Consultative Committee for Space Data Systems

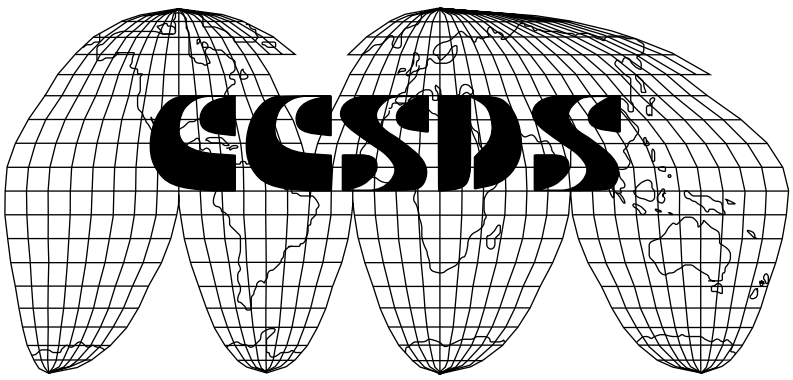
DRAFT RECOMMENDATION FOR SPACE DATA SYSTEM STANDARDS

ORBIT DATA MESSAGES

CCSDS 502.0-R-2

RED BOOK

June 2002



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(WHEN THIS RECOMMENDATION IS FINALIZED, IT WILL CONTAIN THE FOLLOWING STATEMENT OF AUTHORITY:)

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 draft Recommendation is published and maintained by:

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FOREWORD

(WHEN THIS RECOMMENDATION IS FINALIZED, IT WILL CONTAIN THE FOLLOWING FOREWORD:)

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

This draft 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 draft Recommendation and may incorporate features not addressed by this draft Recommendation.

Through the process of normal evolution, it is expected that expansion, deletion or modification to this document may occur. This draft 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:

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PREFACE

This document is a draft CCSDS Recommendation. Its 'Red Book' status indicates that the CCSDS believes the document to be technically mature and has released it for formal review by appropriate technical organizations. As such, its technical contents are not stable, and several iterations of it may occur in response to comments received during the review process. Implementers are cautioned **not** to fabricate any final equipment in accordance with this document's technical content.

DOCUMENT CONTROL

Document	Title and Issue	Date	Status
CCSDS 502.0-R-1	*Orbit Data Messages*, Issue 1	June 2001	Original Issue, superseded
CCSDS 502.0-R-2	*Orbit Data Messages,* Issue 2	June 2002	Current Issue: - Extensive changes throughout based on RIDs from GSFC, DLR and ESTEC, and informal comments from ESOC and JPL P1J participants, per the November 6-8, 2001 P1J meeting at ESTEC. Also some additional changes in organization. Assorted corrections and clarifications were added. Minor revisions to make sections 3 and 4 more consistent were made throughout, per the April 8-11, 2002 P1J meeting at ESOC.

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1 INTRODUCTION

1.1 PURPOSE

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

d) orbit comparisons.

This draft Recommendation does not address precision and accuracy of the derived spacecraft position and velocity.

This draft Recommendation includes sets of requirements and criteria that the message formats have been designed to meet. For exchanges where the existing requirements do not capture the needs of the participating agencies, the participating agencies may agree to use another mechanism for that particular exchange.

1.2 SCOPE AND APPLICABILITY

This draft Recommendation contains two orbit data messages designed for applications involving data interchange in space data systems. It does not prescribe which message to use for any particular application. 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 draft Recommendation. Applicability information specific to each orbit data message format appears in sections 3 and 4, as well as in subsection A3.

1.3 REFERENCES

The following documents contain provisions which, through reference in this text, constitute provisions of this draft Recommendation. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this draft 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, 1982.

[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-7.4. Yellow Book. Issue 7.4 (interim update). Washington, D.C.: CCSDS, January 2001.

2 OVERVIEW

NOTE – Two CCSDS-recommended orbit data messages are described in this document: the Orbit Parameter Message (OPM) and the Ephemeris Message (EPM).

2.1 ORBIT PARAMETER MESSAGE (OPM)

An OPM is an ASCII description of the position and velocity of an 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. The OPM is fully self-contained; no additional information is required.

2.2 EPHEMERIS MESSAGE (EPM)

An EPM is an ASCII table representation of the position and velocity history of an object over a specified time range. The EPM is suited to inter-agency exchanges that (1) involve automated interaction, and (2) require high-fidelity dynamic modeling.

The EPM requires the use of an interpolation technique to interpret the position and velocity at times different from the tabular epochs. The EPM is fully self-contained; no additional information is required.

3 ORBIT PARAMETER MESSAGE (OPM)

3.1 OVERVIEW

3.1.1 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 receiver site must have an orbit propagator available that is able to propagate the OPM state vector to compute the orbit at 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.

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

a) an orbit propagator is run at the receiver's site;

b) 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.

3.2 OPM REQUIREMENTS

NOTE – This subsection contains formatting, syntax, and contents rules for the OPM.

3.2.1 OPM FILE

3.2.1.1 The OPM shall be a text file, consisting of orbit data for a single object.

3.2.1.2 The OPM shall be easily readable by both humans and computers.

3.2.1.3 Each OPM file shall contain all obligatory fields.

3.2.1.4 The particular file naming specification shall be agreed to on a case-by-case basis between the participating agencies, typically using an Interface Control Document (ICD).

3.2.2 LINES

NOTE – The OPM contains header lines, data lines, and optional comment lines.

3.2.2.1 All OPM lines must not exceed 80 characters, not including end-of-line characters.

3.2.2.2 All header and data lines shall use 'keyword = value' syntax.

NOTE – White space is not significant on the left side of the 'equals' sign.

3.2.2.3 Only a single 'keyword = value' assignment shall be made on each line.

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

NOTE – Blank lines are allowed at any position within the file.

3.2.2.5 All comment lines shall are optional and may occur at any position in the file after the header.

3.2.2.6 The native end-of-line control sequence shall be used for line termination.

3.2.3 KEYWORDS

3.2.3.1 Only those keywords shown in tables 3-1 and 3-2 shall be allowed; some are obligatory and some are optional.

3.2.3.2 Keywords must be uppercase and must contain blanks.

3.2.3.3 The order of the occurrence of obligatory and optional items, with the exception of blank or comment lines, shall be fixed as shown in tables 3-1 and 3-2.

3.2.4 VALUES

3.2.4.1 In value fields that are text, individual blanks shall be retained (are significant), but multiple blanks shall be equivalent to a single blank. Underscores shall be equivalent to a single blank. Blanks shall be prohibited within numeric values and time strings

3.2.4.2 Within a given OPM file, non-integer numeric values may be expressed in either fixed or floating point notation. When floating point is used, the participating agencies must ensure that the following are consistent with the capabilities and expectations of both agencies, as specified in an ICD:

a) the decimal point location;

b) the limit on the number of digits in the mantissa;

c) the range of digits in the exponent;

d) the limit on the magnitude of any number;

e) the character used to denote exponentiation (i.e. ‘D,’ ‘d,’ ‘E,’ or ‘e’).

3.2.4.3 Value fields may be constructed using mixed case (i.e., case is not significant).

3.2.4.4 A value must be specified for each occurrence of a keyword.

NOTE – Trailing blanks are not significant.

3.2.5 UNITS

3.2.5.1 Only units specified in table 3-2 shall be allowed.

3.2.5.2 For clarity, units may be included as ASCII text after a value, but they shall not supersede the units specified in table 3-2. 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. '[deg]');

c) exponents of units shall be denoted with a double asterisk (i.e. '**').

3.3 HEADER KEYWORD SET

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

3.3.2 The header shall provide a CCSDS Orbit Data Message version number that identifies the format version in 'keyword = value' format; this is included to anticipate future changes. The keyword is CCSDS_OPM_VERS, and the value associated with the first approved version of this draft Recommendation shall be 1.0. The header shall also include the CREATION_DATE keyword with the value set to the Universal Time Coordinated (UTC) date and time the file was created. A description of OPM header items and values is provided in table 3-1.

Table 3-1: OPM Header Description

Keyword	Description	Examples of Values	Obligatory
CCSDS_OPM_VERS	Format version	1.0	Yes
CREATION_DATE	File creation date and time	2001-11-06T11:17:33 2002-204T15:56:23	Yes

3.4 OPM KEYWORD SET

3.4.1 Excepting the header items described in table 3-1, the keywords used in an OPM file shall be those given in table 3-2. Table 3-2 specifies the following for each item:

a) its required sequence of occurrence in the OPM file;

b) the keyword to be used;

c) a short description of the item;

d) the required units, if applicable; and

e) whether the item is obligatory or optional.

3.4.2 Keywords identified as 'Obligatory' must appear in every OPM file.

Table 3-2: OPM Keyword Descriptions

Keyword	Description	Units	Obligatory
General Information			
OBJECT_NAME	Object Name	n/a	Yes
OBJECT_ID	Object International ID Specification	n/a	Yes
CENTER_NAME	Coordinate System Center	n/a	Yes
REF_FRAME	Coordinate System	n/a	Yes
TIME_SYSTEM	Time System Representation	n/a	Yes
EPOCH	State Vector Epoch	n/a	Yes
State Vector Components in the Specified Coordinate System			
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 Coordinate System (none or all parameters of this block are to 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 are to be given))			
MAN_EPOCH_IGNITION	Epoch of ignition	v	No
MAN_DURATION	Maneuver duration	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	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
Comments (allowed everywhere in the message after the OPM version no.)			
COMMENT	Each comment line has to begin with this keyword.	n/a	No

3.5 OPM DATA

NOTE – OPM data are provided as a set of keyword = value assignments as described in subsections 3.5.1 through 3.5.5.

3.5.1 GENERAL INFORMATION KEYWORDS

a) ***Name of Spacecraft (OBJECT_NAME)***: The spacecraft name, which shall be specified before each mission (e.g., STS-105, ASTRA 1B, CLUSTER 2/FM6 etc.).

b) ***Spacecraft ID (OBJECT_ID)***: International spacecraft designator (as published in the SPACEWARN Bulletin (reference [2])). Valid values have the format *YYYY-NNNP{PP}*, where:

1) YYYY = year of launch;

2) NNN = three-digit serial number of launch in year YYYY (with leading zeros);

3) P{PP} = at least one capital letter for the identification of the part brought into space by the launch.

c) ***Center of Coordinate Frame (CENTER_NAME)***: The center of the reference frame in which the state vector and optional Keplerian elements are given (e.g., EARTH, EARTH BARYCENTER, SOLAR SYSTEM BARYCENTER, MARS, MARS BARYCENTER, etc.).

d) ***Coordinate Frame (REF_FRAME)***: The reference frame in which the state vector and optional Keplerian elements (if applicable) are given. The allowed values are as follows:

1) International Celestial Reference Frame (ICRF);

2) International Terrestrial Reference Frame (ITRF)-93;

3) ITRF-97;

4) ITRF2000;

5) ITRFxxxx;

6) True Equator and Equinox of Date (TOD);

7) Earth Mean Equator and Equinox of J1950 (EME1950);

8) Earth Mean Equator and Equinox of J2000 (EME2000).

e) ***Time System (TIME_SYSTEM)***: The time system representation in which epochs are given. The allowable values are as follows:

1) Universal Time Coordinated (UTC);

2) International Atomic Time (TAI);

3) Terrestrial Dynamical Time (TT);

4) Global Positioning System (GPS);

5) Barycentric Dynamical Time (TDB);

6) Barycentric Coordinated Time (TCB).

f) ***Epoch of Orbit Data (EPOCH)***: Epoch of the state vector (and optional Keplerian elements) given in the message. Can be given in (1) ISO/CCSDS ASCII formats, and (2) Julian Date strings. For example:

ISO Formats:[1]
1996-12-18T14:28:15.1172
1996-277T07:22:54

Julian Date Strings:
2451534.29812

NOTE – It is prohibited to use embedded blanks in all time strings.

3.5.2 STATE VECTOR KEYWORDS

State vector keywords shall be used to specify position (**X, Y, Z**) and velocity (**X_DOT, Y_DOT, Z_DOT**) components at the given epoch in the units km and km/s, respectively.

3.5.3 OSCULATING KEPLERIAN ELEMENTS AND GRAVITATIONAL COEFFICIENT KEYWORDS

3.5.3.1 If both meaningful and useful, osculating Keplerian elements may be included in the OPM (in addition to the state vector) to aid the message recipient in performing consistency checks. The use of osculating Keplerian elements for consistency checking is to be arranged within an ICD.

3.5.3.2 The **GM** value (Gravitational Coefficient = Gravitational Constant x Central Mass), used by the transmitter of the message for the conversion of state vector to Keplerian elements (or vice versa), must also be given. The required units for GM are km^3/s^2.

3.5.3.3 If included, this block must be listed in its entirety.

3.5.4 SPACECRAFT PARAMETER KEYWORDS

Spacecraft parameter keywords shall be used to specify the following:

a) ***Spacecraft Mass (MASS)***: The spacecraft mass at the epoch of orbit data, given in kg.

b) ***Solar Radiation Pressure (SOLAR_RAD_AREA, SOLAR_RAD_COEFF)***: The values for parameters A_R and C_R may be given for modeling the solar radiation pressure (see reference [1]). If $C_R = 0$ is set, no solar radiation pressure shall be taken into account.

[1] The two ASCII time code variations are subsets of ISO 8601 (*Data Elements and Interchange Formats—Information Interchange—Representation of Dates and Times*, International Standard, ISO 8601:2000, 2nd ed., Geneva: ISO, 2000).

c) ***Atmospheric Drag Parameters (DRAG_AREA, DRAG_COEFF)***: The values for parameters A_D and C_D may be given for modeling the atmospheric drag (see reference [1]). If $C_D = 0$ is set, no atmospheric drag shall be taken into account.

3.5.5 MANEUVER KEYWORDS

3.5.5.1 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).

3.5.5.2 If included in an OPM, the following set of maneuver parameter keywords shall be repeated for each maneuver:

a) ***MAN_EPOCH_IGNITION***: The epoch of start of the thrust phase, given in the time system specified with the TIME_SYSTEM keyword.

b) ***MAN_DURATION***: The duration of the thrust phase, given in seconds. For impulsive maneuvers the duration is set to zero.

c) ***MAN_DELTA_MASS***: The mass change during the maneuver, given in kg. This parameter can be used for both finite and impulsive maneuvers. The value is to be a negative number.

d) ***MAN_REF_FRAME***: The coordinate frame in which the velocity increment vector components are given. Allowed values for this keyword include (1) those allowed for keyword **REF_FRAME**, and (2) the RTN reference frame, which is usually more suitable for the description of the velocity increment vector. The RTN reference frame is similar to the HCL (height, cross-track, along-track) coordinate system.

RTN Reference Frame:

R = Component in direction of the position vector; $\hat{R} = \vec{r} / |\vec{r}|$

T = Component in the orbital plane perpendicular to the radial direction; $\hat{T} = \hat{N} \times \hat{R}$

N = Component perpendicular to the orbital plane in the direction of the angular momentum vector; $\hat{N} = \vec{r} \times \vec{v} / |\vec{r} \times \vec{v}|$

e) ***MAN_DV_1, MAN_DV_2, MAN_DV_3***: The components of the velocity increment vector in the above-specified reference frame, given in km/sec.

3.6 COMMENTS IN AN OPM

3.6.1 PURPOSE

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, yet is not officially required for successful processing of a file.

NOTE – 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, it is recommended that this information be expressed in the form of comments, and that the ICD be used to provide further specifications.

3.6.2 COMMENT FORMAT

3.6.2.1 All comment lines shall begin with the 'COMMENT' token. This token must appear on every comment line, not just on the first such line.

3.6.2.2 White space is retained (is significant) in comments and shall separate the 'COMMENT' token from the text of the comment.

3.6.3 RECOMMENDED COMMENTS

a) Source or message originator, e.g., Centre National d'Etudes Spatiales (CNES), European Space Operations Centre (ESOC), Goddard Space Flight Center (GSFC), German Space Operations Center (GSOC), Jet Propulsion Laboratory (JPL), National Space Development Agency of Japan (NASDA), etc.:

```
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 are to 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.
```

3.6.4 OPM EXAMPLES

Figures 3-1 and 3-2 are examples of OPMs.

```
CCSDS_OPM_VERS = 1.0
CREATION_DATE  = 2001-11-06T09:23:57
COMMENT GEOCENTRIC, CARTESIAN, EARTH FIXED
OBJECT_NAME    = GODZILLA 5
OBJECT_ID      = 2000-028A
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
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
EPOCH              =  2006-06-03T00:00:00.000

COMMENT  State Vector

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 EPHEMERIS MESSAGE (EPM)

4.1 OVERVIEW

The ephemeris message (EPM) shall be represented as a combination of the following:

a) a header;

b) metadata (data about data);

c) comments (explanatory information), and

d) ephemeris data.

EPM files have a set of minimum required sections; some can be repeated. Table 4-1 outlines the content of an EPM.

Table 4-1: EPM File Layout Specifications

Required Sections	1. Header (first non-blank line) 2. Metadata 3. Ephemeris Data
Allowable Repetitions of Sections	Sections of metadata and ephemeris data can be repeated: Metadata Ephemeris Data Metadata Ephemeris Data Metadata Ephemeris Data, …etc.

4.2 EPM REQUIREMENTS

NOTE – A number of formatting, syntax, and contents rules for the EPM are provided in subsections 4.2.1 through 4.2.5. The design is intended to strike an appropriate balance between simplicity (for both producers and consumers) and safety.

4.2.1 EPM FILE

4.2.1.1 The EPM shall be a text file, consisting of orbit data for a single object.

4.2.1.2 The EPM shall be easily readable by both humans and computers.

4.2.1.3 The particular file naming specification shall be agreed to by the participating Agencies on a case-by-case basis, typically using an ICD.

4.2.2 LINES

4.2.2.1 The EPM line length must not exceed 255 characters, not including end-of-line characters.

4.2.2.2 All header and metadata lines shall use 'keyword = value' syntax.

4.2.2.3 White space is not significant on the left side of the 'equals' sign.

4.2.2.4 Only a single 'keyword = value' assignment may be made on each header and metadata line.

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

4.2.2.6 Blank lines shall be allowed at any position within the file.

4.2.2.7 All comment lines are optional and may occur at any position within the file after the header, excepting within any block of ephemeris data lines.

4.2.2.8 The native end-of-line control sequence shall be used for line termination.

4.2.3 KEYWORDS

4.2.3.1 Only those keywords shown in tables 3-1 and 3-2 shall be allowed. Some are obligatory and some are optional.

4.2.3.2 Keywords shall be all uppercase and shall not contain blanks.

NOTE – Keywords are not order-dependent in an EPM.

4.2.4 VALUES

4.2.4.1 In value fields that are text, individual blanks shall be retained (are significant), but multiple blanks shall be equivalent to a single blank. Underscores shall be equivalent to a single blank.

NOTE – Blanks are prohibited within numeric values and time strings.

4.2.4.2 Within a given EPM file, non-integer numeric values may be expressed in either fixed or floating point notation. When floating point is used, the participating agencies must ensure that the following are consistent with the capabilities and expectations of both agencies, as specified in an ICD:

a) the decimal point location;

b) the limit on the number of digits in the mantissa;

c) the range of digits in the exponent;

d) the limit on the magnitude of any number; and

e) the character used to denote exponentiation (i.e., 'D,' 'd,' 'E,' or 'e') is consistent with the capabilities and expectations of both agencies, as specified in an ICD.

4.2.4.3 Value fields may be constructed using mixed case (i.e., case is not significant).

4.2.4.4 A value for each obligatory keyword must be specified in each occurrence of the metadata block.

NOTE – Trailing blanks are not significant.

4.2.5 UNITS

4.2.5.1 Units for position and velocity components are in km and km/s, respectively.

4.2.5.2 For clarity, units can be included as ASCII text after a value, but they do not supersede the units specified in subsection 4.2.5.1. 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. '[deg]'); and

c) exponents of units shall be denoted with a double asterisk (i.e., '**').

NOTE – Units are not allowed in ephemeris data lines

4.3 HEADER KEYWORD SET

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

4.3.2 The header shall provide a CCSDS Orbit Data Standard version number that identifies the format version in a 'keyword = value' format; this is included to anticipate future changes. The keyword is CCSDS_EPM_VERS, and the value associated with the first approved version of this draft Recommendation shall be 1.0. The header shall also include the CREATION_DATE keyword with the value set to the UTC date and time the file was created. A description of EPM header items and values is provided in table 4-2.

Table 4-2: EPM Header Description

Keyword	Description	Examples of Values	Obligatory
CCSDS_EPM_VERS	Format version	1.0	Yes
CREATION_DATE	File creation date and time	2001-11-06T11:17:33 2002-204T15:56:23	Yes

4.4 METADATA KEYWORD SET

4.4.1 The metadata provide the key information needed by the customer of the product to interpret the spacecraft ephemeris data.

4.4.2 Metadata shall be expressed using the 'keyword = value' notation provided in table 4-3.

NOTE – Table 4-3 specifies for each item (1) the keyword to be used, (2) a short description, and (3) example values. The table shows the full set of metadata; only those keywords shown in the table are allowed. For some keywords there are no definitive lists of authorized values maintained by a control authority; the recommended references are the best known candidates for authorized values to date.

Table 4-3: EPM Metadata Keywords

Keywords	Description	Examples of Values	Obligatory
`META_START, META_STOP`	The EPM message contains both metadata and ephemeris data; these keywords are used to delineate the metadata blocks within the message. Metadata are provided in a block, surrounded by '`META_START`' and '`META_STOP`' markers to facilitate file parsing. These keywords must appear on lines by themselves.	See the Examples in 4.7.	Yes

`OBJECT_NAME (See Note)`	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`
		`NAVSTAR 24`
		`NEAR`
			Yes

OBJECT_ID (See Note)	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.	2000-052A 1996-068A 2000-053A 1992-009A 1996-008A	Yes
CENTER_NAME	Origin of reference frame, which can 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).	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. **Only** those frames shown in the examples section to the right are allowed.	ICRF ITRF-93 ITRF-97 ITRF2000 ITRFxxxx True Equator and Equinox of Date (TOD) Earth Mean Equator and Equinox of J1950 (EME1950) Earth Mean Equator and Equinox of J2000 (EME2000)	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, STOP_TIME	Start and 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
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 on 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

Note: The SPACEWARN bulletin is the closest (current) approximation to a full database of assets launched by the CCSDS agencies. It does not contain records for the earliest launches (pre-1963), nor does it contain separate designations for remotely released hardware (e.g., planetary probes, rovers, etc.). For navigation message exchanges where the relevant asset is not covered by the SPACEWARN bulletin, the OBJECT_ID value will be noted in an ICD.

4.5 EPHEMERIS DATA

4.5.1 For Ephemeris Messages, each set of ephemeris data, including the time tag, must be provided on a single line. The order in which data items are given is fixed: (**Epoch**, **X, Y, Z**, **X_DOT, Y_DOT, Z_DOT)**. Units for position (**X, Y, Z**) and velocity (**X_DOT, Y_DOT, Z_DOT**) components at the given epoch are in km and km/s, respectively.

4.5.2 At least one blank character (not including TAB) must be used to delimit the seven items in each ephemeris data line.

NOTE – Blank spaces are not allowed within time tags.

4.5.3 The allowable time formats shall be the same as those for the metadata keywords `START_TIME` and `STOP_TIME`.

4.5.4 The TIME_SYSTEM value must remain fixed within an EPM.

4.5.5 White space is not allowed within (inside any of) the six numbers making up the state vector.

4.5.6 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 is not to be done. This method can be used for proper modeling of propulsive maneuvers or any other source of a discontinuity such as eclipse entry or exit.

4.6 COMMENTS IN AN EPM

4.6.1 PURPOSE

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, yet is not officially required for successful processing of a file.

NOTE – 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, it is recommended that this information be expressed in the form of comments, and that the ICD be used to provide further specifications.

4.6.2 COMMENT FORMAT

4.6.2.1 All comment lines shall begin with the '`COMMENT`' token. This token must appear on every comment line, not just on the first such line.

4.6.2.2 Internal white space is retained (is significant) in comments and shall separate the '`COMMENT`' token from the text of the comment.

NOTE – Trailing white space is not significant.

4.6.3 RECOMMENDED COMMENTS

a) Source or message originator (e.g., CNES, ESOC, GSFC, GSOC, JPL, NASDA, etc.):

```
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 are to 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) Interpolation Method: The originator of the message should include information on how to best interpolate the ephemeris data entries:

```
COMMENT Recommended interpolation method: Hermite, fifth order
```

4.6.4 DETAILS

Details about interpolation method should be included in the ICD as well as in COMMENT lines within the EPM. 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 EPM.

4.7 EXAMPLE OF AN EPM

A simple example of the proposed ephemeris file standard is shown in figure 4-1.

```
CCSDS_EPM_VERS = 1.0
CREATION_DATE = 1996-11-04T17:22:31

META_START
OBJECT_NAME          = Mars Global Surveyor
OBJECT_ID            = 1996-062A
CENTER_NAME          = Mars Barycenter
REF_FRAME            = EME2000
TIME_SYSTEM          = UTC
START_TIME           = 1996-12-18T12:05:00.5
USABLE_START_TIME    = 1996-12-18T12:10:00.5
USABLE_STOP_TIME     = 1996-12-28T21:23:00.5
STOP_TIME            = 1996-12-28T21:28:00.5
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.
COMMENT  Interpolation Method: Hermite, degree 7.

1996-12-18T12:00:00.5  2789.619 -280.045 -1746.755  4.73372 -2.49586 -1.04195
1996-12-18T12:01:00.5  2783.419 -308.143 -1877.071  5.18604 -2.42124 -1.99608
1996-12-18T12:02:00.5  2776.033 -336.859 -2008.682  5.63678 -2.33951 -1.94687

   < intervening data records omitted here >

1996-12-28T21:28:00.5 -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            = 1996-12-28T21:29:07.2
USABLE_START_TIME     = 1996-12-28T22:08:02.5
USABLE_STOP_TIME      = 1996-12-30T01:18:02.5
STOP_TIME             = 1996-12-30T01:28:02.5
META_STOP

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

1996-12-28T21:29:07.2 -2432.166 -063.042 1742.754  7.33702 -3.495867 -1.041945
1996-12-28T21:59:02.5 -2445.234 -878.141 1873.073  1.86043 -3.421256 -0.996366
1996-12-28T22:00:02.5 -2458.079 -683.858 2007.684  6.36786 -3.339563 -0.946654

   < intervening data records omitted here >

1996-12-30T01:28:02.5 2164.375 1115.811 -688.131  -3.53328 -2.88452 0.88535
```

Figure 4-1: EPM Example

ANNEX A

RATIONALE FOR ORBIT DATA MESSAGES

(This annex is **not** part of the draft 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 draft 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 draft Recommendation.

A2 PRIMARY REQUIREMENTS ACCEPTED BY THE ORBIT DATA CODES

Table A-1: Primary Requirements

Requirement	Accepted for OPM?	Accepted for EPM?
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 systems.	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 EPM?
Ephemeris data is reliably convertible into the SPICE SPK 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) 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 EPM?
The standard applies to non-traditional objects, such as landers, rovers, balloons, and natural bodies (asteroids, comets).	N	Y
The standard allows state vectors to be provided in other than the traditional J2000 inertial reference frame; one example is the International Astronomical Union (IAU) Mars body-fixed frame. (In such a case, provision or ready availability of supplemental information needed to transform data into a standard frame must be arranged.)	Y	Y
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 EPM?
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 EPM?
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

A5 DISCUSSION OF RECOMMENDED MESSAGES

A5.1 GENERAL

All the Recommended orbit data messages are ASCII. 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 EPM 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.

A5.2 ORBIT PARAMETER MESSAGE (OPM)

The Orbit Parameter Message code is suited to inter-Agency exchanges which (1) involve automated interaction, and/or (2) involve human interaction, and (3) do not require high-fidelity dynamic modeling.

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. OPMs require the use of an orbit propagator at the receiver's site, leading to a higher level of effort for software implementation than for the EPM.

A5.3 EPHEMERIS MESSAGE (EPM)

The Ephemeris Message code is particularly suited to applications that (1) involve automated interaction, and (2) require high-fidelity dynamic modeling.

The code allows for any dynamic modeling of any number of gravitational and non-gravitational accelerations. The ephemeris message is particularly suitable for use in computer-to-computer communication where frequent, fast automated time interpretation and processing is required, and where high precision is needed.

ANNEX B

ABBREVIATIONS AND ACRONYMS

ASCII	American Standard Code for Information Interchange
CCIR	International Coordinating Committee for Radio Frequencies
CCSDS	Consultative Committee on Space Data Systems
EME	Earth Mean Equator and Equinox
EPM	Ephemeris Message
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
ODM	Orbit Data Message
OPM	Orbit Parameter Message
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	Universal Time Coordinated