Consultative Committee for Space Data Systems

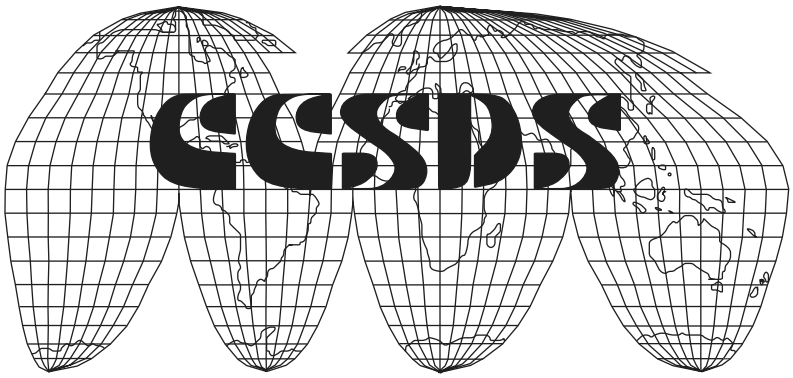
DRAFT RECOMMENDATION FOR SPACE DATA SYSTEM STANDARDS

ORBIT DATA MESSAGES

CCSDS 502.0-R-3

RED BOOK

November 2003



AUTHORITY

Issue:	Red Book, Issue 3
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Location:	Washington, DC, USA

(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.

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Office of Space Communication (Code M-3)
National Aeronautics and Space Administration
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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.

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  • The anticipated date of initial operational capability.

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

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- 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.
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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	Superseded
CCSDS 502.0-R-2	*Orbit Data Messages,* Issue 2	June 2002	Superseded
CCSDS 502.0-R-3	*Orbit Data Messages,* Issue 3	November 2003	Current Issue: Changed Ephemeris Message (EPM) to Orbit Ephemeris Message (OEM). Restatement of plans regarding accommodation of eXtensible Markup Language (XML).

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1 INTRODUCTION

1.1 PURPOSE

This draft Orbit Data Message (ODM) Recommendation specifies two standard message formats for use in transferring spacecraft orbit information between Member 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); and

d) orbit comparisons.

This draft 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 draft Recommendation 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 draft Recommendation. Applicability information specific to each orbit data message format appears in sections 3 and 4, as well as in subsection A3.

This draft Recommendation is applicable only to the message layout. The transmission of the message between Agencies could be based on the use of eXtensible Markup Language (XML). Description of the message formats based on XML may be added to a future issue of this draft Recommendation.

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 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-9. Yellow Book. Issue 9. Washington, D.C.: CCSDS, November 2003.

2 OVERVIEW

2.1 ORBIT DATA MESSAGE TYPES

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

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. The OPM is fully self-contained; no additional information is required.

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, and (2) require high-fidelity dynamic modeling.

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

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.

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.

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.

The OPM file naming scheme shall be agreed to on a case-by-case basis between the participating Agencies, and is typically 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 MESSAGE CONTENT

An OPM consists of a header, data, and optional comments.

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 items shown are allowed.

Table 3-2 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 items shown are allowed. (Some important notes about the items in table 3-2 appear immediately after that table.)

Table 3-1: OPM Header

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
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

Table 3-1: OPM Header (continued)

Keyword	Description	Examples of Values	Obligatory
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 state vector and optional Keplerian element data are given. **Only** those frames shown in the examples column to the right are allowed.	ICRF ITRF-93 ITRF-97 ITRF2000 ITRFxxxx (Template for a future version) TOD (True Equator and Equinox of Date) EME1950 (Earth Mean Equator and Equinox of J1950) EME2000 (Earth Mean Equator and Equinox of J2000)	Yes
TIME_SYSTEM	Time system used for state vector and maneuver data (also see table 3-2). It is recommended to use names from *Navigation Definitions and Conventions* (reference [1]). Times may be given in 1) ISO/CCSDS ASCII format and 2) Julian Date strings.	UTC, TAI, TT, GPS, TDB, TCB	Yes

Table 3-2: OPM Data

Keyword	Description	Units	Obligatory
State Vector Components in the Specified Coordinate System			
EPOCH	Epoch of state vector and 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 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	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	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 number.)			
COMMENT	Each comment line has to 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 3-2 is broken into five blocks, each of which has a descriptive heading. Those descriptive headings are not to be included in an OPM.

3 The gravitational coefficient, G_M (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 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 is set to zero. MAN_DELTA_MASS can be used for both finite and impulsive maneuvers; the value is to be a negative number. Permissible reference frames for the velocity increment vector are 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]).

3.3 COMMENTS IN AN OPM

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.

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 to put certain information into comments, and to use the ICD to provide further specifications.

The following comments are recommended:

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:

```
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 are to be identified so that the recipient can, in a consistent manner, make computations involving other centers.

with the ODM are to be identified so that the recipient can, in a consistent manner, make computations involving other centers.

3.4 OPM FILE CONTENTS

NOTE – The OPM is a plain text file, using the syntax described in subsections 3.4.1 through 3.4.6.

3.4.1 LINES

OPM lines are 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.

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

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

Blank lines are allowed at any position within the file.

All comment lines are optional and may occur at any position in the file after the first line of the header.

3.4.2 KEYWORD = VALUE NOTATION AND ORDER OF ASSIGNMENT STATEMENTS

All header and data lines shall use ‘keyword = value’ notation, abbreviated as KVN.

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

Keywords must be uppercase and must not contain blanks.

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

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

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

The order of occurrence of obligatory and optional KVN assignments is fixed as shown in tables 3-1 and 3-2.

3.4.3 VALUES

In value fields that are text, an underscore is equivalent to a single blank. Individual blanks are retained (are significant), but multiple blanks are equivalent to a single blank.

Blanks are prohibited within numeric values and time strings.

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

When floating point notation is used, the participating agencies need to 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').

When fixed point notation is used, the participating Agencies need to ensure that the format and the number of digits allowed are consistent with the capabilities and expectations of both Agencies, as specified in an ICD.

Text value fields may be constructed using mixed case. Case is not significant.

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

3.4.4 UNITS

For clarity, units can be included as ASCII text after a value, but they must match 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., '[km]'); and

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

3.4.5 COMMENTS

All comment lines shall begin with the '`COMMENT`' token followed by a single space. This token must appear on every comment line, not just the first such line, and must begin in column one. The remainder of the line is the comment value. White space is retained (is significant) in comment values.

3.4.6 OPM KEYWORD SET

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 is CCSDS_OPM_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. The initial version approved by the CCSDS as an official Recommendation shall be 1.0.

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 items and values is provided in table 3-1.

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

Comments may appear anywhere after the first header line.

Only those keywords shown in tables 3-1 and 3-2 are allowed. Some keywords represent obligatory items and some are optional. KVN assignments representing optional items may be skipped.

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 included, the entire set of elements must be provided.

Multiple sets of maneuver parameters are allowed. For each maneuver, all the maneuver parameters are repeated in the order shown in table 3-2.

3.5 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

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 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 with 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 MESSAGE CONTENT

The OEM 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.

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

The OEM header and metadata 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 items shown are allowed. For some keywords there are no definitive lists of authorized values maintained by a control authority; the references listed in subsection 1.4 are the best known sources for authorized values to date.

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.)

Table 4-2: OEM Header and Metadata

Keyword	Description	Examples of Values	Obligatory
CCSDS_OEM_VERS	Format version	1.0	Yes
CREATION_DATE	File creation date and time	2001-11-06T11:17:33 2002-204T15:56:23	Yes
META_START, META_STOP	The OEM 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.	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

Table 4-2. OEM Header and Metadata (continued)

Keyword	Description	Examples of Values	Obligatory
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 (template for future versions) TOD (True Equator and Equinox of Date) EME1950 (Earth Mean Equator and Equinox of J1950) EME2000 (Earth Mean Equator and Equinox of J2000)	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 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

4.3 COMMENTS IN AN OEM

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.

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 to put certain information into comments, and to use the ICD to provide further specifications. The following comments are recommended:

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:

```
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 are to be identified so that the recipient can, in a consistent manner, make computations involving other centers.

c) Interpolation Method:

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

The originator of the message should include information on how to best interpolate the ephemeris data entries.

4.4 OEM FILE CONTENTS

NOTE – The OEM is a plain text file, using the syntax described in subsections 4.4.1 through 4.4.6.

4.4.1 LINES

OEM lines are 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.

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

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

Blank lines are allowed at any position within the file.

All comment lines are optional and may occur at any position in the file after the first line of the header, except that comment lines may not appear within any block of ephemeris lines.

4.4.2 KEYWORD = VALUE NOTATION AND ORDER OF ASSIGNMENT STATEMENTS

All header and meta data elements shall use 'keyword = value' notation, abbreviated as KVN.

Only a single 'keyword = value' assignment may be made on a line.

Keywords must be uppercase and must not contain blanks.

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

Any white space immediately preceding or following the 'equals' sign is not significant.

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

The order of occurrence of obligatory and optional KVN assignments is fixed as shown in tables 4-1 and 4-2.

4.4.3 VALUES

In value fields that are text, an underscore is equivalent to a single blank. Individual blanks are retained (are significant), but multiple blanks are equivalent to a single blank.

Blanks are prohibited within numeric values and time strings.

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

When floating point notation is used, the participating agencies need to 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').

When fixed point notation is used, the participating Agencies need to ensure the format and the number of digits allowed are consistent with the capabilities and expectations of both Agencies, as specified in an ICD.

Text value fields may be constructed using mixed case. Case is not significant.

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

4.4.4 UNITS

In an OEM, units are km and km/sec but are not displayed.

4.4.5 EPHEMERIS DATA LINES

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 is fixed: **Epoch**, **X, Y, Z**, **X_DOT, Y_DOT, Z_DOT**.

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

Ephemeris data lines must be ordered by increasing time, and no time tag may be repeated. The time step duration need not be constant within a given OEM.

The TIME_SYSTEM value must remain fixed within an OEM.

The occurrence of a second (or greater) metadata block after some ephemeris data indicates that interpolation using succeeding ephemeris data with ephemeris data occurring prior to that metadata block 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.

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

4.4.6 COMMENTS

All comment lines shall begin with the '`COMMENT`' token followed by a single space. This token must appear on every comment line, not just the first such line, and must begin in column one. The remainder of the line is the comment value. White space is retained (is significant) in comment values.

4.4.7 OEM KEYWORD SET

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 is 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. The initial version approved by the CCSDS as an official Recommendation shall be 1.0.

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 items and values is provided in table 4-2.

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

Comments may appear anywhere after the first header line.

Only those keywords shown in table 4-2 are allowed. Some keywords represent obligatory items and some are optional. The two keywords marked as optional items might not be necessary, depending on the recommended interpolation method. (It is safer to use the USEABLE START/STOP TIME capability in all cases.)

A single METADATA group will precede each EPHEMERIS_DATA block. Multiple occurrences of a METADATA group followed by an EPHEMERIS_DATA block are allowed.

Before each METADATA group the string ‘META_START’ will appear on a separate line and after each METADATA group (and before the associated EPHEMERIS_DATA block) the string ‘META_END’ will appear on a separate line.

4.5 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

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
USABLE_START_TIME    = 1996-12-18T12:10:00.331
USABLE_STOP_TIME     = 1996-12-28T21:23:00.331
STOP_TIME            = 1996-12-28T21:28:00.331
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.

1996-12-18T12:00:00.331  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
USABLE_START_TIME    = 1996-12-28T22:08:02.5
USABLE_STOP_TIME     = 1996-12-30T01:18:02.5
STOP_TIME            = 1996-12-30T01:28:02.267
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 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 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 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 OEM?
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 OEM?
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 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

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 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.

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 OEM.

A5.3 ORBIT EPHEMERIS MESSAGE (OEM)

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

The OEM allows for any dynamic modeling of any number of gravitational and non-gravitational accelerations. The OEM 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.

A5.4 USE OF EXTENSIBLE MARKUP LANGUAGE (XML)

Description of the OPM and OEM based on Extensible Markup Language (XML) is under investigation. It is anticipated that this will be added to the Recommendation in a future update.

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
EME1950	Earth Mean Equator and Equinox of J1950 (Julian Date 1950)
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