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Space data and information transfer systems — Attitude data messages

Systèmes de transfert des informations et données spatiales — Messages de données d'attitude

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted (see www.iso.org/directives).

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This document was prepared by the Consultative Committee for Space Data Systems (CCSDS) (as CCSDS 504.0-B-1 Cor.1, July 2015) and was adopted (without modifications) by Technical Committee ISO/TC 20, *Space vehicles,* Subcommittee SC 13, *Space data and information transfer systems*.

This second edition cancels and replaces the first edition (ISO 13541:2010), which has been technically revised.

The main changes compared to the previous edition are as follows:

— adds clarifying text to 1.3, Conventions and Definitions.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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1 INTRODUCTION

1.1 PURPOSE

1.1.1 This 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;

– carrying out attitude propagations and/or sensor predictions;

– testing to initialize sub-system simulators (communications, power, etc.).

1.1.2 This Recommended Standard includes sets of requirements and criteria that the message formats have been designed to meet. For exchanges where these requirements do not capture the needs of the participating agencies, 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 B 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 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 B3.

1.2.2 This 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) will be available. An XML schema is defined by the CCSDS Recommended Standard titled 'XML Specification for Navigation Data Messages' (reference [5]). Agencies should specify, via ICD, the ASCII file format to be exchanged (Keyword Value Notation [KVN] or XML).

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.

As in some attitude dynamics references, in this document the term 'nutation' is used to mean the motion of the spin axis of a body about an inertial axis. In many other references this motion is called 'precession'. Cor. 1

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 Section 5 provides details regarding syntax of the APM and AEM messages.

1.4.5 Section 6 provides information regarding security concerns related to the access and transmission of the Attitude Data Messages.

1.4.6 Annex B provides a list of approved values for selected keywords in the ADM Metadata sections.

1.4.7 Annex B 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.

1.4.8 Annex C 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.

1.4.9 Annex D is a list of abbreviations and acronyms applicable to the ADM.

1.4.10 Annex E 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] *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.

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

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

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

[5] *XML Specification for Navigation Data Messages*. Draft Recommendation for Space Data System Standards, CCSDS 505.0-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, November 2005.

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

[7] *Orbit Data Messages*. Recommendation for Space Data System Standards, CCSDS 502.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2004.

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

2 OVERVIEW

2.1 ATTITUDE DATA MESSAGE TYPES

2.1.1 Two CCSDS-recommended Attitude Data Messages (ADMs) are described in this 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 downloads of text files or objects to displays or printers are possible without preprocessing. The penalty for this convenience is inefficiency.

2.1.3 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 to specify the attitude; if local orbital frames are specified, then an APM must be used in conjunction with an Orbit Parameter Message (reference [7]).

2.2.3 The APM allows for modeling of any number of finite maneuvers and simple modeling of solar radiation pressure and atmospheric torque. Note that an Orbit Parameter Message (OPM) is needed for proper solar radiation pressure modeling. 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.

2.3.3 The AEM is fully self-contained; no additional information is required when inertial reference frames are specified. If local orbital reference frames are specified, then an AEM must be used in conjunction with an Orbit Ephemeris Message (reference [7]).

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 [E4].

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 [E4]) 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 shall be available at the receiver's location;

– the receiver's modeling of satellite attitude dynamics, atmospheric torque, other internal and external torques (e.g., magnetic, gravitational, etc.), thrust maneuvers, and attitude control (see reference [E4]) 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

3.2.2.1 Table 3-1 specifies for each header item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

3.2.2.2 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
`COMMENT`	Comments (allowed at the beginning of the APM Header after the APM version number). Each comment line shall begin with this keyword.	`This is a comment`	No

`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`
		`1996-12-18T14:28:15.1172`
			Yes

`ORIGINATOR`	Creating agency (value should be specified in an ICD).	`CNES, ESOC, GSFC, GSOC, JPL, JAXA, etc.`	Yes

3.2.3 APM METADATA

3.2.3.1 Table 3-2 specifies for each metadata item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

3.2.3.2 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 and annex E are the best known sources for authorized values to date.

Table 3-2: APM Metadata

Keyword	Description	Normative Values / Examples	Obligatory
COMMENT	Comments (allowed only at the beginning of the APM Metadata before OBJECT_NAME). Each comment line shall begin with this keyword.	COMMENT This is a comment	No
OBJECT_NAME	Spacecraft name of the object corresponding to the attitude data to be given. 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 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 [2]). 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 [3]).	EARTH EARTH BARYCENTER MOON SOLAR SYSTEM BARYCENTER SUN JUPITER BARYCENTER STS 106 EROS	No
TIME_SYSTEM	Time system used for attitude and maneuver data (also see table 3-3). The full set of allowed values is enumerated in annex A, with an excerpt provided in the 'Normative Values/Examples' column. Explanations of these time systems can be found in *Navigation Definitions and Conventions* (reference [E4]).	UTC, TAI, TT, GPS, TDB, TCB	Yes

3.2.4 APM DATA

3.2.4.1 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.

3.2.4.2 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	Normative Units/Values	Obligatory
Comments (Shall appear only at the beginning of the logical blocks, but not between components of the logical blocks.)			
COMMENT	Each comment line shall begin with this keyword.	n/a	No
EPOCH	Epoch of the attitude elements & optional logical blocks and denotes a spacecraft event time.	n/a	Yes
Attitude Quaternion Components in the Specified Coordinate System (All obligatory elements of the logical block are to be provided.)			
Q_FRAME_A	The name of the reference frame specifying one frame of the transformation, whose direction is specified using the keyword Q_DIR. The full set of values is enumerated in annex A, with an excerpt provided in the 'Units/Values' column. For a definition of these various frames, the reader is directed to reference [E4]. Note that if a frame is used that does not appear in annex A, a description should be placed in an ICD.	SC_BODY_1 STARTRACKER_1 INSTRUMENT_A LVLH ICRF	Yes
Q_FRAME_B	Name of the reference frame specifying the second portion of the transformation, whose direction is specified using the keyword Q_DIR. The full set of values is enumerated in annex A, with an excerpt provided in the 'Units/Values' column. For a definition of these various frames, the reader is directed to *Navigation Definitions and Conventions* (reference [E4]). Note that if a reference frame is to be used that does not appear in annex A, a description should be placed in an ICD.	ICRF ITRF-97 ITRF2000 ITRFxxxx TOD EME2000 LVLH RTN SC_BODY_1 INSTRUMENT_A	Yes
Q_DIR	Rotation direction of the attitude quaternion, specifying from which frame the transformation is to: - A2B specifies an attitude transforming from the Q_FRAME_A to the Q_FRAME_B - B2A specifies an attitude transforming from the Q_FRAME_B to the Q_FRAME_A	A2B B2A	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

Keyword	Description	Normative Units/Values	Obligatory
QC	cos(ϕ/2) ϕ = rotation angle	n/a	Yes
Q1_DOT	Derivative of Q_1	1/s	No
Q2_DOT	Derivative of Q_2	1/s	No
Q3_DOT	Derivative of Q_3	1/s	No
QC_DOT	Derivative of Q_C	1/s	No
Euler angle elements in the Specified Reference Frame for a Three-Axis Stabilized Satellite (In using this logical block, the sender must specify a sequence of three Euler angles or rates, along with any other parameters, to specify the attitude. See 3.2.5.4.3 for further clarification.)			
COMMENT	Each comment line shall begin with this keyword.	n/a	No
EULER_FRAME_A	The name of the reference frame specifying one frame of the transformation, whose direction is specified using the keyword EULER_DIR. The full set of values is enumerated in annex A, with an excerpt provided in the 'Units/Values' column. For a definition of these various frames, the reader is directed to reference [E4]. Note that if a frame is used that does not appear in annex A, a description should be placed in an ICD.	SC_BODY_1 STARTRACKER_1 INSTRUMENT_A ICRF LVLH	No
EULER_FRAME_B	Name of the reference frame specifying the second portion of the transformation, whose direction is specified using the keyword EULER_DIR. The full set of values is enumerated in annex A, with an excerpt provided in the 'Units/Values' column. Note that if a reference frame is to be used that does not appear in annex A, a description should be placed in an ICD.	ICRF ITRF-93 ITRF-97 ITRF2000 LVLH SC_BODY_1 INSTRUMENT_A	No
EULER_DIR	Rotation direction of the attitude Euler angles, specifying from which frame the transformation is to: - A2B specifies an attitude transforming from the EULER_FRAME_A to the EULER_FRAME_B - B2A specifies an attitude transforming from the EULER_FRAME_B to the EULER_FRAME_A	A2B B2A	No
EULER_ROT_SEQ	Rotation order of the EULER_FRAME_A to EULER_FRAME_B or vice versa, as specified using the EULER_DIR keyword, in X Y Z notation (e.g., 312, where X=1, Y=2, Z=3). The order of the transformation is from left to right, where the leftmost integer represents the first rotation axis.	123 321	No
RATE_FRAME	The value of this keyword expresses the relevant keyword to use that denotes the frame of reference in which the X_RATE, Y_RATE and Z_RATE are expressed. The allowed values are those shown in the box at right. The rates as given here express the time rate of change of the attitude of one frame with respect to the other, the direction being consistent with the EULER_DIR keyword.	EULER_FRAME_A EULER_FRAME_B	No
X_ANGLE	X body rotation angle	deg	No
Y_ANGLE	Y body rotation angle	deg	No
Z_ANGLE	Z body rotation angle	deg	No
X_RATE	X body rotation rate	deg/s	No
Y_RATE	Y body rotation rate	deg/s	No
Z_RATE	Z body rotation rate	deg/s	No

Keyword	Description	Normative Units/Values	Obligatory
Attitude parameters in the Specified Reference Frame for a Spin Stabilized Satellite (The sender shall give parameters from this logical block that are necessary to uniquely specify the attitude.)			
COMMENT	Each comment line shall begin with this keyword.	n/a	No
SPIN_FRAME_A	The name of the reference frame specifying one frame of the transformation, whose direction is specified using the keyword SPIN_DIR. The full set of values is enumerated in annex A, with an excerpt provided in the 'Units/Values' column. For a definition of these various frames, the reader is directed to reference [E4]. Note that if a frame is used that does not appear in annex A, a description should be placed in an ICD.	SC_BODY_1 STARTRACKER_1 INSTRUMENT_A ICRF LVLH	No
SPIN_FRAME_B	Name of the reference frame specifying the second portion of the transformation, whose direction is specified using the keyword SPIN_DIR. The full set of values is enumerated in annex A, with an excerpt provided in the 'Units/Values' column. Note that if a reference frame is to be used that does not appear in annex A, a description should be placed in an ICD.	ICRF ITRF-93 ITRF-97 ITRF2000 SC_BODY_1 INSTRUMENT_A	No
SPIN_DIR	Rotation direction of the Spin angles, specifying from which frame the transformation is to: - A2B specifies an attitude transforming from the SPIN_FRAME_A to the SPIN_FRAME_B - B2A specifies an attitude transforming from the SPIN_FRAME_B to the SPIN_FRAME_A	A2B B2A	No
SPIN_ALPHA	Right ascension of spin axis vector	deg	No
SPIN_DELTA	Declination of the spin axis vector	deg	No
SPIN_ANGLE	Phase of the satellite about the spin axis	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
NUTATION_PHASE	Inertial nutation phase	deg	No
Spacecraft Parameters (1, 2, 3 are a set of orthogonal axes. None or all parameters of this block are to be given.)			
COMMENT	Each comment line shall begin with this keyword.	n/a	No
INERTIA_REF_FRAME	Coordinate system for the inertia tensor	n/a	No
I11	Moment of Inertia about the 1-axis	kg*m**2	No
I22	Moment of Inertia about the 2-axis	kg*m**2	No
I33	Moment of Inertia about the 3-axis	kg*m**2	No
I12	Inertia Cross Product of the 1 & 2 axes	kg*m**2	No
I13	Inertia Cross Product of the 1 & 3 axes	kg*m**2	No
I23	Inertia Cross Product of the 2 & 3 axes	kg*m**2	No
Maneuver Parameters (Repeat for each maneuver. None or all parameters of this block are to be given.)			
COMMENT	Each comment line shall begin with this keyword.	n/a	No
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

3.2.5 REMARKS

3.2.5.1 DATA FORMAT

3.2.5.1.1 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.

3.2.5.1.2 See 'CREATION_DATE' in table 3-1 or see reference [4] for examples of how to format the EPOCH and MAN_EPOCH_START. Note that any epoch specified denotes a spacecraft event time.

3.2.5.1.3 In specifying the EPOCH of the message, care must be taken if UTC is used as the TIME_SYSTEM. If an APM 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-xxT23:59:58.000 .. 200x-xx-xxT23:59:59.000 .. 200x-xx-xxT23:59:60.000 .. 200x-xx-xxT00:00:00.000)

3.2.5.2 GENERAL

3.2.5.2.1 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.

3.2.5.2.2 For examples of values for 'Q_FRAME_*', 'EULER_FRAME_*', and 'SPIN_FRAME_*', where '*' is either A or B, the reader is directed to annex A for keywords, and to reference [E4] for descriptions of the reference frames. If one of these values is not applicable, the value used should be specified in an ICD.

3.2.5.2.3 The generalization of the attitude representation in this message may lead to ambiguity. To avoid this ambiguity, the keyword *_DIR is provided to specify the direction of the attitude rotation, where '*' denotes Q, EULER, or SPIN. There are two values for this keyword, A2B or B2A, which uniquely specify the direction of the attitude rotation; e.g., for A2B, the attitude parameters specify a rotation from the Q_FRAME_A to the Q_FRAME_B.

3.2.5.2.4 Rates specified in the APM should be consistent with the direction given by the *_DIR keyword, where '*' denotes Q, EULER, or SPIN. If *_DIR is given as 'A2B', then the rates given should be the rates of the *_FRAME_A with respect to *_FRAME_B frame, expressed in the appropriate frame. When quaternion derivatives or spin axis rates and nutation are given, no additional information is necessary as these quantities are expressed in the correct reference frame. However, when Euler rates are given, it is necessary to specify the reference frame that expresses the rates, hence the keyword RATE_FRAME. Euler rates are expressed in either EULER_FRAME_A or EULER_FRAME_B reference frame, as denoted by the value of the RATE_FRAME keyword. For further clarification and relevant equations, the reader is referred to reference [E4].

3.2.5.2.5 Parameters for the inertia elements of the object may be optionally given. The keyword INERTIA_REF_FRAME is provided to specify the reference frame for the inertia values, and the allowed values for this keyword are enumerated in annex A. Since the inertia matrix of a rigid body is symmetric, it is necessary to only specify six elements instead of nine. To reconstruct the full inertia matrix, the elements I21 = I12, I31 = I13, and I32 = I23. The inertia cross products used for this message assume a negative double integral.

3.2.5.2.6 Parameters for attitude change maneuvers may be optionally given for the computation of the attitude during or after maneuver execution (see reference [E4] for the simplified modeling of such maneuvers). Permissible reference frames for the torque vector ('MAN_REF_FRAME') shall be those allowed for the keywords 'Q_FRAME_*', 'EULER_FRAME_*' or 'SPIN_FRAME_*', where '*' denotes 'A', or 'B', as enumerated in annex A.

3.2.5.2.7 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.

3.2.5.3 QUATERNION

3.2.5.3.1 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 non-negative ($0 \leq QC \leq 1$), which thereby constrains the rotation angle to -180 degrees $\leq \Phi \leq 180$ degrees. This avoids large attitude discontinuities of $\pm$ 180 degrees.

3.2.5.3.2 e_1, e_2, and e_3 are the components of the rotation unit vector.

3.2.5.3.3 The message allows the occurrence of the keyword QC, and its associated value, to appear at either the beginning of the quaternion specification, or at the end (e.g., QC, Q1, Q2, Q3 or Q1, Q2, Q3, QC). Quaternion rates, if specified, should follow the order of the quaternions given in the message for consistency.

3.2.5.4 EULER ANGLES

3.2.5.4.1 Valid and recommended values for the EULER_ROT_SEQ are: 123, 132, 213, 231, 312, 321. The Euler angle keywords should be given in the order specified by the EULER_ROT_SEQ (e.g., for a 321 sequence, the angular information would appear in the order Z_ANGLE, Y_ANGLE, X_ANGLE). Note that care must be taken in specifying the orientation of the reference frame in either the EULER_FRAME_A or EULER_FRAME_B with respect to each other. If necessary, this should be documented in an ICD. The order of the transformation is from left to right, where the leftmost integer represents the first rotation axis.

3.2.5.4.2 Additional, but not recommended, valid values for the EULER_ROT_SEQ are: 121, 131, 212, 232, 313, 323. These are discouraged as their use can cause confusion. To specify a repeated axis rotation in the APM, the appropriate keywords should be used to specify the axis rotation, even though keywords will be repeated (e.g., a sequence of 121 shall have the keywords X_ANGLE, Y_ANGLE, X_ANGLE). See figure 3-6 for a full example.

3.2.5.4.3 Specification of Euler angle rotations around only one or two axes may be handled by entering the appropriate sequence for the desired one or two axis rotation and freely choosing the final axis of rotation and giving a value of zero for the rotation value. Therefore, this standard does not allow for a specification of less than three Euler rotation axes (e.g., for a Y then X rotation, EULER_ROT_SEQ = 212, or 213 are permissible, with a value of 0 for the final rotation; however EULER_ROT_SEQ = 21 is not). While repeated Euler rotation axes are permissible in a sequence, sequential rotations about the same axis are not.

3.2.5.4.4 Euler angle and rate ordering should be consistent with the order given in the EULER_ROT_SEQ keyword.

3.2.5.5 SPIN STABILIZED

Care must be taken when using the keywords for Spin Stabilized Spacecraft. For reference frames not enumerated in annex A (nor defined in reference [E4]), 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 [E4].

3.2.6 APM KEYWORD SET

3.2.6.1 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.

3.2.6.2 The header shall include the CREATION_DATE keyword with the value set to the Coordinated Universal Time (UTC) when the file was created, formatted according to reference [4]. A description of APM header keywords and values is provided in table 3-1.

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

3.2.6.4 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 omitted.

3.2.6.5 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 message provider must provide all those elements necessary to specify a unique attitude, with the exception as noted in 3.2.5.4.3 regarding Euler angles or rates.

3.2.6.6 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.

3.3 APM EXAMPLES

Figures 3-1 through 3-8 are examples of Attitude Parameter Messages.

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


COMMENT          GEOCENTRIC, CARTESIAN, EARTH FIXED
COMMENT          OBJECT_ID:  1997-009A
COMMENT $ITIM  = 1997 NOV 21 22:26:18.40000000, $ original launch time
OBJECT_NAME    = TRMM
OBJECT_ID      = 1997-009A
CENTER_NAME    = EARTH
TIME_SYSTEM    = UTC

COMMENT          Current attitude for orbit 335
COMMENT          Attitude state quaternion
COMMENT          Accuracy of this attitude is 0.02 deg RSS.

EPOCH          = 2003-09-30T14:28:15.1172
Q_FRAME_A      = SC_BODY_1
Q_FRAME_B      = ITRF-97
Q_DIR          = A2B

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

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

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


COMMENT          GEOCENTRIC, CARTESIAN, EARTH FIXED
COMMENT          OBJECT_ID:  1999-068A
COMMENT $ITIM  = 1999 DEC 18 $ original launch time

OBJECT_NAME    = TERRA
OBJECT_ID      = 1999-068A
CENTER_NAME    = EARTH
TIME_SYSTEM    = UTC

COMMENT          Current attitude for orbit 335
COMMENT          Attitude state quaternion
COMMENT          SC_BODY_A references EO-1 body frame
COMMENT          OPM = EO1_2003_09_30_1900 2100.ephem

EPOCH          = 2003-09-30T14:28:15.1172
Q_FRAME_A      = SC_BODY_1
Q_FRAME_B      = SC_BODY_A
Q_DIR          = A2B

Q1             = 0.00005
Q2             = 0.00362
Q3             = 0.00013
QC             = 0.99934
```

Figure 3-2: APM File Example Using Frame of Another Spacecraft

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

COMMENT          OBJECT_ID:  1999-068A
COMMENT $ITIM  = 1999 DEC 18 $ original launch time

OBJECT_NAME    = TERRA
OBJECT_ID      = 1999-068A
CENTER_NAME    = EARTH
TIME_SYSTEM    = UTC

COMMENT          Current attitude for orbit 335
COMMENT          Attitude state quaternion
COMMENT          Defines orientation between the body axes and DSS_1 sensor.

EPOCH          = 2003-09-30T14:28:15.1172
Q_FRAME_A      = DSS_1
Q_FRAME_B      = SC_BODY_1
Q_DIR          = A2B

Q1             = 0.07481
Q2             = 0.38175
Q3             = 0.30317
QC             = 0.86992
```

Figure 3-3: APM File Example Describing Sensor Frame to Body Frame Transform

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

COMMENT          OBJECT_ID:  1999-068A
COMMENT $ITIM  = 1999 DEC 18 $ original launch time

OBJECT_NAME    = TERRA
OBJECT_ID      = 1999-068A
CENTER_NAME    = EARTH
TIME_SYSTEM    = UTC

COMMENT          Current attitude for orbit 335
COMMENT          Attitude state quaternion
COMMENT          Defines orientation of MODIS (INSTRUMENT_A).

EPOCH          = 2003-09-30T14:28:15.1172
Q_FRAME_A      = INSTRUMENT_A
Q_FRAME_B      = ITRF-97
Q_DIR          = A2B

Q1             = 0.32915
Q2             = 0.12209
Q3             = 0.84888
QC             = 0.39517
```

Figure 3-4: APM File Example Describing Orientation of Instrument

```
CCSDS_APM_VERS  = 1.0
CREATION_DATE   = 2004-02-14T19:23:57
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           Attitude state quaternion
EPOCH           = 2004-02-14T14:28:15.1172
Q_FRAME_A       = SC_BODY_1
Q_FRAME_B       = ITRF-97
Q_DIR           = A2B

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

COMMENT           Euler rates
EULER_FRAME_A   = SC_BODY_1
EULER_FRAME_B   = ITRF-97
EULER_DIR       = A2B
EULER_ROT_SEQ   = 312
RATE_FRAME      = EULER_FRAME_A
Z_RATE          = 0.02156  [deg/s]
X_RATE          = 0.1045   [deg/s]
Y_RATE          = 0.03214  [deg/s]
```

Figure 3-5: APM File Example with Euler Angle Rates

```
CCSDS_APM_VERS  = 1.0
CREATION_DATE   = 2006-03-13T13:13:33
ORIGINATOR      = GSFC

OBJECT_NAME     = GOES-P
OBJECT_ID       = 2006-003A
CENTER_NAME     = EARTH
TIME_SYSTEM     = UTC
COMMENT           GEOSYNCHRONOUS, CARTESIAN, EARTH FIXED

COMMENT OBJECT_ID: 2006-003A
COMMENT $ITIM  = 2006 FEB 5 03:23:45.60000000, $ original launch time

COMMENT           Attitude state quaternion
EPOCH           = 2006-03-12T09:56:39.4987
Q_FRAME_A       = SC_BODY_1
Q_FRAME_B       = ITRF-97
Q_DIR           = A2B

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

COMMENT           Euler rates
EULER_FRAME_A   = SC_BODY_1
EULER_FRAME_B   = ITRF-97
EULER_DIR       = A2B
EULER_ROT_SEQ   = 212
RATE_FRAME      = EULER_FRAME_A
Y_ANGLE         = -26.78 [deg ]
X_ANGLE         =  46.26 [deg ]
Y_ANGLE         = 144.10 [deg ]
Y_RATE          = 0.1045   [deg/s]
X_RATE          = 0.03214  [deg/s]
Y_RATE          = 0.02156  [deg/s]
```

Figure 3-6: APM File Example with Euler Angle Rates (Repeated Axis)

```
CCSDS_APM_VERS   = 1.0
CREATION_DATE    = 2008-03-08T13:13:33
ORIGINATOR       = JSC

OBJECT_NAME      = ISS
OBJECT_ID        = 2008-003A
CENTER_NAME      = EARTH
TIME_SYSTEM      = MET
COMMENT            International Space Station, Kibo segment

COMMENT    OBJECT_ID: 2008-003A
COMMENT    MET Relative to the following Epoch:
COMMENT    UTC   2008-03-12T06:54:37

COMMENT            Attitude state quaternion
EPOCH            = 0000-045T15:43:28.93
Q_FRAME_A         = SC_BODY_1
Q_FRAME_B        = J2000
Q_DIR             = A2B

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

COMMENT            Euler rates
EULER_FRAME_A    = SC_BODY_1
EULER_FRAME_B    = J2000
EULER_DIR         = A2B
EULER_ROT_SEQ    = 123
RATE_FRAME        = EULER_FRAME_A
X_RATE           = 0.05901    [deg/s]
Y_RATE           = 0.00348   [deg/s]
Z_RATE           = 0.00214   [deg/s]
```

Figure 3-7: APM File Example with Mission Elapsed Time

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

OBJECT_NAME     = MARS SPIRIT
OBJECT_ID       = 2004-003A
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_A        = INSTRUMENT_A
Q_FRAME_B       = ITRF-97
Q_DIR            = A2B

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

COMMENT           Attitude specified as Euler elements
EULER_FRAME_A   = INSTRUMENT_A
EULER_FRAME_B   = ITRF-97
EULER_DIR        = A2B
EULER_ROT_SEQ   = 312
RATE_FRAME       = EULER_FRAME_A
Z_ANGLE         = -53.3688 [deg]
X_ANGLE         = 139.7527 [deg]
Y_ANGLE         = 25.0658  [deg]
Z_RATE          = 0.02156  [deg/s]
X_RATE          = 0.1045   [deg/s]
Y_RATE          = 0.03214  [deg/s]

COMMENT           Spacecraft Parameters
I11             = 6080.0   [kg*m**2]
I22             = 5245.5   [kg*m**2]
I33             = 8067.3   [kg*m**2]
I12             = -135.9   [kg*m**2]
I13             = 89.3     [kg*m**2]
I23             = -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   = INSTRUMENT_A
MAN_TOR_1       = -1.25    [N*m]
MAN_TOR_2       = -0.5     [N*m]
MAN_TOR_3       = 0.5      [N*m]
```

Figure 3-8: 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

4.2.1.1 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.

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

4.2.1.3 Table 4-1 outlines the contents of an AEM.

Table 4-1: AEM File Layout Specifications

Item			Obligatory?
Header			Yes
Body	Segment 1	Metadata 1	Yes
		Data 1	
	Segment 2	Metadata 2	No
		Data 2	
	. . .	. . .	No
	Segment n	Metadata n	No
		Data n	

4.2.2 AEM HEADER

4.2.2.1 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.

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

Table 4-2: AEM Header

Keyword	Description	Normative Values / Examples	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
COMMENT	Comments (allowed after AEM version number and META_START and before a data block of ephemeris lines). Each comment line shall begin with this keyword.	This is a comment.	No
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 1996-12-18T14:28:15.1172	Yes
ORIGINATOR	Creating agency (value should be specified in an ICD).	CNES, ESOC, GSFC, GSOC, JPL, JAXA, etc.	Yes

4.2.3 AEM METADATA

4.2.3.1 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.

4.2.3.2 Only those keywords shown shall be used in AEM 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 4-3: AEM Metadata

Keyword	Description	Normative Values / Examples	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	Spacecraft name of the object corresponding to the attitude data to be given. 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 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 [2]). 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 [3]).	EARTH EARTH BARYCENTER MOON SOLAR SYSTEM BARYCENTER SUN JUPITER BARYCENTER STS 106 EROS	No

Keyword	Description	Normative Values / Examples	Obligatory

`REF_FRAME_A`	The name of the reference frame specifying one frame of the transformation, whose direction is specified using the keyword ATTITUDE_DIR. The full set of values is enumerated in annex A, with an excerpt provided in the 'Values / Examples' column. For a definition of these various frames, the reader is directed to *Navigation Definitions and Conventions* (reference [E4]).
	Note that if a reference frame is to be used that does not appear in [E4], a description should be placed in an ICD.
		`ICRF`
		`ITRF-93`
		`ITRF-97`
		`ITRF2000`
		`ITRFxxxx`
		`TOD`
		`EME2000`
		`LVLH`
		`NTW`
		`SC_BODY_1`
		`INSTRUMENT_A`
			Yes

`REF_FRAME_B`	Name of the reference frame specifying the second portion of the transformation, whose direction is specified using the keyword ATTITUDE_DIR. The full set of values is enumerated in annex A, with an excerpt provided in the 'Values / Examples' column. For a definition of these various frames, the reader is directed to reference [E4]. Note that if a frame is used that does not appear in [E4], a description should be placed in an ICD.	`SC_BODY_1`
		`STARTRACKER_1`
		`INSTRUMENT_A`
		`ICRF`
		`ITRF2000`
		`EME2000`
			Yes

`ATTITUDE_DIR`	Rotation direction of the attitude specifying from which frame the transformation is to: - A2B specifies a transformation from the REF_FRAME_A to the REF_FRAME_B - B2A specifies a transformation from the REF_FRAME_B to the REF_FRAME_A.	`A2B` `B2A`	Yes
`TIME_SYSTEM`	Time system used for both attitude ephemeris data and metadata (also see tables 4-3 and 4-4). The full set of allowed values is enumerated in annex A, with an excerpt provided in the 'Values/Examples' column. Explanations of these time systems can be found in *Navigation Definitions and Conventions* (reference [E4]).	`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.	`1996-12-18T14:28:15.1172` `2001-277T07:22:54`	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.	`1996-12-18T14:28:15.1172`
		`2001-277T07:22:54`
			No

Keyword	Description	Normative Values / Examples	Obligatory
STOP_TIME	End of TOTAL time span covered by the attitude ephemeris data immediately following this metadata block. The STOP_TIME time tag for the block of attitude ephemeris data must be equal to or less than the START_TIME time tag of the next block.	1996-12-18T14:28:15.1172 2001-277T07:22:54	Yes
ATTITUDE_TYPE	The format of the data lines in the message. This keyword must have a value from the set specified at the right. See 4.2.5 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	The placement of the scalar portion of the quaternion (QC) in the attitude data. This keyword shall be provided if the ATTITUDE_TYPE used in the message denotes quaternions.	FIRST LAST	No
EULER_ROT_SEQ	The rotation sequence of the Euler angles that rotate from REF_FRAME_A to REF_FRAME_B, or vice versa, as specified using the ATTITUDE_DIR keyword. This keyword is applicable only if ATTITUDE_TYPE specifies the use of Euler angles. See 4.2.5.4.5 for details on rotation sequence conventions.	131 231 321	No
RATE_FRAME	The frame of reference in which Euler rates are specified. The allowed values are shown at right. This keyword is applicable only if ATTITUDE_TYPE specifies the use of rates in conjunction with either quaternions or Euler angles.	REF_FRAME_A REF_FRAME_B	No
INTERPOLATION _METHOD	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 end of a metadata block within the message. 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

4.2.3.3 Keywords START_TIME, USEABLE_START_TIME, USEABLE_STOP_TIME, and STOP_TIME all denote a spacecraft event time.

4.2.4 AEM DATA

4.2.4.1 See 4.2.5, Attitude Ephemeris Data Lines, for specifications regarding AEM data.

4.2.4.2 The Data section of the AEM shall be delineated by the 'DATA_START' and 'DATA_STOP' keywords. These keywords are intended to facilitate parsing, and will also serve to advise the recipient that all the attitude data records associated with the immediately preceding AEM Metadata section have been received (the rationale for including this is that data volumes can be very large, so knowing when the data begins and ends is desirable). The AEM recipient may process the 'DATA_STOP' keyword as a 'local' end-of-file marker.

4.2.5 ATTITUDE EPHEMERIS DATA LINES

4.2.5.1 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, with the exception of Euler angle data for which the order of angle data must correspond with the sequence given by EULER_ROT_SEQ.

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

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, X_RATE, Y_RATE, Z_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, X_RATE, Y_RATE, Z_RATE
Euler Angle Options (note that keywords and values appear only in Metadata)		
ATTITUDE_TYPE	EULER_ANGLE	Epoch, X_ANGLE, Y_ANGLE, Z_ANGLE
	EULER_ANGLE/ RATE	Epoch, X_ANGLE, Y_ANGLE, Z_ANGLE, X_RATE, Y_RATE, Z_RATE
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, NUTATION_PHASE

4.2.5.3 FORMAT

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

4.2.5.3.2 See 'CREATION_DATE' in table 3-1 or see reference [4] for examples of how to format the EPOCH. Note that any epoch specified denotes spacecraft event time.

4.2.5.3.3 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-xxT23:59:58.000 .. 200x-xx-xxT23:59:59.000 .. 200x-xx-xxT23:59:60.000 .. 200x-xx-xxT00:00:00.000)

4.2.5.4 TECHNICAL

4.2.5.4.1 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.

4.2.5.4.2 The TIME_SYSTEM value must remain fixed within an AEM.

4.2.5.4.3 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.

4.2.5.4.4 The generalization of the attitude representation in this message may lead to ambiguity. To avoid this ambiguity, the keyword ATTITUDE_DIR is provided to specify the direction of the attitude rotation. There are two values for this keyword, A2B or B2A, which uniquely specify the direction of the attitude rotation; e.g., for A2B, the attitude parameters specify a rotation from the REF_FRAME_A to the REF_FRAME_B reference frame.

4.2.5.4.5 Rates specified in the AEM should be given in the rotation direction consistent with the value specified in the ATTITUDE_DIR keyword. Therefore, if ATTITUDE_DIR is ‘A2B’, then the rates given in the message should be of the REF_FRAME_A with respect to the REF_FRAME_B reference frame, and vice versa, expressed in the appropriate frame. When quaternion derivatives or spin axis rates and nutation are given, no additional information is necessary as these quantities are expressed in the correct reference frame. However, when Euler rates are given, it is necessary to specify the reference frame that expresses the rates, hence the keyword RATE_FRAME. Euler rates are expressed in either the REF_FRAME_A or the REF_FRAME_B, as denoted by the value of the RATE_FRAME keyword. For further clarification and relevant equations, the reader is referred to reference [E4].

4.2.5.4.6 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.

4.2.5.5 QUATERNION

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 non-negative ($0 \leq QC \leq 1$), thereby constraining the rotation angle to -180 degrees $\leq \Phi \leq$ 180 degrees and avoiding large attitude errors around ± 180 degrees.

4.2.5.6 EULER ANGLES

4.2.5.6.1 Valid and recommended values for the EULER_ROT_SEQ are: 123, 132, 213, 231, 312, 321. Again, Euler angle ephemeris data should be given in the order specified by the EULER_ROT_SEQ (e.g., for a 321 sequence, the angular information would appear in the order Z_ANGLE, Y_ANGLE, X_ANGLE). Note that care must be taken in specifying the orientation of the REF_FRAME_* with respect to each other. If necessary, this should be documented in an ICD. The order of the transformation is from left to right, where the leftmost integer represents the first rotation axis.

4.2.5.6.2 Additional, but not recommended, valid values for the EULER_ROT_SEQ are: 121, 131, 212, 232, 313, 323. These are discouraged as their use can cause confusion. To specify a repeated axis rotation in the AEM, the Euler angle ephemeris data must match the EULER_ROT_SEQ specified (e.g., for a 121 rotation, the ephemeris data should be ordered as X_ANGLE, Y_ANGLE, X_ANGLE).

4.2.5.6.3 Specification of Euler angle rotations around only one or two axes may be handled by entering the appropriate sequence for the desired one or two axis rotation and freely choosing the final axis of rotation and giving a value of zero for the rotation value. Therefore, this standard does not allow for a specification of less than three Euler rotation axes (e.g., for a Y then X rotation, EULER_ROT_SEQ = 212, or 213 are permissible, with a value of 0 for the final rotation; however EULER_ROT_SEQ = 21 is not). While repeated Euler rotation axes are permissible in a sequence, sequential rotations about the same axis are not.

4.2.6 AEM KEYWORD SET

4.2.6.1 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.

4.2.6.2 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 [4]. A description of AEM header keywords and values is provided in table 4-2.

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

4.2.6.4 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.)

4.2.6.5 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 (e.g., METADATA, DATA, METADATA, DATA, etc.).

4.2.6.6 Before each METADATA group the string 'META_START' shall appear on a separate line and after each METADATA group (and before the associated DATA_START keyword) the string 'META_STOP' shall appear on a separate line.

4.3 AEM EXAMPLE

4.3.1 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

META_START
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.
OBJECT_NAME            = MARS GLOBAL SURVEYOR
OBJECT_ID              = 1996-062A
CENTER_NAME            = mars barycenter
REF_FRAME_A            = EME2000
REF_FRAME_B            = SC_BODY_1
ATTITUDE_DIR           = A2B
TIME_SYSTEM            = UTC
START_TIME             = 1996-11-28T21:29:07.2555
USEABLE_START_TIME     = 1996-11-28T22:08:02.5555
USEABLE_STOP_TIME      = 1996-11-30T01:18:02.5555
STOP_TIME              = 1996-11-30T01:28:02.5555
ATTITUDE_TYPE          = QUATERNION
QUATERNION_TYPE        = LAST
INTERPOLATION_METHOD = hermite
INTERPOLATION_DEGREE = 7
META_STOP

DATA_START
1996-11-28T21:29:07.2555 0.56748   0.03146   0.45689   0.68427
1996-11-28T22:08:03.5555 0.42319   -0.45697  0.23784   0.74533
1996-11-28T22:08:04.5555 -0.84532  0.26974   -0.06532  0.45652
        < intervening data records omitted here >
1996-11-30T01:28:02.5555  0.74563   -0.45375  0.36875   0.31964
DATA_STOP

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_A            = EME2000
REF_FRAME_B            = SC_BODY_1
ATTITUDE_DIR           = A2B
TIME_SYSTEM            = UTC
START_TIME             = 1996-12-18T12:05:00.5555
USEABLE_START_TIME     = 1996-12-18T12:10:00.5555
USEABLE_STOP_TIME      = 1996-12-28T21:23:00.5555
STOP_TIME              = 1996-12-28T21:28:00.5555
ATTITUDE_TYPE          = QUATERNION
QUATERNION_TYPE        = LAST
META_STOP

DATA_START
1996-12-18T12:05:00.5555  -0.64585  0.018542   -0.23854  0.72501
1996-12-18T12:10:05.5555  0.87451   -0.43475   0.13458   -0.16767
1996-12-18T12:10:10.5555  0.03125   -0.65874   0.23458   -0.71418
        < intervening records omitted here >
1996-12-28T21:28:00.5555  -0.25485  0.58745   -0.36845   0.67394
DATA_STOP
```

Figure 4-1: AEM Example

4.3.2 Figure 4-2 is an example of an AEM describing a spinning spacecraft. Note that some attitude ephemeris lines were omitted.

```
CCSDS_AEM_VERS = 1.0
CREATION_DATE       = 2008-071T17:09:49
ORIGINATOR          = GSFC FDF

META_START
OBJECT_NAME         = ST5-224
OBJECT_ID           = 2006224
CENTER_NAME         = EARTH
REF_FRAME_A         = J2000
REF_FRAME_B         = SC_BODY_1
ATTITUDE_DIR        = A2B
TIME_SYSTEM         = UTC
START_TIME          = 2006-090T05:00:00.071
USEABLE_START_TIME = 2006-090T05:00:00.071
USEABLE_STOP_TIME  = 2006-090T05:00:00.946
STOP_TIME           = 2006-090T05:00:00.946
ATTITUDE_TYPE       = SPIN
META_STOP

DATA_START
COMMENT                Spin KF ground solution, SPINKF rates
   2006-090T05:00:00.071   2.6862511e+002   6.8448486e+001  1.5969509e+002 -1.0996528e+002
   2006-090T05:00:00.196   2.6863990e+002   6.8432197e+001  1.4593720e+002 -1.0996493e+002
   2006-090T05:00:00.321   2.6864591e+002   6.8412960e+001  1.3218766e+002 -1.0996455e+002
   2006-090T05:00:00.446   2.6863697e+002   6.8392049e+001  1.1845280e+002 -1.0996402e+002
   2006-090T05:00:00.571   2.6861072e+002   6.8371266e+001  1.0473305e+002 -1.0996370e+002
   2006-090T05:00:00.696   2.6856625e+002   6.8353279e+001  9.1030304e+001 -1.0996339e+002
   2006-090T05:00:00.821   2.6850631e+002   6.8340398e+001  7.7341548e+001 -1.0996317e+002
   2006-090T05:00:00.946   2.6843571e+002   6.8332398e+001  6.3662262e+001 -1.0996304e+002
DATA_STOP
```

Figure 4-2: AEM Spinner Example

5 ADM SYNTAX

5.1 INTRODUCTION

This section details the syntactical requirements for attitude messages. All APM and AEM messages shall observe the syntax described in subsections 5.2 through 5.6.

5.2 APM

The APM shall be a plain text file, using keyword descriptions given in 3.2.1 through 3.2.6.

5.3 AEM

The AEM shall be a plain text file, using the keyword descriptions given in 4.2.1 through 4.2.6.

5.4 LINES

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

5.4.2 Only printable ASCII characters and blanks shall be used. Control characters (such as TAB, etc.) shall not be used, except as indicated below for the termination of lines.

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

5.4.4 Comment lines shall be optional. See 5.8.2 for details regarding the placement of comment lines in an APM. See 5.8.3 for details regarding the placement of comment lines in an AEM.

5.4.5 APM and 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.

5.5 KEYWORDS

5.5.1 All header, metadata, and APM data lines, with exceptions as noted in 5.5.8, shall use ‘keyword = value’ notation, abbreviated as KVN.

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

5.5.3 Keywords must be uppercase and must not contain blanks.

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

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

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

5.5.7 The order of occurrence of obligatory and optional KVN assignments shall be fixed as shown in tables 3-1, 3-2, and 3-3 for the APM, and as shown in tables 4-2 and 4-3 for the AEM. Exceptions to this rule for the APM shall be for quaternion and Euler angle ordering, as described in 3.2.5.

5.5.8 The keywords COMMENT, META_START, META_STOP, DATA_START and DATA_STOP, and AEM data lines are exceptions to the KVN syntax.

5.6 VALUES

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

5.6.2 Blanks shall not appear within numeric values and time values.

5.6.3 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:

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

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

5.6.4.1 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. At least 1 digit is required before and after a decimal point. The number of digits shall be 16 or fewer.

5.6.4.2 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.

5.6.5 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 (reference [6]). Floating-point numbers in IEEE extended-single or IEEE extended-double precision may be represented, but do require an ICD between participating agencies because of their implementation-specific attributes (reference [6]). Note that NaN, +Inf, -Inf, and -0 are not supported values.

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

5.6.7 A non-empty value field must be specified for each keyword provided, except as noted in 5.5.8.

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

5.6.9 In value fields that represent a timetag or epoch, one of the following two formats shall be used:

YYYY-MM-DD:Thh:mm:ss[.d∏d][Z]

or

YYYY-DDDThh:mm:ss[.d∏d][Z]

where ‘YYYY’ is the year, ‘MM’ is the two-digit month, ‘DD’ is the two-digit day, ‘DDD’ is the three-digit day of year, ‘T’ is constant, ‘hh:mm:ss[.d∏d] is the time in hours, minutes seconds, and optional fractional seconds; ‘Z’ is an optional time code terminator (the only permitted value is ‘Z’ for Zulu, i.e., UTC). All fields shall have leading zeros. See reference [4], ASCII Time Code A and B.

5.7 UNITS

5.7.1 APM RESTRICTIONS

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

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

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

c) multiplication of units shall be denoted with a single asterisk '*' (e.g., '[N*m]');

d) exponents of units shall be denoted with a double asterisk '**' (e.g., '[kg*m**2]').

5.7.2 AEM RESTRICTIONS

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

- dimensionless: EPOCH, Q1, Q2, Q3, QC;
- 1/s: Q1_DOT, Q2_DOT, Q3_DOT, QC_DOT;
- deg: X_ANGLE, Y_ANGLE, Z_ANGLE, SPIN_ALPHA, SPIN_DELTA, SPIN_ANGLE, NUTATION, NUTATION_PHASE;
- deg/s: X_RATE, Y_RATE, Z_RATE, SPIN_ANGLE_VEL;
- s: NUTATION_PER.

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

5.8 COMMENTS

5.8.1 GENERAL

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

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

5.8.1.3 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 or AEM producer should put certain information into comments and use the ICD to provide further specifications.

5.8.1.4 The following comment should be provided in an APM or AEM message: information regarding the genesis, history, interpretation, intended use, etc., of the attitude state and any additional information that may be of use to the receiver of the APM or AEM. Example:

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

5.8.2 APM SPECIFIC

5.8.2.1 Comments are optional and may appear only at the beginning of the APM Header and APM Metadata sections, as shown in tables 3-1 and 3-2. In the APM Data section, comments shall appear only 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.

5.8.2.2 The following type of comment may be provided as part of the APM to provide information regarding the 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.

5.8.3 AEM SPECIFIC

5.8.3.1 General

Comments are optional and may appear only after the specification of the keyword CCSDS_AEM_VERS, at the beginning of Metadata sections (only after META_START and before OBJECT_NAME), and immediately following the DATA_START keyword. Comments must not appear between attitude ephemeris data lines, nor after the DATA_STOP keyword.

5.8.3.2 AEM Accuracy vs. Efficiency

The producer of an AEM may optionally report in comment lines the expected accuracy of the attitude ephemeris. The user may then use this additional information to smooth or otherwise compress the data without affecting the accuracy of the attitude, but is not required to utilize this information to successfully process the message. 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).

6 SECURITY

6.1 INTRODUCTION

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

6.2 SECURITY CONCERNS WITH RESPECT TO THIS RECOMMENDED STANDARD

6.2.1 DATA PRIVACY

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

6.2.2 DATA INTEGRITY

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

6.2.3 AUTHENTICATION OF COMMUNICATING ENTITIES

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

6.2.4 DATA TRANSFER BETWEEN COMMUNICATING ENTITIES

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

6.2.5 CONTROL OF ACCESS TO RESOURCES

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

6.2.6 AVAILABILITY OF RESOURCES

This Recommended Standard assumes an adequate availability of resources on the systems on which provider formatting and recipient processing are performed.

6.2.7 AUDITING OF RESOURCE USAGE

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

6.3 POTENTIAL THREATS AND ATTACK SCENARIOS

There are no known potential threats or attack scenarios that apply specifically to the technologies specified in this Recommended Standard. Potential threats or attack scenarios applicable to the systems and networks on which this Recommended Standard is implemented should be addressed by the management of those systems and networks. 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 data formatted in compliance with this Recommended Standard.

6.4 CONSEQUENCES OF NOT APPLYING STATED SECURITY TO THE TECHNOLOGY

There are no known consequences of not applying the security to the technologies specified in this Recommended Standard. The consequences of not applying security to the systems and networks on which this Recommended Standard is implemented could include potential loss, corruption, and theft of data.

6.5 DATA SECURITY IMPLEMENTATION SPECIFICS

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

ANNEX A

VALUES FOR SELECTED KEYWORDS

(NORMATIVE)

A1 OVERVIEW

The values in this annex represent the acceptable values for selected keywords. Each keyword's values delineated here are present in either an APM or AEM message. For details and descriptions of the keyword interpretations, the reader is directed to reference [E4]. If exchange partners wish to use different settings, they should be documented in an ICD.

A2 TIME_SYSTEM METADATA KEYWORD

TIME_SYSTEM Value	Meaning/Description
GMST	Greenwich Mean Sidereal Time
GPS	Global Positioning System
MET	Mission Elapsed Time
MRT	Mission Relative Time
SCLK	Spacecraft Clock (receiver)
TAI	International Atomic Time
TCB	Barycentric Coordinated Time
TDB	Barycentric Dynamical Time
TT	Terrestrial Time
UT1	Universal Time
UTC	Coordinated Universal Time

Note that if MET or MRT are chosen as the TIME_SYSTEM, then the epoch of either the start of the mission for MET, or of the event for MRT, should either be given in a comment in the message, or provided in an ICD. The time system for the start of the mission or the event should also be provided in the comment or the ICD. If these values are used for the TIME_SYSTEM, then the times given in the file denote a duration from the mission start or