Consultative Committee for Space Data Systems

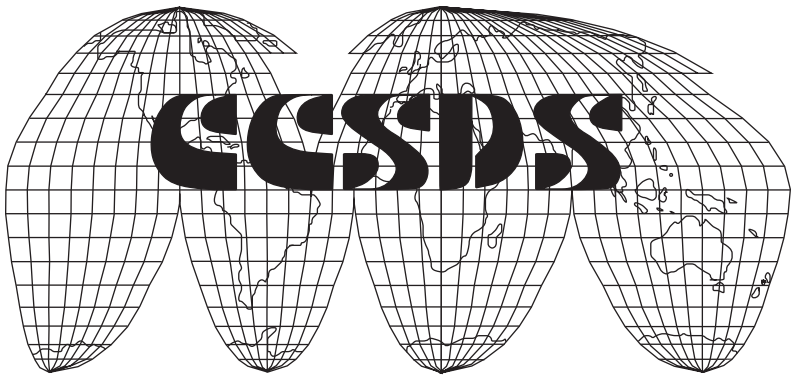
RECOMMENDATION FOR SPACE DATA SYSTEM STANDARDS

ORBIT DATA MESSAGES

CCSDS 502.0-B-1

BLUE BOOK

September 2004



AUTHORITY

Issue:	Blue Book, Issue 1
Date:	September 2004
Location:	Electronic Ballot

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 Recommendations is detailed in the *Procedures Manual for the Consultative Committee for Space Data Systems* (reference [5]), and the record of Agency participation in the authorization of this document can be obtained from the CCSDS Secretariat at the address below.

This Recommendation is published and maintained by:

CCSDS Secretariat
Office of Space Communication (Code M-3)
National Aeronautics and Space Administration
Washington, DC 20546, USA

STATEMENT OF INTENT

The Consultative Committee for Space Data Systems (CCSDS) is an organization officially established by the management of member space Agencies. 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 **Recommendations** and are not considered binding on any Agency.

This **Recommendation** is issued by, and represents the consensus of, the CCSDS Plenary body. Agency endorsement of this **Recommendation** is entirely voluntary. Endorsement, however, indicates the following understandings:

– Whenever an Agency establishes a CCSDS-related **standard**, this **standard** will be in accord with the relevant **Recommendation**. Establishing such a **standard** does not preclude other provisions which an Agency may develop.

– Whenever an Agency establishes a CCSDS-related standard, the Agency will provide other CCSDS member Agencies with the following information:

  • The **standard** itself.

  • The anticipated date of initial operational capability.

  • The anticipated duration of operational service.

– Specific service arrangements are made via memoranda of agreement. Neither this Recommendation nor any ensuing standard is a substitute for a memorandum of agreement.

No later than five years from its date of issuance, this **Recommendation** 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 **Recommendation** is issued, existing CCSDS-related Agency standards and implementations are not negated or deemed to be non-CCSDS compatible. It is the responsibility of each Agency to determine when such standards or implementations are to be modified. Each Agency is, however, strongly encouraged to direct planning for its new standards and implementations towards the later version of the Recommendation.

FOREWORD

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

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

Through the process of normal evolution, it is expected that expansion, deletion or modification to this document may occur. This Recommendation is therefore subject to CCSDS document management and change control procedures, as 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.
- Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)/Germany.
- European Space Agency (ESA)/Europe.
- Federal Space Agency (FSA)/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.
- Central Research Institute of Machine Building (TsNIIMash)/Russian Federation.
- Centro Tecnico Aeroespacial (CTA)/Brazil.
- Chinese Academy of Space Technology (CAST)/China.
- Commonwealth Scientific and Industrial Research Organization (CSIRO)/Australia.
- Communications Research Laboratory (CRL)/Japan.
- Danish Space Research Institute (DSRI)/Denmark.
- European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)/Europe.
- European Telecommunications Satellite Organization (EUTELSAT)/Europe.
- Federal Science Policy Office (FSPO)/Belgium.
- 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.
- MIKOMTEK: CSIR (CSIR)/Republic of South Africa.
- Ministry of Communications (MOC)/Israel.
- National Oceanic & Atmospheric Administration (NOAA)/USA.
- National Space Program Office (NSPO)/Taipei.
- Space and Upper Atmosphere Research Commission (SUPARCO)/Pakistan.
- Swedish Space Corporation (SSC)/Sweden.
- United States Geological Survey (USGS)/USA.

DOCUMENT CONTROL

Document	Title and Issue	Date	Status
CCSDS 502.0-B-1	Orbit Data Messages, Issue 1	September 2004	Current Issue

CONTENTS

CONTENTS (continued)

Figure **Page**

Table **Page**

1 INTRODUCTION

1.1 PURPOSE

This Orbit Data Message (ODM) Recommendation specifies two standard message formats for use in transferring spacecraft orbit information between space Agencies: the Orbit Parameter Message (OPM) and the Orbit Ephemeris Message (OEM). 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; and

e) carrying out navigation operations such as orbit propagation.

This Recommendation 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 another mechanism may be selected.

1.2 SCOPE AND APPLICABILITY

This document contains two orbit data messages designed for applications involving data interchange in space data systems. The rationale behind the design of each message is described in Annex A 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 Recommendation and should be specified via Interface Control Document (ICD) between data exchange participants. Applicability information specific to each orbit data message format appears in sections 3 and 4, as well as in subsection A3.

This Recommendation is applicable only to the message format and content, but not to its transmission. The transmission of the message between Agencies 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 under investigation. It is anticipated that an XML schema will be defined by a future Recommendation on the XML implementation of Navigation data messages.

1.3 CONVENTIONS AND DEFINITIONS

The following conventions apply throughout this Recommendation:

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.

1.4 STRUCTURE OF THIS DOCUMENT

Chapter 2 provides a brief overview of the CCSDS-recommended Orbit Data Message types, the Orbit Parameter Message (OPM) and Orbit Ephemeris Message (OEM).

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

Chapter 4 provides details about the structure and content of the OEM.

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

Annex B lists a number of items that should be covered in interagency Interface Control Documents (ICD) 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.

Annex C is a list of abbreviations and acronyms applicable to the ODM.

1.5 REFERENCES

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

[1] *Navigation Data—Definitions and Conventions*. Report Concerning Space Data System Standards, CCSDS 500.0-G-1. Green Book. Issue 1. Washington, D.C.: CCSDS, June 2001. [http://www.ccsds.org/green_books.html]

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

[3] *Standard Frequencies and Time Signals*. Volume 7 of *Recommendations and Reports of the CCIR: XVth Plenary Assembly*. Geneva: CCIR,1990.

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

[5] *Procedures Manual for the Consultative Committee for Space Data Systems*. CCSDS A00.0-Y-9. Yellow Book. Issue 9. Washington, D.C.: CCSDS, November 2003.

[6] NASA/JPL Solar System Dynamics Group [*http://ssd.jpl.nasa.gov*].

[7] XML Schema Part 2: Datatypes, W3C Recommendation 02 May 2001, http://www.w3.org/TR/2001/REC-xmlschema-2-20010502/

[8] IEEE Standard for Binary Floating-Point Arithmetic, IEEE Standard 754-1985, IEEE, http://grouper.ieee.org/groups/754/

2 OVERVIEW

2.1 ORBIT DATA MESSAGE TYPES

Two CCSDS-recommended Orbit Data Messages (ODMs) are described in this Recommendation: the Orbit Parameter Message (OPM) and the Orbit Ephemeris Message (OEM).

The recommended orbit data messages are ASCII text format. While binary-based orbit data message formats are computer efficient and minimize overhead on uplinked/downlinked data streams, there are ground-segment applications for which an ASCII character-based message is more appropriate. For example, when files or data objects are created using text editors or word processors, ASCII character-based orbit data format representations are necessary. They are also useful in transferring text files between heterogeneous computing systems, because the ASCII character set is nearly universally used and is interpretable by all popular systems. In addition, direct human-readable dumps of text files or objects to displays or printers are possible without preprocessing. The penalty for this convenience is inefficiency.

> **NOTE** As currently specified, an OPM or OEM file is to represent orbit data for a single vehicle. It is possible that the architecture may support multiple vehicles 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. This message is suited to inter-agency exchanges that (1) involve automated interaction and/or human interaction, and (2) do not require high-fidelity dynamic modeling.

The OPM requires the use of a propagation technique to determine the position and velocity at times different from the specified epoch, leading to a higher level of effort for software implementation than for the OEM. The OPM is fully self-contained; no additional information is required.

The code 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 attributes of this code also make it suitable for applications such as exchanges by FAX or voice, or applications where the message is to be frequently interpreted by humans.

2.3 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 inter-agency 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 is fully self-contained; no additional information is required.

2.4 EXCHANGE OF MULTIPLE MESSAGES

For a given object, multiple OPM or OEM messages may be provided in a message exchange session to achieve ephemeris fidelity requirements. If ephemeris information for multiple objects is to be exchanged, then multiple OPM or OEM files must be used.

2.5 DEFINITIONS

Definitions of time systems, reference frames and planetary models are provided in reference [1].

3 ORBIT PARAMETER MESSAGE (OPM)

3.1 OVERVIEW

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

b) The use of the OPM shall be applicable under the following conditions:

   1) an orbit propagator must be run at the receiver's site;

   2) the receiver's modeling of gravitational forces, solar radiation pressure, atmospheric drag and thrust phases (see reference [1]) must fulfill accuracy requirements established between the agencies.

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

d) The OPM file naming scheme shall be agreed to on a case-by-case basis between the participating Agencies, and should be documented in an Interface Control Document (ICD). The method of exchanging OPMs shall be decided on a case-by-case basis by the participating Agencies and documented in an ICD.

3.2 OPM CONTENT

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

a) a header;

b) metadata (data about data);

c) optional comments (explanatory information); and

d) data.

3.2.1 OPM HEADER

Table 3-1 specifies for each header item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

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

Table 3-1: OPM Header

Keyword	Description	Examples of Values	Obligatory
CCSDS_OPM_VERS	Format version in the form of 'x.y', where 'y' is incremented for corrections and minor changes, and 'x' is incremented for major changes.	1.0	Yes
CREATION_DATE	File creation date/time in one of following formats: YYYY-MM-DDThh:mm:ss[.ttttt] or YYYY-DDDThh:mm:ss[.ttttt] where "YYYY" is the year, "MM" is the 2 digit month, "DD" is the 2 digit day, "DDD" is the 3 digit day of year, "T" is constant, "hh:mm:ss[.ttttt]" is the UTC time in hours, minutes, seconds, and optional fractional seconds. All fields require leading zeros.	2001-11-06T11:17:33 2002-204T15:56:23	Yes
ORIGINATOR	Creating agency (value should be specified in an ICD).	CNES, ESOC, GSFC, GSOC, JPL, JAXA, etc.	Yes
COMMENT	Comments (allowed everywhere in the OPM Header after the OPM version number). Each comment line shall begin with this keyword.	n/a	No

3.2.2 OPM METADATA

Table 3-2 specifies for each metadata item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

Only those keywords shown in Table 3-2 shall be used in OPM metadata. For some keywords (OBJECT_NAME, OBJECT_ID, CENTER_NAME, REF_FRAME) there are no definitive lists of authorized values maintained by a control authority; the references listed in subsection 1.5 are the best known sources for authorized values to date.

Table 3-2: OPM Metadata

Keyword	Description	Examples of Values	Obligatory
OBJECT_NAME	There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the SPACEWARN Bulletin (reference [2]), which include Object name and international designator of the participant.	EUTELSAT W1 MARS PATHFINDER STS 106 NEAR	Yes
OBJECT_ID	International spacecraft designator (as published in the SPACEWARN Bulletin (reference [2])). Valid values have the format YYYY-NNNP{PP}, where: YYYY = Year of launch. NNN = Three digit serial number of launch in year YYYY (with leading zeros). P{PP} = At least one capital letter for the identification of the part brought into space by the launch. In cases where the asset is not listed in the bulletin the value should be provided in an ICD.	2000-052A 1996-068A 2000-053A 1996-008A	Yes
CENTER_NAME	Origin of reference frame, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this case the value for 'CENTER_NAME' is subject to the same rules as for 'OBJECT_NAME'). There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the NASA/JPL Solar System Dynamics Group (at http://ssd.jpl.nasa.gov (reference [6])).	EARTH EARTH BARYCENTER MOON SOLAR SYSTEM BARYCENTER SUN JUPITER BARYCENTER STS 106 EROS	Yes
REF_FRAME	Name of the reference frame in which the state vector and optional Keplerian element data are given. It is recommended to use reference frames from *Navigation Definitions and Conventions* (reference [1]).	ICRF ITRF-93 ITRF-97 ITRF2000 ITRFxxxx (Template for a future version) TOD (True Equator/Equinox of Date) EME2000 (Earth Mean Equator and Equinox of J2000) TDR (true of date rotating) GRC (Greenwich rotating coordinate frame)	Yes
TIME_SYSTEM	Time system used for state vector and maneuver data (also see Table 3-3). It is recommended to use names from *Navigation Definitions and Conventions* (reference [1]). Times may be given in 1) ISO/CCSDS ASCII format or 2) Julian Date strings.	UTC, TAI, TT, GPS, TDB, TCB	Yes
COMMENT	Comments (allowed everywhere in the OPM Metadata). Each comment line shall begin with this keyword.	n/a	No

3.2.3 OPM DATA

Table 3-3 provides an overview of the four logical blocks in the OPM Data section (State Vector, Keplerian Elements, Spacecraft Parameters, and Maneuver Parameters), and specifies for each data item:

a) the keyword to be used;

b) a short description of the item;

c) the units to be used;

d) whether the item is obligatory or optional.

Only those keywords shown in Table 3-3 shall be used in OPM data. (Some important notes about the keywords in Table 3-3 appear immediately after the table.)

Table 3-3: OPM Data

Keyword	Description	Units	Obligatory
State Vector Components in the Specified Coordinate System			
EPOCH	Epoch of state vector & optional Keplerian elements	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
Keplerian Elements in the Specified Reference Frame (none or all parameters of this block must be given.)			
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	KM**3 / S**2	No
Spacecraft Parameters			
MASS	S/C Mass at Epoch	KG	Yes
SOLAR_RAD_AREA	Solar Radiation Pressure Area (A_R).	M**2	Yes
SOLAR_RAD_COEFF	Solar Radiation Pressure Coefficient (C_R).	n/a	Yes
DRAG_AREA	Drag Area (A_D).	M**2	Yes
DRAG_COEFF	Drag Coefficient (C_D).	n/a	Yes
Maneuver Parameters (Repeat for each maneuver. None or all parameters of this block must be given.)			
MAN_EPOCH_IGNITION	Epoch of ignition	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	n/a	No
MAN_DV_1	1^{st} component of the velocity increment	KM/S	No
MAN_DV_2	2^{nd} component of the velocity increment	KM/S	No
MAN_DV_3	3^{rd} component of the velocity increment	KM/S	No
Comments (shall appear only at the beginning or end of the logical blocks, but not between components of the logical blocks.)			
COMMENT	Each comment line shall begin with this keyword.	n/a	No

NOTES

1 See 'CREATION_DATE' in Table 3-1 for examples of how to format the EPOCH.

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

3 The gravitational coefficient, GM (Gravitational Coefficient = Gravitational Constant x Central Mass), used by the originator of the message for the conversion of state vector to Keplerian elements (or vice versa) must be included if the optional set of Keplerian elements is provided. The required units for GM are km^3/s^2.

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

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

6 Parameters for thrust phases may be optionally given for the computation of the trajectory during or after maneuver execution (see reference [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 allowed for the keyword REF_FRAME in Table 3-1 and the Radial, Transverse (along-track) and Normal (RTN) reference frame (see reference [1]).

3.2.4 COMMENTS IN AN OPM

a) 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.

b) 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 OPM producer should put certain information into comments and use the ICD to provide further specifications.

c) Comments may appear anywhere within the OPM Header and OPM Metadata sections. In the OPM Data section, comments shall only appear at the beginning or end of a logical block. Comments must not appear between the components of

any logical block in the OPM Data section. The logical blocks in the OPM Data section are indicated in Table 3-3.

d) The following comments should be provided:

1) Information regarding the genesis, history, interpretation, intended use, etc. of the state vector, spacecraft, and maneuver that may be of use to the receiver of the OPM:

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

2) Natural body ephemeris information:

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

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.

3.3 OPM SYNTAX

The OPM shall be a plain text file, using the syntax described in subsections 3.3.1 through 3.3.6.

3.3.1 LINES

a) Each OPM line must not exceed 78 ASCII characters and spaces (excluding line termination character[s]).

b) Only printable ASCII characters and blanks shall be used. Control characters (such as TAB, etc.) shall not be used.

c) Blank lines may be used at any position within the file.

d) Comment lines shall be optional. See Section 3.2.4 for details regarding the placement of comment lines.

e) OPM 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.

3.3.2 KEYWORD = VALUE NOTATION AND ORDER OF ASSIGNMENT STATEMENTS

a) All header, metadata, and data lines shall use 'keyword = value' notation, abbreviated as KVN.

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

c) Keywords must be uppercase and must not contain blanks.

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

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

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

g) The order of occurrence of obligatory and optional KVN assignments shall be fixed as shown in Table 3-1, Table 3-2, and Table 3-3.

3.3.3 VALUES

a) 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 blanks shall be equivalent to a single blank.

b) Blanks must not appear within numeric values and time strings.

c) 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 .

d) Non-integer numeric values may be expressed in either fixed or floating-point notation. Both representations may be used within an OPM.

e) 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. If the fractional part is zero, the period and following zero(es) may be omitted. There must be a leading zero if -1.0 < x < 1.0 . The number of digits shall be 18 or less.

f) Non-integer numeric values expressed in floating point notation shall consist of a sign, a mantissa, an alphabetic character indicating the division between the

mantissa and exponent, and an exponent, constructed according to the following rules:

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

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

3) The character used to denote exponentiation shall be "E" or "e". If the character indicating the exponent and the following exponent are omitted, an exponent value of 0 shall be assumed (essentially yielding a fixed point value).

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

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

NOTE These specifications for integer, fixed point and floating point values conform to the XML specifications for the data types "integer", "decimal" and "double" respectively. The specifications for floating point values conform to the IEEE double precision type (references [7], [8]). Floating point numbers in IEEE extended-single or IEEE extended-double precision may be represented, but do require an ICD between participating agencies due to their implementation specific attributes (reference [8]).

g) Text value fields may be constructed using mixed case. Case shall not be significant.

h) A non-null value field must be specified for each keyword provided.

3.3.4 UNITS

For clarity, units may be included as ASCII text after a value, but they must match the units specified in Table 3-3. 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., '**'); and

d) units documentation may be constructed using mixed case (case shall not be significant).

3.3.5 COMMENTS

All comment lines shall begin with the 'COMMENT' keyword followed by a single 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.

3.3.6 OPM KEYWORD SET

a) The header shall provide a CCSDS Orbit Data Message version number that identifies the format version; this is included to anticipate future changes. The version keyword shall be CCSDS_OPM_VERS and 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 1.0 shall be reserved for the initial version accepted by the CCSDS as an official Recommended Standard ("Blue Book"). Testing shall be conducted using OPM version numbers less than 1.0 (e.g., 0.x). Participating agencies should specify in the ICD the specific OPM version numbers they will support.

b) The header shall include the CREATION_DATE keyword with the value set to the Coordinated Universal Time (UTC) when the file was created, according to the ISO standard. A description of OPM header keywords and values is provided in Table 3-1.

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

d) Comments may appear anywhere within the OPM Header and OPM Metadata sections. In the OPM Data section, comments shall only appear at the beginning or end of a logical block. Comments must not appear between the components of any logical block in the OPM Data section. The logical blocks in the OPM Data section are indicated in Table 3-3.

e) Only those keywords shown in Table 3-1 , Table 3-2, and Table 3-3 shall be used in an OPM. Some keywords represent obligatory items and some are optional. KVN assignments representing optional items may be skipped.

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

g) 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.

3.4 OPM EXAMPLES

Figures 3-1 and 3-2 are examples of Orbit Parameter Messages.

```
CCSDS_OPM_VERS = 1.0
CREATION_DATE  = 2001-11-06T09:23:57
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

COMMENT          OBJECT_ID: 1998-057A
COMMENT $ITIM  = 1998 OCT 09 22:26:18.40000000, $ original launch time 21:58
COMMENT $ITIM  = 1998 OCT 09 22:23:18.40000000, $ reflects -3mn shift 21:55
COMMENT $ITIM  = 1998 OCT 09 22:28:18.40000000, $ reflects +5mn shift 22:00
COMMENT $ITIM  = 1998 OCT 09 22:58:18.40000000, $ reflects+30mn shift 22:30
COMMENT $ITIM  = 1998 OCT 09 23:18:18.40000000, $ reflects+20mn shift 22:50

EPOCH =          1996-12-18T14:28:15.1172
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: OPM File Example Using Comments to Denote Updates

```
CCSDS_OPM_VERS    =  1.0
CREATION_DATE     =  2000-06-03T05:33:00.000
ORIGINATOR        =  GSOC

OBJECT_NAME       =  EUTELSAT W4
OBJECT_ID         =  2000-028A

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

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

4 ORBIT EPHEMERIS MESSAGE (OEM)

4.1 OVERVIEW

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

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

The file naming scheme shall be agreed to on a case-by-case basis between the participating agencies, typically using an Interface Control Document (ICD). The method of exchanging OEMs shall be decided on a case-by-case basis by the participating agencies and documented in an ICD.

4.2 OEM CONTENT

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

a) a header;

b) metadata (data about data);

c) optional comments (explanatory information); and

d) ephemeris data.

OEM files must have a set of minimum required sections; some may be repeated. Table 4-1 outlines the contents of an OEM.

Table 4-1: OEM File Layout Specifications

Required Sections	Header Metadata Ephemeris Data (Appropriate comments should also be included, although they are not absolutely required.)
Allowable Repetitions of Sections	Metadata Ephemeris Data Metadata Ephemeris Data Metadata Ephemeris Data …etc. (Appropriate comments should also be included.)

4.2.1 OEM HEADER

The OEM header assignments are shown in Table 4-2, which specifies for each item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

Only those keywords shown shall be used in an OEM header.

Table 4-2: OEM Header

Keyword	Description	Examples of Values	Obligatory
CCSDS_OEM_VERS	Format version in the form of 'x.y', where 'y' is incremented for corrections and minor changes, and 'x' is incremented for major changes.	1.0	Yes
CREATION_DATE	File creation date and time in one of the two following formats: YYYY-MM-DDThh:mm:ss[.ttttt] YYYY-DDDThh:mm:ss[.ttttt] where "YYYY" is the year, "MM" is the 2 digit month, "DD" is the 2 digit day, "DDD" is the 3 digit day of year, "T" is constant, "hh:mm:ss[.ttttt]" is the UTC time in hours, minutes, seconds, and optional fractional seconds. All fields require leading zeros.	2001-11-06T11:17:33 2002-204T15:56:23	Yes
ORIGINATOR	Creating agency (value should be specified in an ICD).	CNES, ESOC, GSFC, GSOC, JPL, JAXA, etc.	Yes
COMMENT	Comments (allowed everywhere in the message after the OEM version number, except between ephemeris data lines). Each comment line shall begin with this keyword.	n/a	No

4.2.2 OEM METADATA

The OEM metadata assignments are shown in Table 4-3, which specifies for each item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

Only those keywords shown shall be used in OEM metadata. For some keywords (OBJECT_NAME, OBJECT_ID, CENTER_NAME, REF_FRAME) there are no definitive lists of authorized values maintained by a control authority; the references listed in subsection 1.5 are the best known sources for authorized values to date.

Table 4-3: OEM Metadata

Keyword	Description	Examples of Values	Obligatory
META_START	The OEM message contains both metadata and ephemeris 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
OBJECT_NAME	There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the SPACEWARN Bulletin (reference [2]), which include Object name and international designator of the participant.	EUTELSAT W1 MARS PATHFINDER STS 106 NEAR	Yes
OBJECT_ID	International spacecraft designator (as published in reference [2]). Valid values have the format YYYY-NNNP{PP}, where: YYYY = Year of launch. NNN = Three-digit serial number of launch in year YYYY (with leading zeros). P{PP} = At least one capital letter for the identification of the part brought into space by the launch. In cases where the asset is not listed in reference [2], the value should be provided in an ICD.	2000-052A 1996-068A 2000-053A 1996-008A	Yes
CENTER_NAME	Origin of reference frame, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this case the value for 'CENTER_NAME' is subject to the same rules as for 'OBJECT_NAME'). There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the NASA/JPL Solar System Dynamics Group (at http://ssd.jpl.nasa.gov (reference [6])).	EARTH EARTH BARYCENTER MOON SOLAR SYSTEM BARYCENTER SUN JUPITER BARYCENTER STS 106 EROS	Yes
REF_FRAME	Name of the reference frame in which the ephemeris data are given. It is recommended to use reference frames from Navigation Definitions and Conventions (reference [1]).	ICRF ITRF-93 ITRF-97 ITRF2000 ITRFxxxx (template for future versions) TOD (True Equator and Equinox of Date) EME2000 (Earth Mean Equator and Equinox of J2000) TDR (true of date rotating) GRC (Greenwich rotating coordinate frame... another name for TDR)	Yes
TIME_SYSTEM	Time system used for both ephemeris data and metadata. It is recommended to use names from *Navigation Definitions and Conventions* (reference [1]).	UTC, TAI, TT, GPS, TDB, TCB	Yes
START_TIME	Start of TOTAL time span covered by ephemeris data immediately following this metadata block. The START_TIME time tag at a new block of ephemeris data must be equal to or greater than the STOP_TIME time tag of the previous block.	Calendar Formats: 1996-12-18T14:28:15.1172 1996-277T07:22:54 Julian Date Strings: 2451534.29812	Yes

Keyword	Description	Examples of Values	Obligatory
USEABLE_ START_TIME, USEABLE_ STOP_TIME	Optional start and end of USEABLE time span covered by ephemeris data immediately following this metadata block. To allow for proper interpolation near the ends of the ephemeris data block it may be necessary, depending upon the interpolation method to be used, to utilize these keywords with values within the time span covered by the ephemeris data records as denoted by the START/STOP_TIME time tags.	Calendar Formats: 1996-12-18T14:28:15.1172 1996-277T07:22:54 Julian Date Strings: 2451534.29812	No
STOP_TIME	End of TOTAL time span covered by ephemeris data immediately following this metadata block. The START_TIME time tag at a new block of ephemeris data must be equal to or greater than the STOP_TIME time tag of the previous block.	Calendar Formats: 1996-12-18T14:28:15.1172 1996-277T07:22:54 Julian Date Strings: 2451534.29812	Yes
INTERPOLATION	This keyword may be used to specify the recommended interpolation method for ephemeris data in the immediately following set of ephemeris lines.	Hermite Linear Lagrange	No
INTERPOLATION_ DEGREE	Recommended interpolation degree for ephemeris data in the immediately following set of ephemeris lines. Must be an integer value. This keyword must be used if the "INTERPOLATION" keyword is used.	5 1	No
META_STOP	The OEM message contains both metadata and ephemeris 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
COMMENT	Comments (allowed everywhere in the message after the OEM version number, except between ephemeris data lines). Each comment line shall begin with this keyword.	n/a	No

4.2.3 OEM DATA

See Section 4.3.5, "Ephemeris Data Lines", for specifications regarding OEM data.

4.2.4 COMMENTS IN AN OEM

a) 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.

b) 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 OEM producer should put certain information into comments and use the ICD to provide further specifications.

c) The following comments are recommended:

1) Information regarding the genesis, history, interpretation, intended use, etc. of the ephemeris data that may be of value to the receiver of the OEM:

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

2) Natural Body Ephemeris Information:

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

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.

3) OEM Accuracy vs. Efficiency: 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).

4.3 OEM SYNTAX

The OEM shall be a plain text file, using the syntax described in subsections 4.3.1 through 4.3.7.

4.3.1 LINES

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

b) Only printable ASCII characters and blanks shall be used. Control characters (such as TAB, etc.) shall not be used.

c) Blank lines may be used at any position within the file.

d) Comment lines shall be optional and may occur at any position in the file after the first line of the header, except that comment lines must not appear within any block of ephemeris lines.

e) OEM 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.

4.3.2 KEYWORD = VALUE NOTATION AND ORDER OF ASSIGNMENT STATEMENTS

a) All header and metadata elements shall use 'keyword = value' notation, abbreviated as KVN.

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

c) Keywords must be uppercase and must not contain blanks.

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

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

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

g) The order of occurrence of obligatory and optional KVN assignments shall be fixed as shown in Table 4-2 and Table 4-3.

4.3.3 VALUES

a) 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 blanks shall be equivalent to a single blank.

b) Blanks must not appear within numeric values and time strings.

c) 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.

d) Non-integer numeric values may be expressed in either fixed or floating-point notation. Both representations may be used within an OEM.

e) 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. If the fractional part is zero,

the period and following zero(es) may be omitted. There must be a leading zero if $-1.0 < x < 1.0$. The maximum number of digits shall be 18 or less.

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

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

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

3) The character used to denote exponentiation shall be "E" or "e". If the character indicating the exponent and the following exponent are omitted, an exponent value of 0 shall be assumed (essentially yielding a fixed point value).

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

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

NOTE These specifications for integer, fixed point and floating point values conform to the XML specifications for the data types "integer", "decimal" and "double" respectively. The specifications for floating point values conform to the IEEE double precision type (references [7], [8]). Floating point numbers in IEEE extended-single or IEEE extended-double precision may be represented, but do require an ICD between participating agencies due to their implementation specific attributes (reference [8]).

g) Text value fields may be constructed using mixed case. Case shall not be significant.

h) A non-null value field must be specified for each obligatory keyword.

4.3.4 UNITS

In an OEM, units shall be km and km/s but shall not be displayed.

4.3.5 EPHEMERIS DATA LINES

a) For OEMs, 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**.

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

c) Ephemeris data lines must be ordered by increasing time, and time tags must not be repeated, except in the case where the STOP_TIME of a set of ephemeris data lines is equal to the START_TIME of the following set of ephemeris data lines. The time step duration may vary within a given OEM.

d) The TIME_SYSTEM value must remain fixed within an OEM.

e) 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.

f) 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.

4.3.6 COMMENTS

All comment lines shall begin with the '`COMMENT`' keyword followed by a single 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.

4.3.7 OEM KEYWORD SET

a) The header shall provide a CCSDS Orbit Data Message version number that identifies the format version; this is included to anticipate future changes. The version keyword shall be CCSDS_OEM_VERS and the value shall have the form of 'x.y', where 'y' is incremented for corrections and minor changes, and 'x' is incremented for major changes. Version 1.0 shall be reserved for the initial version accepted by the CCSDS as an official Recommended Standard ("Blue Book"). Testing shall be conducted using OEM version numbers less than 1.0 (e.g., 0.x). Participating agencies should specify in the ICD the specific OEM version numbers they will support.

b) The header shall include the CREATION_DATE keyword with the value set to the Coordinated Universal Time (UTC) when the file was created, according to the ISO standard. A description of OEM header keywords and values is provided in Table 4-2 and Table 4-3.

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

d) Comments may appear anywhere after the first header line, except that comment lines must not appear between ephemeris data lines.

e) Only those keywords shown in Table 4-2 and Table 4-3 shall be used in an OEM. Some keywords represent obligatory items and some are optional. KVN assignments representing optional items may be skipped. The two USEABLE_START/STOP_TIME keywords marked as optional items may not be necessary, depending on the recommended interpolation method. (It is safer to use the USEABLE_START/STOP_TIME capability in all cases.)

f) 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.

g) 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.

4.4 OEM EXAMPLE

Figure 4-1 is an example of an OEM. Note that some ephemeris data lines have been omitted to save space.

```
CCSDS_OEM_VERS = 1.0
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 OCT 11. 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 4-1: OEM Example

ANNEX A

RATIONALE FOR ORBIT DATA MESSAGES

(This annex is **not** part of the Recommendation)

A1 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. 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 or its Member Agencies.

b) Heritage Requirements: These are additional requirements that derive from pre-existing Member Agency requirements, conditions or needs. Ultimately these carry the same weight as the Primary Requirements. This Recommendation reflects heritage requirements pertaining to some of the panels' home institutions collected during the preparation of the document; it does not speculate on heritage requirements that could arise from other Member Agencies. 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 Recommendation.

A2 PRIMARY REQUIREMENTS ACCEPTED BY THE ORBIT DATA CODES

Table A-1: Primary Requirements

Requirement	Accepted for OPM?	Accepted for OEM?
Data must be provided in digital form (computer file).	Y	Y
The file specification must not require of the receiving Agency the separate application of, or modeling of, spacecraft dynamics or gravitational force models, or integration or propagation.	N	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
State vector information must be provided in a reference frame that is clearly identified and unambiguous.	Y	Y
Identification of the object and the center(s) of motion must be clearly identified and unambiguous.	Y	Y
Time measurements (time stamps, or epochs) must be provided in a commonly used, clearly specified system.	Y	Y
The time bounds of the ephemeris must be unambiguously specified.	N/A	Y
The standard must provide for clear specification of units of measure.	Y	Y
Files must be readily ported between, and useable within, 'all' computational environments in use by Member Agencies.	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
File name syntax and length must not violate computer constraints for those computing environments in use by Member Agencies.	Y	Y

Table A-2: Heritage Requirements

Requirement	Accepted for OPM?	Accepted for OEM?
Ephemeris data is reliably convertible into the SPICE SPK format and IIRV format using a standard, multi-mission, unsupervised pipeline process. A complete ephemeris, not subject to integration or propagation by the customer, must be provided.	N	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	Y
The standard is, or includes, an ASCII format.	Y	Y
The standard does not require software supplied by other Agencies.	Y	Y

Table A-3: Desirable Characteristics

Requirement	Accepted for OPM?	Accepted for OEM?
The standard applies to non-traditional objects, such as landers, rovers, balloons, and natural bodies (asteroids, comets).	Y	Y
The 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
The standard is extensible with no disruption to existing users/uses.	Y	Y
The standard is consistent with, and ideally a part of, ephemeris products and processes used for other space science purposes.	N	N
The standard is as consistent as reasonable with any related CCSDS ephemeris standards used for earth-to-spacecraft or spacecraft-to-spacecraft applications.	Y	Y

A3 APPLICABILITY OF CRITERIA TO CODE OPTIONS

The selection of one particular code will depend on the optimization criteria in the given application. Table A-4 compares the two recommended codes in terms of the relevant selection criteria identified by the CCSDS:

Table A-4: Applicability of the Criteria to Orbit Data Codes

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

A4 SERVICES RELATED TO THE DIFFERENT ORBIT DATA CODE FORMATS

The different orbit data codes have been distinguished by the self-interpretability of the codes. Both orbit data codes provide for recognizing the boundaries of the orbit data code field and thus can transfer that field, as a block, to another location. The different services that can be achieved without special arrangements between users of the CCSDS orbit data codes are listed in Table A-5.

Table A-5: Services Available with Orbit Data Codes

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

ANNEX B

ITEMS FOR AN INTERFACE CONTROL DOCUMENT

(This annex is **not** part of the Recommendation)

In several places in this document there are references to items which should be specified in an Interface Control Document (ICD) between agencies participating in an exchange of ephemeris data. The ICD should be jointly produced by both Agencies participating in a cross-support involving the transfer of ephemeris data. This section compiles those recommendations into a single section.

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

1. OPM and OEM file naming conventions

2. Method of physically exchanging ODMs (transmission)

3. Definition of orbit accuracy requirements pertaining to any particular ODM

4. Specific OPM and/or OEM version numbers that will be exchanged.

5. Format on values used for the "ORIGINATOR" keyword

6. Situations where the OBJECT_ID is not published in the SPACEWARN Bulletin (reference [2]).

7. 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 participating agencies.

8. Information which must appear in comments for any given ODM exchange

9. Information regarding the interpretation of the information in an ODM that is not suitable for COMMENTs in the file itself.

10. Whether the format of the ODM will be ASCII or XML (note: XML implementation not yet in scope).

ANNEX C

ABBREVIATIONS AND ACRONYMS

ASCII	American Standard Code for Information Interchange
CCIR	International Coordinating Committee for Radio Frequencies
CCSDS	Consultative Committee on Space Data Systems
EME2000	Earth Mean Equator and Equinox of J2000 (Julian Date 2000)
GPS	Global Positioning System
IAU	International Astronomical Union
ICD	Interface Control Document
ICRF	International Celestial Reference Frame
IEC	International Electrotechnical Commission
ISO	International Standards Organization
ITRF	International Terrestrial Reference Frame
KVN	Keyword = Value Notation
ODM	Orbit Data Message
OEM	Orbit Ephemeris Message
OPM	Orbit Parameter Message
RTN	Radial, Transverse (along-track) and Normal
TAI	International Atomic Time
TCB	Barycentric Coordinated Time
TDB	Barycentric Dynamical Time
TOD	True Equator and Equinox of Date
TT or TDT	Terrestrial Dynamical Time
UTC	Coordinated Universal Time

XML	eXtensible Markup Language