The Consultative Committee for Space Data Systems

Recommendation for Space Data System Standards

ATTITUDE DATA MESSAGES

RECOMMENDED STANDARD

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PROPOSED PINK BOOK

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In those instances when a new version of a **Recommended Standard** is issued, existing CCSDS-related member standards and implementations are not negated or deemed to be non-CCSDS compatible. It is the responsibility of each member to determine when such standards or implementations are to be modified. Each member is, however, strongly encouraged to direct planning for its new standards and implementations towards the later version of the Recommended Standard.

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 Recommended Standard 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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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 and commercial or governmental spacecraft operators: 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 E 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 E3.

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) is available. 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.

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 ANNEX A provides the Implementation Conformance Statement (ICS) requirements list.

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

1.4.7 ANNEX C details the conventions relative to ADM data used in this document.

1.4.8 ANNEX D gives the complete list of changes between ADM versions 1 and 2.

1.4.9 ANNEX E 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.

1.4.10 ANNEX F 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.

1.4.11 ANNEX G is a list of abbreviations and acronyms applicable to the ADM.

1.4.12 ANNEX H is a list of informative references.

1.4.13 ANNEX I is relative to security, SANA, and patents considerations.

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] *United Nations Office of Outer Space Affairs satellite designator/index, searchable at* <http://www.unoosa.org/oosa/osoindex>

[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-4. Blue Book. Issue 4. Washington, D.C.: CCSDS, November 2010.

[5] *XML Specification for Navigation Data Messages*. The XML Specification for Navigation Data Messages Recommended Standard describes an integrated XML schema set that is suited to interagency exchanges of navigation data messages, CCSDS 505.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, December 2010.

[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-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, November 2009.

NOTE – A list of informative references can be found in ANNEX H.

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.

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 accompanied by a corresponding 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 [H4].

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 [H4]) 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, reaction wheel data, other data from momentum exchange devices, 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 [H4]) 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) whether the values are normative (N) values or just examples (E);

d) values (either the list of all normative values or examples);

e) whether the item is mandatory 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	N/E	Values	Mandatory
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.	N	2.0	Yes
COMMENT	Comments (allowed at the beginning of the APM Header after the APM version number). Each comment line shall begin with this keyword.	E	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.	E	2001-11-06T11:17:33 2001-101T11:17:33	Yes
ORIGINATOR	Creating agency. The value for the "ORIGINATOR" keyword "should" come from the SANA Registry.	E	CNES ESOC GSFC GSOC JPL JAXA Other agency	Yes
MESSAGE_ID	ID that uniquely identifies a message from a given originator. The format and content of the message identifier value are at the discretion of the originator.	201113719185 ABC-12_34	**No**	MESSAGE_ID

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) whether the values are normative (N) values or just examples (E);

d) values (either the list of all normative values or examples);

e) whether the item is mandatory 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 H are the best known sources for authorized values to date.

Table 3-2: APM Metadata

Keyword	Description	N/E	Values	Mandatory
COMMENT	Comments (allowed only at the beginning of the APM Metadata before OBJECT_NAME). Each comment line shall begin with this keyword.	E	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 international designators from the UN Office of Outer Space Affairs.	E	EUTELSAT W1 MARS PATHFINDER	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, it is recommended to use names from the UN Office of Outer Space Affairs.	E	2000-052A	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]).	E	EARTH EARTH BARYCENTER MOON	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 B, with an excerpt provided in the 'Normative Values/Examples' column. Explanations of these time systems can be found in *Navigation Definitions and Conventions* (reference [H4]).	E	UTC TAI	Yes

3.2.4 APM DATA

3.2.4.1 Table 3-3 provides an overview of the six logical blocks in the APM Data section (attitude quaternion, attitude Euler angles, spin data, angular velocity data, spacecraft parameters, maneuver parameters), and specifies for each data item:

a) the keyword to be used;

b) a short description of the item;

c) whether the values are normative (N) values or just examples (E);

d) values (either the list of all normative values or examples);

e) whether the item is mandatory or optional.

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

3.2.4.3 There shall be as many logical blocks as necessary.

3.2.4.4 Any particular type of block may be repeated several times.

Table 3-3: APM Data

Keyword	Description	N/E	Values / units	Mandatory
COMMENT	One or more comment line(s). Each comment line shall begin with this keyword.	E	This is a comment	No
EPOCH	Epoch of the attitude elements & optional logical blocks.	E	`2001-11-06T11:17:33`	Yes
Block: Attitude Quaternion *All mandatory elements are to be provided if the block is present.* *See ANNEX C for conventions and further detail.*				
COMMENT	One or more comment line(s). Each comment line shall begin with this keyword.	E	This is a comment	No
QUAT_START	Indicator of start of data block	n/a	n/a	Yes
REF_FRAME_A	Name of the reference frame that defines the starting point of the transformation. The full set of values is enumerated in annex B. For a definition of these various frames, the reader is directed to reference [H4].	E	ICRF INSTRUMENT_A	Yes
REF_FRAME_B	Name of the reference frame that defines the end point of the transformation. The full set of values is enumerated in annex B. For a definition of these various frames, the reader is directed to *Navigation Definitions and Conventions* (reference [H4]).	E	SC_BODY_1 STARTRACKER	Yes

Keyword	Description	N/E	Values / units	Mandatory
Q1	e_1 * sin(θ/2) θ = rotation angle, e1 = 1st component of rotation axis	n/a	n/a	Yes
Q2	e_2 * sin(θ/2) θ = rotation angle, e2 = 2nd component of rotation axis	n/a	n/a	Yes
Q3	e_3 * sin(θ/2) θ = rotation angle, e3 = 3rd component of rotation axis	n/a	n/a	Yes
QC	cos(θ/2) θ = rotation angle	n/a	n/a	Yes
Q1_DOT	Derivative of Q_1	n/a	1/s	No
Q2_DOT	Derivative of Q_2	n/a	1/s	No
Q3_DOT	Derivative of Q_3	n/a	1/s	No
QC_DOT	Derivative of Q_C	n/a	1/s	No
QUAT_STOP	Indicator of end of data block	n/a	n/a	Yes
Block: Euler angle elements *All mandatory elements of the logical block are to be provided if the block is present.* *See ANNEX C for conventions and further detail.*				
COMMENT	One or more comment line(s). Each comment line shall begin with this keyword.	E	This is a comment	No
EULER_START	Indicator of start of data block	n/a	n/a	Yes
REF_FRAME_A	Name of the reference frame that defines the starting point of the transformation. The full set of values is enumerated in annex B. For a definition of these various frames, the reader is directed to reference [H4].	E	SC_BODY_1 STARTRACKER_1	Yes
REF_FRAME_B	Name of the reference frame that defines the end point of the transformation. The full set of values is enumerated in annex B.	E	LVLH SC_BODY_1	Yes
EULER_ROT_SEQ	Rotation sequence that defines the REF_FRAME_A to REF_FRAME_B transformation. The order of the transformation is from left to right, where the leftmost letter represents the rotation axis of the first rotation.	E	XYZ ZXZ	Yes
ANGLE_1	Angle of the first rotation	n/a	deg	Yes
ANGLE_2	Angle of the second rotation	n/a	deg	Yes
ANGLE_3	Angle of the third rotation	n/a	deg	Yes
ANGLE_1_DOT	Time derivative of angle of the first rotation	n/a	deg/s	No
ANGLE_2_DOT	Time derivative of angle of the second rotation	n/a	deg/s	No
ANGLE_3_DOT	Time derivative of angle of the third rotation	n/a	deg/s	No
EULER_STOP	Indicator of end of data block	n/a	n/a	Yes
Block: angular velocity vector *All mandatory elements are to be provided if the block is present.* *See ANNEX C for conventions and further detail.*				
COMMENT	One or more comment line(s). Each comment line shall begin with this keyword.	E	This is a comment	No
ANGVEL_START	Indicator of start of data block	n/a	n/a	Yes
DATA_TYPE	Type of data	N	ANGVEL	Yes

Keyword	Description	N/E	Values / units	Mandatory
REF_FRAME_A	Name of the reference frame that defines the starting point of the transformation. The full set of values is enumerated in annex B. For a definition of these various frames, the reader is directed to reference [H4].	E	SC_BODY_1 ICRF	Yes
REF_FRAME_B	Name of the reference frame that defines the end point of the transformation. The full set of values is enumerated in annex B.	E	ICRF INSTRUMENT_A	Yes
ANGVEL_FRAME	Reference frame in which the components of the angular velocity vector are given.	N	REF_FRAME_A REF_FRAME_B	Yes
ANGVEL_X	Component of the angular velocity vector on the X axis	n/a	deg/s	Yes
ANGVEL_Y	Component of the angular velocity vector on the Y axis	n/a	deg/s	Yes
ANGVEL_Z	Component of the angular velocity vector on the Z axis	n/a	deg/s	Yes
ANGVEL_STOP	Indicator of end of data block	n/a	n/a	Yes
Block: Spin *All mandatory elements are to be provided if the block is present.* *See ANNEX C for conventions and further detail.*				
COMMENT	One or more comment line(s). Each comment line shall begin with this keyword.	E	This is a comment	No
SPIN_START	Indicator of start of data block	n/a	n/a	Yes
REF_FRAME_A	The name of the reference frame that defines the starting point of the transformation. The full set of values is enumerated in annex B. For a definition of these various frames, the reader is directed to reference [H4].	E	SC_BODY_1 ICRF	Yes
REF_FRAME_B	The name of the reference frame that defines the end point of the transformation. The full set of values is enumerated in annex B.	E	ICRF SC_BODY_1	Yes
SPIN_ALPHA	Right ascension of spin axis vector	n/a	deg	Yes
SPIN_DELTA	Declination of the spin axis vector	n/a	deg	Yes
SPIN_ANGLE	Phase of the satellite about the spin axis	n/a	deg	Yes
SPIN_ANGLE_VEL	Angular velocity of satellite around spin axis	n/a	deg/s	Yes
NUTATION	Nutation angle of spin axis	n/a	deg	Yes
NUTATION_PER	Body nutation period of the spin axis	n/a	s	Yes
NUTATION_PHASE	Inertial nutation phase	n/a	deg	Yes
SPIN_STOP	Indicator of end of data block	n/a	n/a	Yes
Block: Inertia *All mandatory elements are to be provided if the block is present.* *See ANNEX C for conventions and further detail.*				
COMMENT	One or more comment line(s). Each comment line shall begin with this keyword.	E	This is a comment	No
INERTIA_START	Indicator of start of data block	n/a	n/a	Yes

Keyword	Description	N/E	Values / units	Mandatory
INERTIA_REF_FRAME	Coordinate system for the inertia tensor. Allowed values for this keyword are enumerated in annex B.	E	SC_BODY_1	Yes
IXX	Moment of Inertia about the X-axis	n/a	kg*m**2	Yes
IYY	Moment of Inertia about the Y-axis	n/a	kg*m**2	Yes
IZZ	Moment of Inertia about the Z-axis	n/a	kg*m**2	Yes
IXY	Inertia Cross Product of the X & Y axes	n/a	kg*m**2	Yes
IXZ	Inertia Cross Product of the X & Z axes	n/a	kg*m**2	Yes
IYZ	Inertia Cross Product of the Y & Z axes	n/a	kg*m**2	Yes
INERTIA_STOP	Indicator of end of data block	n/a	n/a	Yes
Block: Maneuver Parameters *All obligatory elements are to be provided if the block is present.* *See ANNEX C for conventions and further detail.*				
COMMENT	One or more comment line(s). Each comment line shall begin with this keyword.	E	This is a comment	No
MANEUVER_START	Indicator of start of data block	n/a	n/a	Yes
MAN_EPOCH_START	Epoch of start of maneuver	n/a	n/a	Yes
MAN_DURATION	Maneuver duration	n/a	s	Yes
MAN_REF_FRAME	Coordinate system for the torque vector. Allowed values for this keyword are enumerated in annex B.	n/a	n/a	Yes
MAN_TOR_X	1st component of the torque vector	n/a	N*m	Yes
MAN_TOR_Y	2nd component of the torque vector	n/a	N*m	Yes
MAN_TOR_Z	3rd component of the torque vector	n/a	N*m	Yes
MANEUVER_STOP	Indicator of end of data block	n/a	n/a	Yes

3.2.5 REMARKS

3.2.5.1 DATA FORMAT

3.2.5.1.1 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.

3.2.5.1.2 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 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.

3.2.5.2.2 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 angle.

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.

3.3 APM EXAMPLES

Figures 3-1 through 3-3 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

QUAT_START
REF_FRAME_A    = SC_BODY_1
REF_FRAME_B    = ITRF-97

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

Figure 3-1: APM File containing quaternion

```
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 given by Euler angles

EPOCH           = 2006-03-12T09:56:39.4987

COMMENT           Euler angles
EULER_START
DATA_TYPE       = SC_BODY_1
REF_FRAME_A     = EULER
REF_FRAME_B     = ITRF-97
EULER_ROT_SEQ   = YXY

ANGLE_1          = -26.78 [deg]
ANGLE_2          =  46.26 [deg]
ANGLE_3          = 144.10 [deg]
EULER_STOP
```

Figure 3-2: APM File Example with Euler Angles

```
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.

EPOCH           = 2004-02-14T14:28:15.1172

COMMENT           Attitude state quaternion
QUAT_START
REF_FRAME_A      = ITRF-97 INSTRUMENT_A
REF_FRAME_B     = INSTRUMENT_A ITRF-97

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

COMMENT           Spacecraft Parameters
DATA_START
DATA_TYPE       = INERTIA
IXX             = 6080.0   [kg*m**2]
IYY             = 5245.5   [kg*m**2]
IZZ             = 8067.3   [kg*m**2]
IXY             = -135.9   [kg*m**2]
IXZ             = 89.3     [kg*m**2]
IYZ             = -90.7    [kg*m**2]
QUAT_STOP

COMMENT           Data follows for 1 planned maneuver.

COMMENT           First attitude maneuver for: MARS SPIRIT
COMMENT           Impulsive, torque direction fixed in body frame
MANEUVER_START
MAN_EPOCH_START = 2004-02-14T14:29:00.5098
MAN_DURATION    = 3        [s]
MAN_REF_FRAME   = INSTRUMENT_A
MAN_TOR_X       = -1.25    [N*m]
MAN_TOR_Y       = -0.5     [N*m]
MAN_TOR_Z       = 0.5      [N*m]
MANEUVER_STOP
```

Figure 3-3: APM File Example with various contents

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 suitable 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			**Mandatory ?**
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) whether the values are normative (N) values or just examples (E);

d) values (either the list of all normative values or examples);

e) whether the item is mandatory or optional.

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

Table 4-2: AEM Header

Keyword	Description	N/E	Values	Mandatory
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.	N	2.0	Yes
COMMENT	One or more comment lines. Each comment line shall begin with this keyword.	E	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.	E	2001-11-06T11:17:33	Yes
ORIGINATOR	Creating agency.	E	CNES ESOC GSFC GSOC JPL JAXA	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) whether the values are normative (N) values or just examples (E);

d) values (either the list of all normative values or examples);

e) whether the item is mandatory 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	N/E	Values	Mandatory
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	n/a	Yes
COMMENT	Comments allowed only at the beginning of the Metadata section. Each comment line shall begin with this keyword.	E	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 international designators from the UN Office of Outer Space Affairs.	E	EUTELSAT W1	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, it is recommended to use names from the UN Office of Outer Space Affairs.	E	2000-052A	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]).	E	EARTH STS 106	No
REF_FRAME_A	Name of the reference frame that defines the starting point of the transformation. The full set of values is enumerated in annex B. For a definition of these various frames, the reader is directed to *Navigation Definitions and Conventions* (reference [H4]).	E	ICRF SC_BODY_1 INSTRUMENT_A	Yes
REF_FRAME_B	Name of the reference frame that defines the end point of the transformation. The full set of values is enumerated in annex B. For a definition of these various frames, the reader is directed to reference [H4].	E	SC_BODY_1 INSTRUMENT_A	Yes

Keyword	Description	N/E	Values	Mandatory
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 B. Explanations of these time systems can be found in *Navigation Definitions and Conventions* (reference [H4]).	E	UTC TAI	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.	E	1996-12-18T14:28:15.1172	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.	E	1996-12-18T14:28:15.1172	No
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.	E	1996-12-18T14:28:15.1172	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.	N	QUATERNION QUATERNION/DERIVATIVE QUATERNION/ANGVEL EULER_ANGLE EULER_ANGLE/DERIVATIVE EULER_ANGLE/ANGVEL SPIN SPIN/NUTATION	Yes
EULER_ROT_SEQ	The rotation sequence of the Euler angles that rotate from REF_FRAME_A to REF_FRAME_B. This keyword is applicable only if ATTITUDE_TYPE specifies the use of Euler angles.	E	ZXZ XYZ	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.	N	REF_FRAME_A REF_FRAME_B	No

Keyword	Description	N/E	Values	Mandatory
INTERPOLATION_METHOD	Recommended interpolation method for attitude ephemeris data in the block immediately following this metadata block.	E	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.	E	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	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)		
ATTITUDE_TYPE	QUATERNION	Epoch, QC, Q1, Q2, Q3
	QUATERNION/DERIVATIVE	Epoch, QC, Q1, Q2, Q3, QC_DOT, Q1_DOT, Q2_DOT, Q3_DOT
	QUATERNION/ANGVEL	Epoch, QC, Q1, Q2, Q3, ANGVEL_X, ANGVEL_Y, ANGVEL_Z
ATTITUDE_TYPE	QUATERNION	Epoch, Q1, Q2, Q3, QC
	QUATERNION/DERIVATIVE	Epoch, Q1, Q2, Q3, QC, Q1_DOT, Q2_DOT, Q3_DOT, QC_DOT
	QUATERNION/ANGVEL	Epoch, Q1, Q2, Q3, QC, ANGVEL_X, ANGVEL_Y, ANGVEL_Z
Euler Angle Options (note that keywords and values appear only in Metadata)		
ATTITUDE_TYPE	EULER_ANGLE	Epoch, ANGLE_1, ANGLE_2, ANGLE_3
	EULER_ANGLE/DERIVATIVE	Epoch, ANGLE_1, ANGLE_2, ANGLE_3, ANGLE_1_DOT, ANGLE_2_DOT, ANGLE_3_DOT
	EULER_ANGLE/ANGVEL	Epoch, ANGLE_1, ANGLE_2, ANGLE_3, ANGVEL_X, ANGVEL_Y, ANGVEL_Z
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 The units used shall be the following:

– dimensionless: EPOCH, Q1, Q2, Q3, QC;

– 1/s: Q1_DOT, Q2_DOT, Q3_DOT, QC_DOT;

– deg: ANGLE_1, ANGLE_2, ANGLE=_3, SPIN_ALPHA, SPIN_DELTA, SPIN_ANGLE, NUTATION, NUTATION_PHASE;

– deg/s: ANGVEL_X, ANGVEL_Y, ANGVEL_Z, SPIN_ANGLE_VEL;

– s: NUTATION_PER.

4.2.5.4 FORMAT

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

4.2.5.4.2 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.

4.2.5.4.3 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)

4.2.5.5 TECHNICAL

4.2.5.5.1 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.

4.2.5.5.2 The TIME_SYSTEM value must remain fixed within an AEM segment.

4.2.5.5.3 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.

4.2.5.5.4 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.

4.2.5.5.5 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.

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
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
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
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
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 5.8.

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 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 If accompanying descriptive text designed to clarify and/or remove ambiguities in provided ADM data does not fit well into the single comment line paradigm, it is recommended that the APM or AEM producer convey key elements of that information in comments and use an ICD to provide further details.

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).

ANNEX A

IMPLEMENTATION CONFORMANCE STATEMENT (ICS) PROFORMA

(NORMATIVE)

A1 INTRODUCTION

A1.1 OVERVIEW

This annex provides the Implementation Conformance Statement (ICS) Requirements List (RL) for an implementation of [Specification]. The ICS for an implementation is generated by completing the RL in accordance with the instructions below. An implementation claiming conformance must satisfy the mandatory requirements referenced in the RL.

A1.2 ABBREVIATIONS AND CONVENTIONS

The RL consists of information in tabular form. The status of features is indicated using the abbreviations and conventions described below.

<u>Item Column</u>

The item column contains sequential numbers for items in the table.

<u>Feature Column</u>

The feature column contains a brief descriptive name for a feature. It implicitly means “Is this feature supported by the implementation?”

<u>Status Column</u>

The status column uses the following notations:

- M mandatory;
- O optional;
- C conditional;
- X prohibited;
- I out of scope;
- N/A not applicable.

Support Column Symbols

The support column is to be used by the implementer to state whether a feature is supported by entering Y, N, or N/A, indicating:

Y Yes, supported by the implementation.

N No, not supported by the implementation.

N/A Not applicable.

The support column should also be used, when appropriate, to enter values supported for a given capability.

A1.3 INSTRUCTIONS FOR COMPLETING THE RL

An implementer shows the extent of compliance to the Recommended Standard by completing the RL; that is, the state of compliance with all mandatory requirements and the options supported are shown. The resulting completed RL is called an ICS. The implementer shall complete the RL by entering appropriate responses in the support or values supported column, using the notation described in A1.2. If a conditional requirement is inapplicable, N/A should be used. If a mandatory requirement is not satisfied, exception information must be supplied by entering a reference X*i*, where *i* is a unique identifier, to an accompanying rationale for the noncompliance.

A2 ICS PROFORMA FOR [SPECIFICATION]

A2.1 GENERAL INFORMATION

A2.1.1 Identification of ICS

Date of Statement (DD/MM/YYYY)	
ICS serial number	
System Conformance statement cross-reference	

A2.1.2 Identification of Implementation Under Test

Implementation Name	
Implementation Version	
Special Configuration	
Other Information	

A2.1.3 Identification of Supplier

Supplier	
Contact Point for Queries	
Implementation Name(s) and Versions	
Other information necessary for full identification, e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)	

A2.1.4 Identification of Specification

[CCSDS Document Number]	
Have any exceptions been required? NOTE – A YES answer means that the implementation does not conform to the Recommended Standard. Non-supported mandatory capabilities are to be identified in the ICS, with an explanation of why the implementation is non-conforming.	Yes [ ] No [ ]

A2.2 REQUIREMENTS LIST

[See CCSDS A20.1-Y-1, *CCSDS Implementation Conformance Statements* (Yellow Book, Issue 1, April 2014).]

ANNEX B

VALUES FOR SELECTED KEYWORDS

(NORMATIVE)

B1 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 [H4]. If exchange partners wish to use different settings, they should be documented in an ICD.

B2 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 event. However, for clarity, an ICD should be used to fully specify the interpretation of the times if these values are to be used. Note that the time format should only utilize three digit days from the MET or MRT epoch, not months and days of the months.

Note that if SCLK is chosen as a TIME_SYSTEM, the transformation of this time to one of the other specified time systems in B2 should be given in an ICD. The intent of this keyword is to allow for the use of SCLK as a TIME_SYSTEM, but there is currently no standard way to transform this time system to other time systems listed in B2.

B3 INERTIAL AND LOCAL ORBITAL FRAME KEYWORD VALUES

The following table enumerates the allowable keywords for inertial frames that can be used by ADM messages. They are valid for keywords: Q_FRAME_*, EULER_FRAME_*, and SPIN_FRAME_* in an APM, and REF_FRAME_* in an AEM, where '*' denotes 'A' or 'B'.

Keyword Value	Meaning/Description
EME2000	Earth Mean Equator and Equinox of J2000
GTOD	Greenwich True of Date
ICRF	International Celestial Reference Frame
ITRF2000	International Terrestrial Reference Frame 2000
ITRF-93	International Terrestrial Reference Frame 1993
ITRF-97	International Terrestrial Reference Frame 1997
ITRF	International Terrestrial Reference Frame
ITRFyyyy	International Terrestrial Reference Frame associated to year yyyy
J2000	Earth Mean Equator and Equinox of J2000
LVLH	Local Vertical Local Horizontal
RTN, QSW	Radial, Transverse, Normal Orbital Frame
TOD	True of Date
TNW, NTW	Tangential, Normal, Omega (W) Orbital Frame
RSW	Relative Orbit Frame describing the relative motion of two satellites (Clohessy-Wiltshire Equations)

B4 LOCAL SPACECRAFT BODY REFERENCE FRAMES

The following table enumerates the allowed values for the keyword FRAME_* in the APM and AEM messages, where '*' denotes 'A' or 'B'. These frames will vary from object to object, but provide a mechanism of denoting different reference frames than the object's BODY axes to specify an orientation. It is the responsibility of the end user to have an understanding of the location of these frames for their particular object, typically via an ICD.

Keyword Value	Meaning/Description
ACTUATOR_x	Actuator reference frame ('x' = 0→9): could denote reaction wheels, solar arrays, thrusters, etc.
CSS_xy	Coarse Sun Sensor ('x' = 0→9, 'y' = 0→9)
DSS_x	Digital Sun Sensor ('x' = 0→9)
GYRO_x	Gyroscope Reference Frame ('x' = 0→9)
INSTRUMENT_y	Instrument 'y' reference frame ('y' = A→Z, 0→9)
SC_BODY_x	Spacecraft Body Frame ('x' = 0→9)
SC_BODY_y	Spacecraft Body Frame of another object ('y' = A→Z)
SENSOR_x	Sensor 'x' reference frame ('x' = A→Z, 0→9)
STARTRACKER_x	Star Tracker Reference Frame ('x' = 0→9)
TAM_x	Three Axis Magnetometer Reference Frame ('x' = 0→9)

ANNEX C

CONVENTIONS FOR ADM DATA

(INFORMATIVE)

C1 OVERVIEW

This paragraph details the conventions used in this document for the definition of Attitude data.

C2 QUATERNIONS

The quaternion called "from frame A to frame B" is defined as the quaternion of the rotation that transforms the basis vectors of frame A into the basis vectors of frame B. That is to say that the basis vectors of frame B are the respective images of the basis vectors of frame A by the rotation.

The quaternion is defined by four components:

$q1 = \sin(\phi/2) * e1$

$q2 = \sin(\phi/2) * e2$

$q3 = \sin(\phi/2) * e3$

$qc = \cos(\phi/2)$

Where:

ϕ is the rotation angle,

e1, e2 and e3 are the coordinates of the rotation axis in either frame A or frame B.

The quaternion is related to the frame transformation matrix in the following way:

Let X_A be the coordinates of some vector in frame A, and X_B the coordinates of the <u>same</u> vector in frame B.

The frame transformation matrix M_{BA} that transforms coordinates in frame A to coordinates in frame B is defined by:

$$X_B = M_{BA} * X_A$$

where M_{BA} is a function of the quaternion components:

$$M_{BA} = \begin{bmatrix} q_1^2 - q_2^2 - q_3^2 + q_c^2 & 2\,(q_1\,q_2 + q_3\,q_c) & 2\,(q_1\,q_3 - q_2\,q_c) \\ 2\,(q_1\,q_2 - q_3\,q_c) & -q_1^2 + q_2^2 - q_3^2 + q_c^2 & 2\,(q_2\,q_3 + q_1\,q_c) \\ 2\,(q_1\,q_3 + q_2\,q_c) & 2\,(q_2\,q_3 - q_1\,q_c) & -q_1^2 - q_2^2 + q_3^2 + q_c^2 \end{bmatrix}$$

The real component (qc) of the quaternion shall be made non negative by convention.

C3 EULER ANGLES

The Euler angles called "from frame A to frame B" are the rotation angles of the 3 successive rotations that transform frame A into frame B.

Let's call θ1, θ2, θ3 the 3 rotation angles, and a1, a2, a3 the respective rotation axes (X-axis, Y-axis or Z-axis). The images of the basis vectors of frame A by the 3 successive rotations of angle θ1 and axis a1, angle θ2 and axis a2, angle θ3 and axis a3 are the respective basis vectors of frame B.

Example :

Let's consider the 3 successive rotations around axes a1=X, a2=Y, a3=Z of respective angles θ1, θ 2, θ3.

Let's define the frame transformation matrix M such that :

$X_B = M * X_A$

where X_A denotes the coordinates of some vector in frame A, and X_B the coordinates of the same vector in frame B.

Then we have:

$$M = \begin{bmatrix} cos\theta_3 & sin\theta_3 & 0 \\ -sin\theta_3 & cos\theta_3 & 0 \\ 0 & 0 & 1 \end{bmatrix} . \begin{bmatrix} cos\theta_2 & 0 & -sin\theta_2 \\ 0 & 1 & 0 \\ sin\theta_2 & 0 & cos\theta_2 \end{bmatrix} . \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\theta_1 & sin\theta_1 \\ 0 & -sin\theta_1 & cos\theta_1 \end{bmatrix}$$

C4 ANGULAR VELOCITY VECTOR

The angular velocity vector from frame A to frame B represents the angular velocity vector of FRAME B with respect to frame A.

The components can be defined either in Frame A or frame B.

C5 SPIN DATA

The spin data enable the user of the message to propagate the attitude of an object using a simple model.

The spin data from frame A to frame B are defined as follows:

The spin axis is the Z axis of frame B, a principal axis.

The initial attitude is defined as the result of 3 successive rotations of respective angles spin_alpha, spin_delta, spin_angle around the successive axes Z, Y, Z starting from frame A.

Nutation_angle is the angle between the principal axis (spin axis) and angular momentum.

Nutation_phase describe the initial orientation of the spin axis in his motion around the angular momentum vector.

The following assumption is assumed:

The angular momentum vector has components in the frame B:

- alpha, delta
- Pi/2 - delta is the nutation angle
- Alpha - pi is the offset angle

C6 INERTIA DATA

Inertia data consist of:

- Moments of inertia (diagonal terms)

- Inertial cross products (off diagonal terms)

$$I = \begin{bmatrix} I11 & -I12 & -I13 \\ -I12 & -I22 & -I23 \\ -I13 & -I23 & -I33 \end{bmatrix}$$

The cross product terms are negative.

The inertia matrix is defined relative to a particular frame (defined by its axis and origin).

ANNEX D

LIST OF CHANGES VERSUS ADM VERSION 1

(INFORMATIVE)

The present section gives the main changes between ADM 1.0 and ADM 2.

Changes relative to APM :

Number	Description	See section
2	The "*_DIR" keywords have been removed	
3	The quaternion block is now optional.	
4	Any block can now be present as many times as necessary.	
5	The meaning of quaternion, Euler angles, spin data, ...is now clearly defined by the standard. Any changes in meaning with respect to the standard should be detailed in an ICD.	
6	Euler rotation sequences ("EULER_ROT_SEQ" keyword) are specified by letter (X, Y, Z) instead of number, e.g. XYX instead of 121.	
7	The logical block "Euler angles" now contains angle derivatives rather than components of the angular velocity vector.	
8	A new block for the angular velocity vector has been added: ANGVEL.	
9	The keywords for the moments of inertia have changed: IXY instead of I12, etc...	
10	Data blocks have been added. Data types such as quaternion, Euler angles... are explicitly enclosed between DATA_START ... DATA_STOP delimiters.	

Changes relative to AEM:

Number	Description	See section
1	Euler rotation sequences ("EULER_ROT_SEQ" keyword) are specified by letter (X, Y, Z) instead of number, e.g. XYX instead of 121.	
2	A new value has been introduced for the "ATTITUDE_TYPE" keyword: EULER_ANGLE/DERIVATIVE	
3	The order for quaternion components (real part first or last) is now imposed by the standard.	
4	The ATTITUDE_DIR keyword has been removed.	

ANNEX E

RATIONALE FOR ATTITUDE DATA MESSAGES

(INFORMATIVE)

E1 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 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 Recommended Standard.

E2 PRIMARY REQUIREMENTS ACCEPTED BY THE ATTITUDE DATA MESSAGES

Table E-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
Attitude state information must be provided in a reference frame that is clearly identified and unambiguous.	Y	Y
Identification of the object must be clearly identified and unambiguous.	Y	Y
Identification of the center of attitude motion must be clearly identified and unambiguous. NOTE – The specification of a center name is not required for the unambiguous specification of attitude but may be provided if desired.	N	N
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 E-2: Heritage Requirements

Requirement	Accepted for APM?	Accepted for AEM?
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 E-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.	Y	Y

E3 APPLICABILITY OF CRITERIA TO MESSAGE OPTIONS

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

Table E-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

E4 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 E-5.

Table E-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 F

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 F-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 3.1.4 4.1.3
3	Definition of attitude accuracy requirements pertaining to data in an ADM as well as attitude dynamics modeling.	1.2.1 3.1.2 5.8.2.2
4	Specific APM and/or AEM version numbers that will be exchanged.	3.2.6.1 4.2.6.1
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 international designators list by the UN Office of Outer Space Affairs (reference [2]).	table 3-2 table 4-3
7	Values and definition of the 'FRAME_*’ keywords to be used in ADM exchanges, if the value is not given in annex B.	3.2.4
8	Convention for values of the ‘SPIN_ANGLE’ keyword if not expressed in reference [H4].	**3.2.4**
9	If floating-point numbers in extended-single or extended-double precision are to be used, then discussion of implementation-specific attributes is required.	5.6.5

[1] 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.	5.8.1.3
11	Whether the format of the ADM will be KVN or XML[1].	1.2.3
12	A reference orientation should be specified in an ICD if a body-fixed frame is to be used for the specification of Euler angles. For instance, demonstrating the alignment of the body axes with the local orbit frame or an inertial frame that gives a context to interpret the Euler angle data.	
13		
14	Provisions that are made to ensure information security.	ANNEX I
15	Values used for those keywords listed in annex B when those values are different from those given in annex B.	B
16	Specification of interpretation of MET, MRT and SCLK, if to be exchanged, and how to transform it to a standardized time system such as UTC, TAI, etc. An ICD should specify that elapsed days are to be used for epochs, with year starting at zero.	B2
17	Exact specification of reference frames used in messages, if different from those specified in annex B.	B4

[1] XML implementation awaiting approval as a standard.

ANNEX G

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
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 H

INFORMATIVE REFERENCES

(INFORMATIVE)

[H1] *XML Schema Part 2: Datatypes*. 2nd ed. P. Biron and A. Malhotra, eds. W3C Recommendation 28. n.p.: W3C, 2004.

[H2] *Standard Frequencies and Time Signals*. Volume 7 of *Recommendations and Reports of the CCIR: XVIIth Plenary Assembly*. Geneva: CCIR, 1990.

[H3] *Organization and Processes for the Consultative Committee for Space Data Systems,* CCSDS A02.1-Y-4. Yellow Book. Issue 4. Washington, D.C.: CCSDS, April 2014.

[H4] *Navigation Data—Definitions and Conventions*. Report Concerning Space Data System Standards, CCSDS 500.0-G-2. Green Book. Issue 3. Washington, D.C.: CCSDS, May 2010.

NOTE – Normative references are provided in 1.5.

ANNEX I

SECURITY, SANA, AND PATENT CONSIDERATIONS

(INFORMATIVE)

A1 SECURITY CONSIDERATIONS

A1.1 ANALYSIS OF SECURITY CONSIDERATIONS

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

A1.2 CONSEQUENCES OF NOT APPLYING SECURITY TO THE TECHNOLOGY

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. Because these messages are used in collision avoidance analyses and potential maneuvers, the consequences of not applying security to the systems and networks on which this Recommended Standard is implemented could include compromise or loss of the mission if malicious tampering of a particularly severe nature occurs.

A1.3 POTENTIAL THREATS AND ATTACK SCENARIOS

Potential threats or attack scenarios include, but are not limited to, (a) unauthorized access to the programs/processes that generate and interpret the messages, and (b) unauthorized access to the messages during transmission between exchange partners. Protection from unauthorized access during transmission 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. It is strongly recommended that potential threats or attack scenarios applicable to the systems and networks on which this Recommended Standard is implemented be addressed by the management of those systems and networks.

A1.4 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.

A1.5 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.

A1.6 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.

A1.7 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 Information Technology Security functionaries of exchange participants.

A1.8 CONTROL OF ACCESS TO RESOURCES

Control of access to resources should be managed by the systems upon which originator formatting and recipient processing are performed.

A1.9 AUDITING OF RESOURCE USAGE

Auditing of resource usage should be handled by the management of systems and networks on which this Recommended Standard is implemented.

A1.10 UNAUTHORIZED ACCESS

Unauthorized access to the programs/processes that generate and interpret the messages should be prohibited in order to minimize potential threats and attack scenarios.

A1.11 DATA SECURITY IMPLEMENTATION SPECIFICS

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

A2 SANA CONSIDERATIONS

The following ADM related items will be registered with the SANA Operator. The registration rule for new entries in the registry is the approval of new requests by the CCSDS

Navigation Working Group chair. New requests for this registry should be sent to SANA (mailto:info@sanaregistry.org).

- The ADM XML schema
- A transform from the ADM XML to the ADM KVN version

A3 PATENT CONSIDERATIONS

The recommendations of this document have no patent issues.