The Consultative Committee for Space Data Systems

**Recommendation for Space Data System Standards**

# ORBIT DATA MESSAGES

PROPOSED STANDARD

**CCSDS 502.0.P-2.35~~33~~**

PINK BOOK
6 Octl~~11 July~~ 2016 DRAFT

## AUTHORITY

| | |
|---|---|
| Issue: | **Proposed Standard**, **Issue 3** |
| Date: | **6 Octl~~11 July~~ 2016 DRAFT** |
| Location: | Washington, DC, USA |

This document has been approved for publication by the Management Council of the Consultative Committee for Space Data Systems (CCSDS) and represents the consensus technical agreement of the participating CCSDS Member Agencies. The procedure for review and authorization of CCSDS documents is detailed in the *Procedures Manual for the Consultative Committee for Space Data Systems*, and the record of Agency participation in the authorization of this document can be obtained from the CCSDS Secretariat at the address below.

This document is published and maintained by:

CCSDS Secretariat
Space Communications and Navigation Office, 7L70
Space Operations Mission Directorate
NASA Headquarters
Washington, DC 20546-0001, USA

## STATEMENT OF INTENT

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

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

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

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

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

# FOREWORD

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

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

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

http://www.ccsds.org/

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

At time of publication, the active Member and Observer Agencies of the CCSDS were:

Member Agencies

- Agenzia Spaziale Italiana (ASI)/Italy.
- British National Space Centre (BNSC)/United Kingdom.
- Canadian Space Agency (CSA)/Canada.
- Centre National d'Etudes Spatiales (CNES)/France.
- China National Space Administration (CNSA)/People's Republic of China.
- Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)/Germany.
- European Space Agency (ESA)/Europe.
- Russian Federal Space Agency (RFSA)/Russian Federation.
- Instituto Nacional de Pesquisas Espaciais (INPE)/Brazil.
- Japan Aerospace Exploration Agency (JAXA)/Japan.
- National Aeronautics and Space Administration (NASA)/USA.

Observer Agencies

- Austrian Space Agency (ASA)/Austria.
- Belgian Federal Science Policy Office (BFSPO)/Belgium.
- Central Research Institute of Machine Building (TsNIIMash)/Russian Federation.
- Centro Tecnico Aeroespacial (CTA)/Brazil.
- Chinese Academy of Sciences (CAS)/China.
- Chinese Academy of Space Technology (CAST)/China.
- Commonwealth Scientific and Industrial Research Organization (CSIRO)/Australia.
- CSIR Satellite Applications Centre (CSIR)/Republic of South Africa.
- Danish National Space Center (DNSC)/Denmark.
- European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)/Europe.
- European Telecommunications Satellite Organization (EUTELSAT)/Europe.
- Geo-Informatics and Space Technology Development Agency (GISTDA)/Thailand.
- Hellenic National Space Committee (HNSC)/Greece.
- Indian Space Research Organization (ISRO)/India.
- Institute of Space Research (IKI)/Russian Federation.
- KFKI Research Institute for Particle & Nuclear Physics (KFKI)/Hungary.
- Korea Aerospace Research Institute (KARI)/Korea.
- Ministry of Communications (MOC)/Israel.
- National Institute of Information and Communications Technology (NICT)/Japan.
- National Oceanic and Atmospheric Administration (NOAA)/USA.
- National Space Organization (NSPO)/Chinese Taipei.
- Naval Center for Space Technology (NCST)/USA.
- Scientific and Technological Research Council of Turkey (TUBITAK)/Turkey.
- Space and Upper Atmosphere Research Commission (SUPARCO)/Pakistan.
- Swedish Space Corporation (SSC)/Sweden.
- United States Geological Survey (USGS)/USA.

# DOCUMENT CONTROL

| Document | Title | Date | Status |
|---|---|---|---|
| CCSDS 502.0-B-1 | Orbit Data Messages, Issue 1 | September 2004 | Original issue, superseded |
| **CCSDS 502.0.P-2.3533** | ORBIT DATA MESSAGES, **Proposed Standard**, **Issue 3** | **6 Octl1 July 2016 DRAFT** | Current issue:<br>– changes from the original issue are documented in ANNEX H |
| EC 1 | Editorial Change 1 | | Corrects erroneous cross references and table of contents entries; corrects typographical anomaly in annex E; updates informative references to current issues in ANNEX H, Subsection H2 |
| **CCSDS 502.0.R-2, Cor. 1** | Technical Corrigendum 1 | | Corrects/clarifies text; updates references [1] and [4] to current issues in 1.7. |
| **CCSDS 502.0.P-2.3533** | Orbit Comprehensive Message | | Added Orbit Comprehensive Message (OCM) |

# CONTENTS


| Section | | Page |
|---|---|---|
| **1** | **INTRODUCTION** | **1-1-1** |
| 1.1 | PURPOSE AND SCOPE | 1-1-1 |
| 1.2 | APPLICABILITY | 1-1-1 |
| 1.3 | RATIONALE | 1-2-1-2 |
| 1.4 | DOCUMENT STRUCTURE | 1-2-1-2 |
| 1.5 | DEFINITIONS | 1-3-1-3 |
| 1.6 | NOMENCLATURE | 1-3-1-3 |
| 1.7 | REFERENCES | 1-3-1-3 |
| **2** | **OVERVIEW** | **2-1-2-1** |
| 2.1 | ORBIT DATA MESSAGE TYPES | 2-1-2-1 |
| 2.2 | ORBIT PARAMETER MESSAGE (OPM) | 2-1-2-1 |
| 2.3 | ORBIT MEAN-ELEMENTS MESSAGE (OMM) | 2-2 |
| 2.4 | ORBIT EPHEMERIS MESSAGE (OEM) | 2-2-2-2 |
| 2.5 | ORBIT COMPREHENSIVE MESSAGE (OCM) | 2-2-2-2 |
| 2.6 | EXCHANGE OF MULTIPLE MESSAGES | 2-3-2-3 |
| 2.7 | DEFINITIONS | 2-4-2-4 |
| **3** | **ORBIT PARAMETER MESSAGE (OPM)** | **3-1-3-1** |
| 3.1 | GENERAL | 3-1-3-1 |
| 3.2 | OPM CONTENT/STRUCTURE | 3-1-3-1 |
| 3.3 | OPM EXAMPLES | 3-8-3-8 |
| **4** | **ORBIT MEAN-ELEMENTS MESSAGE (OMM)** | **4-1-4-1** |
| 4.1 | GENERAL | 4-1-4-1 |
| 4.2 | OMM CONTENT/STRUCTURE | 4-2-4-2 |
| 4.3 | OMM EXAMPLES | 4-8-4-8 |
| **5** | **ORBIT EPHEMERIS MESSAGE (OEM)** | **5-1-5-1** |
| 5.1 | GENERAL | 5-1-5-1 |
| 5.2 | OEM CONTENT/STRUCTURE | 5-1-5-1 |
| 5.3 | OEM EXAMPLES | 5-8-5-8 |
| **6** | **ORBIT COMPREHENSIVE MESSAGE (OCM)** | **6-1** |
| 6.1 | GENERAL | 6-1 |
| 6.2 | OCM CONTENT/STRUCTURE | 6-2 |
| 6.3 | OCM EXAMPLES | 6-36 |
| **7** | **ORBIT DATA MESSAGE SYNTAX** | **7-44** |
| 7.1 | OVERVIEW | 7-44 |
| 7.2 | GENERAL | 7-44 |
| 7.3 | ODM LINES | 7-44 |
| 7.4 | KEYWORD = VALUE NOTATION AND ORDER OF ASSIGNMENT STATEMENTS | 7-45 |
| 7.5 | VALUES | 7-46 |
| 7.6 | UNITS IN THE ORBIT DATA MESSAGES | 7-48 |
| 7.7 | COMMENTS IN THE ORBIT DATA MESSAGES | 7-49 |
| 7.8 | ORBIT DATA MESSAGE KEYWORDS | 7-507-50 |


Field Code Changed

ANNEX A IMPLEMENTATION CONFORMANCE STATEMENT PRO FORMA (NORMATIVE) ..... A-2
ANNEX B VALUES FOR TIME_SYSTEM AND FRAME RELATED KEYWORDS (NORMATIVE) ..... B-6
ANNEX C SATELLITE PHYSICAL CHARACTERISTICS SPECIFICATION (INFORMATIVE) ..... C-11
ANNEX D APPARENT-TO-ABSOLUTE VISUAL MAGNITUDE RELATIONSHIP (INFORMATIVE) ..... D-1D-1
ANNEX E ABBREVIATIONS AND ACRONYMS (INFORMATIVE) ..... E-3E-3
ANNEX F RATIONALE FOR ORBIT DATA MESSAGES (INFORMATIVE) ...F-5F-5
ANNEX G ITEMS FOR AN INTERFACE CONTROL DOCUMENT (INFORMATIVE) ..... G-10G-10
ANNEX H CHANGES IN ODM VERSION 2 (INFORMATIVE) ..... H-12H-12
ANNEX I CREATING A VERSION 1.0 COMPLIANT OPM/OEM (INFORMATIVE) ..... I-14I-14
ANNEX J J-16J-16
ANNEX K INFORMATIVE REFERENCES (INFORMATIVE) ..... K-18K-18

Figure

3-1 SIMPLE OPM FILE EXAMPLE ..... 3-93-9
3-2 OPM FILE EXAMPLE WITH OPTIONAL KEPLERIAN ELEMENTS AND TWO MANEUVERS ..... 3-103-10
3-3 OPM FILE EXAMPLE WITH COVARIANCE MATRIX ..... 3-113-11
3-4 OPM FILE EXAMPLE WITH OPTIONAL KEPLERIAN ELEMENTS, COVARIANCE MATRIX, AND A USER DEFINED PARAMETER ..... 3-12
4-1 EXAMPLE TWO LINE ELEMENT SET (TLE) ..... 4-84-8
4-2 OMM FILE EXAMPLE WITHOUT COVARIANCE MATRIX ..... 4-84-8
4-3 OMM FILE EXAMPLE WITH COVARIANCE MATRIX ..... 4-94-9
4-4 OMM WITH UNITS AND A USER DEFINED PARAMETER ..... 4-104-10
5-1 VERSION 1 OEM COMPATIBLE EXAMPLE (NO ACCELERATION, NO COVARIANCE) ..... 5-95-9
5-2 VERSION 2 OEM EXAMPLE WITH OPTIONAL ACCELERATIONS ..... 5-105-10
5-3 VERSION 2 OEM EXAMPLE WITH OPTIONAL COVARIANCE MATRICES .5-115-11
6-1 SIMPLE OPM FILE EXAMPLE ..... 6-366-36

Table

3-1 OPM HEADER ..... 3-23-2
3-2 OPM METADATA ..... 3-33-3
3-3 OPM DATA ..... 3-63-6
4-1 OMM HEADER ..... 4-24-2
4-2 OMM METADATA ..... 4-44-4

Field Code Changed

Field Code Changed

Field Code Changed

Field Code Changed

**4-3 OMM DATA....4-54-5**
**5-1 OEM FILE LAYOUT SPECIFICATIONS....5-25-2**
**5-2 OEM HEADER....5-35-3**
**5-3 OEM METADATA....5-45-4**
**6-1 OEM FILE LAYOUT SPECIFICATIONS....6-3**
**6-2 OPM HEADER....6-4**
**6-3 OPM METADATA....6-7**
**6-4 OPM METADATA....6-9**
**6-5 OPM METADATA....6-14**
**6-6 OPM METADATA....6-17**
**6-7 OPM METADATA....6-19**
**6-8 OPM METADATA....6-24**
**6-9 OPM METADATA....6-27**
**6-10 OPM METADATA....6-32**
**6-11 OPM METADATA....6-356-35**

Field Code Changed
Field Code Changed
Field Code Changed
Field Code Changed
Field Code Changed
Field Code Changed
Field Code Changed
Field Code Changed
Field Code Changed

# 1 INTRODUCTION

## 1.1 PURPOSE AND SCOPE

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

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

b) scheduling tracking support;

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

d) performing orbit comparisons;

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

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

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

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

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

## 1.2 APPLICABILITY

The rationale behind the design of each orbit data message is described in ANNEX F and may help the application engineer to select a suitable message. Definition of the orbit accuracy underlying a particular orbit message is outside of the scope of this Recommended Standard and should be specified via Interface Control Document (ICD) between data exchange participants (or specified via COMMENT sections in the message itself). Applicability information specific to each orbit data message format appears in sections 3, 4, and 5, as well as in F2.4.

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

Description of the message formats based on the use of Extensible Markup Language (XML) is detailed in an integrated XML schema document for all Navigation Data Message Recommended Standards. (See reference [4].)

## 1.3 RATIONALE

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

## 1.4 DOCUMENT STRUCTURE

Section 2 provides a brief overview of the CCSDS-recommended Orbit Data Message types, the Orbit Parameter Message (OPM), Orbit Mean-Elements Message (OMM), 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 0 discusses security requirements for the Orbit Data Messages.

A2.5 lists acceptable values for selected ODM keywords.

ANNEX E is a list of abbreviations and acronyms applicable to the ODM.

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

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

ANNEX H provides a summary of the changes introduced in this version 2 of the ODM and documents the differences between ODM version 1 and ODM version 2.

ANNEX I provides instructions for how to produce a version 2 OPM/OEM that is backwards compatible to version 1 implementations.

ANNEX C provides definitions for orientation-relevant satellite physical characteristics used in this standard

ANNEX D provides instructions for how to compute absolute visual magnitude

ANNEX K provides a listing of informative references.

## 1.5 DEFINITIONS

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

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

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

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

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

## 1.6 NOMENCLATURE

The following conventions apply throughout this Recommended Standard:

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

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

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

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

## 1.7 REFERENCES

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

documents indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS Recommended Standards.

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

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

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

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

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

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

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

# 2 OVERVIEW

## 2.1 ORBIT DATA MESSAGE TYPES

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

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

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

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

## 2.2 ORBIT PARAMETER MESSAGE (OPM)

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

The OPM requires the use of a propagation technique to determine the position and velocity at times different from the specified epoch, leading to a higher level of effort for software implementation than for the OEM. A 6x6 position/velocity covariance matrix that may be used in the propagation process is optional.

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

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

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

## 2.3 ORBIT MEAN-ELEMENTS MESSAGE (OMM)

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

The OMM includes keywords and values that can be used to generate canonical NORAD Two Line Element Sets (TLEs) to accommodate the needs of heritage users (see reference I-4).

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

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

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

## 2.4 ORBIT EPHEMERIS MESSAGE (OEM)

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

The OEM allows for dynamic modeling of any number of gravitational and non-gravitational accelerations. The OEM requires the use of an interpolation technique to interpret the position and velocity at times different from the tabular epochs.

The OEM also contains an optional covariance matrix which reflects the uncertainty of the orbit solution used to generate states in the ephemeris.

## 2.5 ORBIT COMPREHENSIVE MESSAGE (OCM)

An OCM specifies position and velocity of either a single object or an en masse parent/child deployment scenario stemming from a single object. The OCM aggregates and extends OPM,

OEM and OMM content in a single hybrid message (file) and offers the following additional capabilities:

- Optional Earth Orientation (UT1 and UTC) at a nearby (relevant) reference epoch;
- Optional Leap second specification
- Optional area cross-sections for drag, SRP force modeling.
- Optional spacecraft dimensions and orientation information for collision probability estimation
- Optional force model specification;
- Optional maneuver specification (impulsive or finite burn);
- Optional orbit states (specified using one or more of Cartesian and orbit elements and reference frames) for a single or parent object at either a single epoch or as a time history (ephemeris);
- Optional orbit determination data and metrics;
- ~~Optional maneuver specification (impulsive or finite burn);~~
- ~~Optional force model specification;~~
- Optional covariance matrix of selectable/arbitrary order for a single or parent object at either a single epoch or as a time history (ephemeris) which reflects the uncertainty of the orbit solution or Monte Carlo simulation used to obtain the nominal states in the orbit state(s);
- Optional covariance content options (e.g. Cartesian 3x3, 6x6, 7x7, or any combination of order, reference frame and orbit elements)
- Optional State Transition Matrix specification;
- Optional Ephemeris Compression (EC) specification via polynomials;
- ~~Optional area cross-sections for drag, SRP force modeling.~~
- ~~Optional spacecraft dimensions and orientation information for collision probability estimation~~

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 force modeling into an ephemeris time history (akin to the OEM ephemeris), or specify orbital states which can be propagated with supplied force model parameters (akin to OPM content), or both.

## 2.6 EXCHANGE OF MULTIPLE MESSAGES

For a given object, multiple OPM, OMM, or OEM messages may be provided in a message exchange session to achieve ephemeris fidelity requirements, whereas a single, self-contained OCM is typically sufficient. If ephemeris information for multiple objects is to be exchanged, then multiple OPM, OMM, OEM or OCM files must be used, with the exception that the OCM supports parent/child deployment scenario specifications in a single message.

## 2.7 DEFINITIONS

Definitions of time systems, reference frames, planetary models, maneuvers and other fundamental topics related to the interpretation and processing of state vectors and spacecraft ephemerides are provided in reference [I-1].

# 3 ORBIT PARAMETER MESSAGE (OPM)

## 3.1 GENERAL

**3.1.1** Orbit information may be exchanged between two participants by sending a state vector (see reference [I-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.

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

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

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

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

b) the receiver's modeling of gravitational forces, solar radiation pressure, atmospheric drag, and thrust phases (see reference [I-1]) should fulfill accuracy requirements established between the exchange partners.

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

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

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

## 3.2 OPM CONTENT/STRUCTURE

### 3.2.1 GENERAL

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

a) a header;

b) metadata (data about data);

c) data; and

d) optional comments (explanatory information).

### 3.2.2 OPM HEADER

**3.2.2.1** Table 3-1 specifies for each header item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is mandatory or optional.

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

**Table 3-1: OPM Header**

| Keyword | Description | Examples of Values | Mandatory |
|---|---|---|---|
| CCSDS_OPM_VERS | Format version in the form of 'x.y', where 'y' is incremented for corrections and minor changes, and 'x' is incremented for major changes. | 2.0 | Yes |
| COMMENT | Comments (allowed in the OPM Header only immediately after the OPM version number). (See 7.7 for formatting rules.) | COMMENT This is a comment | No |
| CREATION_DATE | File creation date/time in UTC. (For format specification, see 7.5.9) | 2001-11-06T11:17:33<br>2002-204T15:56:23Z | Yes |
| ORIGINATOR | Creating agency or operator (value should be drawn from the SANA "Organizations" registry). The country of origin should also be provided where the originator is not a national space agency. | CNES, ESOC, GSFC, GSOC, JPL, JAXA, INTELSAT/USA, USAF, INMARSAT/UK | Yes |

### 3.2.3 OPM METADATA

**3.2.3.1** Table 3-2 specifies for each metadata item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is mandatory or optional.

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

NOTE – For some keywords (OBJECT_NAME, OBJECT_ID, CENTER_NAME) there are no definitive lists of authorized values maintained by a control authority; the references listed in 1.7 are the best known sources for authorized values to date. For the TIME_SYSTEM and REF_FRAME keywords, the approved values are listed in ANNEX B.

**Table 3-2: OPM Metadata**

| Keyword | Description | Examples of Values | Mandatory |
|---|---|---|---|
| COMMENT | Comments (allowed at the beginning of the OPM Metadata). (See 7.7 for formatting rules.) | COMMENT This is a comment | No |
| OBJECT_NAME | Spacecraft name for which the orbit state is provided. There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the SPACEWARN Bulletin (reference [2]), which include Object name and international designator of the participant. | EUTELSAT W1<br>MARS PATHFINDER<br>STS 106<br>NEAR | Yes |
| OBJECT_ID | Object identifier of the object for which the orbit state is provided. There is no CCSDS-based restriction on the value for this keyword, but it is recommended that values be the international spacecraft designator as published in the SPACEWARN Bulletin (reference [2]). Recommended values have the format YYYY-NNNP{PP}, where:<br>YYYY = Year of launch.<br>NNN = Three digit serial number of launch in year YYYY (with leading zeros).<br>P{PP} = At least one capital letter for the identification of the part brought into space by the launch.<br>In cases where the asset is not listed in the bulletin, or the SPACEWARN format is not used, the value should be provided in an ICD. | 2000-052A<br>1996-068A<br>2000-053A<br>1996-008A | Yes |
| CENTER_NAME | Origin of reference frame, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this case the value for 'CENTER_NAME' is subject to the same rules as for 'OBJECT_NAME'). There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the NASA/JPL Solar System Dynamics Group at http://ssd.jpl.nasa.gov (reference [5]). | EARTH<br>EARTH BARYCENTER<br>MOON<br>SOLAR SYSTEM BARYCENTER<br>SUN<br>JUPITER BARYCENTER<br>STS 106<br>EROS | Yes |

| Keyword | Description | Examples of Values | Mandatory |
|---|---|---|---|
| REF_FRAME | Name of the reference frame in which the state vector and optional Keplerian element data are given. Use of values other than those in ANNEX B, subsection B2 must be documented and conveyed in an ICD. The reference frame must be the same for all data elements, with the exception of the maneuvers and covariance matrix, for which applicable different reference frames may be specified. | ICRF<br>ITRF-93<br>ITRF-97<br>ITRF2000<br>ITRFXXXX (TEMPLATE FOR A FUTURE VERSION)<br>TOD (TRUE EQUATOR/EQUINOX OF DATE)<br>EME2000 (EARTH MEAN EQUATOR AND EQUINOX OF J2000)<br>TDR (TRUE OF DATE ROTATING)<br>GRC (GREENWICH ROTATING COORDINATE FRAME) | Yes |
| REF_FRAME_EPOCH | Epoch of reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.9 for formatting rules.) | 2001-11-06T11:17:33<br>2002-204T15:56:23Z | No |
| TIME_SYSTEM | Time system used for state vector, maneuver, and covariance data (also see table 3-3). Use of values other than those in ANNEX B, subsection B1 must be documented and conveyed in an ICD. | UTC, TAI, TT, GPS, TDB, TCB | Yes |

### 3.2.4 OPM DATA

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

a) the keyword to be used;

b) a short description of the item;

c) the units to be used;

d) whether the item is mandatory or optional.

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

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

**Table 3-3: OPM Data**

| Keyword | Description | Units | Mandatory |
|---|---|---|---|
| State Vector Components in the Specified Coordinate System | | | |
| COMMENT | (See 7.7 for formatting rules.) | n/a | No |
| EPOCH | Epoch of state vector & optional Keplerian elements. (See 7.5.9 for formatting rules.) | n/a | Yes |
| X | Position vector X-component | km | Yes |
| Y | Position vector Y-component | km | Yes |
| Z | Position vector Z-component | km | Yes |
| X_DOT | Velocity vector X-component | km/s | Yes |
| Y_DOT | Velocity vector Y-component | km/s | Yes |
| Z_DOT | Velocity vector Z-component | km/s | Yes |
| Osculating Keplerian Elements in the Specified Reference Frame (none or all parameters of this block must be given.) | | | |
| COMMENT | (See 7.7 for formatting rules.) | n/a | No |
| SEMI_MAJOR_AXIS | Semi-major axis | km | No |
| ECCENTRICITY | Eccentricity | n/a | No |
| INCLINATION | Inclination | deg | No |
| RA_OF_ASC_NODE | Right ascension of ascending node | deg | No |
| ARG_OF_PERICENTER | Argument of pericenter | deg | No |
| TRUE_ANOMALY or MEAN_ANOMALY | True anomaly or mean anomaly | deg | No |
| GM | Gravitational Coefficient (Gravitational Constant x Central Mass) | km**3/s**2 | No |
| Spacecraft Parameters | | | |
| COMMENT | (See 7.7 for formatting rules.) | n/a | No |
| MASS | S/C Mass | kg | No |
| SOLAR_RAD_AREA | Solar Radiation Pressure Area ($A_R$) | m**2 | No |
| SOLAR_RAD_COEFF | Solar Radiation Pressure Coefficient ($C_R$) | n/a | No |
| DRAG_AREA | Drag Area ($A_D$) | m**2 | No |
| DRAG_COEFF | Drag Coefficient ($C_D$) | n/a | No |
| Position/Velocity Covariance Matrix (6x6 Lower Triangular Form. None or all parameters of the matrix must be given. COV_REF_FRAME may be omitted if it is the same as the metadata REF_FRAME.) | | | |
| COMMENT | (See 7.7 for formatting rules.) | n/a | No |
| COV_REF_FRAME | Coordinate system for covariance matrix (value must be selected from ANNEX B, subsections B2 or B3) | n/a | No |
| CX_X | Covariance matrix [1,1] | km**2 | No |
| CY_X | Covariance matrix [2,1] | km**2 | No |
| CY_Y | Covariance matrix [2,2] | km**2 | No |
| CZ_X | Covariance matrix [3,1] | km**2 | No |
| CZ_Y | Covariance matrix [3,2] | km**2 | No |
| CZ_Z | Covariance matrix [3,3] | km**2 | No |
| CX_DOT_X | Covariance matrix [4,1] | km**2/s | No |
| CX_DOT_Y | Covariance matrix [4,2] | km**2/s | No |
| CX_DOT_Z | Covariance matrix [4,3] | km**2/s | No |
| CX_DOT_X_DOT | Covariance matrix [4,4] | km**2/s**2 | No |
| CY_DOT_X | Covariance matrix [5,1] | km**2/s | No |
| CY_DOT_Y | Covariance matrix [5,2] | km**2/s | No |

| Keyword | Description | Units | Mandatory |
|---|---|---|---|
| CY_DOT_Z | Covariance matrix [5,3] | km**2/s | No |
| CY_DOT_X_DOT | Covariance matrix [5,4] | km**2/s**2 | No |
| CY_DOT_Y_DOT | Covariance matrix [5,5] | km**2/s**2 | No |
| CZ_DOT_X | Covariance matrix [6,1] | km**2/s | No |
| CZ_DOT_Y | Covariance matrix [6,2] | km**2/s | No |
| CZ_DOT_Z | Covariance matrix [6,3] | km**2/s | No |
| CZ_DOT_X_DOT | Covariance matrix [6,4] | km**2/s**2 | No |
| CZ_DOT_Y_DOT | Covariance matrix [6,5] | km**2/s**2 | No |
| CZ_DOT_Z_DOT | Covariance matrix [6,6] | km**2/s**2 | No |
| Maneuver Parameters (Repeat for each maneuver. None or all parameters of this block must be given.) | | | |
| COMMENT | (See 7.7 for formatting rules.) | n/a | No |
| MAN_EPOCH_IGNITION | Epoch of ignition. (See 7.5.9 for formatting rules.) | n/a | No |
| MAN_DURATION | Maneuver duration (If = 0, impulsive maneuver) | s | No |
| MAN_DELTA_MASS | Mass change during maneuver (value is < 0) | kg | No |
| MAN_REF_FRAME | Coordinate system for velocity increment vector (value must be selected from ANNEX B, subsection B3) | n/a | No |
| MAN_DV_1 | 1st component of the velocity increment | km/s | No |
| MAN_DV_2 | 2nd component of the velocity increment | km/s | No |
| MAN_DV_3 | 3rd component of the velocity increment | km/s | No |
| User Defined Parameters (all parameters in this section must be described in an ICD). | | | |
| USER_DEFINED_x | User defined parameter, where 'x' is replaced by a variable length user specified character string. Any number of user defined parameters may be included, if necessary to provide essential information that cannot be conveyed in COMMENT statements. Example: USER_DEFINED_EARTH_MODEL = WGS-84 | n/a | No |

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

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

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

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

**3.2.4.7** Parameters for thrust phases may be optionally given for the computation of the trajectory during or after maneuver execution (see reference [I-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. Permissible reference frames for the velocity increment vector shall be those specified in ANNEX B, subsection B3.

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

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

**3.2.4.10** Values in the covariance matrix shall be expressed in the applicable reference frame (COV_REF_FRAME keyword if used, or REF_FRAME keyword if not), and shall be presented sequentially from upper left [1,1] to lower right [6,6], lower triangular form, row by row left to right. Variance and covariance values shall be expressed in standard double precision as related in 7.5. This logical block of the OPM may be useful for risk assessment and establishing maneuver and mission margins. The intent is to provide causal connections between output orbit data and both physical hypotheses and measurement uncertainties. These causal relationships guide operators' corrective actions and mitigations.

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

## 3.3 OPM EXAMPLES

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

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

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

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

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

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

**Figure 3-1: Simple OPM File Example**

```
CCSDS_OPM_VERS    =  2.0

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

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

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

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

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

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

COMMENT  2 planned maneuvers

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

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

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

```
CCSDS_OPM_VERS = 2.0

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

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

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

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

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

**Figure 3-3: OPM File Example with Covariance Matrix**

```
CCSDS_OPM_VERS    =  2.0
COMMENT  Generated by GSOC, R. Kiehling
COMMENT  Current intermediate orbit IO2 and maneuver planning data
CREATION_DATE     =  2000-06-03T05:33:00.000
ORIGINATOR        =  GSOC
OBJECT_NAME       =  EUTELSAT W4
OBJECT_ID         =  2000-028A
CENTER_NAME       =  EARTH
REF_FRAME         =  TOD
TIME_SYSTEM       =  UTC
COMMENT  State Vector
EPOCH             =  2006-06-03T00:00:00.000
X                 =    6655.9942        [km]
Y                 =  -40218.5751        [km]
Z                 =     -82.9177        [km]
X_DOT             =       3.11548208    [km/s]
Y_DOT             =       0.47042605    [km/s]
Z_DOT             =      -0.00101495    [km/s]
COMMENT  Keplerian elements
SEMI_MAJOR_AXIS   =   41399.5123        [km]
ECCENTRICITY      =       0.020842611
INCLINATION       =       0.117746      [deg]
RA_OF_ASC_NODE    =      17.604721      [deg]
ARG_OF_PERICENTER =     218.242943      [deg]
TRUE_ANOMALY      =      41.922339      [deg]
GM                =  398600.4415        [km**3/s**2]
COMMENT  Spacecraft parameters
MASS              =    1913.000         [kg]
SOLAR_RAD_AREA    =      10.000         [m**2]
SOLAR_RAD_COEFF   =       1.300
DRAG_AREA         =      10.000         [m**2]
DRAG_COEFF        =       2.300
COV_REF_FRAME = RTN
CX_X =  3.331349476038534e-04
CY_X =  4.618927349220216e-04
CY_Y =  6.782421679971363e-04
CZ_X =  -3.070007847730449e-04
CZ_Y =  -4.221234189514228e-04
CZ_Z =  3.231931992380369e-04
CX_DOT_X =  -3.349365033922630e-07
CX_DOT_Y =  -4.686084221046758e-07
CX_DOT_Z =  2.484949578400095e-07
CX_DOT_X_DOT =  4.296022805587290e-10
CY_DOT_X =  -2.211832501084875e-07
CY_DOT_Y =  -2.864186892102733e-07
CY_DOT_Z =  1.798098699846038e-07
CY_DOT_X_DOT =  2.608899201686016e-10
CY_DOT_Y_DOT =  1.767514756338532e-10
CZ_DOT_X =  -3.041346050686871e-07
CZ_DOT_Y =  -4.989496988610662e-07
CZ_DOT_Z =  3.540310904497689e-07
CZ_DOT_X_DOT =  1.869263192954590e-10
CZ_DOT_Y_DOT =  1.008862586240695e-10
CZ_DOT_Z_DOT =  6.224444338635500e-10
USER_DEFINED_EARTH_MODEL = WGS-84
```

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

# 4 ORBIT MEAN-ELEMENTS MESSAGE (OMM)

## 4.1 GENERAL

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

**4.1.2** The OMM is intended to allow replication of the data content of an existing TLE in a CCSDS standard format, but the message can also accommodate other implementations of mean elements. All essential fields of the 'de facto standard' TLE are included in the OMM in a style that is consistent with that of the other ODMs (i.e., the OPM and OEM). From the fields in the OMM, it is possible to generate a TLE (see reference [I-3]). Programs that convert OMMs to TLEs must be aware of the structural requirements of the TLE, including the checksum algorithm and the formatting requirements for the values in the TLE. The checksum and formatting requirements of the TLE do not apply to the values in an OMM.

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

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

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

b) the receiver's modeling of gravitational forces, solar radiation pressure, atmospheric drag, etc. (see reference [I-1]), should fulfill accuracy requirements established between the exchange partners.

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

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

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

## 4.2 OMM CONTENT/STRUCTURE

### 4.2.1 GENERAL

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

a) a header;

b) metadata (data about data);

c) data; and

d) optional comments (explanatory information).

### 4.2.2 OMM HEADER

**4.2.2.1** Table 4-1 specifies for each header item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is mandatory or optional.

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

**Table 4-1: OMM Header**

| Keyword | Description | Examples of Values | Mandatory |
|---|---|---|---|
| CCSDS_OMM_VERS | Format version in the form of 'x.y', where 'y' is incremented for corrections and minor changes, and 'x' is incremented for major changes. | 2.0 | Yes |
| COMMENT | Comments (allowed in the OMM Header only immediately after the OMM version number). (See 7.7 for formatting rules.) | COMMENT This is a comment | No |
| CREATION_DATE | File creation date/time in UTC. ( For format specification, see 7.5.9.) | 2001-11-06T11:17:33<br>2002-204T15:56:23Z | Yes |
| ORIGINATOR | Creating agency or operator (value should be drawn from the SANA "Organizations" registry). The country of origin should also be provided where the originator is not a national space agency. | CNES, ESOC, GSFC, GSOC, JPL, JAXA, INTELSAT/USA, USAF, INMARSAT/UK | Yes |

### 4.2.3 OMM METADATA

**4.2.3.1** Table 4-2 specifies for each metadata item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is mandatory or optional.

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

NOTE – For some keywords (OBJECT_NAME, OBJECT_ID, CENTER_NAME) there are no definitive lists of authorized values maintained by a control authority; the references listed in 1.7 are the best known sources for authorized values to date. For the TIME_SYSTEM and REF_FRAME keywords, the approved values are shown in ANNEX B, subsections B1 and B2.

**Table 4-2: OMM Metadata**

| Keyword | Description | Examples of Values | Mandatory |
|---|---|---|---|
| COMMENT | Comments (allowed at the beginning of the OMM Metadata). (See 7.7 for formatting rules.) | COMMENT This is a comment | No |
| OBJECT_NAME | Spacecraft name for which the orbit state is provided. There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the SPACEWARN Bulletin (reference [2]), which include Object name and international designator of the participant. | TELCOM 2<br>SPACEWAY 2<br>INMARSAT 4-F2 | Yes |
| OBJECT_ID | Object identifier of the object for which the orbit state is provided. There is no CCSDS-based restriction on the value for this keyword, but it is recommended that values be the international spacecraft designator as published in the SPACEWARN Bulletin (reference [2]). Recommended values have the format YYYY-NNNP{PP}, where:<br>YYYY = Year of launch.<br>NNN = Three digit serial number of launch in year YYYY (with leading zeros).<br>P{PP} = At least one capital letter for the identification of the part brought into space by the launch.<br>In cases where the asset is not listed in the bulletin, or the SPACEWARN format is not used, the value should be provided in an ICD. | 2005-046B<br>2005-046A<br>2003-022A<br>2005-044A | Yes |
| CENTER_NAME | Origin of reference frame. There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the NASA/JPL Solar System Dynamics Group at http://ssd.jpl.nasa.gov (reference [5]). | EARTH<br>MARS<br>MOON | Yes |
| REF_FRAME | Name of the reference frame in which the Keplerian element data are given. Use of values other than those in ANNEX B, subsection B2 must be documented and conveyed in an ICD. The reference frame must be the same for all data elements, with the exception of the covariance matrix, for which an applicable different reference frame may be specified. | TEME<br>EME2000 | Yes |
| REF_FRAME_EPOCH | Epoch of reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.9 for formatting rules.) | 2001-11-06T11:17:33<br>2002-204T15:56:23Z | No |
| TIME_SYSTEM | Time system used for the orbit state and covariance matrix. Use of values other than those in ANNEX B, subsection B1 must be documented and conveyed in an ICD. | UTC | Yes |
| MEAN_ELEMENT_THEORY | Description of the Mean Element Theory. Indicates the proper method to employ to propagate the state. | SGP4<br>DSST<br>USM | Yes |

### 4.2.4 OMM DATA

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

a) the keyword to be used;

b) a short description of the item;

c) the units to be used;

d) whether the item is mandatory or optional.

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

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

**Table 4-3: OMM Data**

| Keyword | Description | Units | Mandatory |
|---|---|---|---|
| Mean Keplerian Elements in the Specified Reference Frame | | | |
| COMMENT | (See 7.7 for formatting rules.) | n/a | No |
| EPOCH | Epoch of Mean Keplerian elements. (See 7.5.9 for formatting rules.) | n/a | Yes |
| SEMI_MAJOR_AXIS or MEAN_MOTION | Semi-major axis in kilometers (preferred), or, if MEAN_ELEMENT_THEORY = SGP/SGP4, the Keplerian Mean motion in revolutions per day | km<br>rev/day | Yes |
| ECCENTRICITY | Eccentricity | n/a | Yes |
| INCLINATION | Inclination | deg | Yes |
| RA_OF_ASC_NODE | Right ascension of ascending node | deg | Yes |
| ARG_OF_PERICENTER | Argument of pericenter | deg | Yes |
| MEAN_ANOMALY | Mean anomaly | deg | Yes |
| GM | Gravitational Coefficient (Gravitational Constant x Central Mass) | km**3/s**2 | No |
| Spacecraft Parameters | | | |
| COMMENT | (See 7.7 for formatting rules.) | n/a | No |
| MASS | S/C Mass | kg | No |
| SOLAR_RAD_AREA | Solar Radiation Pressure Area ($A_R$) | m**2 | No |
| SOLAR_RAD_COEFF | Solar Radiation Pressure Coefficient ($C_R$) | n/a | No |
| DRAG_AREA | Drag Area ($A_D$) | m**2 | No |
| DRAG_COEFF | Drag Coefficient ($C_D$) | n/a | No |
| TLE Related Parameters (This section is only required if MEAN_ELEMENT_THEORY=SGP/SGP4) | | | |
| COMMENT | (See 7.7 for formatting rules.) | n/a | No |
| EPHEMERIS_TYPE | Default value = 0. (See 4.2.4.7.) | n/a | No |
| CLASSIFICATION_TYPE | Default value = U. (See 4.2.4.7.) | n/a | No |
| NORAD_CAT_ID | NORAD Catalog Number ('Satellite Number') an integer of up to nine digits. This keyword is only required if MEAN_ELEMENT_THEORY=SGP/SGP4. | n/a | No |

| Keyword | Description | Units | Mandatory |
|---|---|---|---|
| ELEMENT_SET_NO | Element set number for this satellite. Normally incremented sequentially, but may be out of sync if it is generated from a backup source. Used to distinguish different TLEs, and therefore only meaningful if TLE-based data is being exchanged (i.e., MEAN_ELEMENT_THEORY = SGP/SGP4). | n/a | No |
| REV_AT_EPOCH | Revolution Number | n/a | No |
| BSTAR | SGP/SGP4 drag-like coefficient (in units 1/[Earth radii]). Only required if MEAN_ELEMENT_THEORY=SGP/SGP4 | 1/ER | No |
| MEAN_MOTION_DOT | First Time Derivative of the Mean Motion (only required if MEAN_ELEMENT_THEORY = SGP) | rev/day**2 | No |
| MEAN_MOTION_DDOT | Second Time Derivative of Mean Motion (only required if MEAN_ELEMENT_THEORY = SGP) | rev/day**3 | No |
| Position/Velocity Covariance Matrix (6x6 Lower Triangular Form. None or all parameters of the matrix must be given. COV_REF_FRAME may be omitted if it is the same as the metadata REF_FRAME.) | | | |
| COMMENT | (See 7.7 for formatting rules.) | n/a | No |
| COV_REF_FRAME | Reference frame for the covariance matrix. The value must be selected from ANNEX B, subsections B2 and B3. | n/a | No |
| CX_X | Covariance matrix [1,1] | km**2 | No |
| CY_X | Covariance matrix [2,1] | km**2 | No |
| CY_Y | Covariance matrix [2,2] | km**2 | No |
| CZ_X | Covariance matrix [3,1] | km**2 | No |
| CZ_Y | Covariance matrix [3,2] | km**2 | No |
| CZ_Z | Covariance matrix [3,3] | km**2 | No |
| CX_DOT_X | Covariance matrix [4,1] | km**2/s | No |
| CX_DOT_Y | Covariance matrix [4,2] | km**2/s | No |
| CX_DOT_Z | Covariance matrix [4,3] | km**2/s | No |
| CX_DOT_X_DOT | Covariance matrix [4,4] | km**2/s**2 | No |
| CY_DOT_X | Covariance matrix [5,1] | km**2/s | No |
| CY_DOT_Y | Covariance matrix [5,2] | km**2/s | No |
| CY_DOT_Z | Covariance matrix [5,3] | km**2/s | No |
| CY_DOT_X_DOT | Covariance matrix [5,4] | km**2/s**2 | No |
| CY_DOT_Y_DOT | Covariance matrix [5,5] | km**2/s**2 | No |
| CZ_DOT_X | Covariance matrix [6,1] | km**2/s | No |
| CZ_DOT_Y | Covariance matrix [6,2] | km**2/s | No |
| CZ_DOT_Z | Covariance matrix [6,3] | km**2/s | No |
| CZ_DOT_X_DOT | Covariance matrix [6,4] | km**2/s**2 | No |
| CZ_DOT_Y_DOT | Covariance matrix [6,5] | km**2/s**2 | No |
| CZ_DOT_Z_DOT | Covariance matrix [6,6] | km**2/s**2 | No |
| User Defined Parameters (all parameters in this section must be described in an ICD). | | | |
| USER_DEFINED_x | User defined parameter, where 'x' is replaced by a variable length user specified character string. Any number of user defined parameters may be included, if necessary to provide essential information that cannot be conveyed in COMMENT statements. Example: USER_DEFINED_EARTH_MODEL = WGS-84 | n/a | No |

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

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

**4.2.4.5** Values in the covariance matrix shall be expressed in the applicable reference frame (COV_REF_FRAME keyword if used, or REF_FRAME keyword if not), and shall be presented sequentially from upper left [1,1] to lower right [6,6], lower triangular form, row by row left to right. Variance and covariance values shall be expressed in standard double precision as related in 6.4. This logical block of the OMM may be useful for risk assessment and establishing maneuver and mission margins.

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

- The value associated with the CENTER_NAME keyword shall be 'EARTH'.
- The value associated with the REF_FRAME keyword shall be 'TEME' (see ANNEX B, subsection B2).
- The value associated with the TIME_SYSTEM keyword shall be 'UTC'.
- The format of the OBJECT_NAME and OBJECT_ID keywords shall be that of the SPACEWARN bulletin (reference [2]).
- The MEAN_MOTION keyword must be used instead of SEMI_MAJOR_AXIS.

**4.2.4.7** For those who wish to use the OMM to represent a TLE, there are a number of considerations that apply with respect to precision of angle representation, use of certain fields by the propagator, reference frame, etc. Some sources suggest the coding for the EPHEMERIS_TYPE keyword: 1=SGP, 2=SGP4, 3=SDP4, 4=SGP8, 5=SDP8. Some sources suggest the following coding for the CLASSIFICATION_TYPE keyword: U=unclassified, S=secret. (For further information see references [I-3] and [I-4])

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

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

## 4.3 OMM EXAMPLES

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

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

**Figure 4-1: Example Two Line Element Set (TLE)**

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

OBJECT_NAME    = GOES 9
OBJECT_ID      = 1995-025A
CENTER_NAME    = EARTH
REF_FRAME      = TEME
TIME_SYSTEM    = UTC
MEAN_ELEMENT_THEORY = SGP/SGP4


EPOCH             = 2007-064T10:34:41.4264
MEAN_MOTION       = 1.00273272
ECCENTRICITY      = 0.0005013
INCLINATION       =   3.0539
RA_OF_ASC_NODE    =  81.7939
ARG_OF_PERICENTER = 249.2363
MEAN_ANOMALY      = 150.1602
GM                = 398600.8
EPHEMERIS_TYPE    = 0
CLASSIFICATION_TYPE = U
NORAD_CAT_ID      = 23581
ELEMENT_SET_NO    = 0925
REV_AT_EPOCH      = 4316
BSTAR             = 0.0001
MEAN_MOTION_DOT   = -0.00000113
MEAN_MOTION_DDOT  = 0.0
```

**Figure 4-2: OMM File Example without Covariance Matrix**

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

OBJECT_NAME    = GOES 9
OBJECT_ID      = 1995-025A
CENTER_NAME    = EARTH
REF_FRAME      = TEME
TIME_SYSTEM    = UTC
MEAN_ELEMENT_THEORY = SGP/SGP4

EPOCH             = 2007-064T10:34:41.4264
MEAN_MOTION       = 1.00273272
ECCENTRICITY      = 0.0005013
INCLINATION       =   3.0539
RA_OF_ASC_NODE    =  81.7939
ARG_OF_PERICENTER = 249.2363
MEAN_ANOMALY      = 150.1602
GM                = 398600.8

EPHEMERIS_TYPE    = 0
CLASSIFICATION_TYPE = U
NORAD_CAT_ID   = 23581
ELEMENT_SET_NO = 0925
REV_AT_EPOCH      = 4316
BSTAR             = 0.0001
MEAN_MOTION_DOT   = -0.00000113
MEAN_MOTION_DDOT  = 0.0

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

**Figure 4-3: OMM File Example with Covariance Matrix**

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

OBJECT_NAME    = GOES 9
OBJECT_ID      = 1995-025A
CENTER_NAME    = EARTH
REF_FRAME      = TEME
TIME_SYSTEM    = UTC
MEAN_ELEMENT_THEORY = SGP/SGP4


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

USER_DEFINED_EARTH_MODEL = WGS-84
```

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

# 5 ORBIT EPHEMERIS MESSAGE (OEM)

## 5.1 GENERAL

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

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

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

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

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

## 5.2 OEM CONTENT/STRUCTURE

### 5.2.1 GENERAL

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

a) a header;

b) metadata (data about data);

c) ephemeris data;

d) optional covariance matrix data; and

e) optional comments (explanatory information).

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

**Table 5-1: OEM File Layout Specifications**

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

### 5.2.2 OEM HEADER

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

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is mandatory or optional.

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

**Table 5-2: OEM Header**

| Keyword | Description | Examples of Values | Mandatory |
|---|---|---|---|
| CCSDS_OEM_VERS | Format version in the form of 'x.y', where 'y' is incremented for corrections and minor changes, and 'x' is incremented for major changes. | 2.0 | Yes |
| COMMENT | Comments (allowed in the OEM Header only immediately after the OEM version number). (See 7.7 for formatting rules.) | COMMENT This is a comment | No |
| CREATION_DATE | File creation date and time in UTC. (For format specification, see 7.5.9.) | 2001-11-06T11:17:33<br>2002-204T15:56:23 | Yes |
| ORIGINATOR | Creating agency or operator (value should be drawn from the SANA "Organizations" registry). The country of origin should also be provided where the originator is not a national space agency. | CNES, ESOC, GSFC, GSOC, JPL, JAXA, INTELSAT/USA, USAF, INMARSAT/UK | Yes |

### 5.2.3 OEM METADATA

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

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is mandatory or optional.

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

NOTE – For some keywords (OBJECT_NAME, OBJECT_ID, CENTER_NAME) there are no definitive lists of authorized values maintained by a control authority; the references listed in 1.7 are the best known sources for authorized values to date. For the TIME_SYSTEM and REF_FRAME keywords, the approved values are listed in ANNEX B, subsection B1.

**5.2.3.3** A single metadata group shall precede each ephemeris data block. Multiple occurrences of a metadata group followed by an ephemeris data block may be used. Before each metadata group the string 'META_START' shall appear on a separate line and after each metadata group (and before the associated ephemeris data block) the string 'META_STOP' shall appear on a separate line.

**Table 5-3: OEM Metadata**

| Keyword | Description | Examples of Values | Mandatory |
|---|---|---|---|
| META_START | The OEM message contains metadata, ephemeris data, and covariance data; this keyword is used to delineate the start of a metadata block within the message (metadata are provided in a block, surrounded by 'META_START' and 'META_STOP' markers to facilitate file parsing). This keyword must appear on a line by itself. | n/a | Yes |
| COMMENT | Comments allowed only immediately after the META_START keyword. (See 7.7 for formatting rules.) | COMMENT This is a comment. | No |
| OBJECT_NAME | The name of the object for which the ephemeris is provided. There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the SPACEWARN Bulletin (reference [2]), which include Object name and international designator of the participant. | EUTELSAT W1<br>MARS PATHFINDER<br>STS 106<br>NEAR | Yes |
| OBJECT_ID | Object identifier of the object for which the ephemeris is provided. There is no CCSDS-based restriction on the value for this keyword, but it is recommended that values be the international spacecraft designator as published in the SPACEWARN Bulletin (reference [2]). Recommended values have the format YYYY-NNNP{PP}, where:<br>YYYY = Year of launch.<br>NNN = Three-digit serial number of launch in year YYYY (with leading zeros).<br>P{PP} = At least one capital letter for the identification of the part brought into space by the launch.<br>In cases where the asset is not listed in reference [2], or the SPACEWARN format is not used, the value should be provided in an ICD. | 2000-052A<br>1996-068A<br>2000-053A<br>1996-008A | Yes |
| CENTER_NAME | Origin of reference frame, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this case the value for 'CENTER_NAME' is subject to the same rules as for 'OBJECT_NAME'). There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the NASA/JPL Solar System Dynamics Group at http://ssd.jpl.nasa.gov (reference [5]). | EARTH<br>EARTH BARYCENTER<br>MOON<br>SOLAR SYSTEM BARYCENTER<br>SUN<br>JUPITER BARYCENTER<br>STS 106<br>EROS | Yes |

| Keyword | Description | Examples of Values | Mandatory |
|---|---|---|---|
| REF_FRAME | Name of the reference frame in which the ephemeris data are given. Use of values other than those in ANNEX B, subsections B2 must be documented and conveyed in an ICD. The reference frame must be the same for all data elements, with the exception of the covariance matrix, for which an applicable different reference frame may be specified. | ICRF<br>ITRF-93<br>ITRF-97<br>ITRF2000<br>ITRFxxxx (template for future versions)<br>TOD (True Equator and Equinox of Date)<br>EME2000 (Earth Mean Equator and Equinox of J2000)<br>TDR (true of date rotating)<br>GRC (Greenwich rotating coordinate frame, another name for TDR) | Yes |
| REF_FRAME_EPOCH | Epoch of reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.9 for formatting rules.) | 2001-11-06T11:17:33<br>2002-204T15:56:23Z | No |
| TIME_SYSTEM | Time system used for metadata, ephemeris data, and covariance data. Use of values other than those in ANNEX B, subsection B1 must be documented and conveyed in an ICD. | UTC, TAI, TT, GPS, TDB, TCB | Yes |
| START_TIME | Start of TOTAL time span covered by ephemeris data and covariance data immediately following this metadata block. (For format specification, see 7.5.9.) | 1996-12-18T14:28:15.1172<br>1996-277T07:22:54 | Yes |
| USEABLE_START_TIME<br><br>USEABLE_STOP_TIME | Optional start and end of USEABLE time span covered by ephemeris data immediately following this metadata block. To allow for proper interpolation near the ends of the ephemeris data block it may be necessary, depending upon the interpolation method to be used, to utilize these keywords with values within the time span covered by the ephemeris data records as denoted by the START/STOP_TIME time tags. (For format specification, see 7.5.9.) These keywords are optional items, and thus may not be necessary, depending on the recommended interpolation method. However, it is recommended to use the USEABLE_START_TIME and USEABLE_STOP_TIME capability in all cases. The USEABLE_START_TIME time tag at a new block of ephemeris data must be greater than or equal to the USEABLE_STOP_TIME time tag of the previous block. | 1996-12-18T14:28:15.1172<br>1996-277T07:22:54 | No |
| STOP_TIME | End of TOTAL time span covered by ephemeris data and covariance data immediately following this metadata block. (For format specification, see 7.5.9.) | 1996-12-18T14:28:15.1172<br>1996-277T07:22:54 | Yes |
| INTERPOLATION | This keyword may be used to specify the recommended interpolation method for ephemeris data in the immediately following set of ephemeris lines. | Hermite<br>Linear<br>Lagrange | No |

| Keyword | Description | Examples of Values | Mandatory |
|---|---|---|---|
| INTERPOLATION_DEGREE | Recommended interpolation degree for ephemeris data in the immediately following set of ephemeris lines. Must be an integer value. This keyword must be used if the 'INTERPOLATION' keyword is used. | 5<br>1 | No |
| META_STOP | The OEM message contains metadata, ephemeris data, and covariance data; this keyword is used to delineate the end of a metadata block within the message (metadata are provided in a block, surrounded by 'META_START' and 'META_STOP' markers to facilitate file parsing). This keyword must appear on a line by itself. | n/a | Yes |

### 5.2.4 OEM DATA: EPHEMERIS DATA LINES

**5.2.4.1** Each set of ephemeris data, including the time tag, must be provided on a single line. The order in which data items are given shall be fixed: **Epoch**, **X, Y, Z**, **X_DOT, Y_DOT, Z_DOT, X_DDOT, Y_DDOT, Z_DDOT**.

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

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

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

**5.2.4.5** The TIME_SYSTEM value must remain fixed within an OEM.

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

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

### 5.2.5 OEM DATA: COVARIANCE MATRIX LINES

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

**5.2.5.2** If present, the covariance matrix data lines in the OEM are separated from the ephemeris data by means of two new keywords: COV_START and COVARIANCE_STOP. The 'COV_START' keyword must appear before the first line of the covariance matrix data. The 'COVARIANCE_STOP' keyword must appear after the last line of covariance data. Each of these keywords shall appear on a line by itself with no time tags or values.

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

**5.2.5.4** Each row of the 6x6 lower triangular covariance matrix must be provided on a single line. The order in which data items are given shall be fixed. The elements in each row of covariates shall be defined by the order in the ephemeris data line (i.e., **X, Y, Z**, **X_DOT, Y_DOT, Z_DOT)**. The six rows of the covariance matrix contain from one to six numbers depending on what row of the matrix is being represented (first row has one element, second row has two, continuing in this fashion until the sixth row has six elements).

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

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

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

## 5.3 OEM EXAMPLES

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

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

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

META_START
OBJECT_NAME          = MARS GLOBAL SURVEYOR
OBJECT_ID            = 1996-062A
CENTER_NAME          = MARS BARYCENTER
REF_FRAME            = EME2000
TIME_SYSTEM          = UTC
START_TIME           = 1996-12-18T12:00:00.331
USEABLE_START_TIME   = 1996-12-18T12:10:00.331
USEABLE_STOP_TIME    = 1996-12-28T21:23:00.331
STOP_TIME            = 1996-12-28T21:28:00.331
INTERPOLATION        = HERMITE
INTERPOLATION_DEGREE = 7
META_STOP
COMMENT  This file was produced by M.R. Somebody, MSOO NAV/JPL, 1996NOV 04. It is
COMMENT  to be used for DSN scheduling purposes only.

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

   < intervening data records omitted here >

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


META_START
OBJECT_NAME          = MARS GLOBAL SURVEYOR
OBJECT_ID            = 1996-062A
CENTER_NAME          = MARS BARYCENTER
REF_FRAME            = EME2000
TIME_SYSTEM          = UTC
START_TIME           = 1996-12-28T21:29:07.267
USEABLE_START_TIME   = 1996-12-28T22:08:02.5
USEABLE_STOP_TIME    = 1996-12-30T01:18:02.5
STOP_TIME            = 1996-12-30T01:28:02.267
INTERPOLATION        = HERMITE
INTERPOLATION_DEGREE = 7
META_STOP

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

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

   < intervening data records omitted here >

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

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

```
CCSDS_OEM_VERS = 2.0

COMMENT  OEM WITH OPTIONAL ACCELERATIONS MUST BE OEM VERSION 2.0

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

META_START
OBJECT_NAME          = MARS GLOBAL SURVEYOR
OBJECT_ID            = 1996-062A
CENTER_NAME          = MARS BARYCENTER
REF_FRAME            = EME2000
TIME_SYSTEM          = UTC
START_TIME           = 1996-12-18T12:00:00.331
USEABLE_START_TIME   = 1996-12-18T12:10:00.331
USEABLE_STOP_TIME    = 1996-12-28T21:23:00.331
STOP_TIME            = 1996-12-28T21:28:00.331
INTERPOLATION        = HERMITE
INTERPOLATION_DEGREE = 7
META_STOP

COMMENT  This file was produced by M.R. Somebody, MSOO NAV/JPL, 2000 NOV 04. It is
COMMENT  to be used for DSN scheduling purposes only.

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

   < intervening data records omitted here >

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

**Figure 5-2: Version 2 OEM Example with Optional Accelerations**

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

META_START
OBJECT_NAME          = MARS GLOBAL SURVEYOR
OBJECT_ID            = 1996-062A
CENTER_NAME          = MARS BARYCENTER
REF_FRAME            = EME2000
TIME_SYSTEM          = UTC
START_TIME           = 1996-12-28T21:29:07.267
USEABLE_START_TIME   = 1996-12-28T22:08:02.5
USEABLE_STOP_TIME    = 1996-12-30T01:18:02.5
STOP_TIME            = 1996-12-30T01:28:02.267
INTERPOLATION        = HERMITE
INTERPOLATION_DEGREE = 7
META_STOP


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

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

   < intervening data records omitted here >

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


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

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

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

# 6 ORBIT COMPREHENSIVE MESSAGE (OCM)

## 6.1 GENERAL

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

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

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

**6.1.4** Orbit information may be exchanged between two participants by sending an ephemeris in the form of one or more time series of orbital states (selectable as orbital elements and/or Cartesian vectors providing position and optionally velocity and accelerations) using an Orbit Comprehensive Message (OCM). If orbital states are desired at arbitrary time(s) contained within the span of the ephemeris, the message recipient is encouraged to use a suitable interpolation method. For times outside of supplied orbit state time spans or if the step size between orbit states is too large to support interpolation [I-8], optional force model parameters should be included with this message and the recipient must have a suitably-compatible orbit propagator.

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

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

## 6.2 OCM CONTENT/STRUCTURE

### 6.2.1 GENERAL

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

1) a single header;
2) a single, optional metadata section (data about data);
3) a data section, comprised of multiple data constituents:
    a. a single, optional space object physical characteristics section
    b. a single, optional force model section
    c. one or more optional maneuver data sections
    d. one or more optional orbit state time histories
    e. a single, optional orbit determination data section
    ~~e.~~f. one or more optional covariance time histories
    ~~f.~~g. one or more optional State Transition Matrix (STM) time histories
    ~~g.~~h one or more optional Ephemeris Compression (EC) time segments
4) optional, user-defined data and supplemental comments (explanatory information).

**Table 6-1: OCM File Layout and Ordering Specification**

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

### 6.2.2 OCM HEADER

**6.2.2.1** Table 6-2 specifies for each header item.

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

**Table 6-2: OCM Header**

| Keyword | Description | Examples of Values | Mandatory |
|---|---|---|---|
| CCSDS_OCM_VERS | Format version in the form of 'x.y', where 'y' is incremented for corrections and minor changes, and 'x' is incremented for major changes. | 1.0 | **Yes** |
| COMMENT | Comments (allowed in the OCM Header only immediately after the OCM version number). (See 7.7 for formatting rules.) | COMMENT This is a comment | No |
| CREATION_DATE | File creation date/time in UTC. (For format specification, see 7.5.9.) | 2001-11-06T11:17:33<br>2002-204T15:56:23Z | **Yes** |
| ORIGINATOR | Creating agency or operator (value should be drawn from the SANA "Organizations" registry). The country of origin should also be provided where the originator is not a national space agency. | CNES, ESOC, GSFC, GSOC, JPL, JAXA, INTELSAT/USA, USAF, INMARSAT/UK | **Yes** |
| EPOCH_TZERO | Epoch from which all OCM relative times are referenced. (For format specification, see 7.5.9.) | EPOCH_TZERO | Yes |

Formatted Table

### 6.2.3 OCM METADATA

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

**6.2.3.2** The "OCM Metadata" section is optional; "mandatory" in~~. In~~ the context of Table 6-3 denotes those~~,~~ keywords which must be included in this section if this section is included.~~ are marked as "Mandatory".~~

**6.2.3.3** The TIME_SYSTEM value must remain fixed within an OCM.

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

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

NOTE – For some keywords (OBJECT_NAME, OBJECT_ID) there are no definitive lists of authorized values maintained by a control authority; the references listed in 1.7 are the best known sources for authorized values to date.

**Table 6-3: OCM Metadata**

Formatted: Font: Bold

| Keyword | Description | Examples of Values | Mandatory |
|---|---|---|---|
| COMMENT | Comments (allowed at any point(s) throughout the OCM Metadata section). (See 7.7 for formatting rules.) | COMMENT This is a comment | No |
| COMMENT | Comments (allowed at any point(s) throughout the OCM Metadata section). (See 7.7 for formatting rules.) | COMMENT This is a comment | No |
| ORIGINATOR _POC | Free text field containing Programmatic or Technical Point-of-Contact (PoC) for OCM | Mr. Rodgers | No |
| ORIGINATOR _PHONE | Free text field containing PoC phone number | +49615130312 | No |
| ORIGINATOR _POSITION | Free text field containing contact position of the PoC | Flight Dynamicist<br>Mission Design Lead | No |
| ORIGINATOR_ADDRESS | Free text field containing Technical PoC information for OCM creator (suggest email, website, or physical address, etc.) | JOHN.DOE@<br>SOMEWHERE.NET | No |
| OBJECT_DESIGNATOR | The satellite catalog designator for the object. | 22444 | No |
| OBJECT_NAME | Spacecraft name for the object. | SPOT, ENVISAT,<br>IRIDIUM, INTELSAT | No |
| INTL_DESIGNATOR | The full international designator for the object. Values shall have the format:<br>YYYY-NNNP{PP}, where:<br>YYYY = Year of launch.<br>NNN = Three digit serial number of launch in year YYYY (with leading zeros).<br>P{PP} = At least one capital letter for the identification of the part brought into space by the launch.<br>In cases where the object has no international designator, the value UNKNOWN may be used. | 2000-052A<br>1996-068A<br>2000-053A<br>1996-008A | No |
| OBJECT_TYPE | The object type. | PAYLOAD<br>ROCKET BODY<br>UPPER STAGE<br>DEBRIS<br>UINKNOWN<br>OTHER | No |
| TIME_SYSTEM | Time system used for reference frame and reference timing epoch. Approved values are listed in ANNEX B, subsection B1; use of values other than these approved values must be documented and conveyed in an ICD.<br><br>**Omission of this non-mandatory field defaults to "UTC"** | UTC, UT1, TAI, TT, GPS, TDB, TCB | No |
| ~~EPOCH_TZERO~~ | ~~Epoch from which OCM relative times are referenced. (For format specification, see 7.5.9.)~~ | ~~2001-11-06T11:17:33~~ | ~~Yes~~ |
| START_TIME | Relative time of the earliest of all time tags corresponding to maneuver, orbital state, covariance, and/or STM data. The epoch is specified in timing system "TIME_SYSTEM"<br><br>(For format specification, see 7.5.9 for absolute time format; relative time is measured in seconds from EPOCH_TZERO) | 1996-12-18T14:28:15.1172<br>1996-277T07:22:54<br>100.0 | No |
| STOP_TIME | Epoch or relative time of the end of TOTAL time span covered by ALL maneuver, orbital state, covariance and/or STM data contained in this message.<br><br>(For format specification, see 7.5.9 for absolute time format; relative time is measured in seconds from EPOCH_TZERO) | 1996-12-18T14:28:15.1172<br>1996-277T07:22:54<br>500.0 | No |

| Keyword | Description | Examples of Values | Mandatory |
|---|---|---|---|
| TAIMUTC_TZERO | Difference (TAI – UTC) in seconds (i.e. total # leap seconds elapsed since 1958) as modeled by the message originator at epoch "EPOCH_TZERO". | 36 [s] | No |
| UT1MUTC_TZERO | Difference (UT1 – UTC) in seconds, as modeled by the originator at epoch "EPOCH_TZERO". | 0.357 [s] | No |
| UT1MUTC_RATE_TZERO | Rate-of-change of (UT1 – UTC) in milliseconds per day, as modeled by the originator at epoch "EPOCH_TZERO" | .0001 [ms/day] | No |
| CENTER_NAME | Origin of reference frame, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this case the value for 'CENTER_NAME' is subject to the same rules as for 'OBJECT_NAME'). There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the NASA/JPL Solar System Dynamics Group at http://ssd.jpl.nasa.gov (reference [5]).<br><br>**Omission of this non-mandatory field defaults to "EARTH'** | EARTH<br>MOON<br>SOLAR SYSTEM<br>BARYCENTER<br>SUN<br>ISS<br>EROS | No |

### 6.2.4 OCM DATA: SPACE OBJECT PHYSICAL CHARACTERISTICS

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

**6.2.4.2** Keyword values shall be provided in the units specified in column three of Table 6-4.

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

**6.2.4.4** Only one space object physical characteristics section shall appear in an~~y~~ OCM.

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

~~6.2.4.5~~6.2.4.6 Further definition of Space Object Physical Characteristics parameters is provided in ANNEX C.

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

| Keyword | Description | Units | Examples of Values | Mandatory |
|---|---|---|---|---|
| COMMENT | Comments (allowed at any point(s) throughout the OCM Space Object Physical Characteristics). (See 7.7 for formatting rules.) | n/a | COMMENT This is a comment | No |
| PHYS_START | Start of a Space Object Physical Characteristics specification | n/a | | Yes |
| COMMENT | Comments (allowed at any point(s) throughout the OCM Space Object Physical Characteristics). (See 7.7 for formatting rules.) | n/a | COMMENT This is a comment | No |
| DRAG_AREA | Additional Drag Area ($A_D$) facing the relative wind vector, not already incorporated into the attitude-dependent "AREA_ALONG_OEB" parameters | m**2 | 2.5 | No |
| DRAG_COEFF | Drag Coefficient ($C_D$) | n/a | 2.2 | No |
| DRAG_SCALE | Drag scale factor (1.0 represents no scaling).<br><br>**Omission of this non-mandatory field defaults to 1.0.** | n/a | 1.0 | No |
| MASS | S/C Mass at the reference epoch "EPOCH_TZERO" | kg | 500 | No |
| PHYSDIM_FRAME | Name of the reference frame which maps to the Optimally-Encompassing Box (OEB) frame via the Euler sequence PHYS_PITCH, PHYS_ROLL and PHYS_YAW. Use of values other than those in ANNEX B, subsections B2 and B3 must be documented and conveyed in an ICD. The reference frame must be the same for all data elements within a given Orbit State Time History interval.<br><br>**Omission of this non-mandatory field defaults to RIC.** | n/a | ITRF-97 | No |
| PHYSDIM_FRAME_EPOCH | Epoch of the PHYSDIM reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.9 for formatting rules.)<br><br>**Where the reference frame epoch is required and not intrinsic to the selected reference frame, omission of this non-mandatory field defaults to EPOCH_TZERO.** | (CCSDS Time Format per section 7.5.9) | 2001-11-06T11:17:33<br>2002-204T15:56:23Z | No |

| Keyword | Description | Units | Examples of Values | Mandatory |
|---|---|---|---|---|
| AREA_ALONG_OEB_MAX | Cross-sectional area of space object when viewed along max OEB ($\hat{X}_{OEB}$) direction as defined in ANNEX C | m**2 | 0.15 | No |
| AREA_ALONG_ OEB_MED | Cross-sectional area of space object when viewed along medium OEB ($\hat{y}_{OEB}$) direction as defined in ANNEX C | m**2 | 0.3 | No |
| AREA_ALONG_ OEB_MIN | Cross-sectional area of space object when viewed along minimum OEB ($\hat{z}_{OEB}$) direction as defined in ANNEX C | m**2 | 0.5 | No |
| OEB_MAX | Maximum physical dimension (along $\hat{X}_{OEB}$) of the Optimally-Encompassing Box (OEB) in meters, | m | 1 | No |
| OEB_MED | Medium physical dimension (along $\hat{y}_{OEB}$) of Optimally-Encompassing Box (OEB) normal to OEB_MAX direction | m | 0.5 | No |
| OEB_MIN | Minimum physical dimension (along $\hat{z}_{OEB}$) of Optimally-Encompassing Box (OEB) in direction normal to both OEB_MAX and OEB_MED directions | m | 0.3 | No |
| PHYS_PITCH | Pitch angle of the (Yaw/Pitch/Roll ordered sequence) that maps from the "PHYSDIM" frame (defined in ANNEX C) to the OEB frame. A value of "-999" denotes a tumbling space object. | deg | 1.7 | No |
| PHYS_ROLL | Roll angle of the (Yaw/Pitch/Roll ordered sequence) that maps from the "PHYSDIM" frame (defined in ANNEX C) to the OEB frame. A value of "-999" denotes a tumbling space object. | deg | -10 | No |
| PHYS_YAW | Yaw angle of the (Yaw/Pitch/Roll ordered sequence) that maps from the "PHYSDIM" frame (defined in ANNEX C) to the OEB frame. A value of "-999" denotes a tumbling space object. | deg | 30 | No |
| RCS | Effective Radar Cross Section of the object | m**2 | 1.0 | No |
| SOLAR_RAD_AREA | Additional total Solar Radiation Pressure Area ($A_R$) facing the Sun, not already incorporated into the attitude-dependent "AREA_ALONG_OEB" parameters. However, note that for GEO spacecraft, this supplied "SOLAR_RAD_AREA" parameter shall not include (i.e. be degraded by) solar declination-induced area variations. | m**2 | 1.0 | No |
| SOLAR_RAD_COEFF | Solar Radiation Pressure Coefficient ($C_R$) | n/a | 1.7 | No |
| SOLAR_RAD_SCALE | Solar Radiation Pressure scale factor (1.0 represents no scaling) | n/a | 1.0 | No |
| VM_ABS | Absolute Visual Magnitude "normalized" as discussed in ANNEX D to a 1 AU Sun-to-target distance, a phase angle of 0° and a 40,000 km target-to-sensor distance (equivalent of GEO satellite tracked at 15.6° above local horizon) | n/a | 15.0 | No |
| PHYS_STOP | End of a Space Object Physical Characteristics specification | n/a | | Yes |

### 6.2.5 OCM DATA: FORCE MODEL SPECIFICATION

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

**6.2.5.2** The "OCM Data: Force Model Specification" section is optional; "mandatory" in the context of Table 6-5 denotes those keywords which must be included in this section if this section is included.

**6.2.5.3** Only one force model data section shall appear in an OCM.

**6.2.5.4** The Force Model section in the OCM shall be indicated by two keywords: FORCE_START and FORCE_STOP.

~~6.2.5.3~~**6.2.5.5** If the solar radiation coefficient, $C_R$, is set to zero, no solar radiation pressure shall be taken into account (see description of SOLAR_RAD_COEFF~~$C_R$~~ in Table 6-4).

~~6.2.5.4~~**6.2.5.6** If the atmospheric drag coefficient, $C_D$, is set to zero, no atmospheric drag shall be taken into account (see description of DRAG_COEFF~~$C_D$~~ in Table 6-4).

~~**6.2.5.5** Only a single force model data section shall appear in any OCM.~~

**Table 6-5: OCM Data: Force Model Specification**

| Keyword | Description | Units | Examples of Values | Mandatory |
|---|---|---|---|---|
| COMMENT | Comments (allowed at any point(s) throughout the OCM Force Model Specification Data). (See 7.7 for formatting rules.) | n/a | COMMENT This is a comment | No |
| FORCE_START | Start of a Force Model specification | n/a | | Yes |
| COMMENT | Comments (allowed at any point(s) throughout the OCM Force Model Specification Data). (See 7.7 for formatting rules.) | n/a | COMMENT This is a comment | No |
| GM | Gravitational Coefficient of attracting body (Gravitational Constant x Central Mass) | km**3/s**2 | 398600.4 | No |
| GRAVITY_MODEL | The name of the geopotential model for central body, followed by the degree (D) and order (O) of the spherical harmonic coefficients applied. Note that specifying a zero value for "order" (i.e. 2O) denotes zonals ($J_2 \cdots J_D$) only. | n/a | EGM-96: 36D 36O<br>WGS-84: 8D 8O<br>GGM-01: 12D 12O<br>TEG-4: 8D 2O | No |
| EQUATORIAL_RADIUS | Oblate spheroid equatorial radius | km | 6378.137 | No |
| OBLATE_FLATTENING | Oblate spheroid oblateness for the polar-symmetric oblate central body model | n/a | 1/298.257223563 | No |
| CENTRAL_BODY_ROTA | Central body angular rotation rate, measured about the major principal axis of the inertia tensor of the central body. | deg/s | 4.17807421629e-3 | No |
| ATMOSPHERIC_MODEL | Name of atmosphere model | n/a | Atmospheric models (e.g., MSISE90, NRLMSIS00, J70, J71, JRob, DTM) | No |
| N_BODY_PERTURBATIONS | N-body gravitational perturbations used | n/a | MOON, SUN | No |

| Keyword | Description | Units | Examples of Values | Mandatory |
|---|---|---|---|---|
| SRP_MODEL | Name of SRP model | n/a | e.g., GPS_ROCK, BOX_WING, CANNONBALL, COD | No |
| SOLID_TIDES_MODEL | Name of solid tides model (optionally specify order or constituent effects (diurnal, semi-diurnal, etc.) | n/a | diurnal | No |
| OCEAN_TIDES_MODEL | Name of ocean tides model (optionally specify order or constituent effects (diurnal, semi-diurnal, etc.) | n/a | diurnal | No |
| ALBEDO | Name of the albedo model | n/a | | No |
| ALBEDO_GRID_SIZE | # of grid points used in the albedo model | n/a | | No |
| EOP_SOURCE | Source of originator's Earth orientation parameters | n/a | e.g., IERS, USNO, NGA | No |
| NUTATION_DEPS or NUTATION_DX | Nutation correction to obliquity $d\varepsilon$ | deg | | No |
| NUTATION_DPSI or NUTATION_DY | Nutation correction to longitude $d\psi$ | deg | | No |
| S_PRECNUT | The S parameter provides the position of the [CIO] on the equator of the CIP corresponding to the kinematical definition of the [non-rotating origin] in the GCRS when the CIP is moving with respect to the GCRS between the reference epoch and the epoch due to precession and nutation (McCarthy and Petit 2003). (Vallado 2013:214) | arcsec | −0.003 021 | No |
| X_PRECNUT | The X-coordinate of the CIP in the ICRS frame, used to locate the GCRF position and velocity vectors [K-9] | arcsec | 80.531 880 | No |
| Y_PRECNUT | The Y-coordinate of the CIP in the ICRS frame, used to locate the GCRF position and velocity vectors [K-9] | arcsec | 7.273 921 | No |
| POLAR_MOTION_XP | Polar motion coordinate Xp of the Celestial Intermediate Pole | arcsec | | No |
| POLAR_MOTION_YP | Polar motion coordinate Yp of the Celestial Intermediate Pole | arcsec | | No |
| SOLAR_F10P7 | Solar flux proxy F10.7 | Solar Flux Units = $10^4$ Jansky= $10^{-22}$ W/(m$^2$*Hz) | 120.0 | No |
| SOLAR_F10P7_MEAN | Centered-average solar flux proxy $\overline{F10.7}$ | Solar Flux Units = $10^4$ Jansky= $10^{-22}$ W/(m$^2$*Hz) | 132.0 | No |
| KSUBP | Planetary 3-hour-range Geomagnetic index Kp | Kp units | 3.2 | No |
| INTERP_METHOD_EOP | Used for EOP data | n/a | LINEAR | No |
| INTERP_METHOD_SPWX | Used for Space Weather data (SOLAR_F10P7, SOLAR_F10P7_MEAN and KSUBP) | n/a | NONE<br>LINEAR | No |
| SHADOW_MODEL | Shadow modeling for Solar Radiation Pressure; dual cone uses both umbra/penumbra regions | n/a | NONE<br>CYLINDRICAL<br>DUAL CONE | No |
| FORCE_STOP | End of a Force Model specification | n/a | | Yes |

**Commented [OD1]:** Add verbiage for IAU 2000

### 6.2.6 OCM DATA: MANEUVER SPECIFICATION

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

**6.2.6.2** The "OCM Data: Maneuver Specification" section is optional; "obligatory" in the context of Table 6-6 denotes those keywords which must be included in this section if this section is included.

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

**6.2.6.4** The 'MAN_TYPE' keyword must appear before the first line of any maneuver time history data.

~~6.2.6.3~~6.2.6.5 Impulsive, thrusting~~finite burn~~ and acceleration maneuver data in the OCM data shall be time-tagged by a relative time value measured with respect to the epoch time specified via the EPOCH_TZERO keyword.

~~6.2.6.4~~6.2.6.6 Within each maneuver specification section, the MAN_TYPE keyword/value specification is mandatory and shall immediately precede maneuver time history lines.

~~6.2.6.5~~6.2.6.7 For impulsive maneuvers (MAN_TYPE=IMPULSE), each ΔV maneuver within the ΔV time series shall be specified on a single line that contains 9~~8~~ parameters: time "T_Relative" in seconds, ΔV components measured in the selected maneuver reference frame ($\Delta V_X$, $\Delta V_Y$, $\Delta V_Z$ in km/s), the maneuver duration (assumed to be centered about the specified maneuver time, in seconds), one-sigma percentage error on ΔV magnitude, the **Maneuver Object Number (MON)** that this maneuver is to be applied to (nominally "0" for the primary or host vehicle) and either the mass decrement (i.e. a negative number) associated with that ΔV (if MON = 0) or the mass of the deployed object (if MON ≠ 0).

~~6.2.6.6~~6.2.6.8 A non-zero MON invokes a parent/child deployment scenario, whereby the parent "host" object (MON=0) deploys one or more child space objects by imparting an impulsive~~a~~ ΔV to the host object as specified by ($\Delta V_X$, $\Delta V_Y$, $\Delta V_Z$ in km/s). In this case, MON shall be a positive number starting at "1" and incrementing through all deployed objects until "N" objects have separated. Where appropriate (e.g. with spring deployment mechanisms), recipients of OCMs using the parent/child deployment capability should incorporate both the deployment ΔV as well as the retrograde ΔV imparted to the host (as a ratio of the host and deployed object relative masses such that momentum is conserved).

**Commented [OD2]:** Need to provide an example of how this works.

~~6.2.6.7~~6.2.6.9 For thrusting (finite burns, ~~(~~MAN_TYPE=THRUST), each thrusting~~finite burn~~ maneuver (or, in the case of low-thrust, long-duration burns, each low-thrust~~maneuver~~ interval) within the maneuver ~~finite burn time~~ series shall be specified on a single line that contains 10~~9~~ parameters. The message creator may indicate a change in thrust conditions over which interpolation should not be performed by providing exactly two adjacent lines containing the same time stamp. The ten~~nine~~ parameters shall be: time "T_Relative" in **seconds**, Thruster ID (non-negative integer number), Thrust components measured in the

selected maneuver reference frame ($T_X$, $T_Y$ and $T_Z$, in **Newtons**), one-sigma percentage error on thrust magnitude, maneuver duration in **seconds** (measured with respect to the START of the specified thrust interval~~finite burn time~~), thrust vector Euler axis/angle interpolation mode between current and next thrust line (0=OFF and 1=ON), specific impulse in **seconds** and burn efficiency "η" (e.g. 0.95) and additional mass change (a negative number denotes a loss of mass) associated with that. Note that a maneuver can be specified as a time history sequence of lines, each containing these ten~~nine~~ parameters. Note also that thrust interval~~thruster finite burn~~ data may be abutting, overlapping, alternating or even intermingled in the maneuver time history block, to accommodate multiple thrusters simultaneously in operation or to accommodate changes in thrust direction, efficiency, mass change, etc.

**~~6.2.6.8~~6.2.6.10** A thrust~~An~~ acceleration profile (MAN_TYPE=ACCEL) allows aggregate modeling of both maneuvers and additional non-conservative forces that the OCM originator may model without the OCM recipient needing to. The message creator may indicate a change in acceleration over which interpolation should not be performed by providing exactly two adjacent lines containing the same time stamp. The acceleration time series shall be specified on a single line that contains eight~~seven~~ parameters: time "T_Relative" at the start of this acceleration interval in **seconds**, acceleration components measured in the selected maneuver reference frame ($A_X$, $A_Y$ and $A_Z$, **in m/s**2**), one-sigma percentage error on acceleration magnitude, maneuver duration in **seconds** (measured with respect to the START of the specified acceleration interval time), the mass decrement (i.e. a negative number) associated with this acceleration interval and acceleration vector Euler axis/angle interpolation mode between current and next acceleration line (0=OFF and 1=ON).

**~~6.2.6.9~~6.2.6.11** One or more maneuver time histories may be represented in this section. However, multiple representations shall appear only if each maneuver specification is unique from all other maneuver specifications in at least one of the following respects:

1) the data basis (e.g. PREDICTED, DETERMINED, etc.);

2) the timespans have no overlap.

**Table 6-6: OCM Data: Maneuver Specification**

| Keyword | Description | Units | Examples of Values | Mandatory |
|---|---|---|---|---|
| COMMENT | Comments (allowed at any point(s) throughout the OCM Maneuver Specification section). (See 7.7 for formatting rules.) | n/a | COMMENT This is a comment | No |
| MAN_START | Start of a maneuver data interval specification | n/a | | Yes |
| COMMENT | Comments (allowed at any point(s) throughout the OCM Maneuver Specification section). (See 7.7 for formatting rules.) | n/a | COMMENT This is a comment | No |
| MAN_ID | Optional identification number for this maneuver | n/a | E/W 20160305A | No |
| MAN_PURPOSE | Specifies the intent of the maneuver; select:<br>Aerobraking (AEROBRAKE),<br>Attitude adjust (ATT_ADJUST)<br>Collision avoidance (COLA)<br>Disposal (DISPOSAL)<br>Flyby targeting (FLYBY_TARG),<br>Launch & Early Orbit (LEOP)<br>Maneuver cleanup (MNVR_CLEANUP)<br>Mass adjust (MASS_ADJUST)<br>Orbit trim (TRIM)<br>Other (OTHER)<br>Period reduction (PER_RED),<br>Relocation (RELOCATION)<br>Science objective (SCI_OBJ),<br>Spin rate adjust (SPIN_RATE_ADJUST)<br>Station-keeping (SK)<br>Trajectory correction (TRAJ_CORR) | n/a | DISPOSAL | No |
| BASIS | Basis of this maneuver time history data:<br>PREDICTED or DETERMINED | n/a | DETERMINED | No |
| MAN_REF_FRAME | Name of the reference frame in which the maneuver vector direction data is provided, if not intrinsic to the definition of the maneuver data. Use of values other than those in ANNEX B, subsections B2 and B3 must be documented and conveyed in an ICD. The reference frame must be the same for all data elements within a given Maneuver Time History interval.<br><br>**Omission of this non-mandatory field defaults to TNW.** | n/a | EME2000 | No |
| MAN_FRAME_EPOCH | Epoch of the maneuver reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.9 for formatting rules.)<br><br>**Where the reference frame epoch is required and not intrinsic to the selected reference frame, omission of this non-mandatory field defaults to EPOCH_TZERO.** | (CCSDS Time Format) | 2001-11-06T11:17:33<br>2002-204T15:56:23Z | No |
| MAN_TYPE | Specifies type of maneuver being specified. Select impulsive ΔV (MAN_TYPE = IMPULSE~~DV~~) or finite burn thrust (MAN_TYPE = THRUST~~FINITE~~) or acceleration profile (MAN_TYPE = ACCEL) time history (see 6.2.6.~~7~~3, 6.2.6.94 and 6.2.6.10~~5~~ for details). | n/a | IMPULSE<br>THRUST<br>~~DV~~<br>~~FINITE~~<br>ACCEL | Yes |
| MAN_STOP | End maneuver data interval specification | n/a | | Yes |

### 6.2.7 OCM DATA: ORBIT STATE TIME HISTORY

**6.2.7.1** Table 6-7 provides an overview of the OCM orbit state time history ("ephemeris") section. Only those keywords shown in table 6-7 shall be used in OCM orbit state time history data specification.

**6.2.7.2** The "OCM Data: Orbit State Time History" section is optional; "mandatory" in the context of Table 6-7 denotes those keywords which must be included in this section if this section is included.

**6.2.7.3** Orbit state time history data intervals in the OCM shall be indicated by two keywords: ORBEPH_START and ORBEPH_STOP.

~~6.2.7.3~~6.2.7.4 The 'ORB_TYPE' keyword must appear before the first line of any orbit state time history metadata or state vector data.

**6.2.7.5** The ORB_TYPE keyword value shall be selected from Table B4.

~~6.2.7.4~~6.2.7.6 One or more orbit state time histories may be represented in this section (spanning ORBEPH_START to ORBEPH_STOP). However, multiple representations shall appear only if each orbit state time history is unique from all other orbit state time histories in at least one of the following respects:

1) the specified orbit state element sets;

2) the data basis (e.g. PREDICTED, ACTUAL, etc.);

3) the reference frame;

4) the orbit center;

5) the timespan.

~~6.2.7.5~~6.2.7.7 ~~The ORB_TYPE keyword value shall be selected from Table B4.~~ The ORBEPH_STOP keyword must appear after the last line of orbit state data and metadata. Each of these keywords shall appear on a line by itself.

~~6.2.7.6~~6.2.7.8 All orbit state values in the OCM data shall be time-tagged by a relative time value measured with respect to the epoch time specified via the EPOCH_TZERO keyword.

~~6.2.7.7~~6.2.7.9 Each orbit state time history shall be time-ordered to be monotonically increasing, with the exception that the message creator may indicate a change in state over which interpolation should not be performed by providing exactly two consecutive lines containing a duplicate timestamp (e.g. following application of an impulsive maneuver or spacecraft or orbit event). In the case of such a duplicate timestamp, interpolation prior to the duplicate timestamp shall use the first of the two duplicate timestamp orbit states, and interpolation after the duplicate timestamp shall use the second of the two.

~~6.2.7.8~~6.2.7.10 If the user includes orbit states at key events, those events should be annotated as such by a preceding descriptive comment line.

~~6.2.7.9~~6.2.7.11 Time tags of consecutive orbit states within the ordered sequence may be separated by uniform or non-uniform step size(s).

~~6.2.7.10~~6.2.7.12 Orbit state time tags may or may not match those of maneuver, covariance and/or state transition matrix time histories.

~~6.2.7.11~~6.2.7.13 Each set of orbit ephemeris data, including the time tag, must be provided on a single line. The order in which data items are given shall be fixed: **T_Relative** followed by the orbit state as defined in ANNEX B, subsection B4.

~~6.2.7.12~~6.2.7.14 At least one space character must be used to separate the items in each orbit ephemeris data line.

~~6.2.7.13~~6.2.7.15 The digits of precision and time steps suitable for interpolation of an orbit ephemeris time history should be chosen according to best practice to avoid positional and interpolation loss of precision [I-8].

Formatted: (none)

Formatted: Don't keep with next

**Table 6-7: OCM Data: Orbit State Time History**

| Keyword | Description | Units | Examples of Values | Mandatory |
|---|---|---|---|---|
| COMMENT | Comments (allowed at any point(s) throughout the OCM Orbit State Time History section). (See 7.7 for formatting rules.) | n/a | COMMENT This is a comment | No |
| ORB~~ORBEPH~~_START | Start of an orbit state vector or time history~~ephemeris~~ section | n/a | n/a | Yes |
| COMMENT | Comments (allowed at any point(s) throughout the OCM Orbit State Time History section). (See 7.7 for formatting rules.) | n/a | COMMENT This is a comment | No |
| ORB_N | Number of elements contained in the element set.<br><br>**This keyword may be used to override the number of elements implied by the selected ORB_TYPE, in which case ORB_TYPE shall be set to ICD.**<br><br>**Omission of this non-mandatory field defaults to the number of elements implied by ORB_TYPE (Table B4).** | n/a | 8 | No |
| BASIS | Basis of this orbit state time history data: PREDICTED or SOLVED. **Omission of this non-mandatory field defaults to PREDICTED.** | n/a | PREDICTED | No |
| ELEMENT_AVERAGING | Keyword specifying whether provided orbit state/elements are either osculating or mean element definitions. The type of averaging singly- or doubly-averaged, Kozai or Brouwer, etc.) may be specified via ICD. **Omission of this non-mandatory field defaults to OSCULATING.** | n/a | OSCULATING<br>MEAN | No |
| ORB_REF_FRAME | Name of the reference frame in which the orbit data is provided, if not intrinsic to the definition of the orbit data. Use of values other than those in ANNEX B, subsection B2 must be documented and conveyed in an ICD. The reference frame must be the same for all data elements within a given Orbit State Time History interval.<br><br>**Where the reference frame is not intrinsic to the selected orbit set, omission of this non-mandatory field defaults to ITRF-97.** | n/a | EME2000 | No |
| ORB_FRAME_EPOCH | Epoch of the orbit data reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.9 for formatting rules.)<br><br>**Where the reference frame epoch is required and not intrinsic to the selected reference frame, omission of this non-mandatory field defaults to EPOCH_TZERO.** | (CCSDS Time Format) | 2001-11-06T11:17:33<br>2002-204T15:56:23Z | No |
| ORB_TYPE | Specifies the orbit element set type via "ORB_TYPE = YYY" where YYY is selected from annex B, Table B4. | n/a | n/a | Yes |
| ORB~~ORBEPH~~_STOP | End of an orbit state vector or time history~~ephemeris~~ section | n/a | n/a | Yes |

### 6.2.8 OCM DATA: ORBIT DETERMINATION DATA

**6.2.8.1** Table 6-8 provides an overview of the OCM orbit determination data section. Only those keywords shown in table 6-8 shall be used in OCM orbit determination data specification.

**6.2.8.2** The "OCM Data: Orbit Determination Data" section is optional; "mandatory" in the context of Table 6-8 denotes those keywords which must be included in this section if this section is included.

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

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

**6.2.8.5** All orbit determination event times shall be specified in DAYS relative to the epoch time specified via the EPOCH_TZERO keyword.

**6.2.8.6** Definitions:

Observation. Provides a unique measurement 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).

Sensor Track: A set of at least three observations 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).

**Table 6-8: OCM Data: Orbit Determination Data**

| Keyword | Description | Units | Examples of Values | Mandatory |
|---|---|---|---|---|
| COMMENT | Comments (allowed at any point(s) throughout the OCM Orbit Determination Data section). (See 7.7 for formatting rules.) | n/a | COMMENT This is a comment | No |
| OD_START | Start of an orbit determination data section | n/a | n/a | Yes |
| COMMENT | Comments (allowed at any point(s) throughout the OCM Orbit Determination Data section). (See 7.7 for formatting rules.) | n/a | COMMENT This is a comment | No |
| OD_METHOD | Type of orbit determination method used to produce the orbit estimate. Commonly used methods include Batch Weighted Least Squares (BWLS) and the Extended Kalman Filter (EKF). | n/a | BWLS, EKF | Yes |
| DAYS_SINCE_FIRST_OB | Days elapsed between first accepted observation and OD state epoch EPOCH_OD | days | 3.0 | No |
| DAYS_SINCE_LAST_OB | Days elapsed between last accepted observation and OD state epoch EPOCH_OD | days | 1.0 | No |
| RECOMMENDED_OD_SPAN | Number of days of observations recommended for the OD of the object ***(useful only for Batch OD systems)*** | days | 5.0 | No |
| ACTUAL_OD_SPAN | Actual time span used for the OD of the object (NOTE: should equal (DAYS_SINCE_FIRST_OB - DAYS_SINCE_LAST_OB) | days | 2.0 | No |
| OBS_AVAILABLE | The number of observations available within the actual OD time span | Obs | 100 | No |
| OBS_USED | The number of observations accepted within the actual OD time span | Obs | 90 | No |
| TRACKS_AVAILABLE | The number of sensor tracks, for the actual time span, that were available for the OD | Trks | 33 | No |
| TRACKS_USED | The number of sensor tracks, for the actual time span, that were accepted for the OD | Trks | 30 | No |
| MAXIMUM_OBS_GAP | The maximum time between observations in the OD of the object | Days | 1.0 | No |

| | | | | |
|---|---|---|---|---|
| WEIGHTED_RMS | The weighted RMS residual ratio, defined as:<br>$Weighted\ RMS = \sqrt{\frac{\sum_{i=1}^{N} w_i(y_i - \hat{y}_i)^2}{N}}$<br>Where yi is the observation measurement at the ith time<br>$\hat{y}_i$ is the current estimate of yi,<br>$w_i = \frac{1}{\sigma_i^2}$ is the weight (sigma) associated with the measurement at the ith time and N is the number of observations.<br>The measurement variance $\sigma_i^2$, may be computed differently depending on the orbit determination method used. For Batch Weighted Least Squares methods, the measurement variance is typically a constant value across all observations of the same type from the same sensor. In Extended Kalman Filter methods, the measurement variance is typically the sum of the current state error covariance mapped into measurement space and the measurement white noise variance associated with the particular sensor and measurement type.<br>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. ***(useful only for Batch OD systems)*** | (measurement units) | 1.3 | No |
| OD_LAST_OB_EIGMAJ | Positional error ellipsoid 1$\sigma$ major eigenvalue at the epoch of the last observation | Km | .05873 | No |
| OD_LAST_OB_EIGMED | Positional error ellipsoid 1$\sigma$ medium eigenvalue at the epoch of the last observation | Km | .0357 | No |
| OD_LAST_OB_EIGMIN | Positional error ellipsoid 1$\sigma$ minor eigenvalue at the epoch of the last observation | Km | .0215 | No |
| OD_CONFIDENCE | OD confidence metric, which by definition spans 0 to 100%. ***(useful only for Filter-based OD systems).*** The OD Confidence metric shall be defined by ICD. | Percent | 95.3 | No |
| OD_STOP | End of an orbit determination data section | n/a | n/a | Yes |

### ~~6.2.8~~6.2.9 OCM DATA: ORBIT STATE COVARIANCE TIME HISTORY

~~6.2.8.1~~6.2.9.1 Table 6-~~9~~8 provides an overview of the OCM covariance time history section. Only those keywords shown in table 6-~~9~~8 shall be used in OCM covariance time history data specification.

~~6.2.8.2~~6.2.9.2 The "OCM Data: Orbit State Covariance Time History" section is optional; "mandatory" in the context of Table 6-~~9~~8 denotes those keywords which must be included in this section if this section is included.

~~6.2.8.3~~6.2.9.3 Covariance time history data intervals in the OCM shall be indicated by means of two keywords: COV_START and COV_STOP. The COV_START keyword must appear before the first line of any covariance metadata or matrix data. The COV_STOP keyword must appear after the last line of covariance data and metadata. Each of these keywords shall appear on a line by itself.

~~6.2.8.4~~6.2.9.4 One or more covariance time histories may be represented in this section (spanning COV_START to COV_STOP). However, multiple representations shall appear only if they are clearly differentiated from each other by one or more precluding comment(s) or by ICD agreement, and each covariance time history is unique from all other covariance time histories in at least one of the following respects:

1) the covariance's specified orbit state element sets;

2) the covariance data basis (e.g. PREDICTED, ACTUAL, etc.);

3) the reference frame;

4) the orbit center;

5) the covariance timespan.

~~6.2.8.5~~6.2.9.5 The COV_TYPE keyword value shall be selected from Table B4 or B5.

~~6.2.8.6~~6.2.9.6 All covariance matrices in the OCM data shall be time-tagged by a relative time value measured with respect to the epoch time specified via the EPOCH_TZERO keyword.

~~6.2.8.7~~6.2.9.7 Each covariance time history shall be time-ordered to be monotonically increasing, with the exception that the message creator may indicate a change in state over which interpolation should not be performed by providing exactly two consecutive covariance data blocks containing a duplicate timestamp (e.g. following application of an impulsive maneuver or spacecraft or orbit event). In the case of such a duplicate timestamp, interpolation prior to the duplicate timestamp shall use the first of the two duplicate timestamp covariance matrices, and interpolation after the duplicate timestamp shall use the second of the two.

~~6.2.8.8~~6.2.9.8 If the user includes covariances at key events, those events should be annotated by a preceding descriptive comment line.

~~6.2.8.9~~6.2.9.9 Within each covariance time history, one or more covariance matrices may appear at any desired frequency (for example, multiple covariances when based upon Monte Carlo simulations spanning multiple events or when propagated to multiple time points).

~~6.2.8.10~~6.2.9.10 Time tags of consecutive covariance information within the ordered sequence may be separated by uniform or non-uniform step size(s).

~~6.2.8.11~~6.2.9.11 Covariance time tags may or may not match those of maneuver, orbit state and/or state transition matrix time histories.

**6.2.9.12** Interpolation of covariance matrices at neighboring relative time points shall be done by (1) eigenvalue/vector decomposition; (2) linear (or higher-order) interpolation of neighboring eigenvalues; (3) Euler axis/angle rotation of eigenvectors at intermediate time(s) of interest; and (4) Re-composition of attained eigenvalues and eigenvectors into covariances at time(s) of interest [K-16]. Direct interpolation of covariance matrix components can produce invalid (non-positive-semidefinite) covariances.

~~6.2.8.12~~6.2.9.13 The time of the event associated with provided covariance matrices must be provided via the "T = " keyword. The reference frame of the covariance matrix, if different from that of the states in the ephemeris, must be provided via the 'COV_REF_FRAME' keyword.

~~6.2.8.13~~6.2.9.14 Values in the covariance matrix shall be expressed in the applicable reference frame and shall be presented sequentially from upper left [1,1] to lower right in lower triangular form, row-by-row from left to right. Variance and covariance values shall be expressed in standard double precision as related in 7.5.

~~6.2.8.14~~6.2.9.15 Each row of the lower triangular covariance matrix must be provided on a single line. The order in which data items are given shall be fixed. The elements in each row of covariates shall be defined by the COV_TYPE keyword specification. The "N" rows of the covariance matrix shall contain from one to "N" numbers depending on what row of the matrix is being represented (first row has one element, second row has two, continuing in this fashion until the "Nth" row has "N" elements).

~~6.2.8.15~~6.2.9.16 At least one space character must be used to separate the items in each covariance matrix data line.

~~6.2.8.16~~6.2.9.17 The digits of precision and time steps suitable for interpolation of a covariance time history should be chosen according to best practice to avoid covariance and interpolation loss of precision [I-8].

**Table 6-~~9~~8: OCM Data: Covariance Time History**

| Keyword | Description | Units | Examples of Values | Mandatory |
|---|---|---|---|---|
| COV_START | Start of a covariance time history section | n/a | n/a | Yes |
| COMMENT | Comments (allowed at any point(s) throughout the OCM Covariance Time History section). (See 7.7 for formatting rules.) | n/a | COMMENT This is a comment | No |
| COV_BASIS | Basis of this covariance time history data: PREDICTED or SOLVED | n/a | SOLVED | No |
| COV_REF_FRAME | Name of the reference frame in which the covariance data is provided, if not intrinsic to the definition of the covariance data. Use of values other than those in ANNEX B, subsections B2 and B3 must be documented and conveyed via an ICD. The reference frame must be the same for all data elements within a given Covariance Time History interval.<br><br>**Where the reference frame is not intrinsic to the selected covariance set, omission of this non-mandatory field defaults to TNW.** | n/a | EME2000 | No |
| COV_ FRAME_EPOCH | Epoch of the covariance data reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.9 for formatting rules.)<br><br>**Where the reference frame epoch is required and not intrinsic to the selected reference frame, omission of this non-mandatory field defaults to EPOCH_TZERO.** | n/a | 2001-11-06T11:17:33<br>2002-204T15:56:23Z | No |
| COV_NNXNN | Number of diagonal elements contained in the full covariance.<br><br>**This keyword may be used to override the number of elements implied by the selected COV_TYPE. Omission of this non-mandatory field defaults to the number of elements implied by COV_TYPE** (ANNEX B, subsection | n/a | 10 | No |
| COV_TYPE | Indicates covariance composition via "COV_TYPE = YYY" where YYY is selected from ANNEX B, subsection B5). | n/a | n/a | Yes |
| T | Time relative to EPOCH_TZERO | s | 10 | No |
| COV_STOP | End of a covariance time history section | n/a | n/a | Yes |

### ~~6.2.9~~6.2.10 OCM DATA: STATE TRANSITION MATRIX TIME HISTORY

~~6.2.9.1~~6.2.10.1 State Transition Matrices (STMs) can be very useful in mapping both an initial state, and (separately) differences about that state, to other time(s) of interest. Following the terminology and definitions of reference [I-9], pp. 82, 778-780 and 809) allows the analyst to map states, or alternatively state differences, at time $t_0$ to another time $t_i$. As noted in reference [I-9], these are~~this is~~ distinctly different in definition and content from each other. Both types of~~the basic~~ State Transition Matrices are supported, as specified by the STM_MAP_MODE keyword~~Matrix~~.

Formatted: (none)

Formatted: (none)

Formatted: (none)

Formatted: (none)

Formatted: (none)

Formatted: (none)

~~6.2.9.2~~6.2.10.2 Table 6-10~~9~~ provides an overview of the OCM state transition matrix time history section. Only those keywords shown in table 6-10~~9~~ shall be used in OCM state transition matrix time history data specification.

~~6.2.9.3~~6.2.10.3 The "OCM Data: State Transition Matrix Time History" section is optional; "mandatory" in the context of Table 6-10~~9~~ denotes those keywords which must be included in this section if this section is included.

~~6.2.9.4~~6.2.10.4 State transition matrix time history data intervals in the OCM shall be indicated by means of two keywords: STM_START and STM_STOP. The STM_START keyword must appear before the first line of any state transition matrix metadata or matrix data. The STM_STOP keyword must appear after the last line of state transition matrix data and metadata. Each of these keywords shall appear on a line by itself.

~~6.2.9.5~~6.2.10.5 One or more state transition matrix time histories may be represented in this section (spanning STM_START to STM_STOP). However, multiple representations shall appear only if they are clearly differentiated from each other by one or more precluding comment(s) or by ICD agreement, and each state transition matrix time history is unique from all other state transition matrix time histories in at least one of the following respects:

1) the specified orbit state element set;

2) the state transition matrix time history is based upon a unique orbit determination or navigation solution;

3) the data basis (e.g. PREDICTED, ACTUAL, etc.);

4) the reference frame;

5) the orbit center;

6) the state transition matrix timespan.

~~6.2.9.6~~6.2.10.6 The STM_TYPE keyword shall be followed by " = YYY", where YYY is a member of the keywords of Table B4.

~~6.2.9.7~~6.2.10.7 All state transition matrices in the OCM data shall be time-tagged by a relative time value measured with respect to the epoch time specified via the EPOCH_TZERO keyword.

~~6.2.9.8~~6.2.10.8 Each state transition matrix time history shall be time-ordered to be monotonically increasing, with the exception that the message creator may indicate a change in vehicle state by providing exactly two consecutive state transition matrix data blocks containing a duplicate timestamp (e.g. following application of an impulsive maneuver or spacecraft or orbit event).

~~6.2.9.9~~6.2.10.9 No interpolation of the state transition matrix time history shall be undertaken, since the state transition matrix pre- and post-multiplies the state (or covariance) in the mapping process to yield states and covariances that may then be properly interpolated.

~~6.2.9.10~~6.2.10.10 If the user includes state transition matrices at key events, those events should be annotated by a preceding descriptive comment line.

~~6.2.9.11~~6.2.10.11 Time tags of consecutive state transition matrices within the ordered sequence may be separated by uniform or non-uniform step size(s).

~~6.2.9.12~~6.2.10.12 State transition matrix time tags may or may not match those of maneuver, orbit state and/or covariance time histories.

~~6.2.9.13~~6.2.10.13 The time of the event associated with provided state transition matrices must be provided via the "T = " keyword. The reference frame of the state transition matrices, if different from that of the states in the ephemeris, must be provided via the 'STM_FRAME' keyword.

~~6.2.9.14~~6.2.10.14 Values in each state transition matrix shall be expressed in the applicable reference frame and shall be presented sequentially from upper to lower and row-by-row from left to right. State transition matrix values shall be expressed in standard double precision as discussed in 7.5.

Formatted: English (United States)

~~6.2.9.15~~6.2.10.15 Each row of each state transition matrix must be provided on a single line. The order in which data items are given shall be fixed. The elements in each row shall be defined by the STM_TYPE keyword specification. The "N" rows of the state transition matrix shall each contain "N" numbers.

~~6.2.9.16~~6.2.10.16 At least one space character must be used to separate the items in each state transition matrix data line.

~~6.2.9.17~~6.2.10.17 The digits of precision and time steps suitable for state transition matrix time history should be chosen according to best practice to avoid STM propagation loss of precision.

**Table 6-~~10~~9: OCM Data: State Transition Matrix Time History**

| Keyword | Description | Units | Examples of Values | Mandatory |
|---|---|---|---|---|
| STM_START | Start of a state transition matrix time history section | n/a | n/a | Yes |
| STM_MAP_MODE | Indicates whether state transition matrix maps:<br>- An initial state to later states (STATE) or<br>- Initial state differences to later differences (DIFFERENCES) | n/a | STATE<br>DIFFERENCES | Yes |
| STM_REF_TIME | Epoch time of the initial state or initial state differences relative to EPOCH_TZERO, to which the state transition matrix is referenced and at which time the STM ≡ the identity matrix | n/a | 0.0 | Yes |
| COMMENT | Comments (allowed at any point(s) throughout the OCM State Transition Matrix Time History section). (See 7.7 for formatting rules.) | n/a | COMMENT This is a comment | No |
| STM_REF_FRAME | Name of the reference frame in which the state transition matrix data is computed, if not intrinsic to the definition of the state transition matrix data. Use of values other than those in ANNEX B, subsections B2 and B3 must be documented and conveyed via an ICD. The reference frame must be the same for all data elements within a given State Transition Matrix Time History interval.<br><br>**Where the reference frame is not intrinsic to the selected STM set, omission of this non-mandatory field defaults to ICRF2000.** | n/a | EME2000 | No |
| STM_ FRAME_EPOCH | Epoch of the state transition matrix data reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.9 for formatting rules.)<br><br>**Where the reference frame epoch is required and not intrinsic to the selected reference frame, omission of this non-mandatory field defaults to EPOCH_TZERO.** | n/a | 2001-11-06T11:17:33<br>2002-204T15:56:23Z | No |
| STM_N | Dimensionality of the "N x N" state transition matrix.<br><br>**This keyword may be used to override the number of elements implied by the selected STM_TYPE. Omission of this non-mandatory field defaults to the number of elements implied by STM_TYPE (Table B4).** | n/a | 6 | No |
| STM_TYPE | Indicates state transition matrix composition via "STM_TYPE = YYY" where YYY is selected from ANNEX B, subsection B4 or B5. **Omission of this non-mandatory field defaults to CARTPV.** | n/a | n/a | Yes |
| STM_STOP | End of a state transition matrix time history section | n/a | n/a | Yes |

## ~~6.2.10~~6.2.11 OCM DATA: EPHEMERIS COMPRESSION REPRESENTATION(S)

~~6.2.10.1~~6.2.11.1 Ephemeris Compression (EC) techniques are a "lossy" approach to conveying orbit state time history(ies). EC techniques can dramatically reduce message transmission network bandwidth, CPU, I/O and disk storage requirements (e.g. by three orders of magnitude or more) while still retaining sufficient accuracy for many applications. Initial

implementations focused on fitting Cartesian position and velocity [K-13] with Chebyshev polynomials. Though successfully used in that manner operationally for many decades, recent research [K-14] into application of such a compression technique indicates that best EC performance is obtained by: (1) employing "Hybrid" ephemeris compression by adopting an orbit-based element set definition (such as equinoctial elements) rather than a Cartesian representation; (2) adopting an orbit state and an accompanying sharable and efficient orbit propagator to use as the "basis" for the orbit representation; (3) using either exclusive or combined use of Chebyshev or Fourier representations to best "imitate" the residuals between the "truth" and efficient orbit propagator orbit state time histories captured in any of the reference frame definitions contained in ANNEX B, subsection B2 and orbit element set definitions contained in ANNEX B, subsections B4 or B5; ~~ANNEX B, subsection B4;~~ and (4) using one or more consecutively staged ephemeris compression sequences to sequentially absorb the residuals between the adopted/sharable propagator and the precise ephemeris at each stage.

~~6.2.10.2~~6.2.11.2 In the OCM implementation of ephemeris compression, each Chebyshev or Fourier representation's independent time variable shall be "normalized" to a time interval of -1 ≤ $t^*$ ≤ +1 via the following formula [K15], where $a$ denotes the actual start time (i.e. EC_TSTART) of the ephemeris compression representation segment's time interval of validity, $b$ denotes the corresponding actual segment stop time (i.e. EC_TSTOP), $t$ denotes the actual time of interest measured with respect to EPOCH_TZERO and $t^*$ denotes "normalized time":

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

~~6.2.10.3~~6.2.11.3 EC users are encouraged to employ a blending function between subsequent EC data segments to ensure a smooth positional transition. Defining $F_1$ as the desired orbit element functional value at actual time $t$ obtained from the ephemeris compression representation of segment #1 and $F_2$ from segment #2, and $t_1$ and $t_2$ as the overlap blending actual (non-normalized) start and stop times, respectively,

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

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

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

~~6.2.10.4~~6.2.11.4 Table 6-11~~10~~ provides an overview of the OCM ephemeris compression section. Only those keywords shown in table 6-11~~10~~ shall be used in OCM ephemeris compression data specification.

~~6.2.10.5~~6.2.11.5 The "OCM ephemeris compression" section is optional; "mandatory" in the context of Table 6-11~~10~~ denotes those keywords which must be included in this section if this section is included.

~~6.2.10.6~~6.2.11.6 Ephemeris compression sections in the OCM shall be indicated by means of two keywords: EC_START and EC_STOP. The EC_START keyword must appear before the first line of any ephemeris compression metadata or coefficient data. The EC_STOP keyword must appear after the last line of coefficient data and metadata. Each of these keywords shall appear on a line by itself.

~~6.2.10.7~~6.2.11.7 One or more ephemeris compression segments may be represented in this section (spanning EC_START to EC_STOP). However, multiple representations shall appear only if they are clearly differentiated from each other by one or more precluding comment(s) or by ICD agreement, and each ephemeris compression segment is unique from all other ephemeris compression segments in at least one of the following respects:

7) the specified orbit state element set;

8) the ephemeris compression segment is based upon a unique orbit determination or navigation solution;

9) the data basis (e.g. PREDICTED, ACTUAL, etc.);

10) the orbit state (when the EC represents different mission events as a function of time from launch window open);

~~10)~~11) the reference frame;

~~11)~~12) the orbit center;

~~12)~~13) the ephemeris compression timespan.

~~6.2.10.8~~6.2.11.8 The EC_TYPE keyword shall be followed by " = YYY", where YYY is a member of the keywords of ANNEX B, subsections B4 or B5 (sans "COV_NNXNN"). ~~Table B4.~~

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

**6.2.11.10** The OCM EC implementation may also be used to specify orbit states at a specific event which vary as a function of time within a specified launch window (as opposed to sequential orbit states as a function of correspondingly-sequential time). As such, each polynomial segment may be used to provide the time and orbit state corresponding to a specific launch event (e.g. Stage 2 ignition). Such an application would therefore typically draw its

Formatted: (none)

orbit state types (EC_TYPE) from ANNEX B, subsection B5 (rather than subsection B4), allowing event time to accompany the standard six-element orbit state specification.

~~**6.2.10.9** All ephemeris compression segments in the OCM shall be time-tagged by a relative time value measured with respect to the epoch time specified via the EPOCH_TZERO keyword.~~

~~**6.2.10.10**~~**6.2.11.11** The user may choose to use either polynomial and/or series representations to provide orbit state (or orbit state residual) information at key events by having EC_TSTART and EC_TSTOP set to -the same value, whereupon those events should be annotated by a preceding descriptive comment line.

~~**6.2.10.11**~~**6.2.11.12** At least one space character must be used to separate the items in each coefficient data line.

~~**6.2.10.12**~~**6.2.11.13** The digits of precision suitable for ephemeris representation specification should be chosen according to best practice to avoid EC loss of precision for the recipient's intended use case.

**Table 6-11~~10~~: OCM Data: Ephemeris Compression Time History**

| Keyword | Description | Units | Examples of Values | Mandatory |
|---|---|---|---|---|
| EC_START | Start of a Ephemeris Compression Time History section | n/a | n/a | ~~Yes~~ |
| COMMENT | Comments (allowed at any point(s) throughout the OCM Ephemeris Compression Time History section). (See 7.7 for formatting rules.) | n/a | COMMENT This is a comment | No |
| EC_TSTART | Start time relative to **EPOCH_TZERO** of this Ephemeris Compression time interval of applicability | n/a | 0.0 | Yes |
| EC_BASIS_PROP~~TYPE~~ | Provides the orbit propagator which is to serve as the basis, upon which the EC representation additively corrects. Specifying EC_BASIS_PROP = NONE indicates that the EC representation is not a hybrid method and the returned functional values obtained from the EC representation correspond directly with desired orbit state information, whereas specification (in free text, including specification of any non-standardized force model or geodetic system implementations) of a message creator/recipient-shared orbit propagator selects a "Hybrid EC representation" approach in the orbit element definition specified by "EC_TYPE = YYY" above. **Omission of this non-mandatory field defaults to NONE.**~~Indicates EC representation via "EC_TYPE = YYY" where YYY is selected from ANNEX B, subsection B4. **Omission of this non-mandatory field defaults to EQUIN.**~~ | n/a | SGP4~~EQUIN~~ | No |
| EC_ORB_STATE | Provides the orbit state elements for employment of a "Hybrid EC representation" approach in the orbit element definition specified by "EC_TYPE = YYY" above. The number of state vector rows following the EC_ORB_STATE keyword containing the initial state correspond to the "EC_BASIS_PROP" required state vector format (shared either by ICD agreement or common industry understanding). Note the specification of the initial condition state vector epoch may be included in this common understanding. **This keyword and state vector data are mandatory if and only if EC_BASIS_PROP is not set to "NONE"**~~Specifying EC_ORB_STATE = NONE indicates that the EC representation is not a hybrid method and the returned functional values obtained from the EC representation correspond directly with desired orbit state information. **Omission of this non-mandatory field defaults to NONE.**~~ | n/a | 6700.0 0.0 0.0 0.0 0.0 0.839099633 | No |
| EC_REPRESENT | Specifies the type of EC representation used in the coefficients which immediately follow. Valid options are: CHEBYSHEV or FOURIER or ICD. **Where the EC representation is not specified, omission of this non-mandatory field defaults to CHEBYSHEV.** | n/a | CHEBYSHEV | No |
| EC_STATE_TYPE | Indicates EC representation via "EC_TYPE = YYY" where YYY is selected from ANNEX B, subsection B4 or B5 (sans "COV_NNXNN"). **Omission of this non-mandatory field defaults to EQUIN.** | n/a | EQUIN | No |

**Formatted:** Space Before: 0 pt, After: 1 pt, Keep with next, Tab stops: 1.32", Left + 1.88", Left

**Formatted:** Space Before: 0 pt, Keep with next, Tab stops: 1.32", Left + 1.88", Left

**Formatted:** Keep with next

**Formatted:** Space After: 0 pt, Keep with next

**Commented [OD3]:** Comment from reviewer: As the supplied EC data is specific to a particular algorithm, and as the exact implementation of such algorithms is outside the experience of most in the field, I think that algorithm definitions should be explicitly included in the document (along with a simple numerical example). Note that this is different than interpolation where the numerical algorithm is performed on the native data. For EC, specialized data elements are being produced from the native data, without the exact recovery algorithm the end user will not get the correct results.

| Keyword | Description | Units | Examples of Values | Mandatory |
|---|---|---|---|---|
| EC_REF_FRAME | Name of the reference frame in which the Ephemeris Compression data is computed, if not intrinsic to the EC orbit element definition. Use of values other than those in ANNEX B, subsections B2 must be documented and conveyed via an ICD. The reference frame must be the same for all data elements within a given Ephemeris Compression Time History interval.<br><br>**Where the reference frame is not intrinsic to the selected EC set, omission of this non-mandatory field defaults to EME2000.** | n/a | EME2000 | No |
| EC_ FRAME_EPOCH | Epoch of the Ephemeris Compression reference frame, if not intrinsic to the definition of the reference frame. (See 7.5.9 for formatting rules.)<br><br>**Where the reference frame epoch is required and not intrinsic to the selected reference frame, omission of this non-mandatory field defaults to EPOCH_TZERO.** | n/a | 2001-11-06T11:17:33<br>2002-204T15:56:23Z | No |
| ~~EC_ REPRESENT~~ | ~~Specifies the type of EC representation used in the coefficients which immediately follow. Valid options are: CHEBYSHEV or FOURIER or ICD.~~<br><br>~~**Where the EC representation is not specified, omission of this non-mandatory field defaults to CHEBYSHEV.**~~ | ~~n/a~~ | ~~CHEBYSHEV~~ | ~~No~~ |
| EC_ REPR_N | Number of terms (coefficients) in the selected EC representation for this segment. Coefficients shall be supplied in columnar fashion, with the "ith" column corresponding to the "ith" orbital element.<br><br>In the FOURIER representation, the cosine coefficients are supplied for each orbit element, followed (on the same line) by the sine coefficients for each element.<br><br>As such, EC_ REPR_N always denotes the number of coefficient data rows to follow prior to the next EC_REPRESENT or EC_TSTOP specifier. | n/a | 10 | Yes |
| EC_TSTOP | End time relative to **EPOCH_TZERO** of this Ephemeris Compression time interval of applicability | n/a | 86400.0 | Yes |
| EC_STOP | End of a Ephemeris Compression section | n/a | n/a | Yes |

### ~~6.2.11~~6.2.12 OCM DATA: USER-DEFINED PARAMETERS

~~6.2.11.1~~6.2.12.1 A section of User Defined Parameters may be provided if necessary. In principle, this provides flexibility, but also introduces complexity, non-standardization, potential ambiguity, and potential processing errors. Accordingly, if used, the keywords and their meanings must be described in an ICD. User Defined Parameters, if included in an OCM, should be used as sparingly as possible; their use is not encouraged.

~~6.2.11.2~~6.2.12.2 The "OCM Data: User-Defined Parameters" section is optional; "mandatory" in the context of Table 6-12~~10~~ denotes those keywords which must be included in this section if this section is included.

~~6.2.11.3~~6.2.12.3 Table 6-12~~10~~ provides an overview of the OCM user-defined data section. Only those keywords shown in Table 6-12~~10~~ shall be used in OCM user-defined data specification.

**Table 6-12~~10~~: OCM Data: User-Defined Parameters**

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

## 6.3 OCM EXAMPLES

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

```
CCSDS_OCM_VERS  = 1.0
CREATION_DATE   = 1998-11-06T09:23:57
ORIGINATOR      = JAXA
OBJECT_NAME     = GODZILLA 5
EPOCH_TZERO     = 1998-12-18T14:28:15.1172

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

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

```
CCSDS_OCM_VERS  = 1.0

CREATION_DATE         = 1998-11-06T09:23:57
ORIGINATOR            = JAXA
TECH_POC              = Mr. Rodgers, (719)555-5555, email@email.XXX
EPOCH_TZERO           = 1998-12-18T14:28:15.1172
TIME_SYSTEM           = UT1

OBJECT_NAME           = GODZILLA 5
OBJECT_ID             = 1998-999ZZZ
TIME_SYSTEM           = UT1
TAIMUTC_TZERO         = 36      [s]
UT1MUTC_RATE_TZERO    = 0.0001  [ms/day]
UT2MUTC_TZERO         = .357    [s]

COMMENT S/C Physical Characteristics:

PHYS_START
MASS                  = 100.0   [kg]
PHYSDIM_MAX           = 2.0     [m]
PHYSDIM_MED           = 1.0     [m]
PHYSDIM_MIN           = 0.5     [m]
PHYS_YAW              = 30.0    [deg]
PHYS_PITCH            = 1.7     [deg]
PHYS_ROLL             = -10.0   [deg]
AREA_ALONG_PHYSDIM_MAX = 0.15    [m**2]
AREA_ALONG_PHYSDIM_MED = 0.3     [m**2]
AREA_ALONG_PHYSDIM_MIN = 0.5     [m**2]
PHYS_STOP

COMMENT Force Model Specification:

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

COMMENT           GEOCENTRIC, CARTESIAN, EARTH FIXED

ORBEPH_START
ORB_REF_FRAME         = EFG
ORB_TYPE              = CARTPVA
  0.000000 2789.6 -280.0 -1746.8 4.73 -2.50 -1.04 0.008 0.001 -0.159
ORBEPH_STOP
```

**Commented [OD4]:** Add start/stop to these (Force, physical chars ?

**Formatted:** English (United States)

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

```
CCSDS_OCM_VERS   = 1.0

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

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

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

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

COMMENT          = Perform 100-second in-track finite burn w/effic η=0.of 95%
efficiency, Isp=300s, 5% 1-sigma error
MAN_START
BASIS            = PREDICTED
MAN_PURPOSE      = SK
MAN_REF_FRAME    = RTN
MAN_TYPE         = THRUSTFINITE
500.0 0.0 10.0 0.0 5.0 100.0 330.0 0.95
MAN_STOP

ORBEPH_START
ORB_REF_FRAME    = TOD
ORB_FRAME_EPOCH  = 1998-12-18T14:28:15.1172
ORB_TYPE         = CARTPVA
   0.000000 2789.6 -280.0 -1746.8 4.73 -2.50 -1.04 0.008 0.001 -0.159
  10.000000 2783.4 -308.1 -1877.1 5.19 -2.42 -2.00 0.008 0.001 0.001
  20.000000 2776.0 -336.9 -2008.7 5.64 -2.34 -1.95 0.008 0.001 0.159
    < intervening data records omitted here >
500.000000 2164.375 1115.811 -688.131 -3.53328 -2.88452 0.88535
ORBEPH_STOP

ORBEPH_START
ORB_REF_FRAME    = EME2000
ORB_TYPE         = KPLR
   0.000000 6600.0 .03 28.5 50.0 30.0 10.0
  10.000000 6600.0 .03 28.5 50.0 30.0 10.1
  20.000000 6600.0 .03 28.5 50.0 30.0 10.2
    < intervening data records omitted here >
500.000000 6600.0 .03 28.5 50.0 30.0 35.0
ORBEPH_STOP
```

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

```
CCSDS_OCM_VERS   = 1.0

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

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

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

COMMENT S/C Physical Characteristics:
PHYS_START
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
PHYS_STOP

ORBEPH_START
COMMENT            GEOCENTRIC, CARTESIAN, EARTH FIXED
CENTER_NAME      = EARTH
ORB_REF_FRAME    = ITRF-97
ORB_FRAME_EPOCH = 1998-12-18T14:28:15.1172
ORB_TYPE         = CARTPVA

  0.000000 2789.6 -280.0 -1746.8 4.73 -2.50 -1.04 0.008 0.001 -0.159
 10.000000 2783.4 -308.1 -1877.1 5.19 -2.42 -2.00 0.008 0.001 0.001
 20.000000 2776.0 -336.9 -2008.7 5.64 -2.34 -1.95 0.008 0.001 0.159

   < intervening data records omitted here >

500.000000 2164.375 1115.811 -688.131 -3.53328 -2.88452 0.88535

ORBEPH_STOP

COV_START
COV_REF_FRAME    = EME2000
COV_TYPE         = ADBARV

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

   < intervening data records omitted here >

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

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

Formatted: (none)

**Figure 6-4: OCM example with Covariance Matrix**

```
CCSDS_OCM_VERS   = 1.0

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

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

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

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

   < intervening data records omitted here >

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

COMMENT  HERE IS AN EPHEMERIS COMPRESSION DATA BLOCK:
EC_START

COMMENT          HERE ARE EPHEM COMPR COEFS FOR DAY 1 (CHEBY W/FOURIER 2ND STAGE):
EC_TSTART        = 0.0
EC_TYPE          = EQUIN
COMMENT          HERE IS THE BASELINE ORBIT, TO BE AUGMENTED BY CHEBY/FOURIER
EC_BASIS_PROP    = KEPLERIAN
EC_ORB_STATE
   = 6700.0 0.0 0.0 0.0 0.0 0.839099633
EC_REF_FRAME     = ICRF2000

EC_REPRESENT     = CHEBYSHEV
EC_TYPE          = EQUIN
EC_REF_FRAME     = ICRF2000
EC_REPR_N        = 10
1.23456 7.89012 3.45678 9.01234 5.67890 1.23456
   < intervening data records omitted here >
5.67890 1.23456 7.89012 3.45678 9.01234 5.67890

EC_REPRESENT     = FOURIER
EC_REPR_N        = 20
EC_TYPE          = EQUIN
EC_REF_FRAME     = ICRF2000

COMMENT  *** NOTE: Following are COSINE (col 1-6) and SINE (7-12) coeffs ***
1.234 7.890 3.456 9.012 5.678 1.234 1.234 7.890 3.456 9.012 5.678 1.234
   < intervening data records omitted here >
1.234 7.890 3.456 9.012 5.678 1.234 1.234 7.890 3.456 9.012 5.678 1.234
EC_TSTOP       = 86400.0
```

**Formatted:** Border: Left: (Single solid line, Auto, 0.5 pt Line width, From text: 3 pt Border spacing: )

**Formatted:** Border: Left: (Single solid line, Auto, 0.5 pt Line width, From text: 3 pt Border spacing: )

**Formatted:** Border: Left: (Single solid line, Auto, 0.5 pt Line width, From text: 3 pt Border spacing: )

⋮(continued on next page)

```
(continued from previous page)

COMMENT          CHEBYSHEV POLYS FOR ORBIT STATES AT DAY 2 (SANS FOURIER CLEANUP):
EC_TSTART        = 86400.0
EC_TYPE          = EQUIN
EC_BASIS_PROPORB_STATE_  = NONE
EC_REF_FRAME     = ICRF2000

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

EC_STOP
```

Formatted: Border: Left: (Single solid line, Auto, 0.5 pt Line width, From text: 3 pt Border spacing: )

Formatted: (none)

Formatted: Font: 9 pt

**Figure 6-5: OCM example with STM (Cartesian position and velocity elements) and Ephemeris Compression (Equinoctial elements)**

# 7 ORBIT DATA MESSAGE SYNTAX

## 7.1 OVERVIEW

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

## 7.2 GENERAL

The Orbit Data Messages (OPM, OMM, OEM or OCM) shall observe the syntax described in 7.3 through 7.7.

## 7.3 ODM LINES

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

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

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

**7.3.3** Each OCM line shall be one of the following:

- Header line (mandatory in line #1);
- Metadata, spacecraft physical characteristics or force model parameter line;
- Comment line;
- Data line; or
- Blank line.

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

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

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

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

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

## 7.4 KEYWORD = VALUE NOTATION AND ORDER OF ASSIGNMENT STATEMENTS

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

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

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

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

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

**7.4.1.5** OCM orbit state time history data lines shall not use KVN format; rather, the structure of such OCM orbit state time history data lines is comprised of time relative to EPOCH_TZERO followed by the parameters corresponding to the selected orbit set (See 6.2.7).

**7.4.1.6** OCM covariance matrix epoch and covariance reference frame (if used) shall use KVN format. The OCM covariance data lines shall not use KVN format; rather, the OCM covariance data line has a fixed structure containing from one to "N" required fields (a row from the N x N lower triangular form of a square covariance matrix). (See 0.)

**7.4.2** The keywords 'COMMENT', 'PHYS~~META~~_START', 'PHYS_STOP', 'FORCE_START', 'FORCE~~META~~_STOP', 'MAN_START', 'MAN_STOP', 'ORB_START', 'ORB_STOP', 'OD_START', 'OD_STOP', 'COV_START', 'COV_STOP', 'STM_START', 'STM_STOP', 'EC_START', 'EC_STOP' are exceptions to the KVN syntax assignment.

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

**7.4.4** Keywords must be uppercase and must not contain blanks.

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

**Formatted:** English (United States)

**Formatted:** English (United States)

**Formatted:** English (United States)

**Formatted:** English (United States)

**Formatted:** English (United States)

**Commented [OD5]:** Add bunch more keywords

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

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

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

## 7.5 VALUES

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**7.5.9** In value fields that represent an absolute time tag or epoch, times shall be given in one of the following two formats:

YYYY-MM-DDThh:mm:ss[.d→d][Z]

or

YYYY-DDDThh:mm:ss[.d→d][Z]

where 'YYYY' is the year, 'MM' is the two-digit month, 'DD' is the two-digit day, 'DDD' is the three-digit day of year, 'T' is constant, 'hh:mm:ss[.d→d]' is the time in hours, minutes seconds, and optional fractional seconds; 'Z' is an optional time code terminator (the only permitted value is 'Z' for Zulu, i.e., UTC). As many 'd' characters to the right of the period as required may be used to obtain the required precision, up to the maximum allowed for a fixed point number. All fields shall have leading zeros. (See reference [1], ASCII Time Code A or B.). Where such epochs occur within one second after leap second introduction, the hh:mm:ss portion of the above time specification shall use the convention XX:XX:60.XXXX.

**7.5.10** There are eight types of ODM values that represent a time tag or epoch, as shown in the applicable tables. The time system for the CREATION_DATE shall be UTC; the time system for the REF_FRAME_EPOCH, START_TIME, USEABLE_START_TIME, USEABLE_STOP_TIME, STOP_TIME shall be as determined by the TIME_SYSTEM metadata keyword.

## 7.6 UNITS IN THE ORBIT DATA MESSAGES

### 7.6.1 OPM/OMM/OCM UNITS

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

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

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

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

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

### 7.6.2 OEM UNITS

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

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

### 7.6.3 OCM UNITS

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

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

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

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

## 7.7 COMMENTS IN THE ORBIT DATA MESSAGES

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

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

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

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

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

**7.7.6** Comments in the OPM may appear in the OPM Header immediately after the 'CCSDS_OPM_VERS' keyword, at the very beginning of the OPM Metadata section, and at the beginning of a logical block in the OPM Data section. Comments must not appear between the components of any logical block in the OPM Data section.

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

**7.7.7** Comments in the OMM may appear in the OMM Header immediately after the 'CCSDS_OMM_VERS' keyword, at the very beginning of the OMM Metadata section, and at the beginning of a logical block in the OMM Data section. Comments must not appear between the components of any logical block in the OMM Data section.

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

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

**7.7.9** Comments in the OCM may appear anywhere within the OCM Header, Metadata, Space Object Physical Characteristics, Force Model, Maneuver, Orbit State Time History, Covariance Time History, and State Transition Matrix Time History data sections.

**7.7.10** Extensive comments in an ODM are recommended in cases where there is insufficient time to negotiate an ICD. (For an example 'Checklist ICD', see ANNEX G.)

**7.7.11** The following comments should be provided:

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

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

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

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

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

## 7.8 ORBIT DATA MESSAGE KEYWORDS

### 7.8.1 VERSION KEYWORDS

The Header of the OPM, OMM, OEM and OCM shall provide a CCSDS Orbit Data Message version number that identifies the format version; this is included to anticipate future changes.

The version keywords for the OPM, OMM, OEM and OCM shall be CCSDS_OPM_VERS, CCSDS_OMM_VERS, CCSDS_OEM_VERS and CCSDS_OCM_VERS, respectively. The value shall have the form of 'x.y', where 'y' shall be incremented for corrections and minor changes, and 'x' shall be incremented for major changes. Version x.0 shall be reserved for versions accepted by the CCSDS as an official Recommended Standard ('Blue Book'). Testing shall be conducted using OPM, OMM, OEM and OCM version numbers less than 1.0 (e.g., 0.x). Exchange participants should specify in the ICD the specific OPM, OMM, OEM and OCM version numbers they will support. The following version numbers are supported:

| Version Keyword | Version Number | Applicable Recommendation |
|---|---|---|
| CCSDS_OPM_VERS | 1.0 | Silver Book 1.0, 09/2004 |
| CCSDS_OPM_VERS | 2.0 | Blue Book 2.0 (this document) |
| CCSDS_OMM_VERS | 2.0 | Blue Book 2.0 (this document) |
| CCSDS_OEM_VERS | 1.0 | Silver Book 1.0, 09/2004 |
| CCSDS_OEM_VERS | 2.0 | Blue Book 2.0 (this document) |
| CCSDS_OCM_VERS | 2.0 | Blue Book 2.0 (this document) |

### 7.8.2 GENERAL KEYWORDS

**7.8.2.1** Only those keywords shown in table 3-1, table 3-2, and table 3-3 shall be used in an OPM. Some keywords represent mandatory items and some are optional. KVN assignments representing optional items may be omitted.

**7.8.2.2** Only those keywords shown in table 4-1, table 4-2, and table 4-3 shall be used in an OMM. Some keywords represent mandatory items and some are optional. KVN assignments representing optional items may be omitted.

**7.8.2.3** Only those keywords shown in table 5-2 and table 5-3 shall be used in an OEM. Some keywords represent mandatory items and some are optional. KVN assignments representing optional items may be omitted.

**7.8.2.4** Only those keywords shown in tables 6-2, table 6-3, table 6-4, table 6-5, table 6-6, table 6-7, table 6-8, table 6-9, and table 6-10 shall be used in an OCM. Some keywords

represent mandatory items and some are optional. KVN assignments representing optional items may be omitted.

# ANNEX A

# IMPLEMENTATION CONFORMANCE STATEMENT PRO FORMA

# (NORMATIVE)

## A1 INTRODUCTION

### A1.1 OVERVIEW

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

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

### A1.2 ABBREVIATIONS AND CONVENTIONS

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

Item Column

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

Feature Column

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

Status Column

The status column uses the following notations:

- M mandatory;
- O optional;
- C conditional;
- X prohibited;
- I out of scope;
- N/A not applicable.

Support Column Symbols

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

Y Yes, supported by the implementation.

N No, not supported by the implementation.

N/A Not applicable.

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

### A1.3 INSTRUCTIONS FOR COMPLETING THE RL

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

## A2 ICS PROFORMA FOR ORBIT DATA MESSAGE

### A2.1 IDENTIFICATION OF ICS

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

### A2.2 IDENTIFICATION OF IMPLEMENTATION UNDER TEST (IUT )

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

### A2.3 IDENTIFICATION OF SUPPLIES

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

### A2.4 DOCUMENT VERSIONS

| | |
|---|---|
| CCSDS 503.0 Document Version | |
| Have any exceptions been required?<br><br>(Note: A YES answer means that the implementation does not conform to the Recommended Standard. Non-supported mandatory capabilities are to be identified in the ICS, with an explanation of why the implementation is non-conforming.) | Yes _____ No_____ |

## A2.5 REQUIREMENTS LISTS

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

# ANNEX B

# VALUES FOR TIME_SYSTEM AND FRAME RELATED KEYWORDS

# (NORMATIVE)

The values in this annex represent the set of acceptable values for the TIME_SYSTEM, REF_FRAME, PHYSDIM_FRAME, MAN_REF_FRAME, ORB_REF_FRAME, COV_REF_FRAME and STM_REF_FRAME keywords in the OPM, OMM, OEM and OCM. (For details and description of these time systems, see reference [I-1]) If exchange partners wish to use different settings, the settings should be documented in the ICD.

## B1 TIME_SYSTEM METADATA KEYWORD

| Time System Value | Meaning |
|---|---|
| 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 |
| ICD | Other timing system, as defined in ICD |

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

## B2 REF_FRAME KEYWORD

| Fixed Reference Frame Value | Meaning |
|---|---|
| EFG | Earth-Fixed Greenwich (E, F, G) |
| EME2000 | Earth Mean Equator and Equinox of J2000 |
| GCRF | Geocentric Celestial Reference Frame |
| GRC | Greenwich Rotating Coordinates |
| ICRFyyyy | International Celestial Reference Frame (Barycentric) solution as of year "yyyy" (e.g. 2000) |
| ITRFyyyy | International Terrestrial Reference Frame solution as of year "yyyy" (e.g. 2000) |
| ITRF-93 | International Terrestrial Reference Frame 1993 |
| ITRF-97 | International Terrestrial Reference Frame 1997 |
| MCI | Mars Centered Inertial |
| MEME | Mean Equator Mean Equinox |
| MOON_ME | Moon Mean Earth (ME) frame, which has its X axis pointed along the mean direction to the center of the Earth and the Z axis pointing to the mean direction of rotation. The ME frame is typically used to specify the location of objects on the Moon. |
| MOON_MEIAUE | Moon-Centered, Moon Mean Equator and IAU-Node of Epoch frame as specified in [I-11, Fig. 6-2]. |
| MOON_PA | Moon Principal Axis (PA) frame which is defined by the inertial tensor of the Moon. The PA frame is used as the basis for Lunar gravity models, in the numerical integration of the planetary ephemerides, and as the reference for modern moon gravity solutions. Euler angles supplied as part of the JPL DE planetary ephemerides relate the MOON_PA frame to ICRF. |
| TDR | True of Date, Rotating (Realized as ITRF Fixed) |
| TEME | True Equator Mean Equinox (see below NORAD comment) |
| TOD | True of Date (True Equator True Equinox) |
| UVW | Launch go-inertial reference frame, with U in local horizon plane along inertial launch azimuth (downrange), W along the geodetic vertical and V completing the set (cross-range). In typical use the go-inertial epoch should be specified in an accompanying comment field. |
| ICD | Other reference frame, as defined in ICD |

NORAD Two Line Element Sets are implicitly in a True Equator Mean Equinox (TEME) reference frame, which is ill defined in international standard or convention. TEME may be used only for OMMs based on NORAD Two Line Element sets, and in no other circumstances. There are subtle differences between TEME of Epoch and TEME of Date (see reference [I-3] or [I-4]). The effect is very small relative to TLE accuracy, and there is uncertainty regarding which of these is used by NORAD. The preferred option is TEME of Date. Users should specify in the ICD if their assumption is TEME of Epoch.

## B3 MAN_REF_FRAME AND COV_REF_FRAME KEYWORDS

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

| Relative Reference Frame Value | Meaning |
|---|---|
| BODY | Spacecraft body frame; requires clear specification via ICD |
| NSW | "NADIR, Sun, Normal" – This frame aligns the x-axis in the NADIR direction, the y-axis as much as possible toward the Sun while still being normal to the x-axis, and the z-axis completing the right-hand set |
| RIC | 'Radial, In-track, Cross-track" |
| RSW | Another name for 'Radial, Transverse, Normal' |
| RTN | Radial, Transverse, Normal |
| TNW | A local orbital coordinate frame that has the x-axis along the Tangential (or velocity) vector, z-axis ("W") along the orbital angular momentum vector ($\bar{\omega} = \bar{r} \, x \, \bar{v}$), and N completing the right handed system (i.e., for a circular orbit "N" points in the Nadir direction and for an eccentric orbit, "N" points as close to Nadir as possible while still being normal to the T-W plane). |
| VNC | A local orbital coordinate frame that has the x-axis along the Velocity (or tangential) vector, y-axis Normal to the orbit along the orbital angular momentum vector ($\bar{\omega} = \bar{r} \, x \, \bar{v}$), and z-axis is the "Co-normal" direction completing the right handed system (i.e., for a circular orbit "C" points in the radius vector direction whereas for an eccentric orbit, "C" points as close to radial as possible while still being normal to the V-N plane). |
| ICD | Other relative reference frame, as defined in ICD |

## B4 ORBEPH KEYWORDS

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

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

It is not allowed to specify non-inertial reference frames when employing inertial element sets, or to specify inertial reference frames when employing non-inertial element sets.

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

## B5 ADDITIONAL COVARIANCE SET KEYWORDS

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

| Orbit Element Set Value | Meaning |
|---|---|
| TCARTP | 4x4: Time & Cartesian 3-element position (only) errors (X, Y, Z) |
| TCARTPV | 7x7: Time & Cartesian 6-element position and velocity errors (X, Y, Z, XD, YD, ZD) |
| TCARTPVA | 10x10: Time & Cartesian 9-element position, velocity and acceleration errors (X, Y, Z, XD, YD, ZD, XDD, YDD, ZDD) |
| TKPLR | 7x7: Time & Keplerian 6-element classical set ($aei\Omega\omega\nu$: semi-major axis, eccentricity, inclination, right ascension of the ascending node, argument of perigee and true anomaly) errors |
| TKPLRM | 7x7: Time & Keplerian 6-element classical set ($aei\Omega\omega M$: semi-major axis, eccentricity, inclination, right ascension of the ascending node, argument of perigee and mean anomaly) errors |
| TADBARV | 7x7: Time & Spherical 6-element set ($\alpha\delta\beta$Arv: right ascension +E°, declination +N°, inertial flight path angle measured from the radial direction to inertial velocity direction (e.g. 90° for circular orbit), inertial azimuth angle, measured from local North to projection of inertial velocity in local horizontal plane, radius magnitude and velocity magnitude) errors |
| TEQUIN | 7x7: Time & Equinoctial 6-element set ([ahkλpq ] = [a, $a_g$, $a_f$, L=($\Omega + \omega + f_r\ M$), χ, ψ] as defined in Vallado [I-9]) errors |
| TEQUINMOD | 7x7: Time & Equinoctial 6-element modified set ([pfghkL ] = [a(1-$e^2$), $a_f$, $a_g$, χ, ψ, $L = (\Omega + \omega + f_r\ \nu)$] per Vallado [I-9]) |
| TLDBARV | 7x7: Time & Modified spherical 6-element set ($\lambda\delta\beta$Arv: Earth longitude +E°, declination +N°, inertial flight path angle measured from the radial direction to inertial velocity direction (e.g. 90° for circular orbit), inertial azimuth angle, measured from local North to projection of inertial velocity in local horizontal plane, radius magnitude and velocity magnitude) errors |
| COV_NNXNN | Generic NN x NN covariance containing "NN" rows and columns, with "NN" containing a TWO-DIGIT (including leading zero) representation) of the covariance size. Valid examples are: COV_02X02, COV_12X12. The contents of the covariance matrix are as defined in adjacent COMMENTS or ICD |

# ANNEX C

# SATELLITE PHYSICAL CHARACTERISTICS SPECIFICATION

# (INFORMATIVE)

## C1 OVERVIEW

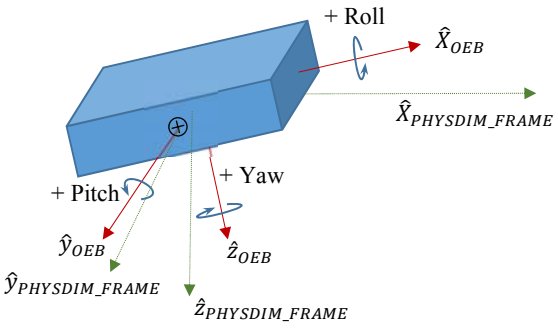
This annex defines satellite dimensional and orientational parameters of the OCM's satellite physical characteristics specification.

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

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

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

- The OEB x-axis is along the longest dimension of the OEB ($\hat{X}_{OEB}$)
- The OEB y-axis is along the intermediate dimension ($\hat{y}_{OEB}$)
- The OEB z-axis is along the short dimension ($\hat{z}_{OEB}$).



A fixed orientation of the OEB with respect to the user-specified "PHYSDIM_FRAME" is defined using an ordered sequence of Euler rotations that map the OEB frame into the PHYSDIM_FRAME. The above figure shows the proper definitions and adopted sign conventions for Yaw, Pitch and Roll angles. The resulting transformation sequence is:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\mathbf{PHYSDIM_FRAME}} = \begin{bmatrix} cos(Yaw) & -sin(Yaw) & 0 \\ sin(Yaw) & cos(Yaw) & 0 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} cos(Pitch) & 0 & sin(Pitch) \\ 0 & 1 & 0 \\ -sin(Pitch) & 0 & cos(Pitch) \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos(Roll) & -sin(Roll) \\ 0 & sin(Roll) & cos(Roll) \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{OEB}$$

The physical dimensions of the OEB (long, intermediate and short dimensions) are specified via PHYSDIM_MAX, PHYSDIM_MED and PHYSDIM_MIN respectively.

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

# ANNEX D

# APPARENT-TO-ABSOLUTE VISUAL MAGNITUDE RELATIONSHIP

# (INFORMATIVE)

## D1 OVERVIEW

This annex presents the relationships to be used to map apparent to absolute visual magnitude for inclusion in an OCM. These equations [based on reference I-12] examine signal magnitude for reflected illumination by an exoatmospheric Resident Space Object (RSO). The equations do not account for spatial distribution across multiple detectors, which involves characterizing the Point Spread Function of the system.

Definitions:

| | |
|---|---|
| $\boldsymbol{E_{EntranceAperture}}$ | Target's specific entrance aperture radiance [W/m$^2$] |
| $I_{Sun}$ | Solar Intensity ≈ $3.088374161 \times 10^{25}$ $[W]$ |
| $d_{SunToTarget}$ | Distance from the sun to the target (e.g. 1 AU = $1.4959787066 \times 10^{11}$ $m$) |
| $E_{Sun}$ | Exoatmospheric solar irradiance (nominally 1380 [$^{W}/_{m^2}$] at 1 AU |
| φ | Phase or CATS angle from sun to the sensor, relative to target [rad] |
| $Phase(\varphi)$ | Geometric reflectance function [between 0 and 1] |
| $F$ | General shadowing term accounting for the penumbra region's influence [unitless ratio between 0 = umbra and 1 = full Sun illumination] |
| $A_{Target}$ | Effective area of the target [$m^2$] |
| $\pi$ | Pi constant |
| $\rho$ | Reflectance of the target [between 0 (none) and 1 (perfect reflectance)] |
| $I_{Target}$ | Intensity of reflected energy from target treated as a point source [W] |
| $E_{Target}$ | Target Irradiance at Sensor w/o atmos loss [W/m$^2$] |
| $r_{Target}$ | Effective radius of the target [$m^2$] |
| $d_{TargetToSensor}$ | Distance from target to sensor [$m$] |
| $\tau_{Atmosphere}$ | Atmospheric transmission [unitless between 0 and 1] |
| $E_0$ | Ref. Visual Magnitude (Vega) Irradiance [$2.77894\times 10^{-8}$ $^{W}/_{m^2}$] |

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

$VM_{apparent} = -2.5 \log_{10} \frac{E_{target}}{E_0}$ [vmag]

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

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

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

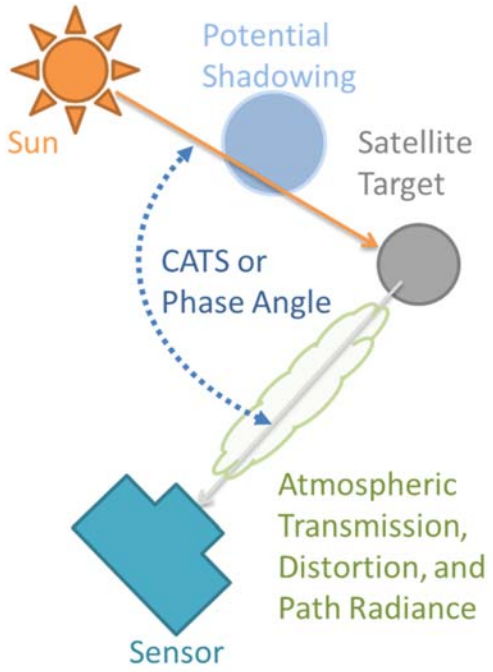
$$E_{Sun} = \frac{I_{Sun}}{d^2_{SunToTarget}}\ [\mathrm{W/m^2}]$$

$$Phase(\varphi) = \frac{\sin\varphi + (\pi - \varphi)\cos\varphi}{\pi}\ [\mathrm{ratio}]$$

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

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

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



# ANNEX E

## ABBREVIATIONS AND ACRONYMS

## (INFORMATIVE)

| | |
|---|---|
| ASCII | American Standard Code for Information Interchange |
| CCSDS | Consultative Committee for Space Data Systems |
| DSST | Draper Semi-Analytic Satellite Theory |
| ECI | Earth Centered Inertial |
| EGM | Earth Gravitational Model, Earth Geopotential Model |
| EME2000 | Earth Mean Equator and Equinox of J2000 (Julian Date 2000) |
| EOP | Earth Orientation Parameters |
| GCRF | Geocentric Celestial Reference Frame |
| GPS | Global Positioning System |
| IAU | International Astronomical Union |
| ICD | Interface Control Document |
| ICRF | International Celestial Reference Frame |
| IEC | International Electrotechnical Commission |
| IERS | International Earth Rotation and Reference Systems Service |
| IIRV | Improved Inter-Range Vector |
| ISO | International Standards Organization |
| ITRF | International Terrestrial Reference Frame |
| ITRS | International Terrestrial Reference System |
| GRC | Greenwich Rotating Coordinate Frame |
| KVN | Keyword = Value Notation |
| NORAD | North American Aerospace Defense Command |
| OD | Orbit Determination |

| | |
|---|---|
| ODM | Orbit Data Message |
| OEB | Optimally-Encompassing Box |
| OEM | Orbit Ephemeris Message |
| OCM | Orbit Comprehensive Message |
| OMM | Orbit Mean-Elements Message |
| OPM | Orbit Parameter Message |
| RTN | Radial, Transverse (along-track) and Normal |
| S/C | Spacecraft |
| SGP4 | US Air Force Simplified General Perturbations No. 4 |
| SPK | Satellite, Planetary Kernel |
| TAI | International Atomic Time |
| TCB | Barycentric Coordinate Time |
| TCG | Geocentric Coordinate Time |
| TDB | Barycentric Dynamical Time |
| TDR | True of Date Rotating |
| TDT | Terrestrial Dynamical Time (see also 'TT') |
| TEME | True Equator Mean Equinox |
| TLE | Two Line Element |
| TOD | True Equator and Equinox of Date |
| TT | Terrestrial Dynamical Time (see also 'TDT') |
| USM | Universal Semianalytical Method |
| UTC | Coordinated Universal Time |
| W3C | World Wide Web Consortium |
| WGS | World Geodetic System |
| XML | Extensible Markup Language |

# ANNEX F

# RATIONALE FOR ORBIT DATA MESSAGES

# (INFORMATIVE)

## F1 OVERVIEW

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

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

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

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

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

# F2 PRIMARY REQUIREMENTS ACCEPTED BY THE ORBIT DATA MESSAGES

## F2.1 PRIMARY REQUIREMENTS

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

## F2.2 HERITAGE REQUIREMENTS

| Requirement | OPM? | OMM? | OEM? | OCM? |
|---|---|---|---|---|
| Ephemeris data is reliably convertible into the SPICE SPK (NASA) format (reference [I-6]) and IIRV (NASA) format (reference [I-7]) using a standard, multi-mission, unsupervised pipeline process. A complete ephemeris, not subject to integration or propagation by the customer, must be provided. | N | N | Y | Y |
| Ephemeris data provided for Deep Space Network (DSN), Ground Network (GN), and Space Network (SN) scheduling or operations (metric predicts) is to be certified by the providing Agency as correct and complete for the intended purpose. The receiving Agency cannot provide evaluation, trajectory propagation or other usability services. | N | N | Y | Y |
| The Recommended Standard is, or includes, an ASCII format. | Y | Y | Y | Y |
| The Recommended Standard does not require software supplied by other Agencies. | Y | N | Y | Y |

## F2.3 DESIRABLE CHARACTERISTICS

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

## F2.4 APPLICABILITY OF CRITERIA TO MESSAGE OPTIONS

The selection of one particular message will depend on the optimization criteria in the given application. Section F2.5 compares the three recommended messages in terms of the relevant selection criteria identified by the CCSDS:

### F2.5 APPLICABILITY OF THE CRITERIA TO ORBIT DATA MESSAGES

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

## F3 INCREASING ORBIT PROPAGATION FIDELITY OF AN OPM OR OMM

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

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

The primary vehicle for the provision of additional optional ancillary information to be used when propagating an OPM/OMM/OCM is the COMMENT mechanism. A number of potential COMMENT statements are included in annex G. Alternatively, the 'USER_DEFINED_' keyword prefix may be used, though this usage is not encouraged.

## F4 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 **Error! Reference source not found.**.

### F4.1 SERVICES AVAILABLE WITH ORBIT DATA MESSAGES

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

# ANNEX G

# ITEMS FOR AN INTERFACE CONTROL DOCUMENT

# (INFORMATIVE)

## G1 STANDARD ICD ITEMS

In several places in this document there are references to items which should be specified in an Interface Control Document (ICD) between participants that supplements an exchange of ephemeris data. The ICD should be jointly produced by both participants in a cross-support involving the transfer of ephemeris data. This annex compiles those recommendations into a single section. Although the Orbit Data Messages described in this document may at times be used in situations in which participants have not negotiated interface control documents (ICD), ICDs based on the content specified in this Recommended Standard should be developed and negotiated whenever possible.[1]

| Item | Section |
|---|---|
| 1) Definition of orbit accuracy requirements pertaining to any particular ODM. | 1.2 |
| 2) Method of physically exchanging ODMs (transmission). | 1.2, 3.1, 4.1, 5.1, 6.1 |
| 3) Whether the ASCII format of the ODM will be KVN or XML. | 2.1 |
| 4) OPM, OMM, OEM and/or OCM file-naming conventions. | 3.1, 4.1, 5.1, 6.1 |
| 5) Format on values used for the 'ORIGINATOR' keyword. | 3.2.2, 4.2.2, 5.2.2, 6.2.2 |
| 6) Situations where the OBJECT_ID is not published in the SPACEWARN Bulletin (reference [2]). | 3.2.3, 4.2.3, 5.2.3, 6.2.3 |
| 7) Detailed description of any user defined parameters used. | 3.2.4, 4.2.4, 6.2.10 |
| 8) Type of TEME reference frame, if applicable (TEME of Epoch or TEME of Date). | 4.2.3 |
| 9) If floating point numbers in extended-single or extended-double precision are to be used, then discussion of implementation specific attributes is required in an ICD between exchange partners. | 7.5 |
| 10) Information which must appear in comments for any given ODM exchange. | 7.7 |

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

| Item | Section |
|---|---|
| 11) Specific OPM, OMM OEM and/or OCM version numbers that will be exchanged. | 7.8.1 |
| 12) Specific information security interoperability provisions that apply between agencies. | 0 |
| 13) Exceptions for the REF_FRAME and/or TIME_SYSTEM metadata keywords that are not drawn from annex A2.5. | annex A2.5 |
| 14) Interpretation of TIME_SYSTEM specified as MET, MRT or SCLK, if to be exchanged, and how to transform them to a standardized time system. The ICD should specify that elapsed days are to be used for epochs, with year starting at zero. | annex A2.5 |

# ANNEX H

# CHANGES IN ODM VERSION 2

# (INFORMATIVE)

This annex lists the differences between ODM 1.0 and ODM 2.0. The differences are divided into those which affect the content of one or more of the orbit data messages, and those which only affect the document.

## H1 CHANGES IN THE MESSAGES

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

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

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

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

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

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

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

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

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

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

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

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

## H2 CHANGES IN THE DOCUMENT

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

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

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

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

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

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

7. The new Orbit Comprehensive Message (OCM) was added.

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

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

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

# ANNEX I

# CREATING A VERSION 1.0 COMPLIANT OPM/OEM

# (INFORMATIVE)

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

## I1 ODM VERSION 1.0 COMPATIBLE OPM

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

- If the software implementation of the exchange partner will not accept a version 2.0 OPM, the value associated with the CCSDS_OPM_VERS keyword must be '1.0'.
- If the software implementation of the exchange partner will accept either version 1.0 or 2.0 OPMs, the value associated with the CCSDS_OPM_VERS keyword may be either '1.0' or '2.0'.
- The OPM line length must not exceed 80 characters (including end of line markers).
- The user must ***not*** code the REF_FRAME_EPOCH metadata keyword.
- The user must code the Spacecraft Parameters logical block.
- The user must ***not*** code the Covariance Matrix logical block.
- The user must ***not*** code the User Defined Parameters logical block.
- If units are desired in the version 1.0 compatible OPM, it may be that an exchange partner's software requires units in upper case characters as they were shown in the Version 1.0 OPM. While it seems unlikely that the case of the units in an OPM would be checked, the user should be aware of this potential issue.

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

## I2 ODM VERSION 1.0 COMPATIBLE OEM

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

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

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

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

# ANNEX J

# SECURITY

# (INFORMATIVE)

## J1 OVERVIEW

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

## J2 SECURITY CONCERNS RELATED TO THIS RECOMMENDED STANDARD

### J2.1 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.

### J2.2 DATA INTEGRITY

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

### J2.3 AUTHENTICATION OF COMMUNICATING ENTITIES

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

### J2.4 DATA TRANSFER BETWEEN COMMUNICATING ENTITIES

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

### J2.5 CONTROL OF ACCESS TO RESOURCES

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

## J2.6 AUDITING OF RESOURCE USAGE

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

## J2.7 POTENTIAL THREATS AND ATTACK SCENARIOS

Potential threats or attack scenarios include, but are not limited to, (a) unauthorized access to the programs/processes that generate and interpret the messages, and (b) unauthorized access to the messages during transmission between exchange partners. Unauthorized access to the programs/processes that generate and interpret the messages should be prohibited. Protection from unauthorized access during transmission is especially important if the mission utilizes open ground networks such as the Internet to provide ground station connectivity for the exchange of data formatted in compliance with this Recommended Standard. It is strongly recommended that potential threats or attack scenarios applicable to the systems and networks on which this Recommended Standard is implemented be addressed by the management of those systems and networks.

## J2.8 CONSEQUENCES OF NOT APPLYING SECURITY TO THE TECHNOLOGY

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

## J2.9 DATA SECURITY IMPLEMENTATION SPECIFICS

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

# ANNEX K

## INFORMATIVE REFERENCES

## (INFORMATIVE)

[K-1] *Navigation Data—Definitions and Conventions*. Report Concerning Space Data System Standards, CCSDS 500.0-G-3. Green Book. Issue 3. Washington, D.C.: CCSDS, May 2010.

[K-2] *Organization and Processes for the Consultative Committee for Space Data Systems*. CCSDS A02.1-Y-3. Yellow Book. Issue 3. Washington, D.C.: CCSDS, July 2011.

[K-3] "CelesTrak." Center for Space Standards & Innovation (CSSI). <http://celestrak.com/>

[K-4] David A. Vallado, et al. "Revisiting Spacetrack Report #3." In *Proceedings of the AIAA/AAS Astrodynamics Specialist Conference and Exhibit* (21–24 August 2006, Keystone, Colorado). AIAA 2006-6753. Reston, Virginia: AIAA, 2006. <http://www.centerforspace.com/downloads/files/pubs/AIAA-2006-6753.pdf>

[K-5] *Attitude Data Messages*. Recommendation for Space Data System Standards, CCSDS 504.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, May 2008.

[K-6] "Documentation." *SPICE: NASA's Solar System Exploration Ancillary Information System*. Navigation and Ancillary Information Facility (NAIF). <http://naif.jpl.nasa.gov/naif/documentation.html>

[K-7] *Ground Network Tracking and Acquisition Data Handbook*. 453-HNDK-GN. Greenbelt, Maryland: Goddard Space Flight Center, May 2007.

[K-8] ~~D.L.~~ Oltrogge, D.L., et al, "Ephemeris Requirements for Space Situational Awareness," AAS 11-151, February 2011.

[K-9] David A. Vallado, et al. *Fundamentals of Astrodynamics and Applications, 4th Ed.*, Microcosm Press and Springer, ISBN 978-1881883180.

[K-10] Williams, J.G., Boggs, D.H., and Folkner, W.M., "DE430 Lunar Orbit, Physical Librations, and Surface Coordinates," Jet Propulsion Laboratory Interoffice Memorandum, IOM 335-JW,DB,WF-20130722-016, 22 July 2013.

[K-11] Jet Propulsion Laboratory, "Lunar Constants and Models Document," JPL D-32296, 23 Sept 2005.

[K-12] Oltrogge, D.L., North, P. and Nicholls, M., "Multi-Phenomenology Observation Network Evaluation Tool (MONET)," AMOS 2015 Space Situational Awareness Conference, Maui, HI, September 2015.

[K-13] Newhall, X.X., "Numerical Representation of Planetary Ephemerides," Celestial Mechanics, vol. 45, pp. 305-310, 1989.

[K-14] Hoots, F.R. and France, R. Richard G., "Hybrid Ephemeris Compression Model," Astrodynamics Specialist Conference, AAS 97-690.

[K-15] Braun, V. and Klinkrad, H., "Providing Orbital Information for Objects in Earth Orbits as Chebyshev Polynomials," in IAC-15, 2015a6,7,9x31103.

[K-16] Woodburn, J., & Tanygin, S. (2002). Position covariance visualization. AIAA/AAS Astrodynamics Specialist Conference and Exhibit, Monterey, California

Formatted: (none)