The Consultative Committee for Space Data Systems

Draft Recommendation for
Space Data System Standards

ATTITUDE DATA MESSAGES

DRAFT RECOMMENDED STANDARD

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FOREWORD

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

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

This Recommended Standard establishes a common framework and provides a common basis for the interchange of attitude 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 Recommended Standard.

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

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1 INTRODUCTION

1.1 PURPOSE

1.1.1 This draft Attitude Data Message (ADM) Recommended Standard specifies two standard message formats for use in transferring spacecraft attitude information between space Agencies: the Attitude Parameter Message (APM) and the Attitude Ephemeris Message (AEM). Such exchanges are used for:

- preflight planning for tracking or attitude estimation support;
- scheduling attitude and data processing support;
- carrying out attitude operations;
- performing attitude comparisons; and
- carrying out attitude propagations and/or sensor predictions.

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

1.2 SCOPE AND APPLICABILITY

1.2.1 This document contains two attitude 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 attitude accuracy underlying a particular attitude message is outside of the scope of this draft Recommended Standard and should be specified via Interface Control Document (ICD) between data exchange participants. Applicability information specific to each Attitude Data Message format appears in sections 3 and 4, as well as in annex subsection A3.

1.2.2 This draft Recommended Standard is applicable only to the message format and content, but not to its transmission. The transmission of the message between Agencies is outside the scope of this document and should be specified in an ICD or by following a CCSDS standard on transmission.

1.2.3 Description of the message formats based on the use of the eXtensible Markup Language (XML) is in progress. It is anticipated that an XML schema will be defined by a future Recommended Standard on the XML implementation of all Navigation Data Messages (orbit, attitude, and tracking).

1.3 CONVENTIONS AND DEFINITIONS

The following conventions apply throughout this Recommended Standard:

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

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

c) the word 'may' implies an optional specification; and

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

1.4 STRUCTURE OF THIS DOCUMENT

1.4.1 Section 2 provides a brief overview of the CCSDS-recommended Attitude Data Message types, the Attitude Parameter Message (APM) and Attitude Ephemeris Message (AEM).

1.4.2 Section 3 provides details about the structure and content of the APM.

1.4.3 Section 4 provides details about the structure and content of the AEM.

1.4.4 Annex A lists a set of requirements that were taken into consideration in the design of the APM and AEM, along with tables and discussion regarding the applicability of the two message types to various attitude estimation tasks and functions.

1.4.5 Annex B lists a number of items that should be covered in ICDs prior to exchanging ADMs on a regular basis. There are several statements throughout the document that refer to the desirability or necessity of such a document; this annex lists all the suggested ICD items in a single place in the document.

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

1.4.7 Annex D is a list of informative references.

1.5 REFERENCES

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

[1] *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.

[2] *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.

[3] *Spacewarn Bulletin*. Greenbelt, MD, USA: WDC-SI. <http://nssdc.gsfc.nasa.gov/spacewarn>

[4] *JPL Solar System Dynamics*. Pasadena, CA, USA: JPL. <http://ssd.jpl.nasa.gov>

[5] *Time Code Formats*. Recommendation for Space Data System Standards, CCSDS 301.0-B-3. Blue Book. Issue 3. Washington, D.C.: CCSDS, January 2002.

NOTE – A list of informative references can be found in annex D.

1.6 INFORMATION SECURITY

Navigation Data Messages (including the ODM, ADM, and TDM) may require moderate security measures to protect the data from unauthorized access. Protection from unauthorized access is especially important if the mission utilizes open ground networks such as the Internet to provide ground station connectivity for the exchange of Navigation Data Messages. In order to provide requisite security, it is recommended that Navigation Data Messages be transferred between participants via Secure FTP (SFTP), real-time authentication such as that incorporated in the Real-Time Radio-Metric Data Transfer Service (RRMDT), or other secure mechanisms approved by the IT security functionaries of exchange participants. As noted elsewhere in this document, this document does not deal specifically with the means of transferring Navigation Data Messages, focusing rather on content. Specific information security provisions that may apply between agencies involved in an exchange should be specified in an ICD.

2 OVERVIEW

2.1 ATTITUDE DATA MESSAGE TYPES

2.1.1 Two CCSDS-recommended Attitude Data Messages (ADMs) are described in this draft Recommended Standard: the Attitude Parameter Message (APM) and the Attitude Ephemeris Message (AEM).

2.1.2 The recommended attitude data messages are ASCII text format. While binary-based attitude 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 attitude 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 APM or AEM file is to represent attitude data for a single vehicle. It is possible that the architecture may support multiple vehicles per file; this could be considered in the future.

2.2 ATTITUDE PARAMETER MESSAGE (APM)

2.2.1 An APM specifies the attitude state 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 (for high-fidelity dynamic modeling, see 2.3, Attitude Ephemeris Message).

2.2.2 The APM requires the use of a propagation technique to determine the attitude state at times different from the specified epoch, leading to a higher level of effort for software implementation than for the AEM. When inertial frames are specified, the APM is fully self-contained and no additional information is required; if local orbital frames are specified, then an APM must be used in conjunction with an OPM or OEM.

2.2.3 The APM allows for modeling of any number of finite maneuvers and simple modeling of solar radiation pressure and atmospheric torque. The attributes of the APM also make it suitable for applications such as exchanges by FAX or voice, or applications where the message is to be frequently interpreted by humans.

2.3 ATTITUDE EPHEMERIS MESSAGE (AEM)

2.3.1 An AEM specifies the attitude state of a single object at multiple epochs, contained within a specified time range. The AEM is suited to inter-agency exchanges that (1) involve

automated interaction (e.g., computer-to-computer communication where frequent, fast, automated time interpretation and processing are required), and (2) require higher fidelity or higher precision dynamic modeling than is possible with the APM (e.g., flexible structures, more complex attitude movement, etc.).

2.3.2 The AEM allows for dynamic modeling of any number of torques (solar pressure, atmospheric torques, magnetics, etc.). The AEM requires the use of an interpolation technique to interpret the attitude state at times different from the tabular epochs. The AEM is fully self-contained; no additional information is required.

2.4 EXCHANGE OF MULTIPLE MESSAGES

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

2.5 DEFINITIONS

Definitions of time systems, reference frames, attitude estimation and prediction methods and models are provided in reference [1].

3 ATTITUDE PARAMETER MESSAGE (APM)

3.1 OVERVIEW

3.1.1 Attitude information may be exchanged between two participants by sending the attitude state (see reference [1]) for a specified epoch using an Attitude Parameter Message (APM). The message recipient must have an attitude propagator available that is able to propagate the APM state to compute the estimated attitude at other desired epochs. For this propagation, additional ancillary information (spacecraft properties such as inertia matrix, torque vectors, and maneuver planning data, if applicable) shall be included with the message.

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

- an attitude propagator must be run at the receiver's site;
- the receiver's modeling of satellite attitude dynamics, atmospheric torque, other internal and external torques (e.g., magnetic, gravitational, etc.), and thrust phases (see reference [1]) must fulfill accuracy requirements established via an ICD between the agencies.

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

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

3.2 APM CONTENT

3.2.1 GENERAL

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

a) a header;

b) metadata (data about the data);

c) optional comments (explanatory information); and

d) data.

3.2.2 APM HEADER

Table 3-1 specifies for each header item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

Only those keywords shown in table 3-1 shall be used in an APM header.

Table 3-1: APM Header

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

3.2.3 APM METADATA

Table 3-2 specifies for each metadata item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

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

Table 3-2: APM Metadata

Keyword	Description	Examples of Values	Obligatory
OBJECT_NAME	There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the SPACEWARN Bulletin (reference [3]), which include the Object name and international designator of the participant.	EUTELSAT W1 MARS PATHFINDER STS106 NEAR	Yes
OBJECT_ID	Spacecraft identifier of the object corresponding to the attitude data to be given. While there is no CCSDS-based restriction on the value for this keyword, the names could be drawn from the SPACEWARN Bulletin (reference [3]). If this is chosen, it is recommended that values have the format YYYY-NNNP{PP}, where: – YYYY = year of launch; – NNN = three-digit serial number of launch in year YYYY (with leading zeros); – P{PP} = at least one capital letter for the identification of the part brought into space by the launch. In cases where the asset is not listed in the bulletin, the value should be provided in an ICD.	2000-052A 1996-068A 2000-053A 1996-008A	Yes
CENTER_NAME	Origin of reference frame, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this 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 (reference [4]).	EARTH EARTH BARYCENTER MOON SOLAR SYSTEM BARYCENTER SUN JUPITER BARYCENTER STS 106 EROS	Yes
TIME_SYSTEM	Time system used for state and maneuver data (also see table 3-3). It is recommended to use names from *Navigation Definitions and Conventions* (reference [1]). Times may be given in 1) ISO/CCSDS ASCII format or 2) Julian Date strings (reference [5]).	UTC, TAI, TT, GPS, TDB, TCB	Yes
COMMENT	Comments (allowed only at the beginning of the APM Metadata). Each comment line shall begin with this keyword.	COMMENT This is a comment	No

3.2.4 APM DATA

Table 3-3 provides an overview of the five logical blocks in the APM Data section (attitude Quaternion, attitude Euler angles (three-axis), spin axis types, Spacecraft Parameters, Maneuver Parameters), and specifies for each data item:

a) the keyword to be used;

b) a short description of the item;

c) the units to be used;

d) whether the item is obligatory or optional.

Only those keywords shown in table 3-3 shall be used in APM data. Some important remarks concerning the keywords in table 3-3 appear immediately after the table.

Table 3-3: APM Data

Keyword	Description	Units/Values	Obligatory
Attitude Quaternion Components in the Specified Coordinate System			
EPOCH	Epoch of the attitude elements & optional Euler angle elements	n/a	Yes
Q_FRAME	Name of the reference frame in which the quaternion is given. It is recommended to use reference frames from *Navigation Definitions and Conventions* (reference [1]). Note that if a reference frame is to be used that does not appear in [1], a description should be placed in an ICD.	ICRF ITRF-93 ITRF-97 ITRF2000 ITRFxxxx TOD EME2000 TDR GRC LVLH RSW NTW	Yes
Q1	$e_1 * \sin(\phi/2)$ ϕ = rotation angle	n/a	Yes
Q2	$e_2 * \sin(\phi/2)$ ϕ = rotation angle	n/a	Yes
Q3	$e_3 * \sin(\phi/2)$ ϕ = rotation angle	n/a	Yes
QC	$\cos(\phi/2)$ ϕ = rotation angle	n/a	Yes
Q1_DOT	Derivative of Q_1	S^{-1}	No
Q2_DOT	Derivative of Q_2	S^{-1}	No
Q3_DOT	Derivative of Q_3	S^{-1}	No
QC_DOT	Derivative of Q_C	S^{-1}	No
Euler angle elements in the Specified Reference Frame for a Three-Axis Stabilized Satellite (None or all parameters of this block are to be given.)			
EULER_FRAME	Inertial reference frame, e.g., J2000 or Local Orbital Reference frame (R,S,W), or (N,T,W) or (LV,LH,W)	n/a	No
EULER_ROT_SEQ	Rotation order of the EULER_FRAME to the body frame in X Y Z notation (e.g., 312, where X=1, Y=2, Z=3)	n/a	No
ROLL	X body rotation angle	DEG	No
PITCH	Y body rotation angle	DEG	No
YAW	Z body rotation angle	DEG	No
ROLL_RATE	X body rotation rate	DEG/S	No
PITCH_RATE	Y body rotation rate	DEG/S	No
YAW_RATE	Z body rotation rate	DEG/S	No
Attitude parameters in the Specified Reference Frame for a Spin Stabilized Satellite (None or all parameters of this block are to be given.)			
SPIN_FRAME	Inertial reference frame, e.g., J2000	n/a	No
SPIN_ALPHA	Right ascension of spin axis vector in the specified reference frame	DEG	No
SPIN_DELTA	Declination of the spin axis vector in the specified reference frame	DEG	No
SPIN_ANGLE	Phase of the satellite about the spin axis at EPOCH	DEG	No
SPIN_ANGLE_VEL	Angular velocity of satellite around spin axis	DEG/S	No
NUTATION	Nutation angle of spin axis	DEG	No
NUTATION_PER	Body nutation period of the spin axis	S	No
Spacecraft Parameters (X, Y, Z are the body axes)			

Keyword	Description	Units/Values	Obligatory
IX	Moment of Inertia about the X-axis	KG*M**2	No
IY	Moment of Inertia about the Y-axis	KG*M**2	No
IZ	Moment of Inertia about the Z-axis	KG*M**2	No
IXY	Inertia Cross Product of the X & Y axes	KG*M**2	No
IXZ	Inertia Cross Product of the X & Z axes	KG*M**2	No
IYZ	Inertia Cross Product of the Y & Z axes	KG*M**2	No
Maneuver Parameters (Repeat for each maneuver. None or all parameters of this block are to be given.)			
MAN_EPOCH_START	Epoch of start of maneuver	n/a	No
MAN_DURATION	Maneuver duration	S	No
MAN_REF_FRAME	Coordinate system for the torque vector	n/a	No
MAN_TOR_1	1st component of the torque vector	N*M	No
MAN_TOR_2	2nd component of the torque vector	N*M	No
MAN_TOR_3	3rd component of the torque vector	N*M	No
Comments (Shall appear only at the beginning or end of the logical blocks, but not between components of the logical blocks.)			
COMMENT	Each comment line shall begin with this keyword.	this is a comment	No

3.2.5 REMARKS

3.2.5.1 See 'CREATION_DATE' in table 3-1 for examples of how to format the EPOCH and MAN_EPOCH_START.

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

3.2.5.3 In specifying the EPOCH of the message, care must be taken if UTC is used as the TIME_SYSTEM. If an AEM message reports attitude during a time of leap seconds, the system making use of the message should be able to recognize 60 as a valid value for the seconds (e.g., 200x-xx-xx:23:59:58.000 .. 200x-xx-xx:23:59:59.000 .. 200x-xx-xx:23:59:60.000 .. 200x-xx-xx:00:00:00.000)

3.2.5.4 For examples of values for 'Q_FRAME', 'EULER_FRAME' and 'SPIN_FRAME', the reader is directed to reference [1]. If one of these values is not applicable, the value used should be specified in an ICD.

3.2.5.5 Generally either the logical block for the three-axis stabilization or spin stabilization would be specified, so only one of the logical blocks would appear in an APM. However, the standard does not exclude the possibility of including both logical blocks.

3.2.5.6 It may become necessary to utilize particular orbit information to process Euler angle elements or a local orbit frame (e.g., LVLH, QSW) properly. An approach to this is to add a 'COMMENT' block specifying a particular OPM message to use in conjunction with a particular APM.

3.2.5.7 While the range on the scalar value of the quaternion is not constrained by the specification of this standard, it is recommended that it remain positive ($0 < QC < 1$), which thereby constrains the rotation angle to $-180 < \Phi < 180$. This avoids large attitude discontinuities of +/- 180 degrees.

3.2.5.8 e1, e2, and e3 are the components of the rotation unit vector.

3.2.5.9 Valid values for the EULER_ROT_SEQ are: 121, 123, 131, 132, 212, 213, 231, 232, 312, 313, 321, and 323. Note that care must be taken in specifying the orientation of the body axes with respect to the desired inertial frame specified in EULER_FRAME. This should be documented in an ICD.

3.2.5.10 Any rates specified in the APM should be of the rate of the body with respect to an inertial frame, expressed in the appropriate frame. For instance, ROLL_RATE, PITCH_RATE, and YAW_RATE would be expressed in EULER_FRAME.

3.2.5.11 Care must be taken when using the keywords for Spin Stabilized Spacecraft. For reference frames not defined in reference [1], an ICD shall be used to define the reference frame. Additionally, the ICD should explain the convention for values of SPIN_ANGLE should they differ from standard definitions, as denoted in reference [1].

3.2.5.12 Since the inertia matrix is symmetric for satellites, it is necessary to only specify six elements instead of nine. To reconstruct the full inertia matrix, the elements IYX = IXY, IZX = IXZ, and IZY = IYZ.

3.2.5.13 Parameters for attitude change maneuvers may be optionally given for the computation of the attitude during or after maneuver execution (see reference [1] for the simplified modeling of such maneuvers). Permissible reference frames for the torque vector ('MAN_REF_FRAME') shall be those allowed for the body frame, or the keywords 'EULER_FRAME' or 'SPIN_FRAME' in table 3-3 (see reference [1]).

3.2.6 COMMENTS IN AN APM

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

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

3.2.6.3 Comments may appear only at the beginning of the APM Header and APM Metadata sections. In the APM data section, comments shall only appear at the beginning of

a logical block. Comments must not appear between the components of any logical block in the APM data section. The logical blocks in the APM Data section are indicated in table 3-3.

3.2.6.4 The following comments should be provided:

– Information regarding the genesis, history, interpretation, intended use, etc. of the attitude state, spacecraft, and maneuver that may be of use to the receiver of the APM:

```
COMMENT  Source: File created by GSFC Flight Dynamics Facility as part
COMMENT  of Launch Operations Readiness Test held on 15 July 2004.
```

– Attitude estimation accuracy

```
COMMENT  The 1-sigma accuracy determined by the GSFC Flight
COMMENT  Dynamics Facility for this attitude solution was
COMMENT  [0.02670  0.00945  0.00832] DEG.
```

The purpose of this comment is to enable some specification on the quality of the attitude estimate. The interpretation of the message or the values placed herein should be specified in an ICD.

3.3 APM SYNTAX

3.3.1 GENERAL

The APM shall be a plain text file, using the syntax described in 3.3.2 through 3.3.7.

3.3.2 LINES

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

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

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

3.3.2.4 Comment lines shall be optional. See 3.2.6 for details regarding the placement of comment lines.

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

3.3.3 KEYWORDS

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

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

3.3.3.3 Keywords must be uppercase and must not contain blanks.

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

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

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

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

3.3.4 VALUES

3.3.4.1 The range of values for angle measurements is -180 <= x < 360 degrees. If agencies wish to exchange using radians, this must be specified in an ICD because it is nominally outside the standard.

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

3.3.4.3 Blanks must not appear within numeric values and time strings.

3.3.4.4 Integer values shall consist of a sequence of decimal digits with an optional leading sign ('+' or '-'). If the sign is omitted, '+' shall be assumed. Leading zeros may be used. The range of values that may be expressed as an integer is: -2 147 483 648 <= x <= +2 147 483 647.

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

3.3.4.6 Non-integer numeric values expressed in fixed-point notation shall consist of a sequence of decimal digits separated by a period as a decimal point indicator, with an optional leading sign ('+' or '-'). If the sign is omitted, '+' shall be assumed. Leading and trailing zeros may be used. If the fractional part is zero, the period and following zero(s) may be omitted. There must be a leading zero if $-1.0 < x < 1.0$. The number of digits shall be 18 or fewer.

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

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

3.3.4.8 These specifications for integer, fixed-point, and floating-point values conform to the XML specifications for the data types four-byte integer 'xsd:int', 'decimal' and 'double' respectively. The specifications for floating-point values conform to the IEEE double precision type (references [D1], [D2]). Floating-point numbers in IEEE extended-single or IEEE extended-double precision may be represented, but do require an ICD between participating agencies due to their implementation-specific attributes (reference [D2]).

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

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

3.3.5 UNITS

For clarity, units may be included as ASCII text after a value, but they must match the units specified in table 3-3. If units are displayed, then:

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

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

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

d) units documentation must be constructed using all uppercase or all lowercase.

3.3.6 COMMENTS

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

3.3.7 APM KEYWORD SET

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

3.3.7.2 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 reference [5]. A description of APM header keywords and values is provided in table 3-1.

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

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

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

3.3.7.6 Euler Angle elements or Spin Axis elements may be included in the APM in addition to the quaternion vector to aid the message recipient in performing consistency checks. If any Euler element or Spin Axis element is included, the entire set of elements must be provided.

3.3.7.7 Multiple sets of maneuver parameters may appear. For each maneuver, all the maneuver parameters shall be repeated in the order shown in table 3-3. If a maneuver is specified, the sender must also specify the vehicle inertias to enable proper attitude propagation.

3.4 APM EXAMPLES

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

```
CCSDS_APM_VERS = 1.0
CREATION_DATE  = 2003-09-30T19:23:57
ORIGINATOR     = GSFC


OBJECT_NAME    = TRMM
OBJECT_ID      = 1997-009A
CENTER_NAME    = EARTH
TIME_SYSTEM    = UTC
COMMENT          GEOCENTRIC, CARTESIAN, EARTH FIXED

COMMENT          OBJECT_ID:  1997-009A
COMMENT $ITIM  = 1997 NOV 21 22:26:18.40000000, $ original launch time

COMMENT          Current attitude for orbit 335
COMMENT          Attitude state quaternion

EPOCH          = 2003-09-30T14:28:15.1172
Q_FRAME        = ITRF-97

Q1             = 0.00005
Q2             = 0.87543
Q3             = 0.40949
QC             = 0.25678


COMMENT          Accuracy of this attitude is 0.02 deg RSS.
```

Figure 3-1: APM File Example Using Comments to Denote Updates

```
CCSDS_APM_VERS  = 1.0
CREATION_DATE   = 2004-02-14T19:23:57
ORIGINATOR      = JPL

OBJECT_NAME     = MARS SPIRIT
OBJECT_ID       = 2004-003
CENTER_NAME     = EARTH
TIME_SYSTEM     = UTC
COMMENT           GEOCENTRIC, CARTESIAN, EARTH FIXED

COMMENT OBJECT_ID: 2004-003
COMMENT  $ITIM  = 2004 JAN 14 22:26:18.400000, $ original launch time 14:36

COMMENT           Generated by JPL
COMMENT           Current attitude for orbit 20 and attitude maneuver
COMMENT           planning data.

COMMENT           Attitude state quaternion
EPOCH           = 2004-02-14T14:28:15.1172
Q_FRAME         = ITRF-97

Q1              = 0.03123
Q2              = 0.78543
Q3              = 0.39158
QC              = 0.47832

COMMENT           Attitude specified as Euler elements
EULER_FRAME     = ITRF-97
EULER_ROT_SEQ   = 312
ROLL            = 139.7527 [DEG]
PITCH           = 25.0658  [DEG]
YAW             = -53.3688 [DEG]
ROLL_RATE       = 0.1045   [DEG/S]
PITCH_RATE      = 0.03214  [DEG/S]
YAW_RATE        = 0.02156  [DEG/S]

COMMENT           Spacecraft Parameters
IX              = 6080.0   [KG*M**2]
IY              = 5245.5   [KG*M**2]
IZ              = 8067.3   [KG*M**2]
IXY             = -135.9   [KG*M**2]
IXZ             = 89.3     [KG*M**2]
IYZ             = -90.7    [KG*M**2]

COMMENT           Data follows for 1 planned maneuver.

COMMENT           First attitude maneuver for: MARS SPIRIT
COMMENT           Impulsive, torque direction fixed in body frame
MAN_EPOCH_START = 2004-02-14T14:29:00.5098
MAN_DURATION    = 3        [S]
MAN_REF_FRAME   = Body-fixed
MAN_TOR_1       = -1.25    [N*M]
MAN_TOR_2       = -0.5     [N*M]
MAN_TOR_3       = 0.5      [N*M]
```

Figure 3-2: APM File Example with Optional Euler Elements and One Maneuver

4 ATTITUDE EPHEMERIS MESSAGE (AEM)

4.1 OVERVIEW

4.1.1 Attitude state information may be exchanged between participants by sending an ephemeris in the form of a series of attitude states using an Attitude Ephemeris Message (AEM). The message recipient must have a means of interpolating across these attitude states to obtain the attitude state at an arbitrary time contained within the span of the attitude ephemeris.

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

4.1.3 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 AEMs shall be decided on a case-by-case basis by the participating agencies and documented in an ICD.

4.2 AEM CONTENT

4.2.1 GENERAL

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

a) a header;

b) metadata (data about data);

c) optional comments (explanatory information); and

d) attitude data.

AEM files must have a set of minimum required sections; some may be repeated.

Table 4-1 outlines the contents of an AEM.

Table 4-1: AEM File Layout Specifications

<table>
<tr><th>Item</th><th></th><th></th><th>Obligatory?</th></tr>
<tr><td>Header</td><td></td><td></td><td>Yes</td></tr>
<tr><td rowspan="6">Body</td><td rowspan="2">Segment 1</td><td>Metadata 1</td><td rowspan="2">Yes</td></tr>
<tr><td>Data 1</td></tr>
<tr><td rowspan="2">Segment 2</td><td>Metadata 2</td><td rowspan="2">No</td></tr>
<tr><td>Data 2</td></tr>
<tr><td>.
.
.</td><td>.
.
.</td><td>No</td></tr>
<tr><td rowspan="2">Segment n</td><td>Metadata n</td><td rowspan="2">No</td></tr>
<tr><td>Data n</td></tr>
</table>

4.2.2 AEM HEADER

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

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

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

Table 4-2: AEM Header

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

4.2.3 AEM METADATA

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

a) the keyword to be used;

b) a short description of the item

c) examples of allowed values; and

d) whether the item is obligatory or optional.

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

Table 4-3: AEM Metadata

Keyword	Description	Examples of Values	Obligatory
META_START	The AEM message contains both metadata and attitude ephemeris data; this keyword is used to delineate the start of a metadata block within the message (metadata are provided in a block, surrounded by 'META_START' and 'META_STOP' markers to facilitate file parsing). This keyword must appear on a line by itself.	n/a	Yes
COMMENT	Comments allowed only at the beginning of the metadata section. Each comment line shall begin with this keyword.	COMMENT This is a comment.	No
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 [3]), which include the Object name and international designator of the participant.	EUTELSAT W1 MARS PATHFINDER STS106 NEAR	Yes
OBJECT_ID	Spacecraft identifier of the object corresponding to the attitude data to be given. While there is no CCSDS-based restriction on the value for this keyword, the names could be drawn from the SPACEWARN Bulletin (reference [3]). If this is chosen, it is recommended that values have the format YYYY-NNNP{PP}, where: – YYYY = year of launch; – NNN = three-digit serial number of launch in year YYYY (with leading zeros); – P{PP} = At least one capital letter for the identification of the part brought into space by the launch. In cases where the asset is not listed in the bulletin, the value should be provided in an ICD.	2000-052A 1996-068A 2000-053A 1996-008A	Yes
CENTER_NAME	Origin of reference frame, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this 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 (reference [4]).	EARTH EARTH BARYCENTER MOON SOLAR SYSTEM BARYCENTER SUN JUPITER BARYCENTER STS 106 EROS	Yes

Keyword	Description	Examples of Values	Obligatory
REF_FRAME	Name of the reference frame in which the attitude data is given. It is recommended to use reference frames from *Navigation Definitions and Conventions* (reference [1]). Note that if a reference frame is to be used that does not appear in [1], a description should be placed in an ICD.	ICRF ITRF-93 ITRF-97 ITRF2000 ITRFxxxx TOD EME2000 TDR GRC LVLH RSW NTW	Yes
TIME_SYSTEM	Time system used for both attitude ephemeris data and metadata (also see tables 4-3 and 4-4). It is recommended to use names from *Navigation Definitions and Conventions* (reference [1]). Times may be given in 1) ISO/CCSDS ASCII format or 2) Julian Date strings (reference [5]).	UTC, TAI, TT, GPS, TDB, TCB	Yes
START_TIME	Start of TOTAL time span covered by attitude ephemeris data immediately following this metadata block. The START_TIME time tag at a new block of attitude 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 2001-277T07:22:54 Julian Date Strings: 2451534.29812	Yes
USEABLE_ START_TIME, USEABLE_ STOP_TIME	Optional start and end of USEABLE time span covered by attitude ephemeris data immediately following this metadata block. To allow for proper interpolation near the ends of the attitude 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 attitude ephemeris data records as denoted by the START/STOP_TIME time tags.	Calendar Formats: 1996-12-18T14:28:15.1172 2001-277T07:22:54 Julian Date Strings: 2451534.29812	No
STOP_TIME	End of TOTAL time span covered by the attitude ephemeris data immediately following this metadata block. The START_TIME time tag at a new block of attitude 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 2001-277T07:22:54 Julian Date Strings: 2451534.29812	Yes
ATTITUDE_TYPE	Specifies the format of the data lines in the message. This keyword must have a value from the set specified at the right. See 4.3.6 for details of the data contained in each line.	QUATERNION QUATERNION/DERIVATIVE QUATERNION/RATE EULER_ANGLE EULER_ANGLE/RATE SPIN SPIN/NUTATION	Yes
QUATERNION_ TYPE	This keyword denotes the placement of the scalar portion of the quaternion (QC) in the attitude data. This keyword is only applicable if the ATTITUDE_TYPE used in the message denotes quaternions.	FIRST LAST	No

Keyword	Description	Examples of Values	Obligatory
EULER_ROT_SEQ	This keyword specifies the rotation sequence of the Euler angles for the data in the message. The allowed values are the same as those in the APM. This keyword is applicable only if ATTITUDE_TYPE specifies the use of Euler angles.	131 231 321	No
INTERPOLATION_METHOD	This keyword may be used to specify the recommended interpolation method for attitude ephemeris data in the block immediately following this metadata block.	Linear Hermite Lagrange	No
INTERPOLATION_DEGREE	Recommended interpolation degree for attitude ephemeris data in the block immediately following this metadata block. It must be an integer value. This keyword must be used if the 'INTERPOLATION_METHOD' keyword is used.	5 1	No
META_STOP	The AEM message contains both metadata and attitude ephemeris data; this keyword is used to delineate the end of a metadata block within the message (metadata are provided in a block, surrounded by 'META_START' and 'META_STOP' markers to facilitate file parsing). This keyword must appear on a line by itself.	n/a	Yes

4.2.4 AEM DATA

See 4.3.6, Attitude Ephemeris Data Lines, for specifications regarding AEM data.

4.2.5 COMMENTS IN AN AEM

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

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

4.2.5.3 The following comments are recommended:

– Information regarding the genesis, history, interpretation, intended use, etc. of the attitude ephemeris data that may be of value to the receiver of the AEM:

```
COMMENT  Source: File created by GSFC Flight Dynamics Facility as part
COMMENT  of Launch Operations Readiness Test held on 15 July 2004.
```

– AEM Accuracy vs. Efficiency: The producer of an AEM should report in comment lines what the expected accuracy of the attitude ephemeris is, so the user can smooth or otherwise compress the data without affecting the accuracy of the attitude. The AEM producer also should strive to achieve not only the best accuracy possible, taking into account prediction errors, but also consider the efficiency of the attitude representation (e.g., step sizes of fractional seconds between attitude ephemeris lines may be necessary for precision scientific reconstruction of an attitude, but may be excessive in some cases).

4.3 AEM SYNTAX

4.3.1 GENERAL

The AEM shall be a plain text file, using the syntax described in 4.3.2 through 4.3.8.

4.3.2 LINES

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

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

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

4.3.2.4 Comment lines shall be optional, and may occur at any position in the header after the first line of the header, at the beginning of the metadata section, and at the beginning or end of a block of attitude ephemeris lines (comment lines must not appear within any block of attitude ephemeris lines).

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

4.3.3 KEYWORDS

4.3.3.1 All header and metadata lines, with exceptions as noted below, shall use ‘keyword = value’ notation, abbreviated as KVN.

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

4.3.3.3 Keywords must be uppercase and must not contain blanks.

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

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

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

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

4.3.3.8 The keywords META_START and META_STOP are exceptions to the KVN syntax.

4.3.4 VALUES

4.3.4.1 The range of values for all angle measurements is -180 <= x < 360 degrees. If agencies wish to exchange using radians, this must be specified in an ICD because it is nominally outside the standard.

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

4.3.4.3 Blanks must not appear within numeric values and time strings.

4.3.4.4 Integer values shall consist of a sequence of decimal digits with an optional leading sign ('+' or '-'). If the sign is omitted, '+' shall be assumed. Leading zeros may be used. The range of values that may be expressed as an integer is: -2 147 483 648 <= x <= +2 147 483 647.

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

4.3.4.6 Non-integer numeric values expressed in fixed-point notation shall consist of a sequence of decimal digits separated by a period as a decimal point indicator, with an optional leading sign ('+' or '-'). If the sign is omitted, '+' shall be assumed. Leading and trailing zeros may be used. If the fractional part is zero, the period and following zero(s) may be omitted. There must be a leading zero if –1.0 < x < 1.0. The number of digits shall be 18 or fewer.

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

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

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

4.3.4.8 These specifications for integer, fixed-point, and floating-point values conform to the XML specifications for the data types four-byte integer 'xsd:int', 'decimal' and 'double' respectively. The specifications for floating-point values conform to the IEEE double precision type (references [D1], [D2]). Floating-point numbers in IEEE extended-single or IEEE extended-double precision may be represented, but do require an ICD between participating agencies due to their implementation-specific attributes (reference [D2]).

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

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

4.3.5 UNITS

In an AEM, units shall be assigned to the keywords as follows:

- dimensionless: EPOCH, Q1, Q2, Q3, QC;
- S^{-1} : Q1_DOT, Q2_DOT, Q3_DOT, QC_DOT;
- DEG: ROLL, PITCH, YAW, SPIN_ALPHA, SPIN_DELTA, SPIN_ANGLE, NUTATION;
- DEG/S: ROLL_RATE, PITCH_RATE, YAW_RATE, SPIN_ANGLE_VEL;
- S: NUTATION_PER.

Units shall not be displayed; the applicable units are determined by the value set for the ATTITUDE_TYPE keyword.

4.3.6 ATTITUDE EPHEMERIS DATA LINES

4.3.6.1 For AEMs, each set of attitude ephemeris data, including the time tag, must be provided on a single line. Table 4-4 lists the allowable combinations of data items, with each item following the same definition as given in table 3-3. The order in which the data items are given shall be fixed as in table 4-4.

Table 4-4: Types of Attitude Ephemeris Data Lines

Keyword	Value	Ephemeris Data Line
Quaternion Options (note that keywords and values appear only in Metadata)		
QUATERNION_TYPE	FIRST	N/A
ATTITUDE_TYPE	QUATERNION	Epoch, QC, Q1, Q2, Q3
	QUATERNION/DERIVATIVE	Epoch, QC, Q1, Q2, Q3, QC_DOT, Q1_DOT, Q2_DOT, Q3_DOT
	QUATERNION/ RATE	Epoch, QC, Q1, Q2, Q3, ROLL_RATE, PITCH_RATE, YAW_RATE
QUATERNION_TYPE	LAST	N/A
ATTITUDE_TYPE	QUATERNION	Epoch, Q1, Q2, Q3, QC
	QUATERNION/DERIVATIVE	Epoch, Q1, Q2, Q3, QC, Q1_DOT, Q2_DOT, Q3_DOT, QC_DOT
	QUATERNION/ RATE	Epoch, Q1, Q2, Q3, QC, ROLL_RATE, PITCH_RATE, YAW_RATE
Euler Angle Options (note that keywords and values appear only in Metadata)		
ATTITUDE_TYPE	EULER_ANGLE	Epoch, ROLL, PITCH, YAW
	EULER_ANGLE/ RATE	Epoch, ROLL, PITCH, YAW, ROLL_RATE, PITCH_RATE, YAW_RATE

Keyword	Value	Ephemeris Data Line
Spin Axis Options (note that keywords and values appear only in Metadata)		
ATTITUDE_TYPE	SPIN	Epoch, SPIN_ALPHA, SPIN_DELTA, SPIN_ANGLE, SPIN_ANGLE_VEL
	SPIN/NUTATION	Epoch, SPIN_ALPHA, SPIN_DELTA, SPIN_ANGLE, SPIN_ANGLE_VEL, NUTATION, NUTATION_PER

The choice of one of the formats in table 4-4 shall be specified via the ATTITUDE_TYPE keyword in the metadata.

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

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

4.3.6.4 The TIME_SYSTEM value must remain fixed within an AEM.

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

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

4.3.6.7 In specifying the EPOCH of the message, care must be taken if UTC is used as the TIME_SYSTEM. If an AEM message reports attitude during a time of leap seconds, the system making use of the message should be able to recognize 60 as a valid value for the seconds (e.g., 200x-xx-xx:23:59:58.000 .. 200x-xx-xx:23:59:59.000 .. 200x-xx-xx:23:59:60.000 .. 200x-xx-xx:00:00:00.000)

4.3.6.8 While the range on the scalar value of the quaternion is not constrained by the specification of this standard, it is recommended that it remain positive ($0 < QC < 1$), which

thereby constrains the rotation angle to $-180 < \Phi < 180$. This avoids seeing large attitude errors around +/- 180 degrees.

4.3.6.9 Valid values for the EULER_ROT_SEQ are: 121, 123, 131, 132, 212, 213, 231, 232, 312, 313, 321, and 323.

4.3.6.10 Any rates specified in the AEM should be of the rate of the body with respect to an inertial frame, expressed in the appropriate frame. For instance, ROLL_RATE, PITCH_RATE, and YAW_RATE would be expressed in REF_FRAME.

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

4.3.7 COMMENTS

All comment lines shall begin with the 'COMMENT' keyword followed by a single space. This keyword must appear on every comment line, not just the first such line. The remainder of the line shall be the comment value. White space shall be retained (shall be significant) in comment values. Comments may appear only after the specification of the keyword CCSDS_AEM_VERS at the beginning of Metadata sections and must not appear between attitude ephemeris data lines.

4.3.8 AEM KEYWORD SET

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

4.3.8.2 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 AEM header keywords and values is provided in table 4-2.

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

4.3.8.4 Only those keywords shown in tables 4-2 and 4-3 shall be used in an AEM. Some keywords represent obligatory items and some are optional. KVN assignments representing optional items may be skipped. The two USEABLE_START/STOP_TIME keywords,

marked as optional items, may not be necessary depending on the recommended interpolation method. (It is safer to use the USEABLE_START/STOP_TIME capability in all cases.)

4.3.8.5 A single METADATA group shall precede each attitude ephemeris data block. Multiple occurrences of a METADATA group followed by an attitude ephemeris data block may be used.

4.3.8.6 Before each METADATA group the string 'META_START' shall appear on a separate line and after each METADATA group (and before the associated attitude ephemeris data block) the string 'META_STOP' shall appear on a separate line.

4.4 AEM EXAMPLE

Figure 4-1 is an example of an AEM. Note that some attitude ephemeris lines were omitted.

```
CCSDS_AEM_VERS = 1.0
CREATION_DATE = 2002-11-04T17:22:31
ORIGINATOR = NASA/JPL

COMMENT  This file was produced by M.R. Somebody, MSOO NAV/JPL, 2002 OCT 04.
COMMENT  It is to be used for attitude reconstruction only.  The relative accuracy of these
COMMENT   attitudes is 0.1 degrees per axis.

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
ATTITUDE_TYPE        = QUATERNION
QUATERNION_TYPE      = LAST
INTERPOLATION_METHOD = Hermite
INTERPOLATION_DEGREE = 7
META_STOP

1996-11-18T12:00:00.55555 0.56748   0.03146   0.45689   0.68427
1996-11-18T12:01:00.55555 0.42319   -0.45697  0.23784   0.74533
1996-11-18T12:03:00.55555 -0.84532  0.26974   -0.06532  0.45652

        < intervening data records omitted here >

1996-11-28T21:28:00.5546  0.74563   -0.45375   0.36875   0.31964

META_START
COMMENT   This block begins after trajectory correction maneuver TCM-3.
OBJECT_NAME          = Mars Global Surveyor
OBJECT_ID            = 1996-062A
CENTER_NAME          = Mars Barycenter
REF_FRAME            = EME2000
TIME_SYSTEM          = UTC
START_TIME           = 1996-11-28T21:29:07.2
USABLE_START_TIME    = 1996-11-28T22:08:02.5
USABLE_STOP_TIME     = 1996-11-30T01:18:02.5
STOP_TIME            = 1996-11-30T01:28:02.5
ATTITUDE_TYPE        = QUATERNION
QUATERNION_TYPE      = LAST
INTERPOLATION_METHOD  = Hermite
INTERPOLATION_DEGREE = 7
META_STOP

1996-12-28T21:29:02.2675  -0.64585  0.018542   -0.23854  0.72501
1996-12-28T21:59:02.2675  0.87451   -0.43475   0.13458   -0.16767
1996-12-28T22:00:02.2675  0.03125   -0.65874   0.23458   -0.71418

        < intervening records omitted here >

1996-12-30T01:28:02.2675  -0.25485  0.58745   -0.36845   0.67394
```

Figure 4-1: AEM Example

ANNEX A

RATIONALE FOR ATTITUDE DATA MESSAGES

(INFORMATIVE)

A1 OVERVIEW

This annex presents the rationale behind the design of each message. It may help the application engineer to select a suitable message. Corrections and/or additions to these requirements are expected during future updates.

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 annex 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 Recommended Standard reflects heritage requirements pertaining to some of the technical participants' home institutions collected during the preparation of the document; it does not speculate on heritage requirements that could arise from other Member Agencies.

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

A2 PRIMARY REQUIREMENTS ACCEPTED BY THE ATTITUDE DATA MESSAGES

Table A-1: Primary Requirements

Requirement	Accepted for APM?	Accepted for AEM?
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 an attitude state 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 attitude motion must be clearly identified and unambiguous.	Y	Y
Time measurements (time stamps, time tags, or epochs) must be provided in a commonly used, clearly specified system.	Y	Y
The time bounds of the attitude ephemeris must be unambiguously specified.	N	Y
The standard must provide for clear specification of units of measure.	Y	Y
Files must be readily ported between, and useable within, *all* Member Agency computational environments that could be used to exchange Attitude Data Messages.	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 Member Agency computing environments that could be used to exchange Attitude Data Messages.	Y	Y

Table A-2: Heritage Requirements

Requirement	Accepted for APM?	Accepted for AEM?
Ephemeris data is reliably convertible into the SPICE SPK format using a standard, multi-mission, unsupervised pipeline process. A complete attitude ephemeris, not subject to integration or propagation by the customer, must be provided.	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 APM?	Accepted for AEM?
The standard applies to non-traditional objects, such as landers, rovers, balloons, and natural bodies (asteroids, comets).	Y	Y
The standard allows attitude states to be provided in other than the traditional EME2000 inertial reference frame; one example is the International Astronomical Union (IAU) Mars body-fixed frame. (In such a case, provision or ready availability of supplemental information needed to transform data into a standard frame must be arranged.)	Y	Y
The standard is extensible with no disruption to existing users or uses.	Y	Y
The standard is consistent with, and ideally a part of, attitude products and processes used for other space science purposes.	N	N
The standard is as consistent as reasonable with any related CCSDS attitude standards used for earth-to-spacecraft or spacecraft-to-spacecraft applications.	Y	Y
The standard allows for the specification of the accuracy of the attitude solution. The representation of the accuracy should be specified in an ICD.	Y	Y

A3 APPLICABILITY OF CRITERIA TO MESSAGE OPTIONS

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

Table A-4: Applicability of the Criteria to Attitude Data Messages

Criteria	Definition	Applicable to APM?	Applicable to AEM?
Modeling Fidelity	Permits modeling of any dynamic perturbation to the attitude.	N	Y
Human Readability	Provides easily readable message corresponding to widely used attitude representations.	Y	Y
Remote Body Extensibility	Permits use for assets on remote solar system bodies.	Y	Y
Lander/Rover Compatibility	Permits exchange of non-orbit attitudes.	Y	Y

A4 SERVICES RELATED TO THE DIFFERENT ATTITUDE DATA MESSAGE FORMATS

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

Table A-5: Services Available with Attitude Data Messages

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

ANNEX B

ITEMS FOR AN INTERFACE CONTROL DOCUMENT

(INFORMATIVE)

In several places in this document there are references to items which should be specified in an ICD between agencies participating in an exchange of attitude data. The ICD should be jointly produced by both Agencies participating in a cross-support activity involving the transfer of attitude data. This annex compiles those recommendations into a single list.[1]

Table B-1: Items Recommended for an ICD

	ICD Item	Section Trace
1	ADM and AEM file naming conventions.	3.1.4 4.1.3
2	Method of exchanging ADMs (transmission).	1.2.2
3	Definition of attitude accuracy requirements pertaining to data in an ADM as well as attitude dynamics modeling.	1.2.1 3.1.2
4	Specific APM and/or AEM version numbers that will be exchanged.	3.3.7.1 4.3.8.1
5	Format on values used for the 'ORIGINATOR' keyword.	table 3-1 table 4-2
6	Values used for the 'OBJECT_ID' keyword for cases when the value is not published in the SPACEWARN Bulletin (reference [3]).	table 3-2 table 4-3
7	Values and definition of the 'Q_FRAME', 'EULER_FRAME', 'SPIN_FRAME', or 'REF_FRAME' keywords to be used in ADM exchanges, if the value is not given in reference [1].	3.2.5.4 table 4-3
8	Values and definition of the 'SPIN_FRAME' keyword if they are going to be used in ADM exchanges, as well as the convention for values of the 'SPIN_ANGLE' keyword.	3.2.5.10
9	If floating-point numbers in extended-single or extended-double precision are to be used, then discussion of implementation-specific attributes is required.	3.3.4.8 4.3.4.8

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

	ICD Item	Section Trace
10	Information which must appear in comments for any given ADM exchange.	3.2.6.2 4.2.5.2
11	Whether the format of the ADM will be ASCII or XML (note: XML implementation not yet in scope).	1.2.3
12	A reference orientation should be specified in an ICD for the body axes. For instance, demonstrating the alignment of the body axes with the local orbit frame or an inertial frame to give a context to interpret the Euler Angle data.	3.2.5.8
13	If the angle units will be radians (outside the standard), this must be specified in the ICD.	3.3.4.1 4.3.4.1
14	Provisions that are made to ensure information security.	1.6

ANNEX C

ABBREVIATIONS AND ACRONYMS

(INFORMATIVE)

ASCII	American Standard Code for Information Interchange
ADM	Attitude Data Message
AEM	Attitude Ephemeris Message
APM	Attitude Parameter Message
CCIR	International Coordinating Committee for Radio Frequencies
CCSDS	Consultative Committee for Space Data Systems
EME2000	Earth Mean Equator and Equinox of J2000 (Julian Date 2000)
GPS	Global Positioning System
IAU	International Astronomical Union
ICD	Interface Control Document
ICRF	International Celestial Reference Frame
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
ITRF	International Terrestrial Reference Frame
KVN	Keyword = Value notation
LVLH	Local Vertical Local Horizontal
NTW	Normal, Tangential (to velocity vector) and Normal to Orbit Plane
ODM	Orbit Data Message
OEM	Orbit Ephemeris Message
OPM	Orbit Parameter Message
RSW	Radial, Along Track, and Normal to Satellite Orbit
TAI	International Atomic Time
TCB	Barycentric Coordinated Time
TDB	Barycentric Dynamical Time
TDM	Tracking Data Message
TOD	True Equator and Equinox of Date
TT	Terrestrial Dynamical Time
UTC	Coordinated Universal Time
XML	eXtensible Markup Language

ANNEX D

INFORMATIVE REFERENCES

(INFORMATIVE)

[D1] *XML Schema Part 2: Datatypes*. 2nd ed. P. Biron and A. Malhotra, eds. W3C Recommendation 28. n.p.: W3C, 2004.

[D2] *IEEE Standard for Binary Floating-Point Arithmetic*. IEEE Std 754-1985. New York: IEEE, 1985.

[D3] *Standard Frequencies and Time Signals*. Volume 7 of *Recommendations and Reports of the CCIR: XVIIth Plenary Assembly*. Geneva: CCIR, 1990.

[D4] *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.

NOTE – Normative references are provided in 1.5.