 | C |  |
| 47 | Covariance[1,1] | CX\_X | Table 4-3 | C |  |
| 48 | Covariance[2,1] | CY\_X | Table 4-3 | C |  |
| 49 | Covariance[2,2] | CY\_Y | Table 4-3 | C |  |
| 50 | Covariance[3,1] | CZ\_X | Table 4-3 | C |  |
| 51 | Covariance[3,2] | CZ\_Y | Table 4-3 | C |  |
| 52 | Covariance[3,3] | CZ\_Z | Table 4-3 | C |  |
| 53 | Covariance[4,1] | CX\_DOT\_X | Table 4-3 | C |  |
| 54 | Covariance[4,2] | CX\_DOT\_Y | Table 4-3 | C |  |
| 55 | Covariance[4,3] | CX\_DOT\_Z | Table 4-3 | C |  |
| 56 | Covariance[4,4] | CX\_DOT\_X\_DOT | Table 4-3 | C |  |
| 57 | Covariance[5,1] | CY\_DOT\_X | Table 4-3 | C |  |
| 58 | Covariance[5,2] | CY\_DOT\_Y | Table 4-3 | C |  |
| 59 | Covariance[5,3] | CY\_DOT\_Z | Table 4-3 | C |  |
| 60 | Covariance[5,4] | CY\_DOT\_X\_DOT | Table 4-3 | C |  |
| 61 | Covariance[5,5] | CY\_DOT\_Y\_DOT | Table 4-3 | C |  |
| 62 | Covariance[6,1] | CZ\_DOT\_X | Table 4-3 | C |  |
| 63 | Covariance[6,2] | CZ\_DOT\_Y | Table 4-3 | C |  |
| 64 | Covariance[6,3] | CZ\_DOT\_Z | Table 4-3 | C |  |
| 65 | Covariance[6,4] | CZ\_DOT\_X\_DOT | Table 4-3 | C |  |
| 66 | Covariance[6,5] | CZ\_DOT\_Y\_DOT | Table 4-3 | C |  |
| 67 | Covariance[6,6] | CZ\_DOT\_Z\_DOT | Table 4-3 | C |  |
| 68 | User-Defined Parameters logical block | N/A | Table 4-3 | O |  |
| 69 | As defined by user, "essential information that cannot be conveyed in COMMENT statements" | USER\_DEFINED\_x | Table 4-3 | O |  |

* + 1. ORBIT Ephemeris MESSAGE Requirements list

| Item | Feature | Keyword | Reference | Status M/O/C | Support |
| --- | --- | --- | --- | --- | --- |
| 1 | OEM Header | N/A | Table 5-2 | M |  |
| 2 | OEM Version | CCSDS\_OEM\_VERS | Table 5-2 | M |  |
| 3 | Comment | COMMENT | Table 5-2 | O |  |
| 4 | Message creation date and time | CREATION\_DATE | Table 5-2 | M |  |
| 5 | Message originator | ORIGINATOR | Table 5-2 | M |  |
| 6 | Unique message identifier | MESSAGE\_ID | Table 5-2 | O |  |
| 7 | Metadata logical block | N/A | Table 5-3 | M |  |
| 8 | Start of OEM Metadata | META\_START | Table 5-3 | M |  |
| 9 | Comment | COMMENT | Table 5-3 | O |  |
| 10 | Name of space object | OBJECT\_NAME | Table 5-3 | M |  |
| 11 | Identifier of space object | OBJECT\_ID | Table 5-3 | M |  |
| 12 | Orbit center | CENTER\_NAME | Table 5-3 | M |  |
| 13 | Reference frame | REF\_FRAME | Table 5-3 | M |  |
| 14 | Epoch of reference frame | REF\_FRAME\_EPOCH | Table 5-3 | C |  |
| 15 | Time system applicable to data | TIME\_SYSTEM | Table 5-3 | M |  |
| 16 | Start of TOTAL time span covered by data | START\_TIME | Table 5-3 | M |  |
| 17 | Start of useable orbit data | USEABLE\_START\_TIME | Table 5-3 | O |  |
| 18 | End of useable orbit data | USEABLE\_STOP\_TIME | Table 5-3 | O |  |
| 19 | End of TOTAL time span covered by data | STOP\_TIME | Table 5-3 | M |  |
| 20 | Recommended interpolation method | INTERPOLATION | Table 5-3 | O |  |
| 21 | Recommended interpolation degree | INTERPOLATION\_DEGREE | Table 5-3 | C |  |
| 22 | End of OEM Metadata | META\_STOP | Table 5-3 | M |  |
| 24 | OEM Data logical block | N/A | Table 5-3 | M |  |
| 23 | Ephemeris lines | … <insert ephemeris data lines here.> | Table 5-3 | M |  |
| 24 | OEM Covariance logical block | N/A | Table 5-3 | O |  |
| 25 | Start of OEM Covariance logical block | COVARIANCE\_START | Table 5-3 | M |  |
| 26 | Epoch of the navigation solution related to the covariance matrix | EPOCH | Table 5-3 | C |  |
| 27 | Reference frame of the covariance matrix, if different from that of the states in the ephemeris | COV\_REF\_FRAME | Table 5-3 | C |  |
| 28 | Covariance lines | … <insert covariance matrices here> | Table 5-3 | O |  |
| 29 | End of OEM Covariance logical block | COVARIANCE\_STOP | Table 5-3 | M |  |

* + 1. ORBIT Comprehensive MESSAGE Requirements list

OCM Header

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Item | Feature | Keyword | Reference | Status M/O/C | Support |
| 1 | OCM Header | N/A | Table 6-2 | M |  |
| 2 | OCM Version | CCSDS\_OCM\_VERS | Table 6-2 | M |  |
| 3 | Comment | COMMENT | Table 6-2 | O |  |
| 4 | Message creation date and time | CREATION\_DATE | Table 6-2 | M |  |
| 5 | Message originator | ORIGINATOR | Table 6-2 | M |  |
| 6 | Unique message identifier | MESSAGE\_ID | Table 6-2 | O |  |

OCM Metadata

| Item | Feature | Keyword | Reference | Status M/O/C | Support |
| --- | --- | --- | --- | --- | --- |
| 1 | Metadata logical block | N/A | Table 6-3 | M |  |
| 2 | OCM Metadata Start | META\_START | Table 6-3 | M |  |
| 3 | Comment | COMMENT | Table 6-3 | O |  |
| 4 | Message classification/caveats | CLASSIFICATION | Table 6-2 | O |  |
| 5 | Spacecraft name for the object | OBJECT\_NAME | Table 6-3 | O |  |
| 6 | International designator for the object | INTERNATIONAL\_DESIGNATOR | Table 6-3 | O |  |
| 7 | Satellite catalog source | CATALOG\_NAME | Table 6-3 | O |  |
| 8 | Unique satellite identification designator | OBJECT\_DESIGNATOR | Table 6-3 | O |  |
| 9 | Alternate name(s) of space object used by spacecraft operator, State Actors, commercial SSA providers and/or media. | ALTERNATE\_NAMES | Table 6-3 | O |  |
| 10 | Message originator or programmatic Point-of-Contact | ORIGINATOR\_POC | Table 6-3 | O |  |
| 11 | Contact position of the originator PoC | ORIGINATOR\_POSITION | Table 6-3 | O |  |
| 12 | Originator PoC phone number | ORIGINATOR\_PHONE | Table 6-3 | O |  |
| 13 | Originator PoC email address | ORIGINATOR\_EMAIL | Table 6-3 | O |  |
| 14 | Originator PoC physical address | ORIGINATOR\_ADDRESS | Table 6-3 | O |  |
| 15 | Creating agency or operator | TECH \_ORG | Table 6-3 | O |  |
| 16 | Technical Point-of-Contact | TECH \_POC | Table 6-3 | O |  |
| 17 | Contact position of the technical PoC | TECH \_POSITION | Table 6-3 | O |  |
| 18 | Technical PoC phone number | TECH \_PHONE | Table 6-3 | O |  |
| 19 | Technical PoC email address | TECH\_EMAIL | Table 6-3 | O |  |
| 20 | Technical PoC physical address | TECH\_ADDRESS | Table 6-3 | O |  |
| 21 | ID that uniquely identifies the previous message from this message originator for this particular space object | PREVIOUS\_MESSAGE\_ID | Table 6-3 | O |  |
| 22 | ID that uniquely identifies the next message from this message originator for this particular space object | NEXT\_MESSAGE\_ID | Table 6-3 | O |  |
| 23 | Unique identifier of linked Attitude Data Message(s) | ADM\_MSG\_LINK | Table 6-3 | O |  |
| 24 | Unique identifier of linked Conjunction Data Message(s) | CDM\_MSG\_LINK | Table 6-3 | O |  |
| 25 | Unique identifier of linked Pointing Request Message(s) | PRM\_MSG\_LINK | Table 6-3 | O |  |
| 26 | Unique identifier of linked Reentry Data Message(s) | RDM\_MSG\_LINK | Table 6-3 | O |  |
| 27 | Unique identifier of linked Tracking Data Message(s) | TDM\_MSG\_LINK | Table 6-3 | O |  |
| 28 | Operator of the space object | OPERATOR | Table 6-3 | O |  |
| 29 | Owner of the space object | OWNER | Table 6-3 | O |  |
| 30 | Country where the owner or responsible party is based | COUNTRY | Table 6-3 | O |  |
| 31 | Name of the constellation | CONSTELLATION | Table 6-3 | O |  |
| 32 | Type of object | OBJECT\_TYPE | Table 6-3 | O |  |
| 33 | Time system for all absolute time stamps in this OCM including EPOCH\_TZERO | TIME\_SYSTEM | Table 6-3 | M |  |
| 34 | Default epoch to which all relative times are referenced | EPOCH\_TZERO | Table 6-3 | M |  |
| 35 | Operational status of the space object | OPS\_STATUS | Table 6-3 | O |  |
| 36 | Type of orbit | ORBIT\_CATEGORY | Table 6-3 | O |  |
| 37 | Elements of information included in this message | OCM\_DATA\_ELEMENTS | Table 6-3 | O |  |
| 38 | Spacecraft clock epoch | SCLK\_OFFSET\_AT\_EPOCH | Table 6-3 | C |  |
| 39 | Spacecraft clock rate | SCLK\_SEC\_PER\_SI\_SEC | Table 6-3 | C |  |
| 40 | Creation epoch of the previous message from this originator for this particular space object | PREVIOUS\_MESSAGE\_EPOCH | Table 6-3 | O |  |
| 41 | Anticipated (or actual) epoch of the next message from this originator for this particular space object | NEXT\_MESSAGE\_EPOCH | Table 6-3 | O |  |
| 42 | Time of the earliest data | START\_TIME | Table 6-3 | O |  |
| 43 | Time of the latest data | STOP\_TIME | Table 6-3 | O |  |
| 44 | Span of time that the OCM covers, measured in days | TIME\_SPAN | Table 6-3 | O |  |
| 45 | Difference (TAI – UTC) in seconds | TAIMUTC\_AT\_TZERO | Table 6-3 | O |  |
| 46 | Epoch of next leap second(s) | NEXT\_LEAP\_EPOCH | Table 6-3 | O |  |
| 47 | Difference (TAI – UTC) after next leap second(s) are introduced | NEXT\_LEAP\_TAIMUTC | Table 6-3 | O |  |
| 48 | Difference (UT1 – UTC) in seconds | UT1MUTC\_AT\_TZERO | Table 6-3 | O |  |
| 49 | Source and version of the message originator’s Earth Orientation Parameters (EOP) | EOP\_SOURCE | Table 6-3 | O |  |
| 50 | Method used to select or interpolate sequential EOP data | INTERP\_METHOD\_EOP | Table 6-3 | O |  |
| 51 | Source and version of the message originator’s celestial body (e.g., Sun/Earth/Planetary) ephemeris data | CELESTIAL\_SOURCE | Table 6-3 | O |  |
| 52 | Metadata Stop | META\_STOP | Table 6-3 | M |  |

OCM Data: Trajectory state Time History

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Item | Feature | Keyword | | Reference | Status M/O/C | Support |
| 1 | Trajectory state time history logical block | | N/A | Table 6-4 | O |  |
| 2 | Trajectory state time history start | | TRAJ\_START | Table 6-4 | M |  |
| 3 | Comment | | COMMENT | Table 6-4 | O |  |
| 4 | Identification number for this trajectory state time history block | | TRAJ\_ID | Table 6-4 | O |  |
| 5 | Identification number for the previous trajectory state time history | | TRAJ\_PREV\_ID | Table 6-4 | O |  |
| 6 | Identification number for the next trajectory state time history | | TRAJ\_NEXT\_ID | Table 6-4 | O |  |
| 7 | Basis of this Trajectory state time history data | | TRAJ\_BASIS | Table 6-4 | O |  |
| 8 | Identification number for the orbit determination, navigation solution, or simulation | | TRAJ\_BASIS\_ID | Table 6-4 | O |  |
| 9 | Recommended interpolation method | | INTERPOLATION | Table 6-4 | O |  |
| 10 | Recommended interpolation degree | | INTERPOLATION\_DEGREE | Table 6-4 | C |  |
| 11 | Orbit averaging technique used | | ORB\_AVERAGING | Table 6-4 | M |  |
| 12 | Orbit propagator used | | PROPAGATOR | Table 6-4 | O |  |
| 13 | Origin of the orbit reference frame | | CENTER\_NAME | Table 6-4 | M |  |
| 14 | Reference frame of the trajectory state time history | | TRAJ\_REF\_FRAME | Table 6-4 | M |  |
| 15 | Epoch of the orbit data reference frame | | TRAJ\_FRAME\_EPOCH | Table 6-4 | C |  |
| 16 | Start of useable orbit data | | USEABLE\_START\_TIME | Table 6-4 | O |  |
| 17 | End of useable orbit data | | USEABLE\_STOP\_TIME | Table 6-4 | O |  |
| 18 | Orbit revolution number (an integer) | | ORB\_REVNUM | Table 6-4 | O |  |
| 19 | Orbit revolution basis number | | ORB\_REVNUM\_BASIS | Table 6-4 | C |  |
| 20 | Orbit element set type | | TRAJ\_TYPE | Table 6-4 | M |  |
| 21 | Orbital element units for data elements that follow the time tag | | TRAJ\_UNITS | Table 6-4 | O |  |
| 22 | OCM trajectory state time history | | … <insert trajectory state time history here> | Table 6-4 | M |  |
| 23 | Trajectory state time history end | | TRAJ\_STOP | Table 6-4 | M |  |

OCM Data: Space Object Physical Characteristics

| Item | Feature | Keyword | Reference | Status M/O/C | | Support |
| --- | --- | --- | --- | --- | --- | --- |
| 1 | Space Object Physical Characteristics logical block | N/A | Table 6-5 | O |  | |
| 2 | Start of a Space Object Physical Characteristics specification | PHYS\_START | Table 6-5 | M |  | |
| 3 | Comment | COMMENT | Table 6-5 | O |  | |
| 4 | Satellite manufacturer name | MANUFACTURER | Table 6-5 | O |  | |
| 5 | Satellite manufacturer’s spacecraft bus model name | BUS\_MODEL | Table 6-5 | O |  | |
| 6 | Space objects that this object is docked to | DOCKED\_WITH | Table 6-5 | O |  | |
| 7 | Additional drag Area facing the relative wind vector beyond that represented by AREA\_ALONG\_OEB\_<MAX, MED, MIN> | DRAG\_CONST\_AREA | Table 6-5 | O |  | |
| 8 | Drag coefficient | DRAG\_COEFF\_NOM | Table 6-5 | O |  | |
| 9 | Drag coeff. 1σ uncertainty | DRAG\_UNCERTAINTY | Table 6-5 | O |  | |
| 10 | Space object total mass at beginning of life | INITIAL\_WET\_MASS | Table 6-5 | O |  | |
| 11 | Space object wet mass | WET\_MASS | Table 6-5 | O |  | |
| 12 | Space object dry mass | DRY\_MASS | Table 6-5 | O |  | |
| 13 | Parent reference frame which maps to the Optimally Enclosing Box (OEB) frame | OEB\_PARENT\_FRAME | Table 6-5 | C |  | |
| 14 | Epoch of the OEB parent reference frame | OEB\_PARENT\_FRAME\_EPOCH | Table 6-5 | C |  | |
| 15 | Quaternion q1 | OEB\_Q1 | Table 6-5 | O |  | |
| 16 | Quaternion q2 | OEB\_Q2 | Table 6-5 | O |  | |
| 17 | Quaternion q3 | OEB\_Q3 | Table 6-5 | O |  | |
| 18 | Quaternion qc | OEB\_QC | Table 6-5 | O |  | |
| 19 | Maximum physical OEB dimension | OEB\_MAX | Table 6-5 | O |  | |
| 20 | Medium physical OEB dimension | OEB\_INT | Table 6-5 | O |  | |
| 21 | Minimum physical dimension | OEB\_MIN | Table 6-5 | O |  | |
| 22 | Cross-sectional area viewed along max OEB dimension | AREA\_ALONG\_OEB\_MAX | Table 6-5 | O |  | |
| 23 | Cross-sectional area viewed along intermediate OEB dimension | AREA\_ALONG\_ OEB\_INT | Table 6-5 | O |  | |
| 24 | Cross-sectional area viewed along min OEB dimension | AREA\_ALONG\_ OEB\_MIN | Table 6-5 | O |  | |
| 25 | Minimum cross-sectional area for collision probability | AREA\_MIN\_FOR\_PC | Table 6-5 | O |  | |
| 26 | Maximum cross-sectional area for collision probability | AREA\_MAX\_FOR\_PC | Table 6-5 | O |  | |
| 27 | Typical cross-sectional area for collision probability | AREA\_TYP\_FOR\_PC | Table 6-5 | O |  | |
| 28 | Typical (50th percentile) effective Radar Cross Section | RCS | Table 6-5 | O |  | |
| 29 | Minimum Radar Cross Section | RCS\_MIN | Table 6-5 | O |  | |
| 30 | Maximum Radar Cross Section | RCS\_MAX | Table 6-5 | O |  | |
| 31 | SRP additional area | SRP\_CONST\_AREA | Table 6-5 | O |  | |
| 32 | Solar Radiation Pressure Coefficient | SOLAR\_RAD\_COEFF | Table 6-5 | O |  | |
| 33 | Solar Radiation Pressure 1σ percent uncertainty | SOLAR\_RAD\_UNCERTAINTY | Table 6-5 | O |  | |
| 34 | Typical (50th percentile) absolute Visual Magnitude | VM\_ABSOLUTE | Table 6-5 | O |  | |
| 35 | Minimum apparent Visual Magnitude | VM\_APPARENT\_MIN | Table 6-5 | O |  | |
| 36 | Typical (50th percentile) apparent Visual Magnitude | VM\_APPARENT | Table 6-5 | O |  | |
| 37 | Maximum apparent Visual Magnitude | VM\_APPARENT\_MAX | Table 6-5 | O |  | |
| 38 | Typical (50th percentile) object surface reflectance | REFLECTANCE | Table 6-5 | O |  | |
| 39 | Primary mode of attitude control | ATT\_CONTROL\_MODE | Table 6-5 | O |  | |
| 40 | Type of actuator for attitude control | ATT\_ACTUATOR\_TYPE | Table 6-5 | O |  | |
| 41 | Accuracy of attitude knowledge | ATT\_KNOWLEDGE | Table 6-5 | O |  | |
| 42 | Ability (e.g. deadband) to control attitude | ATT\_CONTROL | Table 6-5 | O |  | |
| 43 | Combined ability to both knowledge and control attitude | ATT\_POINTING | Table 6-5 | O |  | |
| 44 | Average maneuver frequency | AVG\_MANEUVER\_FREQ | Table 6-5 | O |  | |
| 45 | Maximum composite thrust | MAX\_THRUST | Table 6-5 | O |  | |
| 46 | Total ΔV capability of the spacecraft at beginning of life | DV\_BOL | Table 6-5 | O |  | |
| 47 | Total ΔV remaining | DV\_REMAINING | Table 6-5 | O |  | |
| 48 | Moment of Inertia about the X-axis | IXX | Table 6-5 | O |  | |
| 49 | Moment of Inertia about the Y-axis | IYY | Table 6-5 | O |  | |
| 50 | Moment of Inertia about the Z-axis | IZZ | Table 6-5 | O |  | |
| 51 | Inertia Cross Product of the X & Y axes | IXY | Table 6-5 | O |  | |
| 52 | Inertia Cross Product of the X & Z axes | IXZ | Table 6-5 | O |  | |
| 53 | Inertia Cross Product of the Y & Z axes | IYZ | Table 6-5 | O |  | |
| 54 | End of the Space Object Physical Characteristics specification | PHYS\_STOP | Table 6-5 | M |  | |

OCM Data: Covariance Time History

| Item | Feature | Keyword | Reference | Status M/O/C | Support |
| --- | --- | --- | --- | --- | --- |
| 1 | Covariance time history logical block | N/A | Table 6-6 | O |  |
| 2 | OCM start of a covariance time history section | COV\_START | Table 6-6 | M |  |
| 3 | Comment | COMMENT | Table 6-6 | O |  |
| 4 | Identification number for this covariance time history block | COV\_ID | Table 6-6 | O |  |
| 5 | Identification number for the previous covariance time history | COV\_PREV\_ID | Table 6-6 | O |  |
| 6 | Identification number for the next covariance time history | COV\_NEXT\_ID | Table 6-6 | O |  |
| 7 | Basis of this covariance time history | COV\_BASIS | Table 6-6 | O |  |
| 8 | Identification number for the orbit determination, navigation solution, or simulation | COV\_BASIS\_ID | Table 6-6 | O |  |
| 9 | Reference frame of the covariance time history | COV\_REF\_FRAME | Table 6-6 | M |  |
| 10 | Epoch of the covariance data reference frame | COV\_FRAME\_EPOCH | Table 6-6 | C |  |
| 11 | Minimum scale factor to apply to this covariance data | COV\_SCALE\_MIN | Table 6-6 | O |  |
| 12 | Maximum scale factor to apply to this covariance data | COV\_SCALE\_MAX | Table 6-6 | O |  |
| 13 | Confidence in the covariance errors matching reality | COV\_CONFIDENCE | Table 6-6 | O |  |
| 14 | Covariance composition | COV\_TYPE | Table 6-6 | M |  |
| 15 | Covariance element ordering | COV\_ORDERING | Table 6-6 | M |  |
| 16 | Units of covariance data line standard deviations (i.e., the square root of the variances supplied in the covariance matrix diagonal elements) that follow the time tag | COV\_UNITS | Table 6-6 | O |  |
| 17 | Covariance data | … <Insert covariance data here> | Table 6-6 | M |  |
| 18 | End of a covariance time history section | COV\_STOP | Table 6-6 | M |  |

OCM Data: Maneuver Specification

| Item | Feature | Keyword | Reference | Status M/O/C | Support |
| --- | --- | --- | --- | --- | --- |
| 1 | Maneuver time history logical block | N/A | Table 6-7 | O |  |
| 2 | Start of a maneuver data block | MAN\_START | Table 6-7 | M |  |
| 3 | Comment | COMMENT | Table 6-7 | O |  |
| 4 | Identification number for this maneuver | MAN\_ID | Table 6-7 | M |  |
| 5 | Identification number for the previous maneuver | MAN\_PREV\_ID | Table 6-7 | O |  |
| 6 | Identification number for the next maneuver | MAN\_NEXT\_ID | Table 6-7 | O |  |
| 7 | Basis of this maneuver time history data | MAN\_BASIS | Table 6-7 | O |  |
| 8 | Identification number of the orbit determination | MAN\_BASIS\_ID | Table 6-7 | O |  |
| 9 | Maneuver device identifier | MAN\_DEVICE\_ID | Table 6-7 | M |  |
| 10 | Completion time of the previous maneuver | MAN\_PREV\_EPOCH | Table 6-7 | O |  |
| 11 | Start time of the next maneuver | MAN\_NEXT\_EPOCH | Table 6-7 | O |  |
| 12 | Specifies the purpose of the maneuver | MAN\_PURPOSE | Table 6-7 | O |  |
| 13 | Specifies the source of the orbit and/or attitude state(s) | MAN\_PRED\_SOURCE | Table 6-7 | O |  |
| 14 | Reference frame in which the maneuver vector direction data is provided | MAN\_REF\_FRAME | Table 6-7 | M |  |
| 15 | Epoch of the maneuver data reference frame | MAN\_FRAME\_EPOCH | Table 6-7 | C |  |
| 16 | Origin of maneuver gravitational assist body | GRAV\_ASSIST\_NAME | Table 6-7 | O |  |
| 17 | Duty cycle type to use for this maneuver time history | DC\_TYPE | Table 6-7 | M |  |
| 18 | Start time of the duty cycle-based maneuver window | DC\_WIN\_OPEN | Table 6-7 | C |  |
| 19 | End time of the duty cycle-based maneuver window | DC\_WIN\_CLOSE | Table 6-7 | C |  |
| 20 | Minimum number of “ON” duty cycles | DC\_MIN\_CYCLES | Table 6-7 | O |  |
| 21 | Maximum number of “ON” duty cycles | DC\_MAX\_CYCLES | Table 6-7 | O |  |
| 22 | Start time of the initial duty cycle-based maneuver sequence | DC\_EXEC\_START | Table 6-7 | C |  |
| 23 | End time of the final duty cycle-based maneuver sequence | DC\_EXEC\_STOP | Table 6-7 | C |  |
| 24 | THRUST duty cycle reference time tag | DC\_REF\_TIME | Table 6-7 | C |  |
| 25 | Thruster pulse “ON” duration | DC\_TIME\_PULSE\_DURATION | Table 6-7 | C |  |
| 26 | Elapsed time between the start of one pulse and the start of the next | DC\_TIME\_PULSE\_PERIOD | Table 6-7 | C |  |
| 27 | Specifies the “ON” reference unit vector direction | DC\_REF\_DIR | Table 6-7 | C |  |
| 28 | Body reference frame that DC\_BODY\_TRIGGER direction is expressed in | DC\_BODY\_FRAME | Table 6-7 | C |  |
| 29 | Body frame reference unit vector “trigger” direction | DC\_BODY\_TRIGGER | Table 6-7 | C |  |
| 30 | Phase angle offset of thruster pulse start | DC\_PA\_START\_ANGLE | Table 6-7 | C |  |
| 31 | Phase angle of thruster pulse stop | DC\_PA\_STOP\_ANGLE | Table 6-7 | C |  |
| 32 | Set of maneuver elements of information to follow the maneuver time tag | MAN\_COMPOSITION | Table 6-7 | M |  |
| 33 | Units of maneuver data line elements that follow the time tag(s) | MAN\_UNITS | Table 6-7 | O |  |
| 34 | Maneuver time history data | … < Insert maneuver data here> | Table 6-7 | M |  |
| 35 | End maneuver data block | MAN\_STOP | Table 6-7 | M |  |

OCM Data: Perturbations Specification

| Item | Feature | Keyword | Reference | Status M/O/C | Support |
| --- | --- | --- | --- | --- | --- |
| 1 | Orbit perturbations parameters | N/A | Table 6-10 | O |  |
| 2 | Start of the perturbations specification | PERT\_START | Table 6-10 | M |  |
| 3 | Comment | COMMENT | Table 6-10 | O |  |
| 4 | Atmosphere model used in the simulation | ATMOSPHERIC\_MODEL | Table 6-10 | O |  |
| 5 | Gravity model used in the simulation | GRAVITY\_MODEL | Table 6-10 | O |  |
| 6 | Oblate spheroid equatorial radius | EQUATORIAL\_RADIUS | Table 6-10 | O |  |
| 7 | Gravitational coefficient of attracting body | GM | Table 6-10 | O |  |
| 8 | “N-body” gravitational perturbations bodies used | N\_BODY\_PERTURBATIONS | Table 6-10 | O |  |
| 9 | Central body angular rotation rate | CENTRAL\_BODY\_ROTATION | Table 6-10 | O |  |
| 10 | Inverse of the central body’s oblate spheroid oblateness | OBLATE\_FLATTENING | Table 6-10 | O |  |
| 11 | Ocean tides model | OCEAN\_TIDES\_MODEL | Table 6-10 | O |  |
| 12 | Solid tides model | SOLID\_TIDES\_MODEL | Table 6-10 | O |  |
| 13 | Reduction theory used for precession and nutation modeling | REDUCTION\_THEORY | Table 6-10 | O |  |
| 14 | Albedo model | ALBEDO\_MODEL | Table 6-10 | O |  |
| 15 | Number of grid points used in the albedo model | ALBEDO\_GRID\_SIZE | Table 6-10 | O |  |
| 16 | Shadow model used for Solar Radiation Pressure | SHADOW\_MODEL | Table 6-10 | O |  |
| 17 | List of planetary bodies for which SRP shadowing is modeled | SHADOW\_BODIES | Table 6-10 | O |  |
| 18 | SRP model used | SRP\_MODEL | Table 6-10 | O |  |
| 19 | Source and version of the Space Weather data used in the creation of this message | SW\_DATA\_SOURCE | Table 6-10 | O |  |
| 20 | Epoch of the Space Weather data | SW\_DATA\_EPOCH | Table 6-10 | O |  |
| 21 | Method used to select or interpolate any and all sequential space weather data | SW\_INTERP\_METHOD | Table 6-10 | O |  |
| 22 | A fixed (time invariant) value of the planetary 3-hour-range geomagnetic index Kp | FIXED\_GEOMAG\_KP | Table 6-10 | O |  |
| 23 | A fixed (time invariant) value of the 3-hourly (equivalent range) geomagnetic index Ap | FIXED\_GEOMAG\_AP | Table 6-10 | O |  |
| 24 | A fixed (time invariant) value of the planetary 1-hour-range geomagnetic index Dst | FIXED\_GEOMAG\_DST | Table 6-10 | O |  |
| 25 | A fixed (time invariant) value of the solar flux daily proxy F10.7 | FIXED\_F10P7 | Table 6-10 | O |  |
| 26 | A fixed (time invariant) value of the solar flux 81‐day running center-averaged proxy F10.7 | FIXED\_F10P7\_MEAN | Table 6-10 | O |  |
| 27 | A fixed (time invariant) value of the solar flux daily proxy M10.7 | FIXED\_M10P7 | Table 6-10 | O |  |
| 28 | A fixed (time invariant) value of the solar flux 81‐day running center-averaged proxy M10.7 | FIXED\_M10P7\_MEAN | Table 6-10 | O |  |
| 29 | A fixed (time invariant) value of the solar flux daily proxy S10.7 | FIXED\_S10P7 | Table 6-10 | O |  |
| 30 | A fixed (time invariant) value of the solar flux 81‐day running center-averaged proxy S10.7 | FIXED\_S10P7\_MEAN | Table 6-10 | O |  |
| 31 | A fixed (time invariant) value of the solar flux daily proxy Y10.7 | FIXED\_Y10P7 | Table 6-10 | O |  |
| 32 | A fixed (time invariant) value of the solar flux 81‐day running center-averaged proxy Y10.7 | FIXED\_Y10P7\_MEAN | Table 6-10 | O |  |
| 33 | Perturbations Data Block Stop | PERT\_STOP | Table 6-10 | M |  |

OCM Data: Orbit Determination Data

| Item | Feature | Keyword | Reference | Status M/O/C | Support |
| --- | --- | --- | --- | --- | --- |
| 1 | Orbit determination parameters logical block | N/A | Table 6-11 | O |  |
| 2 | Start of an orbit determination data section | OD\_START | Table 6-11 | M |  |
| 3 | Comment | COMMENT | Table 6-11 | O |  |
| 4 | Identification number for this orbit determination | OD\_ID | Table 6-11 | M |  |
| 5 | Identification number for the previous orbit determination | OD\_PREV\_ID | Table 6-11 | O |  |
| 6 | Type of orbit determination method used | OD\_METHOD | Table 6-11 | M |  |
| 7 | UTC epoch of the orbit determination solved-for state | OD\_EPOCH | Table 6-11 | M |  |
| 8 | Days elapsed between first accepted observation and OD\_EPOCH | DAYS\_SINCE\_FIRST\_OBS | Table 6-11 | O |  |
| 9 | Days elapsed between last accepted observation and OD\_EPOCH | DAYS\_SINCE\_LAST\_OBS | Table 6-11 | O |  |
| 10 | Number of days of observations recommended for the OD | RECOMMENDED\_OD\_SPAN | Table 6-11 | O |  |
| 11 | Actual time span in days used for the OD | ACTUAL\_OD\_SPAN | Table 6-11 | O |  |
| 12 | Number of observations available within the actual OD time span | OBS\_AVAILABLE | Table 6-11 | O |  |
| 13 | Number of observations accepted within the actual OD time span | OBS\_USED | Table 6-11 | O |  |
| 14 | Number of sensor tracks available for the OD within the actual time span | TRACKS\_AVAILABLE | Table 6-11 | O |  |
| 15 | Number of sensor tracks accepted for the OD within the actual time span | TRACKS\_USED | Table 6-11 | O |  |
| 16 | Maximum time between observations in the OD | MAXIMUM\_OBS\_GAP | Table 6-11 | O |  |
| 17 | Positional error ellipsoid 1𝜎 major eigenvalue at OD | OD\_EPOCH\_EIGMAJ | Table 6-11 | O |  |
| 18 | Positional error ellipsoid 1𝜎 intermediate eigenvalue at OD | OD\_EPOCH\_EIGMED | Table 6-11 | O |  |
| 19 | Positional error ellipsoid 1𝜎 minor eigenvalue at OD | OD\_EPOCH\_EIGMIN | Table 6-11 | O |  |
| 20 | Max positional error ellipsoid 1𝜎 major eigenvalue | OD\_MAX\_PRED\_EIGMAJ | Table 6-11 | O |  |
| 21 | Min positional error ellipsoid 1𝜎 minor eigenvalue | OD\_MIN\_PRED\_EIGMIN | Table 6-11 | O |  |
| 22 | OD confidence metric, which by definition spans 0 to 100% | OD\_CONFIDENCE | Table 6-11 | O |  |
| 23 | Generalized Dilution of Precision for this orbit determination | GDOP | Table 6-11 | O |  |
| 24 | Number of solve-for states in the orbit determination | SOLVE\_N | Table 6-11 | O |  |
| 25 | State elements solved for in the orbit determination | SOLVE\_STATES | Table 6-11 | O |  |
| 26 | Number of consider parameters used in the orbit determination | CONSIDER\_N | Table 6-11 | O |  |
| 27 | Consider parameters used in the orbit determination | CONSIDER\_PARAMS | Table 6-11 | O |  |
| 28 | Specific Energy Dissipation Rate | SEDR | Table 6-11 | O |  |
| 29 | Number of sensors used in the orbit determination | SENSORS\_N | Table 6-11 | O |  |
| 30 | Sensors used in the orbit determination | SENSORS | Table 6-11 | O |  |
| 31 | Weighted RMS residual ratio | WEIGHTED\_RMS | Table 6-11 | O |  |
| 32 | File name(s) and/or associated identification number(s) of Tracking Data Message (TDM) [9] observations | TDM\_MSG\_LINK | Table 6-11 | O |  |
| 33 | Observation data types utilized in this orbit determination | DATA\_TYPES | Table 6-11 | O |  |
| 34 | End of an orbit determination data section | OD\_STOP | Table 6-11 | M |  |

OCM Data: User-Defined Parameters

| Item | Feature | Keyword | Reference | Status M/O/C | Support |
| --- | --- | --- | --- | --- | --- |
| 1 | User-Defined Parameters logical block | N/A | Table 6-12 | O |  |
| 2 | OCM User-Defined Parameters start | USER\_START | Table 6-12 | M |  |
| 3 | Comment | COMMENT | Table 6-12 | O |  |
| 4 | As defined by user, "essential information that cannot be conveyed in COMMENT statements" | (User-defined keywords) | Table 6-12 | M |  |
| 5 | OCM User-Defined Parameters end | USER\_STOP | Table 6-12 | M |  |

1. Values for Selected KeywordS   
     
   (Normative)

The values in this annex represent the recommended values for selected keywords present in OPM, OMM, OEM, or OCM message. For details and descriptions of the keyword interpretations, the reader is directed to ANNEX H, Reference [H-1], and [H-7]. The message creator should seek to confirm with the recipient(s) that their software can support the selected keyword value, particularly for more complex content such as reference frames, orbital elements, and covariance definitions.

These recommended values are stored on the SANA Registry, globally accessible on the CCSDS SANA registry website located at:

<https://sanaregistry.org/r/navigation_standard_normative_annexes>

Note that the message creator or recipient may wish to automate processing of SANA registry normative content, which can be done by ingesting and processing of such content in electronic format. These formats can be accessed via the “Actions” link on each registry, e.g. for the Orbital Elements registry, a comma separated value (CSV) format can be exported at: <https://www.sanaregistry.org/r/orbital_elements?_export=csv> and a (JSON) format at: <https://www.sanaregistry.org/r/orbital_elements?_export=json>. Note that both the registry and these electronic data formats specify the number of vector elements corresponding to each keyword value.

Exchange partners may submit additional (new) keyword values for consideration of future inclusion into the SANA registry by submitting a detailed email request (mailto:info@sanaregistry.org) per ANNEX C, Section C2. The CCSDS Area or Working Group responsible for the maintenance of the ODM at the time of the request is the approval authority. Until a suggested value is included in the SANA registry, exchange partners may define and use values that are not listed in the SANA registry if mutually agreed between message exchange partners.

* 1. Message originators

The set of recommended values for the **ORIGINATOR** keyword is enumerated in the *SANA Registry of Organizations*, located at:

<https://sanaregistry.org/r/organizations>

* 1. Reference frame centers and third-body perturbations

A set of allowed values for the reference frame center keywords (**CENTER\_NAME** for OPM, OEM, OMM, and OCM, as well as **N\_BODY\_PERTURBATIONS** in the OCM**)** is enumerated in the *SANA Registry of Orbit Centers*, located at:

<https://sanaregistry.org/r/orbit_centers>

Note that these values may also be useful to specify another platform (satellite, airframe, ground vehicle, etc.) as the reference frame origin to permit the specification of relative positional state time history data. In this case, message authors shall clearly communicate to recipients that the orbit center is not a gravitational center, 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.

* 1. Time systems

A set of allowed values for the **TIME\_SYSTEM** keyword is enumerated in the *SANA Registry of Time Systems*, located at:

<https://sanaregistry.org/r/time_systems>

* 1. Celestial body reference frames

A set of allowed celestial body reference frame values for **\*\_REF\_FRAME** keywords is enumerated in the *SANA Registry of Celestial Body Reference Frames*, located at:

<https://sanaregistry.org/r/celestial_body_reference_frames>

* 1. Orbit-relative reference frames

In addition to the above reference frames, maneuver and covariance data may be selected from the list of allowed orbit-relative reference frames using **\*\_REF\_FRAME** keyword values enumerated in the *SANA Registry of Orbit-Relative Reference Frames*, located at:

https://sanaregistry.org/r/orbit\_relative\_reference\_frames

**Note that two types of orbit-relative local reference frames exist: inertial and rotating. When transforming velocity terms between inertial and rotating frames, remember to properly incorporate the contribution.**

* 1. Additional spacecraft and attitude reference frames

An additional allowed set of spacecraft and attitude control reference frame values for **\*\_REF\_FRAME** keywords is enumerated in the *SANA Registry of Spacecraft and Attitude Control Reference Frames*, located at:

<https://sanaregistry.org/r/spacecraft_body_reference_frames>

In numerous instances these spacecraft body reference frames are specified by a keyword followed by an “i” (e.g., ACTUATOR\_i), the “i” should be replaced by an integer value (1, 2, …) to denote the “ith” reference frame within the set of those reference frames.

* 1. Orbital elements

A set of allowed values for the **TRAJ\_TYPE** keyword is enumerated in the *SANA Registry of* *Orbital Elements*, located at:

<https://sanaregistry.org/r/orbital_elements>

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

Orbit elements shall be interpreted as osculating elements unless either explicitly specified via the ORB\_AVERAGING keyword or as mutually agreed between message exchange partners to contain mean elements (e.g., singly or doubly averaged elements based upon Kozai, Brouwer, or other theories).

Inertial reference frames shall be specified when employing inertial element sets.

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

* 1. Additional covariance representations

Covariance matrices may either be specified as representing uncertainties expressed in the above “Orbital Elements” types (e.g., **COV\_TYPE** may be set to an **TRAJ\_TYPE** such as **CARTPVA**) or may specify an event-based covariance type which includes event time uncertainties as enumerated in the *SANA Registry of* *Covariance Representations*, located at:

<https://sanaregistry.org/r/orbital_covariance_matrix_types>

* 1. Atmosphere models

A set of allowed values for the **ATMOSPHERIC\_MODEL** keyword is enumerated in the *SANA Registry of Atmosphere Models*, located at:

<https://sanaregistry.org/r/atmosphere_models>

* 1. Gravity models

A set of allowed values for the **GRAVITY\_MODEL** keyword is enumerated in the *SANA Registry of Gravity Models*, located at:

<https://sanaregistry.org/r/gravity_models>

* 1. Object types

A set of allowed values for the **OBJECT\_TYPE** keyword is enumerated in the *SANA Registry of Object Types*, located at:

<https://sanaregistry.org/r/object_types>

* 1. Operational status

A set of allowed values for the **OPS\_STATUS** keyword is enumerated in the *SANA Registry of Operational Status of Space Object*, located at:

<https://sanaregistry.org/r/operational_status>

* 1. Orbit averaging techniques

A set of allowed values for the **ORB\_AVERAGING** keyword is enumerated in the *SANA Registry of Orbit Averaging Techniques*, located at:

<https://sanaregistry.org/r/orbit_averaging>

* 1. Orbit categories

A set of allowed values for the **ORBIT\_CATEGORY** keyword is enumerated in the *SANA Registry of Orbit Types*, located at:

<https://sanaregistry.org/r/orbit_categories>



**SECURITY, SANA, AND PATENT CONSIDERATIONS**  
  
**(Informative)**

* 1. SECURITY CONSIDERATIONS
     1. ANALYSIS OF SECURITY CONSIDERATIONs

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

* + 1. 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.

* + 1. 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.

* + 1. DATA PRIVACY

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

* + 1. 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.

* + 1. 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.

* + 1. 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.

* + 1. 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.

* + 1. 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.

* + 1. 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.

* + 1. 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.

* 1. SANA Considerations

The following ODM-related items have been registered with the SANA Operator.

* The ODM/XML schema (see Section 8).

The following normative ODM elements should be selected from the SANA registry (see Annex B):

* ODM ORIGINATORs;
* Spacecraft identifiers;
* Reference Frame Center and Third-Body Perturbations;
* Time Systems;
* Reference Frames (inertial, quasi-inertial, orbit-relative, spacecraft & attitude frames);
* Orbital element set and covariance matrix composition definitions;
* Atmosphere models;
* Gravity models;
* Object types;
* Operational status;
* Orbit averaging techniques;
* Orbit types.

The registration rule for new entries in the SANA 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).>

* 1. PATENT CONSIDERATIONS

The recommendations of this document have no patent issues.

1. ABBREVIATIONS AND ACRONYMS  
     
   (Informative)

ASCII American Standard Code for Information Interchange

CCSDS Consultative Committee for Space Data Systems

DSST Draper Semi-Analytic Satellite Theory

EGM Earth Gravitational Model, Earth Geopotential Model

EOP Earth Orientation Parameters

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 Organization for Standardization

ITRF International Terrestrial Reference Frame

GRC Greenwich Rotating Coordinate Frame

J2000 Earth Mean Equator and Equinox of J2000 (Julian Date 2000)

KVN Keyword = Value Notation

LTM Lower Triangular Matrix

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

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

1. RATIONALE FOR THIS STANDARD  
     
   (Informative)
   1. 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:

1. 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.
2. 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.
3. Desirable Characteristics: These are not requirements, but they are felt to be important or useful features of the Recommended Standard.
   1. REQUIREMENTS ACCEPTED BY THE ORBIT DATA MESSAGES
      1. Primary RequirementS

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **#** | **Requirement** | **OPM?** | **OMM?** | **OEM**? | **OCM**? |
| P1 | Data must be provided in digital form (computer file). | Y | Y | Y | Y |
| P2 | 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 |
| P3 | 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 |
| P4 | State vector information must be provided in a reference frame that is clearly identified and unambiguous. | Y | Y | Y | Y |
| P5 | Identification of the object and the center(s) of motion must be clearly identified and unambiguous. | Y | Y | Y | Y |
| P6 | Time measurements (time stamps, or epochs) must be provided in a commonly used, clearly specified system. | Y | Y | Y | Y |
| P7 | The time bounds of the ephemeris must be unambiguously specified. | N/A | N/A | Y | Y |
| P8 | The Recommended Standard must provide for clear specification of units of measure. | Y | Y | Y | Y |
| P9 | Files must be readily ported between, and useable within, ‘all’ computational environments in use by Member Agencies. | Y | Y | Y | Y |
| P10 | 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 |
| P11 | File name syntax and length must not violate computer constraints for those computing environments in use by Member Agencies. | Y | Y | Y | Y |
| P12 | A means to convey information about the uncertainty of the state shall be provided. | Y | Y | Y | Y |

* + 1. Heritage Requirements

| **#** | **Requirement** | **OPM?** | **OMM?** | **OEM**? | **OCM**? |
| --- | --- | --- | --- | --- | --- |
| H1 | Ephemeris data is reliably convertible into the SPICE SPK (NASA) format (Reference [H-4]) and IIRV (NASA) format (Reference [H-5]) 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. | Y | Y | Y | 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 |

* + 1. Desirable Characteristics

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **#** | **Requirement** | **OPM?** | **OMM?** | **OEM?** | **OCM?** |
| DC1 | The Recommended Standard applies to non-traditional objects, such as landers, rovers, balloons, and natural bodies (e.g., asteroids, comets). | Y | N | Y | Y |
| DC2 | The Recommended Standard allows state vectors to be provided in other than the traditional J2000 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. | Y | Y | Y | 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 |

* + 1. APPLICABILITY OF CRITERIA TO MESSAGE OPTIONs

The selection of one message will depend on the optimization criteria in the given application. The following table compares the four recommended messages in terms of the relevant selection criteria identified by the CCSDS.

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 |

* 1. INCREASING ORBIT PROPAGATION FIDELITY OF AN OPM OR OMM

Some OPM or OMM 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.

* 1. 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 E4.1

* + 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 |

1. Technical Material and conventions for ODM data  
     
   (Informative)
   1. Satellite Physical Characteristics: Optimally Encompassing Box (OEB)

This section of the informative technical annex defines satellite dimensional and orientational parameters of the OCM’s satellite physical characteristics specification.

To facilitate improved modeling of the physical space occupied by a space object, the space object’s attitude/orientation, the probability of a hard body collision occurring, and drag and SRP acceleration forces, the OCM allows the specification of an “**Optimally Encompassing Box**” (**OEB**). Note that the OEB describes the physical space occupied by the space object, which may or may not align with the inertia tensor for that object.

For a box-shaped satellite (e.g., a CubeSat) without appendages, the satellite’s volume in three-dimensional space and a corresponding OEB would have a one-to-one mapping.

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.

The OEB shape is shown in Fig. F- 1 below. As illustrated, the OEB reference frame axes (depicted as RED dotted lines) are defined by convention as follows:

* The OEB x-axis is along the **longest** dimension of the box (). This is sometimes referred to the “span” of the space object.
* The OEB y-axis is along the **intermediate** orthonormal dimension ()
* The OEB z-axis is along the **shortest** orthonormal dimension ().

The BOX shape can easily represent a cube by setting all orthonormal dimensions equal. If the longest two or three orthonormal dimensions are equivalent, then is defined as the direction along one of those longest dimensions and the next as .

If the longest two or three principal axis dimensions of the box are equivalent, is defined as the direction along one of those longest principal dimensions and the next as .

The OEB z-axis is always defined as: .



+ Euler Axis/Angle rotations

Fig. F- 1 Depiction of Optimally Enclosing Box and definitions of MAX, INT, and MIN orientation vectors relative to OEB parent frame

NOTE – Parent and body axis are shown in proximity to each other for display purposes only but could generally be in any orientation as specified by the quaternion.

A fixed orientation of the Optimally Encompassing Box with respect to the user-specified “OEB\_PARENT\_FRAME” is defined using aquaternion that maps from the user-specified OEB\_PARENT\_FRAME to the Optimally Encompassing Box vector directions. The above figure shows the proper definitions and sign conventions. The resulting transformation sequence is:

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

The physical dimensions of the OEB (long, intermediate, and short dimensions) are specified via OEB\_MAX, OEB\_INT, and OEB\_MIN respectively.

Cross-sectional area is modeled in the OCM as a combination of two parameter types:

1. an attitude-independent, constant cross-sectional area (e.g., DRAG\_CONST\_AREA or SRP\_CONST\_AREA)
2. attitude-dependent cross-sectional area as viewed along the OEB x, y, and z axes (long, intermediate, and short dimension directions) via AREA\_ALONG\_OEB\_MAX, AREA\_ALONG\_OEB\_INT, and AREA\_ALONG\_OEB\_MIN, respectively.

The analyst may use one or a combination of both parameter types to best represent the total cross-sectional area profile of the space object to be used in drag, lift, and SRP force estimates. The total cross-sectional area observed when viewed from an arbitrary unit-vector direction [x y z] could be:

TOTAL\_AREA = DRAG\_CONST\_AREA +

For example, to model drag forces, a two-meter diameter spherical space object would be best modeled as a constant area (DRAG\_CONST\_AREA=3.1415m2) with all three AREA\_ALONG\_OEB parameters defaulting to zero. Conversely, a ten-meter long, 10 cm box-cross section gravity gradient boom would best be modeled by leaving DRAG\_CONST\_AREA defaulting to zero and setting = = 1 m2 and = 0.01 m2. Finally, one can model a sphere encircling the gravity gradient boom’s centroid using a combination of these approaches by setting DRAG\_CONST\_AREA=3.1415m2, = = 1 m2 and = 0.01 m2.

As a second example, when modeling Solar Radiation Pressure (SRP) forces, note that many GEO spacecraft have very large solar arrays that dominate the total cross-sectional surface of the spacecraft. Importantly, these solar arrays are designed to remain as normal to the Sun as possible irrespective of current spacecraft bus orientation. As such, the cross-sectional area of these arrays is best portrayed in the OCM by setting SRP\_CONST\_AREA to the combined solar array surface area as observed along the Sun viewing vector, and the remaining bus cross-sectional areas can be set using the three attitude-dependent AREA\_ALONG\_OEB parameters.

* 1. Apparent-to-Absolute Visual Magnitude relationship

This section of the informative technical annex presents the relationships to be used to map apparent to absolute visual magnitude for inclusion in an OCM. These equations, based on ANNEX H, Reference [H-8], 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:

Effective area of the target [

The point source irradiance reaching the sensor aperture [W/m2]

Distance from the sun to the target [m] (e.g., 1 AU =

Distance from target to sensor []

Effective diameter of the target, [

Exoatmospheric solar irradiance, nominally 1380 [] at 1 AU

Target Irradiance at Sensor without atmospheric loss [W/m2]

Ref. Visual Magnitude (Vega) Irradiance

[2.77894 ]

General shadowing term accounting for the penumbra region’s influence [unitless, 0 ≤ F ≤1, 0 = umbra, and 1 = full Sun illumination]

Solar Intensity ≈ []

Intensity of reflected energy from target treated as a point source [W/sr]

Geometric reflectance phase function [unitless, 0 < ≤1]

Critical Angle to the Sun (CATS) from sun to the sensor, as shown in Fig. F- 2 and referenced to the observed target [rad]

Pi constant

Reflectance of the target [between 0 (none) and 1 (perfect reflectance)]

Effective transmission of the atmosphere [unitless, 0 < τ ≤ 1]

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

[W/m2]

, measured on the visual magnitude scale

or if known:

[W]

[W/m2]

[m2] {

NOTE 1 – is undefined in umbra (F=0=darkness), or no reflection ().

NOTE2: If reflectance is unknown, one may assume a standard reference reflectance of fifteen percent]

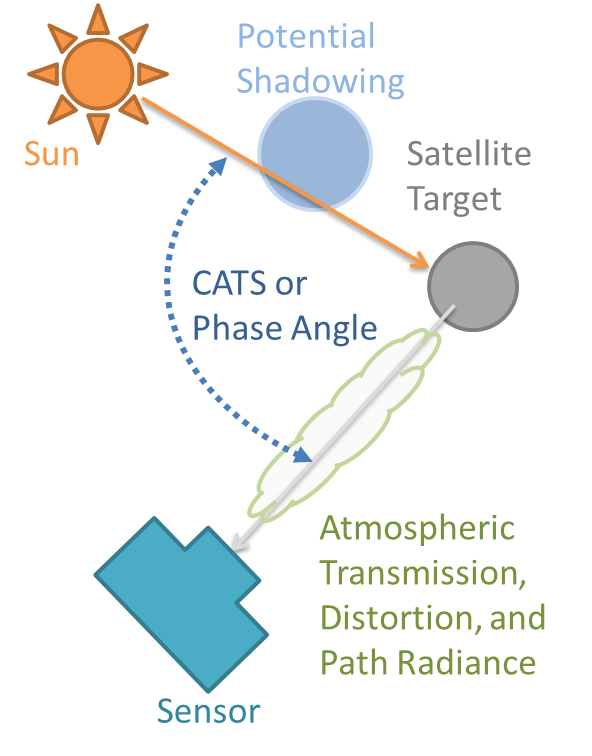
}

From which an effective diameter of the physical object can be roughly approximated as:

From the above equations, “normalized” to a 1 AU Sun-to-target distance, a phase angle of 0° and an example reference 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:

= , from which:

=



CATS angle

Fig. F- 2 Depiction of optical viewing Critical Angle to the Sun (CATS) angle geometry

* 1. Maneuver and Duty Cycle Diagrams

This section of the informative technical annex defines time-based and phase-angle-based duty cycle parameters.

A “duty cycle” is a cycle of thruster operation which operates intermittently rather than continuously, having an “on” interval followed by an “off” interval.

**Time-based duty cycle parameters**

Time-based duty cycle parameters define a window of duty cycle operations, the actual execution interval and “ON” and “OFF” intervals, as shown in Fig. F- 3.

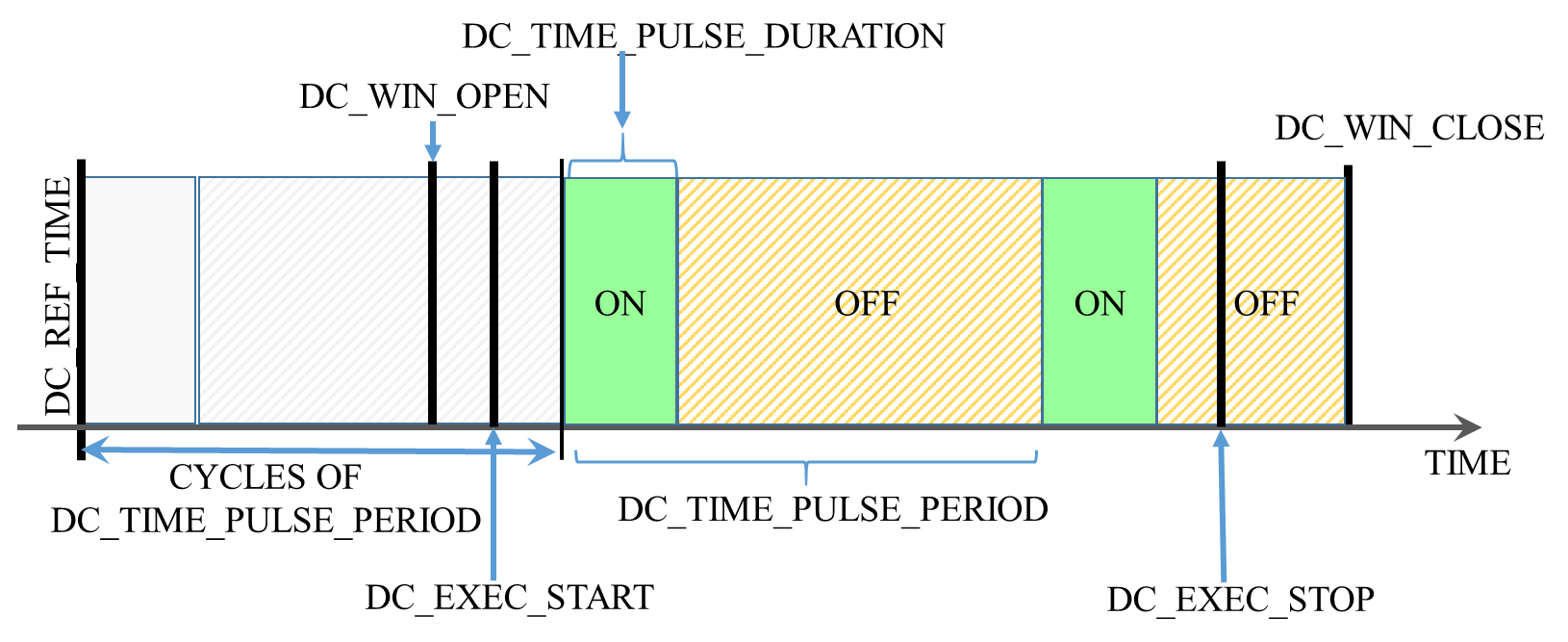


Fig. F- 3 Diagram of time-based duty cycle (DC\_TYPE = “TIME”)

**Angle-based duty cycle parameters**

Angle-based duty cycle parameters also define a window of duty cycle operations and actual execution interval and “ON” and “OFF” intervals, but in this case the “ON” and “OFF” intervals are triggered by angular limits as shown in Fig. F- 4.

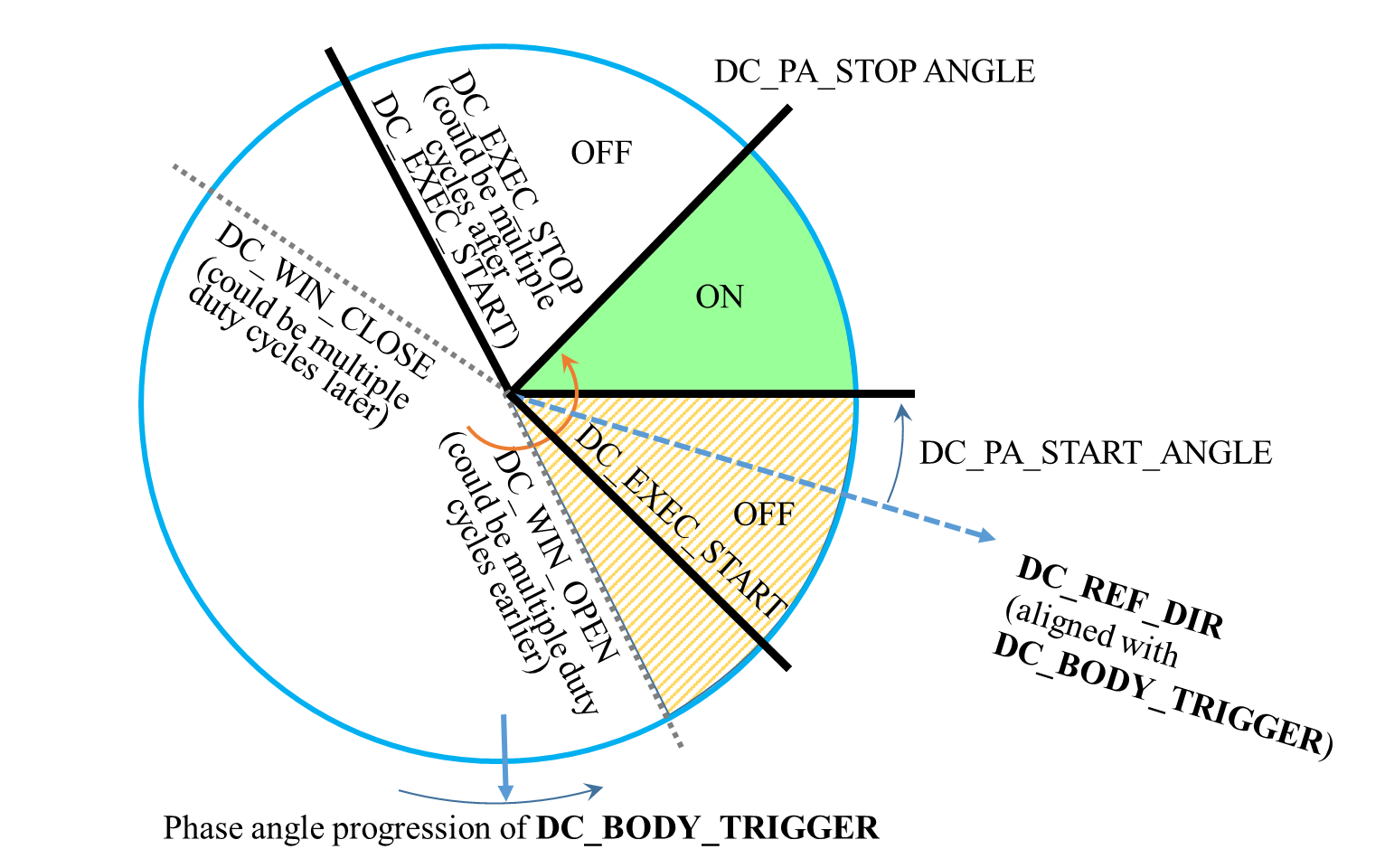


Fig. F- 4 Diagram of a rotating spacecraft body’s progression through an inertial clock angle-based duty cycle (DC\_TYPE = “TIME\_AND\_ANGLE”)

* 1. Orbit Determination Generalized Dilution of Precision (GDoP) formulation

This section of the informative technical annex defines the generalized dilution of precision (GDoP) formulation used in the orbit determination section of the OCM.

As described in ANNEX H, Reference [H-16], Generalized Dilution of Precision (GDoP) provides a method to assess the navigation performance over a time-integrated orbit solution. Generalized DoP broadens the DoP concept from the more common instantaneous geometric or kinematic solution of multiple transmit sources at one time, to a scenario associated with a receiver that can integrate metric range and/or Doppler (or range-rate) measurements over time, potentially from different transmit sources, to estimate the user’s orbital position and velocity state. It is defined as a function of the sum of information matrices to obtain an observability grammian associated with a set of metric tracking measurements collected over time.

The following equation for GDoP represents the uncertainty of an orbit state estimate as observed over time.

Where H represents the measurement matrix modeled in the state estimate, and W is a diagonal matrix of relative weights that represents the accuracy of the measurements. represents the information matrix, the inverse of which is the covariance matrix. By summing over time, one obtains an estimate of the state uncertainty from the time-derived measurement set.

* 1. Euler Axis/Angle interpolation

The Euler Axis and Angle representation of Euler’s Theorem (see ANNEX H, Reference [H-17], pp. 10-14) is an effective way to interpolate a series of covariance matrices, reference frames or maneuver, thrust, or acceleration vector directions.

**Interpolation of a series of three-dimensional vectors:**

As presented in [H-17], and consistent with the nomenclature of [H-1] where , , and represent the three vector components of axis of rotation and represents the angle of rotation, a time-based interpolation of adjacent unit vectors and in a reference frame can be undertaken as:

1. The axis of rotation can be obtained as:
2. Assuming a constant rotational rate during this interval,
3. The orthonormal rotation matrix is then:
4. From which the interpolated vector at time t is then
5. The accompanying vector magnitudes (e.g., eigenvalues or thrust or acceleration magnitudes) may be interpolated using Lagrange polynomials or linear expressions.

**Interpolation of a series of reference (or covariance eigenvector) frames:**

The eigenvector matrix contains the row-wise storage of the major, intermediate and minor eigenvectors at time t, taking care to ensure that this ordered “triad” of vectors adheres to the righthand rule. When interpolating between two eigenvector matrices derived from two adjacent covariance matrices respectively, can be evaluated as:

1. The rotation occurring between is: =
2. Compute
3. The angle of rotation from A to B is:
4. Exercising caution to accommodate nonunique cases (when as described in [H-17], the axis of rotation
5. The angle of rotation at time t is
6. can be computed using the above expression in step (3)
7. And finally, the eigenvector matrix
8. When interpolating a series of covariance matrices, the accompanying eigenvalues may be interpolated using Lagrange polynomials or linear expressions.
   1. Regular Expressions for Validation and Ingest of ODMs

#### To accomplish validation and ingest of KVN versions of the ODM, the use of Regular Expressions (referred to as “Regex”) is strongly encouraged where possible. Regex offers a detailed and rigorous way to ensure proper validation, interpretation and conformace to Orbit Data Message content. Most programming languages support the Regex feature, including C#, C++, Delphi, HTML5, Java and Javascript, MySQL, Oracle, PCRE, Perl, PHP, PowerShell, Python, R, Ruby, Scala, TCL, VBscript, Visual Basic, and XML Schema.

While these RegEx sequences can provide a good level of validation of the entries, the reader is cautioned that using them on a long series of orbit or covariance data can be very inefficient and slow. RegEx sequences are best utilized on individual values such as Keyword=SingleValue.

**Sample Regular Expression for “Keyword = CCSDS Date/Time Format”**

The CCSDS Timecode format specified in Section 7.5.10 provides a convenient illustration of the power of using regular expressions. The color-coded Regex string below may be used to readily match any general ODM KVN line which sets a KVN keyword to a Timecode value. The group naming capability (color-coded in green below) inherent with Regex is particularly useful, where the keyword, year, month, day, hour, minute, and second can be readily extracted and processed. As shown in Fig. F-5, this Regex sequence enforces the requirement that KVN keywords must be uppercase and can only consist of letters A-Z, digits 0-9, or underscores. Note that in this expression, the optional inclusion by the message creator of one or more white space characters with the “(\s\*)?” sequences allow for maximum flexibility while still retaining a rigorous validation. NOTE – in some languages, you must explicitly enable “^” and “$” matching at string line breaks to process a string containing a series of lines of the message.

^(?:\s\*)?(?<keyword>**[**0-9A-Z\_**]**\*)(?:\s\*)?=(?:\s\*)?(?<yr>(?:\d{4}))-(?<mo>(?:\d{1,2}))-(?<dy>(?:\d{1,2}))T(?<hr>(?:\d{1,2})):(?<mn>(?:\d{1,2})):(?<sc>(?:\d{0,2}(?:\.\d\*)?))(?:\s\*)?$

Fig. F- 5 Regex pattern for CCSDS Timecode.

**Regex Pattern Matching Sequence:**

Applying the above CCSDS Timecode Regex to a file containing the string “CREATION\_DATE = 2020-09-13T00:09:47.059345” as an example, Figure F-6 illustrates how this Regex expression is used to rigorously validate and match the string and identify the specified group names.

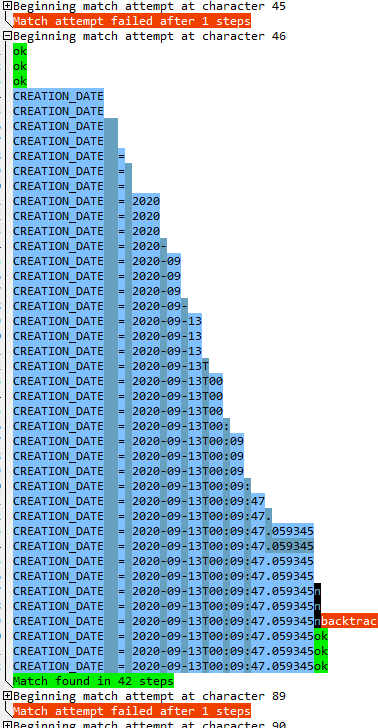


Fig. F- 6 Regex pattern matching sequence for CCSDS Timecode

**Sample Regular Expression for “Keyword = NonDecimalString”**

Another common and useful Regex addresses the setting of keywords to a free-text string. Consistent with requirements for KVN values as specified in Section 7.5, the Regex shown in Fig. F-7 matches this sequence.

^(?:\s\*)(?<keyword>**[**0-9A-Z\_**]**\*)(?:\s\*)=(?:\s\*)(?<value>(?:(?:**[**0-9A-Z\_\- **]**\*)|(?:**[**0-9a-z\_\- **]**\*)))(?:\s\*)$

Fig. F- 7 Regex for a non-decimal string

**Sample Regular Expression for “Keyword = FreeTextString”**

Free-text strings that are contain exclusively uppercase or lowercase alphabetical characters, numbers, and/or the decimal point, hyphen, space or underscore characters may be matched as follows. Note that the inclusion of a decimal point in this Regex sequence means that numerical KVN values can be matched with potentially unintended consequences; numbers should be specifically matched as a number (as shown below). Consistent with requirements for KVN values as specified in Section 7.5, the Regex shown in Fig. F-8 matches this sequence.

^(?:\s\*)(?<keyword>**[**0-9A-Z\_**]**\*)(?:\s\*)=(?:\s\*)(?<value>(?:(?:**[**0-9A-Z\_\.\- **]**\*)|(?:**[**0-9a-z\_\.\- **]**\*)))(?:\s\*)$

Fig. F- 8 Regex for free-text string

**Sample Regular Expression for “Keyword = CCSDS Numerical Value with optional units”**

Consistent with the requirements set forth in Sections 7.5.4 through 7.5.7, KVN values which are integers or non-integer fixed or floating-point numbers may be matched with the Regex sequence provided in Fig. F-9, with named groups “keyword,” “value,” and “units” set accordingly:

^(?:\s\*)(?<keyword>**[**0-9A-Za-z\_**]**\*)(?:\s\*)=(?:\s\*)(?<value>(?:**[**-+**]**?)(?:**[**0-9**]**+)(?:\.\d\*)?(?:**[**eE**][**+-**]**?(?:\d+))?)(?:(?:\s\*)(?:\[(?<unit>**[**0-9A-Za-z/\_\***]**\*)\]?))?(?:\s\*)?$

Fig. F- 9 Regex for string containing numerical value with optional units

**Sample Regular Expression for “Keyword = Multipartite CCSDS Numerical Values”**

For orbit, covariance, and/or maneuver lines providing a multipartite sequence of numerical values, the Regex pattern provided in Fig. F-10 may be used (in this example, to capture and set value1, value2 and value3 for a 3-element set of numbers):

^(?:\s\*)(?<value1>(?:**[**-+**]**?)(?:**[**0-9**]**\*)(?:\.\d\*)?(?:**[**eE**][**+-**]**?\d+)?)(?:\s+)(?<value2>(?:**[**-+**]**?)(?:**[**0-9**]**\*)(?:\.\d\*)?(?:**[**eE**][**+-**]**?\d+)?)(?:\s+)(?<value3>(?:**[**-+**]**?)(?:**[**0-9**]**\*)(?:\.\d\*)?(?:**[**eE**][**+-**]**?\d+)?)(?:\s\*)$

Fig. F- 10 Regex for string containing numerical value with optional units

* 1. Specific Energy Dissipation Rate (SEDR) formulation

An orbit’s Specific Energy Dissipation Rate (SEDR) represents the amount of energy (W/kg) being removed from a satellite’s orbit by atmospheric drag. It is a very useful metric for characterizing satellites since it accounts for both the drag environment (atmospheric density) and the ‘area to mass ratio’ of the specific object. It does this by including *drag acceleration* in the computation. Drag acceleration is proportional to atmospheric density and to satellite area to mass.

SEDR is computed as follows:

Instantaneous SEDR at time t is given by



where,

 = drag acceleration vector (inertial)

 = velocity vector (inertial)

Average SEDR over the orbit determination interval is given by



where, to correctly average over a complete orbital revolution, *T* is an integer multiple of the satellite period. This consideration is primarily for eccentric orbits. Aside from this consideration, *T* is the orbit determination interval.

* 1. Orbit Determination (OD) parameters

Satellite orbit determination (OD) estimates the position and velocity of an orbiting object from discrete observations (for greater detail, see [Reference H-7]). The set of observations includes external measurements from terrestrial or space-based sensors and measurements from instruments on the satellite itself. Satellite orbit propagation estimates the future state of motion of a satellite whose orbit has been determined from past observations. Though a satellite’s motion is described by a set of ideal equations of motion representing physical hypotheses, the observations used in OD are subject to systematic and random uncertainties. Therefore, OD and propagation are probabilistic and can only approximately describe the satellite’s motion. The degree of approximation that can be tolerated depends on the intended use of the orbital information.

Satellite owners/operators employ different techniques to determine orbits from active and passive observations, such that the same data inputs lead to different predictions when they are used in different models. Satellite owners/operators often accept orbit descriptions developed using physical models that others employ. Differences in orbit predictions caused using different physical models and numerical techniques can be significant.

A spacecraft is influenced by a variety of external forces, including terrestrial gravity, atmospheric drag, multibody gravitation, solar radiation pressure, tides, and spacecraft thrusters. Selection of forces for modelling depends on the accuracy and precision required from the OD process and the amount of available data. The complex modelling of these forces results in a highly nonlinear set of dynamical equations. Many physical and computational uncertainties limit the accuracy and precision of the spacecraft state that can be determined. Similarly, the observational data are inherently nonlinear with respect to the state of motion of the spacecraft and some influences might not have been included in models of the observation of the state of motion.

Satellite OD and propagation are stochastic estimation problems because observations are inherently noisy and uncertain and because not all phenomena that influence satellite motion are clearly discernible. Estimation is the process of extracting a desired time-varying signal from statistically noisy observations accumulated over time. Estimation encompasses data smoothing, which is statistical inference from past observations; filtering, which infers the signal from past observations and current observations; and prediction or propagation, which employs past and current observations to infer the future of the signal.

* + 1. Initial OD (IOD)

Initial OD (IOD) methods input tracking measurements with tracking platform locations, and output spacecraft position and velocity estimates. No a priori orbit estimate is required. Associated solution error magnitudes can be very large. IOD methods are sometimes nonlinear methods and are often trivial to implement. Measurement editing is typically not performed during IOD calculations because there are insufficient observations. Operationally, the OD process is frequently begun, or restarted, with IOD. IOD methods were derived by various authors: LaPlace, Poincaré, Gauss, Lagrange, Lambert, Gibbs, Herrick, Williams, Stumpp, Lancaster, Blanchard, Gooding, and Smith. Restarting techniques are most easily accomplished by using a solution from another technique.

* + 1. Methods for Subsequent OD
       1. Least squares differential correction

Least squares (LS) methods input tracking measurements with tracking platform locations and an a priori orbit estimate and output a refined orbit estimate. Associated solution error magnitudes are small when compared to IOD outputs. LS methods consist of an iterative sequence of corrections where sequence convergence is defined as a function of tracking measurement residual root mean square (RMS). Each correction is characterized by a minimization of the sum of squares of tracking measurement residuals. The LS method was derived first by Gauss in 1795 and then independently by Legendre.

* + - 1. Sequential processing

Sequential processing (SP) methods are distinguished from LS processing methods in that batches of data are considered sequentially, collecting a set of observations over a specified time interval and batch-processing one interval after the next. SP can be thought of as a moving time window whose contents are captured and processed at intervals, independent of previously processed batches of data. The analysis does not include process noise inputs and calculations. It is in no way equivalent to filter processing, in which each new observation is added to past observations, improving estimates in a rigorous, traceable manner.

* + - 1. Filter processing

Filter methods output refined state estimates sequentially at each observation time. Filter methods are forward-time recursive sequential methods consisting of a repeating pattern of time updates of the state of motion estimate and measurement updates of the state of motion estimate. The filter time update propagates the state estimate forward, and the filter measurement update incorporates the next measurement. The recursive pattern includes an important interval of filter initialization. Filter-smoother methods are backward-time recursive sequential methods consisting of a repeating pattern of state estimate refinement using filter outputs and backwards transition. Time transitions for both filter and smoother are dominated most significantly by numerical orbit propagators. The search for sequential processing was begun by Wiener, Kalman, Bucy, and others.

* + 1. Required information for orbit determination
       1. Observations

When observation data are communicated for collaborative or independent determination of satellite orbits, it is important to convey the observation types upon which that information is based. Ground-based, airborne, and space-based sensor observations are routinely used in orbit determination. These are conveyed in the CCSDS navigation family of messages using the Tracking Data Message (TDM) [Reference 9]. Many of these parameters are discussed in greater detail in [Reference H-7].

The following table describes some of the various observation types and sources.

Space surveillance observation product description<Tbl\_medium></Tbl\_medium>

|  |  |
| --- | --- |
| **Content** | **Source** |
| two angles and slant range | Radars |
| two angles | Baker-Nunn cameras, telescopes, binoculars, visual sightings |
| Azimuth | Direction finders, radio antenna, Radio telescope |
| Time of closest approach | Radars, radio receivers [for transmitting (Doppler) satellites], relay satellite |
| Range, angles, and rates | Radars, radio antenna, radio telescope |
| Pseudorange and carrier phase, as well as single, double, and triple differences of these basic measurement types | GPS or onboard inertial sensors |
| Direction cosines | Interferometric radars |

* + - 1. Observation location information

When data are communicated for collaborative or independent determination of satellite orbits, the following information about the observation location and measuring devices is important:

— facility location latitude, longitude, altitude, and the reference from which such are measured, (e.g., WGS-84);

— Calibration/correction values associated with the ground path.

— tracking station identification (ID);

— elevation cutoff;

— measurement biases;

— Clock and/or almanac information.

* + - 1. Satellite information

When performing OD using active transponder ranging, the transponder delay must be provided.

* + - 1. Estimation parameters and control

When data are communicated for collaborative or independent determination of satellite orbits, the following information about estimation parameters and control are necessary, as described in Section 6.2.9:

— estimation parameters;

— global force model controls;

— integration controls;

— database controls;

— observation uncertainties.

* + - 1. Force Model settings

Spacecraft are affected by conservative and non-conservative forces. Non-conservative phenomena dissipate spacecraft energy, for example by doing work on and heating the atmosphere, as described in Section 6.2.8.

* + - * 1. Gravity

Central body gravitational fields are typically described using terms of a Jacobi polynomial expansion of finite order and degree. Jacobi polynomials are a complete, orthonormal set over the unit sphere. There are two angular degrees of freedom, equivalent to latitude and longitude. Any analytic function within that space can be represented by a weighted doubly infinite series of Jacobi polynomials.

**Two-body motion or Keplerian motion** considers only the point-mass gravity of the attracting body. Both the spacecraft and the central body are considered point masses, with all mass concentrated at their centres of mass. This is the lowest- order zonal harmonic approximation.

A **J2 zonal perturbation** (first order) accounts for secular (constant rate over time) variations in the orbit elements due to central body oblateness, mainly nodal precession and rotation of the semi-major axis of orbit elements that are otherwise those of unperturbed, Newtonian orbits. J2 is a zonal harmonic coefficient in an infinite Jacobi polynomial series representation of the central body’s gravity field. The even zonal harmonic coefficients of the gravity field are the only coefficients that result in secular changes in satellite orbital elements. The J2 propagator includes only the dominant first-order secular effects.

For **generalized spherical harmonics**, it is impractical to determine the weights (coefficients) for a mathematically complete Jacobi polynomial series representation; therefore, the series is truncated at meaningful (in terms of precision of the representation of the gravity field) order (latitudinal) and degree (longitudinal). Where practical, it is recommended to use the full degree and order of the determined spherical harmonics field, as further truncation leads to introduction of non-conservative forces and deviation from the intended fidelity of the gravitational model.

If the order and degree are equal, the truncation is “square.” Since gravitational and other perturbations are not necessarily symmetrical in latitude and longitude, the best approximation for a given application is not necessarily square. The GRAVITY\_MODEL keyword in Section 6.2.8 can specify (independently) the degree and order that are used.

Static elements of the gravity field are the gravitation of the fixed portions of the distribution of the Earth’s mass. The static gravity field is not uniform. Dynamic elements of the gravity are caused by the fluid elements of the Earth’s core and by variations in the distribution of water. There are solid and ocean tides. The OCEAN\_TIDES\_MODEL and SOLID\_TIDES\_MODEL of Section 6.2.8 can be used to specify these settings.

**Multibody gravitation:** Certain phenomena only exist with more than two gravitationally interacting bodies. It is therefore important to describe information about third-body or multiple-body gravitational interactions if such are considered. The N\_BODY\_PERTURBATIONS keyword in Section 6.2.8 is used to specify which bodies were modelled.

* + - * 1. Atmospheric resistance (“Drag”)

Gas-dynamic resistance can be a significant dissipative force in low altitude orbits about any body with a significant atmosphere, e.g., Earth (LEOs), Venus, and Mars. It is usually sufficient to represent it as aerodynamic drag, the product of dynamic pressure, aggregated drag coefficient, and cross-sectional area.

Drag coefficient

Drag coefficient depends upon satellite geometry, orientation, and gas-dynamic regime described by Knudsen number (ratio of object characteristic dimension to gas mean free path) and Mach number (ratio of object speed to acoustic propagation speed). When describing how atmospheric resistance is represented, data providers provide the value of drag coefficient employed using the keyword in Section 6.2.8.

Atmospheric density model

Density within the Earth’s atmosphere varies temporally and spatially. Those variations are important in LEO. Some acceptable and most-often used atmospheric density models are as follows (although many may be utilized, as specified by the ATMOSPHERIC\_MODEL keyword in Section 6.2.8):

— 1976 Standard Harris-Priester;

— Jacchia 1970 and 1971;

— Jaccia-Roberts;

— Mass-Spectrometer-Incoherent-Scatter (MSIS) model, in several versions and extensions.

— Mars Global Reference Atmosphere Model (MARSGRAM)

— Venus Global Reference Atmosphere Model (VENUSGRAM)

These models typically require measurable input parameters that are “proxies” for the variation of atmospheric parameters. These include solar flux/geomagnetic particle flux which can be inferred from the meteorological observables as set by the keyword SW\_DATA\_SOURCE or FIXED\_YYYYY of Section 6.2.8:

— daily F10.7,

— average F10.7, and

— geomagnetic index.

* + - * 1. Radiation pressure

Momentum transfer from photons to satellites can be an important force for high earth orbits (HEOs), cislunar trajectories, and interplanetary trajectories. For solar sail missions, such radiation pressure is likely the primary source of propulsion. Radiation pressure depends on the area and surface characteristics of the satellite and the nature of the incident radiative fluxes. The Sun is the predominant direct source of electromagnetic radiation, but the Earth and the Moon also emit and reflect electromagnetic radiation. The keywords provided in Section 6.2.8 (SHADOW\_BODIES, SRP\_MODEL, ALBEDO\_MODEL, ALBEDO\_GRID\_SIZE) allow the user to specify radiation pressure settings used in the OD and orbit propagation regarding:

— solar radiation pressure coefficient;

— area-to-mass ratio;

— satellite reflectivity;

— shadow and shape factor models;

— eclipse models (cylindrical, dual-cone);

— Albedo and intensity at the satellite.

* + - 1. Orbit propagation

Orbit propagation or prediction has evolved synchronously with advances in computational capability. Initially, force models were greatly simplified, and most important non-gravitational forces were approximated analytically. These generally linearized approaches were valid only over short intervals or for small variations from two-body Keplerian motion.

Even when more precise numerical integration became feasible, execution times were often too long, and computation was too expensive to employ numerical integration on a regular basis. Semi-analytical techniques emerged that reduced numerical complexity and maintained run speed efficiency (with some compromise to precision) by providing formulae from which significant elements of the propagation workflow could be extracted.

Purely numerical integration of force models (i.e., not employing singly or doubly averaged physical approximations to describe important physical phenomena) are degraded primarily to the numerical phenomena degradation common to all discrete computations.

Analytical, numerical, and semi-analytical orbit propagation techniques are all known as “orbit propagators”.

* + - 1. Orbit elements

Orbit elements are the sets of parameters that emerge from the smoothing, filtering, or predictive estimation schemes. Six independent quantities and orbit elements describe the orbit of a satellite. A seventh variable designates the satellite position at a specific time of interest (epoch). There are many different sets of orbit elements (see orbit element set type; selected per ANNEX B, Section B7). Each is best suited for a particular application, such as aiming antennas, ease of manipulation in various coordinate systems, or estimating orbits from different types of measurements.

The traditionally used set of orbital elements is called the set of Keplerian elements; Keplerian elements parameters can be encoded as text in several formats. In semi-analytical propagation, mean orbit elements are often used, the most common of them is as conveyed in the NASA/NORAD “two-line elements” (TLE) format, originally designed for use with 80-column punched cards (but still in use because it is the most common format).

1. ODM EXAMPLES   
     
   (Informative)

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

* 1. 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.

CCSDS\_OPM\_VERS = 3.0

CREATION\_DATE = 2022-11-06T09:23:57

ORIGINATOR = JAXA

COMMENT GEOCENTRIC, CARTESIAN, EARTH FIXED

OBJECT\_NAME = OSPREY 5

OBJECT\_ID = 1998-999A

CENTER\_NAME = EARTH

REF\_FRAME = ITRF2000

TIME\_SYSTEM = UTC

EPOCH = 2022-12-18T14:28:15.1172

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

Fig. G‑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 = 2021-06-03T05:33:00.000

ORIGINATOR = GSOC

OBJECT\_NAME = EUTELSAT W4

OBJECT\_ID = 2021-028A

CENTER\_NAME = EARTH

REF\_FRAME = TOD

TIME\_SYSTEM = UTC

COMMENT State Vector

EPOCH = 2021-06-03T00:00:00.000

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 = 0.020842611INCLINATION = 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 = 2021-06-03T09:00:34.1

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 = 2021-06-05T18:59:21.0

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]

Fig. G‑2: OPM file example with optional Keplerian elements and two maneuvers

CCSDS\_OPM\_VERS = 3.0

CREATION\_DATE = 2022-11-06T09:23:57

ORIGINATOR = JAXA

MESSAGE\_ID = OPM 201113719185

COMMENT GEOCENTRIC, CARTESIAN, EARTH FIXED

OBJECT\_NAME = OSPREY 5

OBJECT\_ID = 2022-999A

CENTER\_NAME = EARTH

REF\_FRAME = ITRF1997

TIME\_SYSTEM = UTC

EPOCH = 2022-12-18T14:28:15.1172

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

Fig. G‑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 = 2021-06-03T05:33:00.000

ORIGINATOR = GSOC

OBJECT\_NAME = EUTELSAT W4

OBJECT\_ID = 2021-028A

CENTER\_NAME = EARTH

REF\_FRAME = TOD

TIME\_SYSTEM = UTC

COMMENT State Vector

EPOCH = 2021-06-03T00:00:00.000

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 [km\*\*2]

CY\_X = 4.618927349220216e-04 [km\*\*2]

CY\_Y = 6.782421679971363e-04 [km\*\*2]

CZ\_X = -3.070007847730449e-04 [km\*\*2]

CZ\_Y = -4.221234189514228e-04 [km\*\*2]

CZ\_Z = 3.231931992380369e-04 [km\*\*2]

CX\_DOT\_X = -3.349365033922630e-07 [km\*\*2/s]

CX\_DOT\_Y = -4.686084221046758e-07 [km\*\*2/s]

CX\_DOT\_Z = 2.484949578400095e-07 [km\*\*2/s]

CX\_DOT\_X\_DOT = 4.296022805587290e-10 [km\*\*2/s\*\*2]

CY\_DOT\_X = -2.211832501084875e-07 [km\*\*2/s]

CY\_DOT\_Y = -2.864186892102733e-07 [km\*\*2/s]

CY\_DOT\_Z = 1.798098699846038e-07 [km\*\*2/s]

CY\_DOT\_X\_DOT = 2.608899201686016e-10 [km\*\*2/s\*\*2]

CY\_DOT\_Y\_DOT = 1.767514756338532e-10 [km\*\*2/s\*\*2]

CZ\_DOT\_X = -3.041346050686871e-07 [km\*\*2/s]

CZ\_DOT\_Y = -4.989496988610662e-07 [km\*\*2/s]

CZ\_DOT\_Z = 3.540310904497689e-07 [km\*\*2/s]

CZ\_DOT\_X\_DOT = 1.869263192954590e-10 [km\*\*2/s\*\*2]

CZ\_DOT\_Y\_DOT = 1.008862586240695e-10 [km\*\*2/s\*\*2]

CZ\_DOT\_Z\_DOT = 6.224444338635500e-10 [km\*\*2/s\*\*2]

USER\_DEFINED\_EARTH\_MODEL = WGS-84

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

* 1. OPM example in XML

Fig. G‑5 contains an example of an OPM in Extensible Markup Language (XML) format.

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

<opm xmlns:xsi:noNamespaceSchemaLocation="https://sanaregistry.org/r/ndmxml\_unqualified/ndmxml-3.0.0-master-3.0.xsd"

id="CCSDS\_OPM\_VERS" version="3.0">

<header>

<COMMENT>THIS IS AN XML VERSION OF THE OPM</COMMENT>

<CREATION\_DATE>2022-11-06T09:23:57</CREATION\_DATE>

<ORIGINATOR>JAXA</ORIGINATOR>

<MESSAGE\_ID>OPM 201113719185</MESSAGE\_ID>

</header>

<body>

<segment>

<metadata>

<COMMENT>GEOCENTRIC, CARTESIAN, EARTH FIXED</COMMENT>

<OBJECT\_NAME>OSPREY 5</OBJECT\_NAME>

<OBJECT\_ID>2022-999A</OBJECT\_ID>

<CENTER\_NAME>EARTH</CENTER\_NAME>

<REF\_FRAME>ITRF1997</REF\_FRAME>

<TIME\_SYSTEM>UTC</TIME\_SYSTEM>

</metadata>

<data>

<stateVector>

<EPOCH>2022-12-18T14:28:15.1172</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>

</segment>

</body>

</opm>

Fig. G‑5: OPM file example in XML format

The following are examples of Orbit Mean-Element Messages (OMMs). All of these examples are based on the TLE shown in Fig. G‑6.

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

Fig. G‑6: Example Two Line Element Set (TLE)

* 1. OMM examples in KVN

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

CCSDS\_OMM\_VERS = 3.0

CREATION\_DATE = 2020-065T16:00:00

ORIGINATOR = NOAA

MESSAGE\_ID = OMM 202013719185

OBJECT\_NAME = GOES 9

OBJECT\_ID = 1995-025A

CENTER\_NAME = EARTH

REF\_FRAME = TEME

TIME\_SYSTEM = UTC

MEAN\_ELEMENT\_THEORY = SGP/SGP4

EPOCH = 2020-064T10:34:41.4264

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

Fig. G‑7: OMM file example without covariance matrix

CCSDS\_OMM\_VERS = 3.0

CREATION\_DATE = 2020-065T16:00:00

ORIGINATOR = NOAA

OBJECT\_NAME = GOES 9

OBJECT\_ID = 1995-025A

CENTER\_NAME = EARTH

REF\_FRAME = TEME

TIME\_SYSTEM = UTC

MEAN\_ELEMENT\_THEORY = SGP/SGP4

EPOCH = 2020-064T10:34:41.4264

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

Fig. G‑8: OMM file example with covariance matrix

CCSDS\_OMM\_VERS = 3.0

CREATION\_DATE = 2020-065T16:00:00

ORIGINATOR = NOAA

OBJECT\_NAME = GOES 9

OBJECT\_ID = 1995-025A

CENTER\_NAME = EARTH

REF\_FRAME = TEME

TIME\_SYSTEM = UTC

MEAN\_ELEMENT\_THEORY = SGP/SGP4

EPOCH = 2020-064T10:34:41.4264

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

Fig. G‑9: OMM with units and a user-defined parameter

* 1. OMM example in XML

Fig. G‑10 contains an example of an OMM in Extensible Markup Language (XML) format.

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

<omm xmlns: xsi:noNamespaceSchemaLocation="https://sanaregistry.org/r/ndmxml\_unqualified/ndmxml-3.0.0-master-3.0.xsd"

id="CCSDS\_OMM\_VERS" version="3.0">

<header>

<COMMENT> THIS IS AN XML VERSION OF THE OMM </COMMENT>

<CREATION\_DATE>2020-065T16:00:00</CREATION\_DATE>

<ORIGINATOR>NOAA</ORIGINATOR>

<MESSAGE\_ID> OMM 202013719185</MESSAGE\_ID>

</header>

<body>

<segment>

<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>SGP4</MEAN\_ELEMENT\_THEORY>

</metadata>

<data>

<meanElements>

<EPOCH>2020-064T10:34:41.4264</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>3.331349476038534e-04</CX\_X>

<CY\_X>4.618927349220216e-04</CY\_X>

<CY\_Y>6.782421679971363e-04</CY\_Y>

<CZ\_X>-3.070007847730449e-04</CZ\_X>

<CZ\_Y>-4.221234189514228e-04</CZ\_Y>

<CZ\_Z>3.231931992380369e-04</CZ\_Z>

<CX\_DOT\_X>-3.349365033922630e-07</CX\_DOT\_X>

<CX\_DOT\_Y>-4.686084221046758e-07</CX\_DOT\_Y>

<CX\_DOT\_Z>2.484949578400095e-07</CX\_DOT\_Z>

<CX\_DOT\_X\_DOT>4.296022805587290e-10</CX\_DOT\_X\_DOT>

<CY\_DOT\_X>-2.211832501084875e-07</CY\_DOT\_X>

<CY\_DOT\_Y>-2.864186892102733e-07</CY\_DOT\_Y>

<CY\_DOT\_Z>1.798098699846038e-07</CY\_DOT\_Z>

<CY\_DOT\_X\_DOT>2.608899201686016e-10</CY\_DOT\_X\_DOT>

<CY\_DOT\_Y\_DOT>1.767514756338532e-10</CY\_DOT\_Y\_DOT>

<CZ\_DOT\_X>-3.041346050686871e-07</CZ\_DOT\_X>

<CZ\_DOT\_Y>-4.989496988610662e-07</CZ\_DOT\_Y>

<CZ\_DOT\_Z>3.540310904497689e-07</CZ\_DOT\_Z>

<CZ\_DOT\_X\_DOT>1.869263192954590e-10</CZ\_DOT\_X\_DOT>

<CZ\_DOT\_Y\_DOT>1.008862586240695e-10</CZ\_DOT\_Y\_DOT>

<CZ\_DOT\_Z\_DOT>6.224444338635500e-10</CZ\_DOT\_Z\_DOT>

</covarianceMatrix>

</data>

</segment>

</body>

</omm>

Fig. G‑10: OMM file example in XML format

* 1. OEM examples in KVN

The following figures are examples of OEMs in Keyword Value Notation (KVN) format. 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 = 2019-12-18T12:00:00.331

USEABLE\_START\_TIME = 2019-12-18T12:10:00.331

USEABLE\_STOP\_TIME = 2019-12-28T21:23:00.331

STOP\_TIME = 2019-12-28T21:28:00.331

INTERPOLATION = HERMITE

INTERPOLATION\_DEGREE = 7

META\_STOP

COMMENT This file was produced by M.R. Pigs, OSAR NAV/JPL, 2019NOV 04. It is

COMMENT to be used for DSN scheduling purposes only.

2019-12-18T12:00:00.331 2789.619 -280.045 -1746.755 4.73372 -2.49586 -1.04195

2019-12-18T12:01:00.331 2783.419 -308.143 -1877.071 5.18604 -2.42124 -1.99608

2019-12-18T12:02:00.331 2776.033 -336.859 -2008.682 5.63678 -2.33951 -1.94687

*< intervening data records omitted here >*

2019-12-28T21:28:00.331 -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 = 2019-12-28T21:29:07.267

USEABLE\_START\_TIME = 2019-12-28T22:08:02.5

USEABLE\_STOP\_TIME = 2019-12-30T01:18:02.5

STOP\_TIME = 2019-12-30T01:28:02.267

INTERPOLATION = HERMITE

INTERPOLATION\_DEGREE = 7

META\_STOP

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

2019-12-28T21:29:07.267 -2432.166 -063.042 1742.754 7.33702 -3.495867 -1.041945

2019-12-28T21:59:02.267 -2445.234 -878.141 1873.073 1.86043 -3.421256 -0.996366

2019-12-28T22:00:02.267 -2458.079 -683.858 2007.684 6.36786 -3.339563 -0.946654

*< intervening data records omitted here >*

2019-12-30T01:28:02.267 2164.375 1115.811 -688.131 -3.53328 -2.88452 0.88535

Fig. G‑11: OEM Example with No Acceleration, No Covariance

CCSDS\_OEM\_VERS = 3.0

COMMENT OEM WITH OPTIONAL ACCELERATIONS

CREATION\_DATE = 2019-11-04T17:22:31

ORIGINATOR = NASA/JPL

META\_START

OBJECT\_NAME = MARS GLOBAL SURVEYOR

OBJECT\_ID = 1996-028A

CENTER\_NAME = MARS BARYCENTER

REF\_FRAME = EME2000

TIME\_SYSTEM = UTC

START\_TIME = 2019-12-18T12:00:00.331

USEABLE\_START\_TIME = 2019-12-18T12:10:00.331

USEABLE\_STOP\_TIME = 2019-12-28T21:23:00.331

STOP\_TIME = 2019-12-28T21:28:00.331

INTERPOLATION = HERMITE

INTERPOLATION\_DEGREE = 7

META\_STOP

COMMENT This file was produced by M.R. Somebody, MSOO NAV/JPL, 2021 NOV 04. It is

COMMENT to be used for DSN scheduling purposes only.

2019-12-18T12:00:00.331 2789.6 -280.0 -1746.8 4.73 -2.50 -1.04 0.008 0.001 -0.159

2019-12-18T12:01:00.331 2783.4 -308.1 -1877.1 5.19 -2.42 -2.00 0.008 0.001 0.001

2019-12-18T12:02:00.331 2776.0 -336.9 -2008.7 5.64 -2.34 -1.95 0.008 0.001 0.159

< intervening data records omitted here >

2019-12-28T21:28:00.331 -3881.0 564.0 -682.8 -3.29 -3.67 1.64 -0.003 0.000 0.000

Fig. G‑12: OEM Example with Optional Accelerations

CCSDS\_OEM\_VERS = 3.0

CREATION\_DATE = 2019-11-04T17:22:31

ORIGINATOR = NASA/JPL

MESSAGE\_ID = OEM 201113719185

META\_START

OBJECT\_NAME = MARS GLOBAL SURVEYOR

OBJECT\_ID = 1996-062A

CENTER\_NAME = MARS BARYCENTER

REF\_FRAME = EME2000

TIME\_SYSTEM = UTC

START\_TIME = 2019-12-28T21:29:07.267

USEABLE\_START\_TIME = 2019-12-28T22:08:02.5

USEABLE\_STOP\_TIME = 2019-12-30T01:18:02.5

STOP\_TIME = 2019-12-30T01:28:02.267

INTERPOLATION = HERMITE

INTERPOLATION\_DEGREE = 7

META\_STOP

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

2019-12-28T21:29:07.267 -2432.166 -063.042 1742.754 7.33702 -3.495867 -1.041945

2019-12-28T21:59:02.267 -2445.234 -878.141 1873.073 1.86043 -3.421256 -0.996366

2019-12-28T22:00:02.267 -2458.079 -683.858 2007.684 6.36786 -3.339563 -0.946654

*< intervening data records omitted here >*

2019-12-30T01:28:02.267 2164.375 1115.811 -688.131 -3.53328 -2.88452 0.88535

COVARIANCE\_START

EPOCH = 2019-12-28T21:29:07.267

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 = 2019-12-29T21:00:00

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

Fig. G‑13: OEM Example with Optional Covariance Matrices

* 1. OEM example in XML

Fig. G‑14 contains an example of an Orbit Ephemeris Message in Extensible Markup Language (XML) format.

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

<oem xmlns: xsi:noNamespaceSchemaLocation="https://sanaregistry.org/r/ndmxml\_unqualified/ndmxml-3.0.0-master-3.0.xsd"

id="CCSDS\_OEM\_VERS" version="3.0">

<header>

<COMMENT>OEM WITH OPTIONAL ACCELERATIONS</COMMENT>

<CREATION\_DATE>2019-11-04T17:22:31</CREATION\_DATE>

<ORIGINATOR>NASA/JPL</ORIGINATOR>

<MESSAGE\_ID>OEM 201113719185</MESSAGE\_ID>

</header>

<body>

<segment>

<metadata>

<OBJECT\_NAME>MARS GLOBAL SURVEYOR</OBJECT\_NAME>

<OBJECT\_ID>2021-028A</OBJECT\_ID>

<CENTER\_NAME>MARS BARYCENTER</CENTER\_NAME>

<REF\_FRAME>EME2000</REF\_FRAME>

<TIME\_SYSTEM>UTC</TIME\_SYSTEM>

<START\_TIME>2019-12-18T12:00:00.331</START\_TIME>

<USEABLE\_START\_TIME>2019-12-18T12:10:00.331</USEABLE\_START\_TIME>

<USEABLE\_STOP\_TIME>2019-12-28T21:23:00.331</USEABLE\_STOP\_TIME>

<STOP\_TIME>2019-12-28T21:28:00.331</STOP\_TIME>

<INTERPOLATION>HERMITE</INTERPOLATION>

<INTERPOLATION\_DEGREE>7</INTERPOLATION\_DEGREE>

</metadata>

<data>

<COMMENT>Produced by M.R. Sombedody, MSOO NAV/JPL, 2019 OCT 11. It is</COMMENT>

<COMMENT>to be used for DSN scheduling purposes only.</COMMENT>

<stateVector>

<EPOCH>2019-12-18T12:00:00.331</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>2019-12-18T12:01:00.331</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>2019-12-18T12:02:00.331</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>2019-12-28T21:28:00.331</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>2019-12-28T22:28:00.331</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>

</segment>

</body>

</oem>

Fig. G‑14: OEM file example in XML format

* 1. 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 trajectory states, followed by a time history of Keplerian elements; and the fourth includes a time series of covariance matrices.

CCSDS\_OCM\_VERS = 3.0

CREATION\_DATE = 2022-11-06T09:23:57

ORIGINATOR = JAPAN AEROSPACE EXPLORATION AGENCY

META\_START

TIME\_SYSTEM = UTC

EPOCH\_TZERO = 2022-12-18T14:28:15.1172

META\_STOP

TRAJ\_START

TRAJ\_BASIS=SIMULATED

TRAJ\_REF\_FRAME=ITRF2000

TRAJ\_UNITS= [km,km,km,km/s,km/s,km/s]

0.0 2854.5 -2916.2 -5360.7 5.90 4.86 0.52 0.0037 -0.0038 -0.0070

120.0 5478.6 434.3 -3862.5 2.50 5.87 4.29 0.0072 0.0006 -0.0051

240.0 4146.0 -1655.8 -5038.3 4.80 5.58 2.16 0.0054 -0.0022 -0.0066

< intervening data records omitted here >

86400.0 -1553.4 -4848.7 -4406.5 6.73 1.01 -3.53 -0.002 -0.0063 -0.0058

TRAJ\_STOP

Fig. G‑15: Simple/Succinct OCM File example with only Cartesian ephemeris. In this example, CENTER\_NAME defaults to EARTH and orbit type (TRAJ\_TYPE) to CARTPV. In this example, at the expense of readability, KVN values are unaligned to minimize message storage and transmission size.

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 = 2022-11-06T09:23:57

ORIGINATOR = JAPAN AEROSPACE EXPLORATION AGENCY

MESSAGE\_ID = OCM 201113719185

META\_START

OBJECT\_NAME = OSPREY 5

INTERNATIONAL\_DESIGNATOR = 2022-999A

ORIGINATOR\_POC = R. Rabbit

ORIGINATOR\_POSITION = Flight Dynamics Mission Design Lead

ORIGINATOR\_PHONE = (719)555-1234

ORIGINATOR\_ADDRESS = 5040 Spaceflight Ave., Cocoa Beach FL USA 12345

TECH\_POC = Mr. Rodgers

TECH\_PHONE = (719)555-1234

TECH\_EMAIL = email@email.XXX

TIME\_SYSTEM = UT1

EPOCH\_TZERO = 2022-12-18T00:00:00.0000

TAIMUTC\_AT\_TZERO = 36 [s]

UT1MUTC\_AT\_TZERO = .357 [s]

META\_STOP

TRAJ\_START

COMMENT GEOCENTRIC, CARTESIAN, EARTH FIXED

COMMENT THIS IS MY SECOND COMMENT LINE

TRAJ\_BASIS = PREDICTED

TRAJ\_REF\_FRAME = EFG

TRAJ\_TYPE = CARTPV

TRAJ\_UNITS = [km, km, km, km/s, km/s, km/s]

2022-12-18T14:28:25.1172 2854.533 -2916.187 -5360.774 5.688 4.652 0.520

TRAJ\_STOP

PHYS\_START

COMMENT Spacecraft Physical Characteristics:

WET\_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\_INT = 1.0 [m]

OEB\_MIN = 0.5 [m]

AREA\_ALONG\_OEB\_MAX = 0.5 [m\*\*2]

AREA\_ALONG\_OEB\_INT = 1.0 [m\*\*2]

AREA\_ALONG\_OEB\_MIN = 2.0 [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]

N\_BODY\_PERTURBATIONS = MOON, SUN

FIXED\_GEOMAG\_KP = 12.0

FIXED\_F10P7 = 105.0

FIXED\_F10P7\_MEAN = 120.0

PERT\_STOP

USER\_START

USER\_DEFINED\_CONSOLE\_POC = MAXWELL RAFERTY

USER\_DEFINED\_EARTH\_MODEL = WGS-84

USER\_STOP

Fig. G‑16: OCM example with space object characteristics and perturbations

CCSDS\_OCM\_VERS = 3.0

CREATION\_DATE = 2022-11-06T09:23:57

ORIGINATOR = JAPAN AEROSPACE EXPLORATION AGENCY

META\_START

EPOCH\_TZERO = 2022-12-18T14:28:15.1172

META\_STOP

TRAJ\_START

COMMENT ORBIT EPHEMERIS INCORPORATING DEPLOYMENTS AND MANEUVERS (BELOW)

TRAJ\_BASIS = PREDICTED

TRAJ\_REF\_FRAME = TOD\_EARTH

TRAJ\_FRAME\_EPOCH = 2022-12-18T14:28:15.1172

TRAJ\_TYPE = CARTPVA

TRAJ\_UNITS = [km,km,km,km/s,km/s,km/s,km/s\*\*2,km/s\*\*2,km/s\*\*2]

2022-12-18T14:36:05.0 2854.5 -2916.2 -5360.7 5.90 4.86 0.52 0.0037 -0.0038 -0.0070

2022-12-18T14:38:05.0 5478.6 434.3 -3862.5 2.50 5.87 4.29 0.0072 0.0006 -0.0051

2022-12-18T14:40:05.0 4146.0 -1655.8 -5038.3 4.80 5.58 2.16 0.0054 -0.0022 -0.0066

< intervening data records omitted here >

2022-12-19T14:36:05.0 -1553.4 -4848.7 -4406.5 6.73 1.01 -3.53 -0.002 -0.0063 -0.0058

TRAJ\_STOP

PHYS\_START

COMMENT Spacecraft Physical Characteristics:

DRAG\_CONST\_AREA = 10.00 [m\*\*2]

DRAG\_COEFF\_NOM = 2.300

DRAG\_UNCERTAINTY = 5.0

WET\_MASS = 200.0 [kg]

SRP\_CONST\_AREA = 4.00

SOLAR\_RAD\_COEFF = 1.300

PHYS\_STOP

MAN\_START

COMMENT = Ten 1kg objects deployed at 1 m/s from 190kg host over 90 s time

COMMENT = 20 deg off of back-track direction

MAN\_ID = E\_W\_20160305B

MAN\_BASIS = CANDIDATE

MAN\_DEVICE\_ID = DEPLOY

MAN\_PURPOSE = DEPLOY

MAN\_REF\_FRAME = RSW\_ROTATING

MAN\_COMPOSITION = TIME\_RELATIVE, DEPLOY\_ID, DEPLOY\_DV\_X, DEPLOY\_DV\_Y, **<*cont.*>**

DEPLOY\_DV\_Z, DEPLOY\_MASS, DEPLOY\_DV\_SIGMA, DEPLOY\_DV\_RATIO, DEPLOY\_DV\_CDA

MAN\_UNITS = [n/a, km/s, km/s, km/s, kg, %, n/a, m\*\*2]

500.0 CUBESAT\_10 2.8773E-4 -9.3969E-4 1.8491E-4 -1.0 5.0 -0.005025 0.033

510.0 CUBESAT\_11 1.4208E-4 -9.3969E-4 3.1111E-4 -1.0 5.0 -0.005051 0.033

520.0 CUBESAT\_12 -4.8670E-5 -9.3969E-4 3.3854E-4 -1.0 5.0 -0.005076 0.033

530.0 CUBESAT\_13 -2.2398E-4 -9.3969E-4 2.5848E-4 -1.0 5.0 -0.005102 0.033

540.0 CUBESAT\_14 -3.2817E-4 -9.3969E-4 9.6360E-5 -1.0 5.0 -0.005128 0.033

550.0 CUBESAT\_15 -3.2817E-4 -9.3969E-4 -9.6360E-5 -1.0 5.0 -0.005154 0.033

560.0 CUBESAT\_16 -2.2398E-4 -9.3969E-4 -2.5848E-4 -1.0 5.0 -0.005181 0.033

570.0 CUBESAT\_17 -4.8670E-5 -9.3969E-4 -3.3854E-4 -1.0 5.0 -0.005208 0.033

580.0 CUBESAT\_18 1.4208E-4 -9.3969E-4 -3.1111E-4 -1.0 5.0 -0.005236 0.033

590.0 CUBESAT\_19 2.8773E-4 -9.3969E-4 -1.8491E-4 -1.0 5.0 -0.005263 0.033

MAN\_STOP

MAN\_START

COMMENT = 100 s of 0.5N +in-track thr w/η=0.95, Isp=300s, 5% 1-sigma error

COMMENT = NOTE that this OCM specifies a future compound maneuver, with

COMMENT = deployment during low-level host platform thrusting.

MAN\_ID = E\_W\_20160305B

MAN\_BASIS = CANDIDATE

MAN\_DEVICE\_ID = THR\_01

MAN\_PURPOSE = ORBIT

MAN\_REF\_FRAME = RSW\_ROTATING

MAN\_COMPOSITION = TIME\_ABSOLUTE, MAN\_DURA, THR\_X, THR\_Y, THR\_Z, THR\_MAG\_SIGMA, THR\_INTERP, THR\_ISP, THR\_EFFIC

MAN\_UNITS = [s, N, N, N, %, n/a, s, n/a]

2022-12-18T14:36:35.1172 500.0 100.0 0.0 0.5 0.0 5.0 ON 300.0 0.95

MAN\_STOP

PERT\_START

COMMENT Perturbations specification

GM = 398600.4415 [km\*\*3/s\*\*2]

PERT\_STOP

OD\_START

COMMENT Orbit Determination information

OD\_ID = OD #10059

OD\_PREV\_ID = OD #10058

OD\_METHOD = SF: ODTK

OD\_EPOCH = 2022-12-18T11:17:33

OBS\_USED = 273

TRACKS\_USED = 91

OD\_STOP

Fig. G‑17: OCM example with deployed objects and low-level thrusting maneuver during deployment to make “string-of-pearls” deployment.

NOTE 1 – This example is aligned with a multi-deployment simulation for a future mission, thus the specific mission is not identified.

NOTE 2 – The demarcation “<cont.>” indicates that this single line is shown, for display purposes only, in multiple lines. This demarcation shall not be used in the actual OCM message, as all specified content shall be provided on the same line as its matching time tag.

CCSDS\_OCM\_VERS = 3.0

CREATION\_DATE = 2022-11-06T09:23:57

ORIGINATOR = JAPAN AEROSPACE EXPLORATION AGENCY

META\_START

OBJECT\_NAME = OSPREY 5

OBJECT\_DESIGNATOR= 98765

INTERNATIONAL\_DESIGNATOR = 2022-999A

CATALOG\_NAME = CSPOC

TIME\_SYSTEM = UTC

EPOCH\_TZERO = 2022-12-18T14:28:15.1172

META\_STOP

TRAJ\_START

TRAJ\_BASIS = PREDICTED

TRAJ\_REF\_FRAME = TOD\_EARTH

TRAJ\_FRAME\_EPOCH = 2022-12-18T14:28:15.1172

USEABLE\_START\_TIME=2022-12-18T14:32:15.1172

USEABLE\_STOP\_TIME= 2022-12-19T14:26:15.1172

TRAJ\_TYPE = CARTPVA

TRAJ\_UNITS = [km,km,km,km/s,km/s,km/s,km/s\*\*2,km/s\*\*2,km/s\*\*2]

0.0 2854.5 -2916.2 -5360.7 5.90 4.86 0.52 0.0037 -0.0038 -0.0070

120.0 5478.6 434.3 -3862.5 2.50 5.87 4.29 0.0072 0.0006 -0.0051

240.0 4146.0 -1655.8 -5038.3 4.80 5.58 2.16 0.0054 -0.0022 -0.0066

< intervening data records omitted here >

86400.0 -1553.4 -4848.7 -4406.5 6.73 1.01 -3.53 -0.002 -0.0063 -0.0058

TRAJ\_STOP

TRAJ\_START

TRAJ\_BASIS = DETERMINED

TRAJ\_REF\_FRAME = J2000

TRAJ\_TYPE = KEPLERIAN

TRAJ\_UNITS = [km, n/a, deg, deg, deg, deg]

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

TRAJ\_STOP

PHYS\_START

COMMENT Spacecraft Physical Characteristics:

DRAG\_CONST\_AREA = 10.00 [m\*\*2]

DRAG\_COEFF\_NOM = 2.300

WET\_MASS = 100.0 [kg]

SRP\_CONST\_AREA = 4.00

SOLAR\_RAD\_COEFF = 1.300

PHYS\_STOP

MAN\_START

COMMENT = 200 s of 10N thrust (in-track transitioning to radial)

COMMENT = w/effic η=0.95, Isp=300s, 5% 1-sigma error

MAN\_ID = E\_W\_20160305B

MAN\_BASIS = CANDIDATE

MAN\_DEVICE\_ID = THR\_01

MAN\_PURPOSE = ORBIT

MAN\_REF\_FRAME = RSW\_ROTATING

MAN\_COMPOSITION = TIME\_RELATIVE, MAN\_DURA, THR\_X, THR\_Y, THR\_Z, THR\_MAG\_SIGMA, THR\_INTERP, THR\_ISP, THR\_EFFIC

MAN\_UNITS = [s, N, N, N, %, n/a, s, n/a]

500.0 100.0 0.0 10.0 0.0 5.0 ON 300.0 0.95

600.0 100.0 10.0 0.0 0.0 5.0 OFF 300.0 0.95

MAN\_STOP

PERT\_START

COMMENT Perturbations specification

GM = 398600.4415 [km\*\*3/s\*\*2]

PERT\_STOP

OD\_START

COMMENT Orbit Determination information

OD\_ID = OD #10059

OD\_PREV\_ID = OD #10058

OD\_METHOD = BWLS: BAHN

OD\_EPOCH = 2022-12-06T11:17:33

OBS\_USED = 273

TRACKS\_USED = 91

OD\_STOP

Fig. G‑18: OCM example with multiple orbit time histories, a maneuver, OD, Cartesian & Keplerian ephemeris

CCSDS\_OCM\_VERS = 3.0

CREATION\_DATE = 2022-11-06T09:23:57

ORIGINATOR = JAPAN AEROSPACE EXPLORATION AGENCY

META\_START

OBJECT\_NAME = OSPREY 5

INTERNATIONAL\_DESIGNATOR = 2022-999A

TIME\_SYSTEM = UTC

EPOCH\_TZERO = 2022-12-18T14:28:15.1172

META\_STOP

TRAJ\_START

COMMENT GEOCENTRIC, CARTESIAN, EARTH FIXED

TRAJ\_BASIS = PREDICTED

CENTER\_NAME = EARTH

TRAJ\_REF\_FRAME = TOD\_EARTH

TRAJ\_FRAME\_EPOCH = 2022-12-18T14:28:15.1172

TRAJ\_TYPE = CARTPVA

0.0 2854.5 -2916.2 -5360.7 5.90 4.86 0.52 0.0037 -0.0038 -0.0070

120.0 5478.6 434.3 -3862.5 2.50 5.87 4.29 0.0072 0.0006 -0.0051

240.0 4146.0 -1655.8 -5038.3 4.80 5.58 2.16 0.0054 -0.0022 -0.0066

< intervening data records omitted here >

86400 -1553.4 -4848.7 -4406.5 6.73 1.01 -3.53 -0.002 -0.0063 -0.0058

TRAJ\_STOP

PHYS\_START

COMMENT Spacecraft Physical Characteristics:

DRAG\_CONST\_AREA = 10.000 [m\*\*2]

DRAG\_COEFF\_NOM = 2.300

WET\_MASS = 1913.000 [kg]

SRP\_CONST\_AREA = 10.000 [m\*\*2]

SOLAR\_RAD\_COEFF = 1.300

PHYS\_STOP

COV\_START

COV\_BASIS = PREDICTED

COV\_REF\_FRAME = J2000

COV\_TYPE = ADBARV

COV\_ORDERING = LTM

COV\_UNITS = [deg, deg, deg, deg, km, km/s]

10.00 3.331349e-04 4.618927e-04 6.782421e-04 -3.070007e-04 -4.221234e-04 **<*cont.*>** 3.231931e-04 -3.349365e-07 -4.686084e-07 2.484949e-07 4.296022e-10 **<cont.>**

-2.211832e-07 -2.864186e-07 1.798098e-07 2.608899e-10 1.767514e-10 **<*cont.*>**

-3.041346e-07 -4.989496e-07 3.540310e-07 1.869263e-10 1.008862e-10 6.224444e-10

**< … intervening data records omitted here … >**

20.0 3.442450e-04 4.507816e-04 6.893532e-04 -3.060006e-04 -4.110123e-04 **<*cont.*>** 3.342042e-04 -3.238254e-07 -4.575073e-07 2.373838e-07 4.307133e-10 **<*cont.*>**

-2.100721e-07 -2.753075e-07 1.687087e-07 2.507788e-10 1.878625e-10 **<*cont.*>**

-3.030235e-07 -4.878385e-07 3.430200e-07 1.758152e-10 1.007751e-10 6.224444e-10

COV\_STOP

COV\_START

COV\_BASIS = PREDICTED

COV\_REF\_FRAME = FIXED\_EARTH

COV\_TYPE = CARTP

COV\_UNITS = [km, km, km]

2022-12-18T14:31:35.1172 3.331349e-04 4.618927e-04 6.782421e-04 -3.070007e-04 **<*cont.*>** -4.221234e-04 3.231931e-04

COV\_STOP

PERT\_START

COMMENT Perturbations specification

GM = 398600.4415 [km\*\*3/s\*\*2]

PERT\_STOP

Fig. G‑19: OCM example with Covariance Matrix

NOTE – The demarcation “<cont.>” indicates that this single line is shown, for display purposes only, in multiple lines. This demarcation shall not be used in the actual OCM message, as all specified content shall be provided on the same line as its matching time tag.

* 1. OCM example in XML

The following is an example of an Orbit Comprehensive Message in Extensible Markup Language (XML) format.

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

<ocm xmlns: xsi:noNamespaceSchemaLocation="https://sanaregistry.org/r/ndmxml\_unqualified/ndmxml-3.0.0-master-3.0.xsd"

id="CCSDS\_OCM\_VERS" version="3.0">

<header>

<COMMENT>ODM V.3 Example G-2</COMMENT>

<COMMENT>OCM example with space object characteristics and perturbations.</COMMENT>

<COMMENT>This OCM reflects the latest conditions post-maneuver A67Z</COMMENT>

<COMMENT>This example shows the specification of multiple comment lines</COMMENT>

<CREATION\_DATE>2022-11-06T09:23:57</CREATION\_DATE>

<ORIGINATOR>JAPAN AEROSPACE EXPLORATION AGENCY</ORIGINATOR>

<MESSAGE\_ID> OCM 201113719185</MESSAGE\_ID> </header>

<body>

<segment>

<metadata>

<OBJECT\_NAME>OSPREY 5</OBJECT\_NAME>

<INTERNATIONAL\_DESIGNATOR>2022-999A</INTERNATIONAL\_DESIGNATOR>

<ORIGINATOR\_POC>R. Rabbit</ORIGINATOR\_POC>

<ORIGINATOR\_POSITION>Flight Dynamics Mission Design Lead</ORIGINATOR\_POSITION>

<ORIGINATOR\_PHONE>(719)555-1234</ORIGINATOR\_PHONE>

<ORIGINATOR\_ADDRESS>5040 Spaceflight Ave., Cocoa Beach FL USA 12345</ORIGINATOR\_ADDRESS>

<TECH\_POC>Mr. Rodgers</TECH\_POC>

<TECH\_PHONE>(719)555-1234</TECH\_PHONE>

<TECH\_EMAIL>email@email.XXX</TECH\_EMAIL>

<TIME\_SYSTEM>UT1</TIME\_SYSTEM>

<EPOCH\_TZERO>2022-12-18T00:00:00.0000</EPOCH\_TZERO>

<TAIMUTC\_AT\_TZERO units="s">36</TAIMUTC\_AT\_TZERO>

<UT1MUTC\_AT\_TZERO units="s">.357</UT1MUTC\_AT\_TZERO>

</metadata>

<data>

<traj>

<COMMENT>GEOCENTRIC, CARTESIAN, EARTH FIXED</COMMENT>

<COMMENT>THIS IS MY SECOND COMMENT LINE</COMMENT>

<TRAJ\_BASIS>PREDICTED</TRAJ\_BASIS >

<TRAJ\_REF\_FRAME>EFG</TRAJ\_REF\_FRAME>

<TRAJ\_TYPE>CARTPVA</TRAJ\_TYPE>

<trajLine>2022-12-18T14:28:25.1172 2854.5 -2916.2 -5360.7 5.90 4.86 0.52 0.0037 -0.0038 -0.0070</trajLine>

</traj>

<phys>

<COMMENT>Spacecraft Physical Characteristics</COMMENT>

<WET\_MASS units="kg">100.0</WET\_MASS>

<OEB\_Q1>0.03123</OEB\_Q1>

<OEB\_Q2>0.78543</OEB\_Q2>

<OEB\_Q3>0.39158</OEB\_Q3>

<OEB\_QC>0.47832</OEB\_QC>

<OEB\_MAX units="m">2.0</OEB\_MAX>

<OEB\_INT units="m">1.0</OEB\_INT>

<OEB\_MIN units="m">0.5</OEB\_MIN>

<AREA\_ALONG\_OEB\_MAX units="m\*\*2">0.5</AREA\_ALONG\_OEB\_MAX>

<AREA\_ALONG\_OEB\_INT units="m\*\*2">1.0</AREA\_ALONG\_OEB\_INT>

<AREA\_ALONG\_OEB\_MIN units="m\*\*2">2.0</AREA\_ALONG\_OEB\_MIN>

</phys>

<pert>

<COMMENT>Perturbations Specification</COMMENT>

<ATMOSPHERIC\_MODEL>NRLMSIS00</ATMOSPHERIC\_MODEL>

<GRAVITY\_MODEL>EGM-96: 36D 36O</GRAVITY\_MODEL>

<GM units="km\*\*3/s\*\*2">398600.4415</GM>

<N\_BODY\_PERTURBATIONS>MOON, SUN</N\_BODY\_PERTURBATIONS>

<FIXED\_GEOMAG\_KP>12.0</FIXED\_GEOMAG\_KP>

<FIXED\_F10P7>105.0</FIXED\_F10P7>

<FIXED\_F10P7\_MEAN>120.0</FIXED\_F10P7\_MEAN>

</pert>

<user>

<USER\_DEFINED parameter="CONSOLE\_POC">MAXWELL RAFERTY</USER\_DEFINED>

<USER\_DEFINED parameter="EARTH\_MODEL">WGS-84</USER\_DEFINED>

</user>

</data>

</segment>

</body>

</ocm>

Fig. G‑20: OCM example in Extensible Markup Language (XML) format.

* 1. Aggregating Multiple ODMs in a single NDM XML file

The following examples illustrate how multiple Orbit Data Messages can be aggregated in a single XML file using the Navigation Data Message (NDM) "combined instantiation" schema.

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

<ndm xmlns: xsi:noNamespaceSchemaLocation="https://sanaregistry.org/r/ndmxml\_unqualified/ndmxml-3.0.0-master-3.0.xsd">

<omm id="CCSDS\_OMM\_VERS" version="3.0">

<header>

<COMMENT>GENERATED VIA SPACE-TRACK.ORG API</COMMENT>

<CREATION\_DATE>2020-05-16T14:00:01</CREATION\_DATE>

<ORIGINATOR>18 SPCS</ORIGINATOR>

</header>

<body>

<segment>

<metadata>

<OBJECT\_NAME>STARLINK-1073</OBJECT\_NAME>

<OBJECT\_ID>2020-001A</OBJECT\_ID>

<CENTER\_NAME>EARTH</CENTER\_NAME>

<REF\_FRAME>TEME</REF\_FRAME>

<TIME\_SYSTEM>UTC</TIME\_SYSTEM>

<MEAN\_ELEMENT\_THEORY>SGP4</MEAN\_ELEMENT\_THEORY>

</metadata>

<data>

<meanElements>

<EPOCH>2020-05-16T14:00:01</EPOCH>

<MEAN\_MOTION>15.05566242</MEAN\_MOTION>

<ECCENTRICITY>0.0001225</ECCENTRICITY>

<INCLINATION>52.9981</INCLINATION>

<RA\_OF\_ASC\_NODE>157.6133</RA\_OF\_ASC\_NODE>

<ARG\_OF\_PERICENTER>93.35</ARG\_OF\_PERICENTER>

<MEAN\_ANOMALY>295.8599</MEAN\_ANOMALY>

</meanElements>

<tleParameters>

<EPHEMERIS\_TYPE>0</EPHEMERIS\_TYPE>

<CLASSIFICATION\_TYPE>U</CLASSIFICATION\_TYPE>

<NORAD\_CAT\_ID>44914</NORAD\_CAT\_ID>

<ELEMENT\_SET\_NO>999</ELEMENT\_SET\_NO>

<REV\_AT\_EPOCH>176</REV\_AT\_EPOCH>

<BSTAR>0.00057678</BSTAR>

<MEAN\_MOTION\_DOT>0.00008131</MEAN\_MOTION\_DOT>

<MEAN\_MOTION\_DDOT>0</MEAN\_MOTION\_DDOT>

</tleParameters>

<userDefinedParameters>

<USER\_DEFINED parameter="TLE\_LINE0">0 STARLINK-1073</USER\_DEFINED>

<USER\_DEFINED parameter="TLE\_LINE1">

1 44914U 20211A 20137.58334491 +.00008131 +00000-0 +57678-3 0 9994

</USER\_DEFINED>

<USER\_DEFINED parameter="TLE\_LINE2">

2 44914 052.9981 157.6133 0001225 093.3500 295.8599 15.05566242001761

</USER\_DEFINED>

</userDefinedParameters>

</data>

</segment>

</body>

</omm>

<omm id="CCSDS\_OMM\_VERS" version="3.0">

<header>

<COMMENT>GENERATED VIA SPACE-TRACK.ORG API</COMMENT>

<CREATION\_DATE>2020-05-16T14:00:01</CREATION\_DATE>

<ORIGINATOR>18 SPCS</ORIGINATOR>

</header>

<body>

<segment>

<metadata>

<OBJECT\_NAME>STARLINK-1084</OBJECT\_NAME>

<OBJECT\_ID>2020-001B</OBJECT\_ID>

<CENTER\_NAME>EARTH</CENTER\_NAME>

<REF\_FRAME>TEME</REF\_FRAME>

<TIME\_SYSTEM>UTC</TIME\_SYSTEM>

<MEAN\_ELEMENT\_THEORY>SGP4</MEAN\_ELEMENT\_THEORY>

</metadata>

<data>

<meanElements>

<EPOCH>2020-05-16T14:00:01</EPOCH>

<MEAN\_MOTION>15.05603711</MEAN\_MOTION>

<ECCENTRICITY>0.000126</ECCENTRICITY>

<INCLINATION>52.9991</INCLINATION>

<RA\_OF\_ASC\_NODE>157.611</RA\_OF\_ASC\_NODE>

<ARG\_OF\_PERICENTER>75.9191</ARG\_OF\_PERICENTER>

<MEAN\_ANOMALY>151.2104</MEAN\_ANOMALY>

</meanElements>

<tleParameters>

<EPHEMERIS\_TYPE>0</EPHEMERIS\_TYPE>

<CLASSIFICATION\_TYPE>U</CLASSIFICATION\_TYPE>

<NORAD\_CAT\_ID>44915</NORAD\_CAT\_ID>

<ELEMENT\_SET\_NO>999</ELEMENT\_SET\_NO>

<REV\_AT\_EPOCH>1986</REV\_AT\_EPOCH>

<BSTAR>0.0006442</BSTAR>

<MEAN\_MOTION\_DOT>0.00009125</MEAN\_MOTION\_DOT>

<MEAN\_MOTION\_DDOT>0</MEAN\_MOTION\_DDOT>

</tleParameters>

<userDefinedParameters>

<USER\_DEFINED parameter="TLE\_LINE0">0 STARLINK-1084</USER\_DEFINED>

<USER\_DEFINED parameter="TLE\_LINE1">

1 44915U 20211B 20137.58334491 +.00009125 +00000-0 +64420-3 0 9992

</USER\_DEFINED>

<USER\_DEFINED parameter="TLE\_LINE2">

2 44915 052.9991 157.6110 0001260 075.9191 151.2104 15.05603711019869

</USER\_DEFINED>

</userDefinedParameters>

</data>

</segment>

</body>

</omm>

<omm id="CCSDS\_OMM\_VERS" version="3.0">

<header>

<COMMENT>GENERATED VIA SPACE-TRACK.ORG API</COMMENT>

<CREATION\_DATE>2020-05-16T14:00:01</CREATION\_DATE>

<ORIGINATOR>18 SPCS</ORIGINATOR>

</header>

<body>

<segment>

<metadata>

<OBJECT\_NAME>STARLINK-1097</OBJECT\_NAME>

<OBJECT\_ID>2020-001C</OBJECT\_ID>

<CENTER\_NAME>EARTH</CENTER\_NAME>

<REF\_FRAME>TEME</REF\_FRAME>

<TIME\_SYSTEM>UTC</TIME\_SYSTEM>

<MEAN\_ELEMENT\_THEORY>SGP4</MEAN\_ELEMENT\_THEORY>

</metadata>

<data>

<meanElements>

<EPOCH>2020-05-16T14:00:01</EPOCH>

<MEAN\_MOTION>15.05559315</MEAN\_MOTION>

<ECCENTRICITY>0.0001361</ECCENTRICITY>

<INCLINATION>52.999</INCLINATION>

<RA\_OF\_ASC\_NODE>157.6123</RA\_OF\_ASC\_NODE>

<ARG\_OF\_PERICENTER>94.2334</ARG\_OF\_PERICENTER>

<MEAN\_ANOMALY>78.9025</MEAN\_ANOMALY>

</meanElements>

<tleParameters>

<EPHEMERIS\_TYPE>0</EPHEMERIS\_TYPE>

<CLASSIFICATION\_TYPE>U</CLASSIFICATION\_TYPE>

<NORAD\_CAT\_ID>44916</NORAD\_CAT\_ID>

<ELEMENT\_SET\_NO>999</ELEMENT\_SET\_NO>

<REV\_AT\_EPOCH>1986</REV\_AT\_EPOCH>

<BSTAR>0.00072742</BSTAR>

<MEAN\_MOTION\_DOT>0.00010329</MEAN\_MOTION\_DOT>

<MEAN\_MOTION\_DDOT>0</MEAN\_MOTION\_DDOT>

</tleParameters>

<userDefinedParameters>

<USER\_DEFINED parameter="TLE\_LINE0">0 STARLINK-1097</USER\_DEFINED>

<USER\_DEFINED parameter="TLE\_LINE1">

1 44916U 20211C 20137.58334491 +.00010329 +00000-0 +72742-3 0 9997

</USER\_DEFINED>

<USER\_DEFINED parameter="TLE\_LINE2">

2 44916 052.9990 157.6123 0001361 094.2334 078.9025 15.05559315019865

</USER\_DEFINED>

</userDefinedParameters>

</data>

</segment>

</body>

</omm>

</ndm>

Fig. G‑21: Aggregating multiple ODMs into a single NDM file

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

<ndm xmlns: xsi:noNamespaceSchemaLocation="https://sanaregistry.org/r/ndmxml\_unqualified/ndmxml-3.0.0-master-3.0.xsd">

<COMMENT>This example combines an OPM, OMM, OEM, and OCM in a single Navigation Data Message XML.</COMMENT>

<COMMENT>NOTE – In this case the messages are unrelated, but show how, in principle, related </COMMENT>

<COMMENT>messages could be combined to satisfy a specific use case.</COMMENT>

<opm id="CCSDS\_OPM\_VERS" version="3.0">

<header>

<COMMENT>Example Orbit Parameter Message</COMMENT>

<COMMENT>The OPM includes a set of orbital elements at time t, and an impulsive maneuver design with MAN\_EPOCH\_IGNITION = t.</COMMENT>

<CREATION\_DATE>2009-05-18T13:06:00</CREATION\_DATE>

<ORIGINATOR>NASA</ORIGINATOR>

</header>

<body>

<segment>

<metadata>

<OBJECT\_NAME>SOHO</OBJECT\_NAME>

<OBJECT\_ID>2009-000A</OBJECT\_ID>

<CENTER\_NAME>EARTH</CENTER\_NAME>

<REF\_FRAME>EME2000</REF\_FRAME>

<TIME\_SYSTEM>UTC</TIME\_SYSTEM>

</metadata>

<data>

<stateVector>

<EPOCH>2009-05-12T15:30:00</EPOCH>

<X>687754.36358524448</X>

<Y>941287.85553999904</Y>

<Z>520080.81101286016</Z>

<X\_DOT>-0.41396551860286032</X\_DOT>

<Y\_DOT>0.29174462217893128</Y\_DOT>

<Z\_DOT>0.11756781919443198</Z\_DOT>

</stateVector>

<maneuverParameters>

<COMMENT>The below contains information for the impulsive maneuver.</COMMENT>

<MAN\_EPOCH\_IGNITION>2009-05-12T15:30:00</MAN\_EPOCH\_IGNITION>

<MAN\_DURATION>0</MAN\_DURATION>

<MAN\_DELTA\_MASS>-0.0252069575402913408</MAN\_DELTA\_MASS>

<MAN\_REF\_FRAME>EME2000</MAN\_REF\_FRAME>

<MAN\_DV\_1>0.000028562811624</MAN\_DV\_1>

<MAN\_DV\_2>3.0883529021E-7</MAN\_DV\_2>

<MAN\_DV\_3>1.4646782842E-8</MAN\_DV\_3>

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<omm id="CCSDS\_OMM\_VERS" version="3.0">

<header>

<COMMENT> Example Orbit Mean-Elements Message</COMMENT>

<COMMENT> ODM PROTOTYPING FOR CCSDS 502.0-P-1.1 - TEST NUMBER 4</COMMENT>

<CREATION\_DATE>2009-091T16:00:00</CREATION\_DATE>

<ORIGINATOR>CNES</ORIGINATOR>

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<body>

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<OBJECT\_ID>2022-067A</OBJECT\_ID>

<CENTER\_NAME>EARTH</CENTER\_NAME>

<REF\_FRAME>TEME</REF\_FRAME>

<TIME\_SYSTEM>UTC</TIME\_SYSTEM>

<MEAN\_ELEMENT\_THEORY>SGP4</MEAN\_ELEMENT\_THEORY>

</metadata>

<data>

<COMMENT>USAF SGP4 IS THE ONLY PROPAGATOR THAT SHOULD BE USED FOR THIS DATA</COMMENT>

<meanElements>

<EPOCH>2009-087T11:58:23.211264</EPOCH>

<MEAN\_MOTION>15.71784080</MEAN\_MOTION>

<ECCENTRICITY>0.0009738</ECCENTRICITY>

<INCLINATION>51.6429</INCLINATION>

<RA\_OF\_ASC\_NODE>0.4159</RA\_OF\_ASC\_NODE>

<ARG\_OF\_PERICENTER>166.5533</ARG\_OF\_PERICENTER>

<MEAN\_ANOMALY>354.9076</MEAN\_ANOMALY>

</meanElements>

<tleParameters>

<EPHEMERIS\_TYPE>0</EPHEMERIS\_TYPE>

<CLASSIFICATION\_TYPE>U</CLASSIFICATION\_TYPE>

<NORAD\_CAT\_ID>25544</NORAD\_CAT\_ID>

<ELEMENT\_SET\_NO>557</ELEMENT\_SET\_NO>

<REV\_AT\_EPOCH>59325</REV\_AT\_EPOCH>

<BSTAR>-0.21414E-3</BSTAR>

<MEAN\_MOTION\_DOT>0.00027894</MEAN\_MOTION\_DOT>

<MEAN\_MOTION\_DDOT>0.0</MEAN\_MOTION\_DDOT>

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</segment>

</body>

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<header>

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<ORIGINATOR>JAXA</ORIGINATOR>

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<body>

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<OBJECT\_NAME>SELENE</OBJECT\_NAME>

<OBJECT\_ID>131</OBJECT\_ID>

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<TIME\_SYSTEM>UTC</TIME\_SYSTEM>

<START\_TIME>2007-09-14T10:43:00.000000</START\_TIME>

<STOP\_TIME>2007-09-14T10:47:00.000000</STOP\_TIME>

<INTERPOLATION>Hermite</INTERPOLATION>

<INTERPOLATION\_DEGREE>7</INTERPOLATION\_DEGREE>

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<data>

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<Y>9.480146566872711E+04</Y>

<Z>3.266088528177066E+04</Z>

<X\_DOT>-6.305293974707967E-01</X\_DOT>

<Y\_DOT>1.848864859994888E+00</Y\_DOT>

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<stateVector>

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<Z>3.277332412355368E+04</Z>

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</oem>

<ocm id="CCSDS\_OCM\_VERS" version="3.0">

<header>

<COMMENT>Example G-4 from OCM P2.40</COMMENT>

<COMMENT>OCM example with multiple trajectory state time histories, a maneuver, OD, Cartesian and Keplerian ephemeris</COMMENT>

<CREATION\_DATE>2022-11-06T09:23:57</CREATION\_DATE>

<ORIGINATOR>JAPAN AEROSPACE EXPLORATION AGENCY</ORIGINATOR>

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<OBJECT\_DESIGNATOR>98765</OBJECT\_DESIGNATOR>

<INTERNATIONAL\_DESIGNATOR>2022-999A</INTERNATIONAL\_DESIGNATOR>

<CATALOG\_NAME>CSPOC</CATALOG\_NAME>

<TIME\_SYSTEM>UTC</TIME\_SYSTEM>

<EPOCH\_TZERO>2022-12-18T14:28:15.1172</EPOCH\_TZERO>

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<TRAJ\_BASIS>PREDICTED</TRAJ\_BASIS>

<TRAJ\_REF\_FRAME>TOD\_EARTH</TRAJ\_REF\_FRAME>

<TRAJ\_FRAME\_EPOCH>2022-12-18T14:28:15.1172</TRAJ\_FRAME\_EPOCH>

<USEABLE\_START\_TIME>2022-12-18T14:28:15.1172</USEABLE\_START\_TIME>

<USEABLE\_STOP\_TIME>2022-12-18T14:28:45.1172</USEABLE\_STOP\_TIME>

<TRAJ\_TYPE>CARTPVA</TRAJ\_TYPE>

<TRAJ\_UNITS>[km, km, km, km/s, km/s, km/s, km/s\*\*2, km/s\*\*2, km/s\*\*2]</TRAJ\_UNITS>

<trajLine> 0.0 2854.5 -2916.2 -5360.7 5.90 4.86 0.52 0.0037 -0.0038 -0.0070</trajLine>

<trajLine>120.0 5478.6 434.3 -3862.5 2.50 5.87 4.29 0.0072 0.0006 -0.0051</trajLine>

<trajLine>240.0 4146.0 -1655.8 -5038.3 4.80 5.58 2.16 0.0054 -0.0022 -0.0066</trajLine>

<trajLine>500.0 -1553.4 -4848.7 -4406.5 6.73 1.01 -3.53 -0.002 -0.0063 -0.0058</trajLine>

</traj>

<traj>

<TRAJ\_BASIS>DETERMINED</TRAJ\_BASIS>

<TRAJ\_REF\_FRAME>J2000</TRAJ\_REF\_FRAME>

<TRAJ\_TYPE>KEPLERIAN</TRAJ\_TYPE>

<TRAJ\_UNITS>[km, n/a, deg, deg, deg, deg]</TRAJ\_UNITS>

<trajLine>0.000000 6600.0 .03 28.5 50.0 30.0 10.0</trajLine>

<trajLine>120.000000 6600.0 .03 28.5 50.0 30.0 10.1</trajLine>

<trajLine>240.000000 6600.0 .03 28.5 50.0 30.0 10.2</trajLine>

<trajLine>500.000000 6600.0 .03 28.5 50.0 30.0 35.0</trajLine>

</traj>

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<COMMENT>Spacecraft Physical Characteristics</COMMENT>

<DRAG\_CONST\_AREA units="m\*\*2">10.00</DRAG\_CONST\_AREA>

<DRAG\_COEFF\_NOM>2.3</DRAG\_COEFF\_NOM>

<WET\_MASS units="kg">100.0</WET\_MASS>

<SRP\_CONST\_AREA units="m\*\*2">4</SRP\_CONST\_AREA>

<SOLAR\_RAD\_COEFF >1.3</SOLAR\_RAD\_COEFF >

</phys>

<man>

<COMMENT>200 s of 10N thrust (in-track transitioning to radial)</COMMENT>

<COMMENT>w/effic η=0.95, Isp=300s, 5% 1-sigma error</COMMENT>

<MAN\_ID>E\_W\_20160305B</MAN\_ID>

<MAN\_BASIS>CANDIDATE</MAN\_BASIS>

<MAN\_DEVICE\_ID>THR\_01</MAN\_DEVICE\_ID>

<MAN\_PURPOSE>ORBIT</MAN\_PURPOSE>

<MAN\_REF\_FRAME>RSW\_ROTATING</MAN\_REF\_FRAME>

<MAN\_COMPOSITION>TIME\_RELATIVE MAN\_DURA, THR\_X, THR\_Y, THR\_Z, THR\_MAG\_SIGMA, THR\_INTERP, THR\_ISP, THR\_EFFIC</MAN\_COMPOSITION>

<MAN\_UNITS>[s, N, N, N, %, n/a, s, n/a]</MAN\_UNITS>

<manLine>500.0 100.0 0.0 10.0 0.0 5.0 ON 300.0 0.95</manLine>

<manLine>600.0 100.0 10.0 0.0 0.0 5.0 OFF 300.0 0.95</manLine>

</man>

<pert>

<COMMENT>Perturbations specification</COMMENT>

<GM>398600.4415</GM>

</pert>

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<COMMENT>  Orbit Determination information</COMMENT>

<OD\_ID>OD #10059</OD\_ID>

<OD\_PREV\_ID>OD #10058</OD\_PREV\_ID>

<OD\_METHOD>BWLS: BAHN</OD\_METHOD>

<OD\_EPOCH>2001-11-06T11:17:33</OD\_EPOCH>

<OBS\_USED>273</OBS\_USED>

<TRACKS\_USED>91</TRACKS\_USED>

</od>

</data>

</segment>

</body>

</ocm>

</ndm>

Fig. G‑22: Aggregating OPM, OMM, OEM, and OCM in a single Navigation Data Message XML.

1. INFORMATIVE REFERENCES  
     
   (Informative)

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[H-10] Tanygin, S., “Attitude Interpolation,” AAS Spaceflight Mechanics Conference 2003, <<https://comspoc.com/Papers/Attitude-Interpolation.pdf>>.

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[H-17] Peter C. Hughes, *Spacecraft Attitude Dynamics*, John Wiley and Sons Inc., ISBN 0-471-81842-9.

1. ITEMS FOR AN INTERFACE CONTROL DOCUMENT (ICD)  
     
   (Informative)
   1. STANDARD ICD ITEMS

In several places in this document there are references to items which should be specified in an 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 ICDs, they should be developed and negotiated whenever specified in this Recommended Standard.

| **Item** | **Section** |
| --- | --- |
| 1. Detailed description of any user defined OPM, OMM, OEM, and OCM parameters used. | 3.2, 4.2, 5.2, 6.2 |
| 1. Detailed description of any exceptions for keyword values not drawn from the SANA registry (sanaregistry.org). | Annex B, Section B6 |
| 1. Specific information security interoperability provisions that apply between agencies. | Annex M |

1. CHANGES Versus Previous Version  
     
   (Informative)

This annex lists the differences between ODM 2.0 and ODM 3.0. 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.

* 1. CHANGES IN THE MESSAGES

1. The Orbit Comprehensive Message (OCM) was added to provide better support for ISO Technical Committee 20, Subcommittee 14 objectives (see Section 4).
2. MESSAGE\_ID was added to the OPM, OMM, and OEM to provide better satisfaction of requirement P10 (identification and annotation of messages).
   1. CHANGES IN THE DOCUMENT
3. 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/](%20https://sanaregistry.org/r/navigation_standard_normative_annexes/). See Annex B for details on the affected keywords and links to the content.
4. Several annexes were added. Some are required by CCSDS rule changes, and some are for the provision of supplementary material.
5. Examples for OPM, OMM, and OEM that formerly appeared in Sections 3, 4, and 5 respectively have been moved to an Informative Annex.
6. 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.