The Consultative Committee for Space Data Systems

Recommendation for Space Data System Standards

ATTITUDE DATA MESSAGES

RECOMMENDED STANDARD

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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 three standard message formats for use in transferring spacecraft attitude information between space agencies and commercial or governmental spacecraft operators: the Attitude Parameter Message (APM), the Attitude Ephemeris Message (AEM), and the Attitude Comprehensive Message (ACM). Such exchanges are used for:

– preflight planning for 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 three 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. Applicability information specific to each Attitude Data Message format appears in sections 3, 4, and 5 as well as in annex subsection E3. 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.

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 Interface Control Document (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 (see section 6). 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”.

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), the Attitude Ephemeris Message (AEM), and the Attitude Comprehensive Message (ACM).

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 about the structure and content of the ACM.

1.4.5 Section 6 provides details about constructing an ADM/XML instance.

1.4.6 Section 7 provides details about ADM KVN syntax.

1.4.7 Section 8 provides details about ADM XML syntax.

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

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

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

1.4.11 ANNEX D gives a summary of changes between ADM versions 1 and 2.

1.4.12 ANNEX E lists a set of requirements that were taken into consideration in the design of the APM, AEM, and ACM, along with tables and discussion regarding the applicability of the three message types to various attitude estimation tasks and functions.

1.4.13 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.

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

1.4.15 ANNEX H is a list of informative references.

1.4.16 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] *Time Code Formats*. Recommendation for Space Data System Standards, CCSDS 301.0-B-4. Blue Book. Issue 4. Washington, D.C.: CCSDS, November 2010.

[4] *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.

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

[6] *Orbit Data Messages.* Recommended standard, CCSDS 502.0-B-2. Blue Book, Issue 2. Washington, D.C.: CCSDS. November 2009 (with Technical Corrigendum 1, May 2012).

[7] Henry S. Thompson, et al., eds. *XML Schema Part 1: Structures*. 2nd ed. W3C Recommendation. N.p.: W3C, October 2004.

[8] Paul V. Biron and Ashok Malhotra, eds. *XML Schema Part 2: Datatypes*. 2nd ed. W3C Recommendation. N.p.: W3C, October 2004.

[9] “Orbit Centers.” Space Assigned Numbers Authority (SANA). https://sanaregistry.org/r/orbit_centers.

[10] “Time Systems.” Space Assigned Numbers Authority (SANA). https://sanaregistry.org/r/time_systems.

[11] “Celestial Body Reference Frames.” Space Assigned Numbers Authority (SANA). https://sanaregistry.org/r/celestial_body_reference_frames.

[12] “Orbit-relative Reference Frames.” Space Assigned Numbers Authority (SANA). https://sanaregistry.org/r/orbit_relative_reference_frames.

2. OVERVIEW

2.1 ATTITUDE DATA MESSAGE TYPES

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

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, AEM, or ACM 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 and 2.4, Attitude Comprehensive 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 Data Message (reference [6]).

2.2.3 The APM allows for modeling of any number of finite maneuvers.

2.2.4 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 Data Message (reference [6]).

2.4 ATTITUDE COMPREHENSIVE MESSAGE (ACM)

2.4.1 An ACM specifies the attitude state of a single object at multiple epochs, contained within a specified time range. The ACM aggregates and extends APM and AEM content in a single comprehensive hybrid message and offers the following capabilities:

- Optional rate data elements
- Optional spacecraft physical properties
- Optional covariance matrix
- Optional maneuver parameters
- Optional estimator information

2.4.2 The ACM is well-suited for 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 more detailed information such as estimator type, additional estimator states (e.g., gyro bias), sensor details, and covariance data.

2.4.3 The ACM is fully self-contained; no additional information is required when inertial reference frames are specified. If local orbital reference frames are specified, then an ACM must be used in conjunction with an Orbit Data Message (reference [6]).

2.5 EXCHANGE OF MULTIPLE MESSAGES

2.5.1 For a given object, multiple APM, AEM, or ACM 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, AEM, or ACM files must be used.

2.6 DEFINITIONS

2.6.1 Definitions of time systems, reference frames, attitude estimation and prediction methods and models are provided in reference [H2].

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 [H2]) 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:

- Attitude states at specific times have to be exchanged (no propagation is required at the receiver's location).
- Attitude states at other times desired by the recipient have to be exchanged. In this case a propagator including a precise enough modeling of the dynamics has to be available at the receiver's location.

3.1.3 The APM shall be a text file consisting of attitude data for a single object.

3.1.4 The APM file naming scheme should be agreed to on a case-by-case basis between the participating agencies, and should be documented in an 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 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.

3.2.2.2 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[3] - ASCII Time Code A or B. A description of APM header keywords and values is provided in table 3-1.

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

3.2.2.4 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.

3.2.2.5 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 UTC. For format specification, see 7.7.	E	2001-11-06T11:17:33 2001-101T11:17:33	Yes
ORIGINATOR	Creating agency. The value for the "ORIGINATOR" keyword should come from the 'Abbreviation' column in	E	CNES ESOC GSFC	Yes

	the 'Organizations' registry of the SANA Registry (https://sanaregistry.org/r/organizations).		GSOC JPL JAXA Other agency	
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.	E	201113719185 ABC-12_34	No

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 names from the UN Office of Outer Space Affairs (Ref. [2]). In cases where the asset is not listed in the UN Office of Outer Space Affairs name index or that index format is not used, OBJECT_NAME terminology should be mutually agreed in an ICD.	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 international designators from the UN Office of Outer Space Affairs (Ref. [2]). In cases where the asset is not listed in the UN Office of Outer Space Affairs designator index or that index format is not used, OBJECT_ID terminology should be mutually agreed in an ICD.	E	2000-052A	Yes
CENTER_NAME	Celestial body orbited by the object and origin of the 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. The value should be taken from the orbit center column in the SANA orbit centers registry, reference [9].	E	EARTH EARTH BARYCENTER MOON	No
TIME_SYSTEM	Time system used for attitude and maneuver data. The set of allowed values is described in ANNEX B, section B2.	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, angular velocity data, spin data, spacecraft inertia 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 values (N) or just examples (E);

d) the values/units (either the list of all normative values or examples, or units if applicable);

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 The APM message shall contain at least one logical block.

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

3.2.4.5 All data, except for the maneuver ones shall be relative to the same epoch.

Table 3-3: APM Data

Keyword	Description	N/E	Values	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 and 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.*				
QUAT_START	Indicator of start of data block	n/a	n/a	Yes
COMMENT	One or more comment line(s). Each comment line shall begin with this keyword.	E	This is a comment	No
REF_FRAME_A	Name of the reference frame that defines the starting point of the transformation. The set of allowed values is described in ANNEX B, section B3.	E	ICRF INSTRUMENT_A	Yes
REF_FRAME_B	Name of the reference frame that defines the end point of the transformation. The set of allowed values is described in ANNEX B, section B3.	E	SC_BODY_1 STARTRACKER	Yes
Q1	$e_1 * \sin(\phi/2)$ ϕ = rotation angle, e1 = 1st component of rotation axis	n/a	n/a	Yes
Q2	$e_2 * \sin(\phi/2)$ ϕ = rotation angle, e2 = 2nd component of rotation axis	n/a	n/a	Yes
Q3	$e_3 * \sin(\phi/2)$ ϕ = rotation angle, e3 = 3rd component of rotation axis	n/a	n/a	Yes
QC	$\cos(\phi/2)$ ϕ = rotation angle	n/a	n/a	Yes
Q1_DOT	Time derivative of Q_1	n/a	1/s	No
Q2_DOT	Time derivative of Q_2	n/a	1/s	No
Q3_DOT	Time derivative of Q_3	n/a	1/s	No
QC_DOT	Time derivative of Q_C	n/a	1/s	No
QUAT_STOP	Indicator of end of data block	n/a	n/a	Yes

Keyword	Description	N/E	Values	Mandatory
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.*				
EULER_START	Indicator of start of data block	n/a	n/a	Yes
COMMENT	One or more comment line(s). Each comment line shall begin with this keyword.	E	This is a comment	No
REF_FRAME_A	Name of the reference frame that defines the starting point of the transformation. The set of allowed values is described in ANNEX B, section B3.	E	SC_BODY_1 STARTRACKER_1	Yes
REF_FRAME_B	Name of the reference frame that defines the end point of the transformation. The set of allowed values is described in ANNEX B, section B3.	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.*				
ANGVEL_START	Indicator of start of data block	n/a	n/a	Yes
COMMENT	One or more comment line(s). Each comment line shall begin with this keyword.	E	This is a comment	No
REF_FRAME_A	Name of the reference frame that defines the starting point of the transformation. The set of allowed values is described in ANNEX B, section B3.	E	SC_BODY_1 ICRF	Yes
REF_FRAME_B	Name of the reference frame that defines the end point of the transformation. The set of allowed values is described in ANNEX B, section B3.	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

Keyword	Description	N/E	Values	Mandatory
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.*				
SPIN_START	Indicator of start of data block	n/a	n/a	Yes
COMMENT	One or more comment line(s). Each comment line shall begin with this keyword.	E	This is a comment	No
REF_FRAME_A	Name of the reference frame that defines the starting point of the transformation. The set of allowed values is described in ANNEX B, section B3.	E	SC_BODY_1 ICRF	Yes
REF_FRAME_B	Name of the reference frame that defines the end point of the transformation. The set of allowed values is described in ANNEX B, section B3.	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.*				
INERTIA_START	Indicator of start of data block	n/a	n/a	Yes
COMMENT	One or more comment line(s). Each comment line shall begin with this keyword.	E	This is a comment	No
INERTIA_REF_FRAME	Coordinate system for the inertia tensor. The set of allowed values is described in ANNEX B, section B3.	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 and Y axes	n/a	kg*m**2	Yes
IXZ	Inertia Cross Product of the X and Z axes	n/a	kg*m**2	Yes
IYZ	Inertia Cross Product of the Y and 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 mandatory elements are to be provided if the block is present.* *See ANNEX C for conventions and further detail.*				
MANEUVER_START	Indicator of start of data block	n/a	n/a	Yes
COMMENT	One or more comment line(s). Each comment line shall begin with this keyword.	E	This is a comment	No

Keyword	Description	N/E	Values	Mandatory
MAN_EPOCH_START	Epoch of start of maneuver. For format specification, see section 7.7.	n/a	2020-08-02T10:18:30.000	Yes
MAN_DURATION	Maneuver duration	n/a	s	Yes
MAN_REF_FRAME	Coordinate system for the torque vector. The set of allowed values is described in ANNEX B, section B3.	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 section 7.7 for instructions about how to format the EPOCH and MAN_EPOCH_START.

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., 20xx-xx-xxT23:59:58.000 .. 20xx-xx-xxT23:59:59.000 .. 20xx-xx-xxT23:59:60.000 .. 20xx-xx-xxT00:00:00.000)

3.2.5.2 TECHNICAL

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.

3.3 APM EXAMPLES

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

```
CCSDS_APM_VERS = 2.0
CREATION_DATE = 2003-09-30T19:23:57
ORIGINATOR   = GSFC
MESSAGE_ID = A7015Z


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 = 2.0
CREATION_DATE  = 2006-03-13T13:13:33
ORIGINATOR     = GSFC
MESSAGE_ID     = A7015Z

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

EULER_START
COMMENT Euler angles
REF_FRAME_A   = BODY_FRAME_A
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 = 2.0
CREATION_DATE = 2004-02-14T19:23:57
ORIGINATOR   = JPL
MESSAGE_ID = 900018

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

QUAT_START
COMMENT      Attitude state quaternion (ref frame = ITRF-97)
REF_FRAME_A     = ITRF-97
REF_FRAME_B   = INSTRUMENT_A

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

QUAT_START
COMMENT      Attitude state quaternion (ref frame = ICRF)
REF_FRAME_A     = ICRF
REF_FRAME_B   = INSTRUMENT_A

Q1       = 0.02478
Q2       = 0.78576
Q3       = 0.39552
QC       = 0.47491
QUAT_STOP

INERTIA_START
COMMENT Spacecraft Inertia Parameters
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]
INERTIA_STOP

MANEUVER_START
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 = ICRF
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 file naming scheme should 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.

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 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.

4.2.2.2 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 [3] - ASCII Time Code A or B. A description of AEM header keywords and values is provided in table 4-2.

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

4.2.2.4 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.

4.2.2.5 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 UTC. For format specification, see 7.7.	E	2001-11-06T11:17:33	Yes
ORIGINATOR	Creating agency. The value for the "ORIGINATOR" keyword should come from the 'Abbreviation' column in the 'Organizations' registry of the SANA Registry (https://sanaregistry.org/r/organizations).	E	CNES ESOC GSFC GSOC JPL JAXA	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.	E	201113719185 ABC-12_34	No

4.2.3 AEM METADATA

4.2.3.1 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.).

4.2.3.2 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.

4.2.3.3 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.

4.2.3.4 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 names from the UN Office of Outer Space Affairs (Ref. [2]). In cases where the asset is not listed in the UN Office of Outer Space Affairs name index or that index format is not used, OBJECT_NAME terminology should be mutually agreed in an ICD.	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 international designators from the UN Office of Outer Space Affairs (Ref. [2]). In cases where the asset is not listed in the UN Office of Outer Space Affairs designator index or that index format is not used, OBJECT_ID terminology should be mutually agreed in an ICD.	E	2000-052A	Yes
CENTER_NAME	Celestial body orbited by the object and origin of the 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. The value should be taken from the orbit center column in the SANA orbit centers registry, reference [9].	E	EARTH STS 106	No

Keyword	Description	N/E	Values	Mandatory
REF_FRAME_A	Name of the reference frame that defines the starting point of the transformation. The set of allowed values is described in ANNEX B, section B3.	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 set of allowed values is described in ANNEX B, section B3.	E	SC_BODY_1 INSTRUMENT_A	Yes
TIME_SYSTEM	Time system used for both attitude ephemeris data and metadata. The set of allowed values is described in ANNEX B, section B2.	E	UTC TAI	Yes
START_TIME	Start of TOTAL time span covered by attitude ephemeris data immediately following this metadata block. For format specification, see 7.7.	E	1996-12-18T14:28:15.1172	Yes
USEABLE_START_TIME	Optional start of USEABLE time span covered by attitude ephemeris data immediately following this metadata block. To allow for proper interpolation near the beginning/end of the attitude ephemeris data block, it may be necessary to utilize this keyword with values within the time span covered by the attitude ephemeris data records as denoted by the START / STOP_TIME time tags. The USEABLE_START_TIME time tag of a new block of ephemeris data must be greater than or equal to the USEABLE_STOP_TIME time tag of the previous block. For format specification, see 7.7.	E	1996-12-18T14:28:15.1172	No
USEABLE_STOP_TIME	Optional stop of USEABLE time span covered by attitude ephemeris data immediately following this metadata block. See also USEABLE_START_TIME. For format specification, see 7.7.	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. For format specification, see 7.7.	E	1996-12-18T14:28:15.1172	Yes

Keyword	Description	N/E	Values	Mandatory
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
ANGVEL_FRAME	The frame of reference in which angular velocity data 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
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

4.2.4 AEM DATA

4.2.4.1 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 only appear in Metadata section, and values in Data section)		
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 only appear in Metadata section, and values in Data section)		
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 only appear in Metadata section, and values in Data section)		
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: ANGLE_1_DOT, ANGLE_2_DOT, ANGLE_3_DOT, ANGVEL_X, ANGVEL_Y, ANGVEL_Z, SPIN_ANGLE_VEL;

– s: NUTATION_PER.

Note: The units do not appear in the AEM data lines. The data lines only contain values.

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 Section 7.7 for instructions about 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., 20xx-xx-xxT23:59:58.000 .. 20xx-xx-xxT23:59:59.000 .. 20xx-xx-xxT23:59:60.000 .. 20xx-xx-xxT00:00:00.000).

4.2.5.5 TECHNICAL

4.2.5.5.1 Attitude ephemeris data lines in a given data block must be ordered by increasing time, and time tags must not be repeated. 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.

4.2.6 REMARKS

4.2.6.1 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 OEM message to use in conjunction with a particular AEM.

4.2.6.2 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.

4.3 AEM EXAMPLES

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

```
CCSDS_AEM_VERS = 2.0
CREATION_DATE = 2002-11-04T17:22:31
ORIGINATOR = NASA/JPL
MESSAGE_ID = A7015Z

META_START
COMMENT This file was produced by M.R. Somebody, MSOO NAV/JPL.
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
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 = 2.0
CREATION_DATE  = 2008-071T17:09:49
ORIGINATOR     = GSFC FDF
MESSAGE_ID     = 7077456

META_START
OBJECT_NAME    = ST5-224
OBJECT_ID      = 2006-224A
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. ATTITUDE COMPREHENSIVE MESSAGE (ACM)

5.1 GENERAL

5.1.1 Attitude information may be exchanged between two participants using an Attitude Comprehensive Message (ACM). The ACM aggregates and extends APM and AEM content in a single hybrid message. The ACM simultaneously emphasizes flexibility and message conciseness by offering extensive optional standardized content while minimizing mandatory content.

5.1.2 The ACM shall be a plain text file consisting of attitude data for a single space object, or in the case of a parent/child satellite deployment scenario, a single parent object. It shall be easily readable by both humans and computers.

5.1.3 The ACM file-naming scheme should be agreed to on a case-by-case basis between the exchange partners, and should be documented in an ICD. The method of exchanging ACMs should be decided on a case-by-case basis by the exchange partners and documented in an ICD.

5.1.4 If attitude states are desired at arbitrary time(s) contained within the span of the attitude ephemeris, the message recipient is encouraged to use a suitable interpolation or propagation method. For times outside of supplied attitude state time spans or if the step size between attitude states is too large to support interpolation or propagation, optional dynamic parameters should be included with this message and the recipient must have a suitably-compatible attitude dynamics propagator.

NOTE – Detailed syntax rules for the ACM are specified in Section 7.

5.2 ACM CONTENT/STRUCTURE

5.2.1 GENERAL

5.2.1.1 The ACM shall be represented as a combination of the following as shown in Table 5-1. The ordering of these sections is mandatory. The order of occurrence of the ACM sections shall be fixed as shown in Table 5-1.

1) one mandatory header;

2) a single mandatory metadata section (data about data);

3) optional data section(s), comprised of one or more data constituent types:

    a. one or more optional attitude state time histories

    b. one optional space object physical characteristics section

    c. one or more optional covariance time histories

    d. one or more optional maneuver specification section(s)

    e. one optional attitude determination data section

f. one optional, user-defined data and supplemental comments (explanatory information).

Table 5-1: ACM File Layout and Ordering Specification

Section	Content
Header	Mandatory: Header of message
Metadata	Mandatory: Metadata (Informational comments recommended but not required.)
Attitude State Time History	Optional: One or more attitude state time histories (each consisting of one or more attitude states). Referred to as Attitude in metadata.
Space Object Physical Characteristics	Optional: Space object physical characteristics. Referred to as Physical in metadata.
Attitude State Covariance Time History	Optional: One or more covariance time histories (each consisting of one or more covariance matrices). Referred to as Covariance in metadata.
Maneuver Specification	Optional maneuver specifications. Referred to as Maneuver in metaldata.
Attitude Determination Data	Optional attitude determination data. Referred to as AD in metadata.
User-Defined Parameters	Optional: One or more user-defined parameters. Referred to as User in metadata.

5.2.2 ACM HEADER

5.2.2.1 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_ACM_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 ACM version numbers less than 1.0 (e.g., 0.x). Participating agencies should specify in the ICD the specific ACM version numbers they will support.

5.2.2.2 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 [3] - ASCII Time Code A or B. A description of ACM header keywords and values is provided in table 4-2.

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

5.2.2.4 Table 5-2 specifies the keywords for each header item.

5.2.2.5 Only those keywords shown in Table 5-2 shall be used in an ACM header.

5.2.2.6 The order of occurrence of these ACM header keywords shall be fixed as shown in Table 5-2.

Table 5-2: ACM Header

Keyword	Description	Examples of Values	Mandatory
CCSDS_ACM_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.	2.0	Yes
COMMENT	Comments (allowed in the ACM Header only immediately after the ACM version number).	COMMENT This is a comment	No
CREATION_DATE	File creation date/time in UTC. (For format specification, see 7.7.)	2001-11-06T11:17:33 2002-204T15:56:23Z	Yes
ORIGINATOR	Creating agency. Value should come from the ‘Abbreviation’ column in the ‘Organizations’ registry of the SANA registry (https://sanaregistry.org/r/organizations).	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

5.2.3 ACM METADATA

5.2.3.1 Table 5-3 specifies the metadata keywords. Only those keywords shown in Table 5-3 shall be used in ACM metadata.

5.2.3.2 The "ACM Metadata" section is mandatory; "mandatory" in the context of Table 5-3 denotes those keywords which must be included in this section.

5.2.3.3 Each metadata section must begin with keyword META_START and end with keyword META_STOP.

5.2.3.4 The order of occurrence of these ACM metadata keywords shall be fixed as shown in Table 5-3.

5.2.3.5 The TIME_SYSTEM value must remain fixed within an ACM.

5.2.3.6 The ACM shall only contain a single metadata section in the entire scope of the message.

NOTE – For some keywords (OBJECT_NAME, OBJECT_ID) 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.

NOTE 2 – Metadata fields which are relied upon by the subsequent optional ACM message subtypes (e.g. attitude state time histories, maneuver specification, etc.) are designated as such in the right-hand column of Table 5-3.

Table 5-3: ACM Metadata

Keyword	Description	Examples of Values	Mandatory	Any ACM sections relying upon this field ?
META_START	Start of the metadata section	n/a	n/a	n/a
COMMENT	Comments (allowed only at the beginning of the ACM Metadata). Each comment line shall begin with this keyword.	This is a comment.	No	No
ORIGINATOR _POC	Free text field containing Programmatic or Technical Point-of-Contact (PoC) for ACM	Ms. Rodgers	No	No
ORIGINATOR _PHONE	Free text field containing PoC phone number	+49615130312	No	No
ORIGINATOR _POSITION	Free text field containing contact position of the PoC	GNC Engineer ACS Design Lead	No	No
ORIGINATOR_ADDRESS	Free text field containing Technical PoC information for ACM creator (suggest email, website, or physical address, etc.)	JANE.DOE@ SOMEWHERE.NET	No	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 UN Office of Outer Space Affairs (Ref. [2]). In cases where the asset is not listed in the UN Office of Outer Space Affairs name index or that index format is not used, OBJECT_NAME terminology should be mutually agreed in an ICD.	SPOT, ENVISAT, IRIDIUM, INTELSAT	Yes	No

Keyword	Description	Examples of Values	Mandatory	Any ACM sections relying upon this field ?
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 values from the UN Office of Outer Space Affairs (Ref. [2]). In cases where the asset is not listed in the UN Office of Outer Space Affairs designator index or that index format is not used, OBJECT_ID terminology should be mutually agreed in an ICD.	2000-052A	Yes	No
ORB_MESSAGE_LINK	Free text field containing a unique identifier of Orbit Data Message(s) that are linked (relevant) to this Attitude Data Message	ODM_MSG_12345.txt ORB_ID_0123	No	No
CENTER_NAME	Celestial body orbited by the object and origin of the 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. The value should be taken from the orbit center column in the SANA orbit centers registry, reference [9].	EARTH EARTH BARYCENTER MOON	No	No
TIME_SYSTEM	Time system used for metadata, attitude data, covariance data. The set of allowed values is described in ANNEX B, section B2.	UTC TAI	Yes	Yes
EPOCH_TZERO	Epoch from which all ACM relative times are referenced. (For format specification, see 7.7). The time scale for EPOCH_TZERO is the one specified by "TIME_SYSTEM" keyword in the metadata section.	2001-11-06T00:00:00	Yes	Yes
ACM_DATA_ELEMENTS	Comma-delimited list of elements of information data blocks included in this message. See Table 5-1.	ATTITUDE, PHYSICAL, MANEUVER, COVARIANCE[H2], AD, USER	No	No
START_TIME	Relative time of the earliest of all time tags corresponding to maneuver, attitude state, covariance. Relative time is measured in seconds from EPOCH_TZERO.	100.0	No	No
STOP_TIME	Relative time of the end of TOTAL time span covered by ALL maneuver, attitude state, covariance contained in this message. Relative time is measured in seconds from EPOCH_TZERO.	1500.0	No	No
TAIMUTC_TZERO	Difference (TAI – UTC) in seconds (i.e. total # leap seconds elapsed since 1958) as modeled by the message originator at epoch “EPOCH_TZERO”.	37 [s]	No	No
META_STOP	End of the metadata section	n/a	n/a	n/a

5.2.4 ACM DATA: ATTITUDE STATE TIME HISTORY

5.2.4.1 Table 5-4 provides an overview of the ACM attitude state time history section. Only those keywords shown in Table 5-4 shall be used in ACM attitude state time history data specification.

5.2.4.2 Keyword values shall be provided in the units specified in the Units column of Table 5-4.

5.2.4.3 The order of occurrence of these ACM Attitude State Time History keywords shall be fixed as shown in Table 5-4.

5.2.4.4 The "ACM Data: Attitude State Time History" section is optional; "mandatory" in the context of Table 5-4 denotes those keywords which must be included in this section if this section is included.

5.2.4.5 Each attitude state time history data block must begin with keyword ATT_START and end with keyword ATT_STOP.

5.2.4.6 Each keyword shall appear on a line by itself.

5.2.4.7 Multiple Attitude State Time History blocks should appear in an ACM if:

5.2.4.7.1 They are delimited by separate ATT_START and ATT_STOP keywords;

5.2.4.7.2 Each data block is clearly differentiated from the others by one or more preceding comment(s) or by ICD agreement.

5.2.4.7.3 Each orbit state data block should be unique from all others in at least one of the following respects:

1) The selected attitude state set (ATT_STATES) is unique
2) The Attitude State Time History is based upon a unique attitude determination solution
3) The transformations frames are unique (REF_FRAME_A, REF_FRAME_B)
4) The data interval timespan is unique (i.e., has no overlap with any other data interval(s)).

5.2.4.8 All attitude state values in the ACM data shall be time-tagged by a relative time value measured with respect to the epoch time specified via the EPOCH_TZERO keyword.

5.2.4.9 Each attitude state time history shall be time-ordered to be monotonically increasing, with the exception that the message creator may indicate a change in state over which interpolation or propagation should not be performed by providing exactly two consecutive lines containing a duplicate timestamp (e.g. following application of a maneuver or spacecraft or orbit event). In the case of such a duplicate timestamp, interpolation or propagation prior to the duplicate timestamp shall use the first of the two duplicate timestamp attitude states, and interpolation or propagation after the duplicate timestamp shall use the second of the two.

5.2.4.10 If the user includes attitude states at key mission event times, it is recommended that those mission event states be annotated as such by a descriptive comment line(s) immediately following the ATT_START keyword.

5.2.4.11 Time tags of consecutive attitude states within the ordered sequence may be separated by uniform or non-uniform step size(s).

5.2.4.12 Attitude state time tags may or may not match those of maneuver or covariance time histories.

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

Table 5-4: ACM Data: Attitude State Time History

Keyword	Description	Units	Examples of Values	Mandatory
ATT_START	Start of an attitude state time history section	n/a	n/a	Yes
COMMENT	Comments allowed only immediately after the ATT_START keyword	n/a	COMMENT This is a comment	No
ATT_ID	Optional alphanumeric free-text string containing the identification number for this attitude state time history.	n/a	ATT_20160402_XYZ	No
ATT_BASIS	Basis of this attitude state time history data, this is a text field with the following suggested values: 1. “PREDICTED” 2. “DETERMINED_GND” when estimated by post-processing attitude sensor data on the ground 3. “DETERMINED_OBC” when estimated onboard using onboard sensor data 4. “Simulated” for future mission design or other testing purposes	n/a	PREDICTED	No
REF_FRAME_A	Name of the reference frame that defines the starting point of the transformation. The set of allowed values is described in ANNEX B, section B3.	n/a	J2000	Yes
REF_FRAME_B	Name of the reference frame that defines the end point of the transformation. The set of allowed values is described in ANNEX B, section B3.	n/a	SC_BODY	Yes
NUMBER_STATES	Number of data states included. States to be included are attitude states and rate states.	n/a	3 4 7	Yes
ATT_TYPE	Type of attitude data, selected per ANNEX B, section B4. Attitude states must always be listed before RATE_STATES. Attitude data must always be listed before rate data. If ATT_TYPE = EULER_ANGLES, data included will have units of degrees.	n/a	QUATERNION EULER_ANGLES DCM	Yes
RATE_TYPE	Type of rate data, selected per ANNEX B, section B4. If rate data is included, NUMBER_STATES must be at least 6 to include both attitude and rate data. If RATE_TYPE = ANGVEL or GYRO_BIAS, data included will have units of deg/sec.	n/a	ANGVEL GYRO_BIAS Q_DOT NONE	No
… < Insert attitude lines here>				Yes
ATT_STOP	End of an attitude state time history section	n/a	n/a	Yes

5.2.5 ACM DATA: SPACE OBJECT PHYSICAL CHARACTERISTICS

5.2.5.1 Table 5-5 provides an overview of the ACM space object physical characteristics section. Only those keywords shown in Table 5-5 shall be used in ACM space object physical characteristics data.

5.2.5.2 Keyword values shall be provided in the units specified in Table 5-5.

5.2.5.3 The order of occurrence of these ACM Space Objects Physical Characteristics keywords shall be fixed as shown in Table 5-5.

5.2.5.4 The "ACM Data: Space Object Physical Characteristics" section is optional; "mandatory" in the context of Table 5-5 denotes those keywords which must be included in this section if this section is included.

5.2.5.5 Only one space object physical characteristics section shall appear in an ACM.

5.2.5.6 The space object physical characteristics data section in the ACM shall be indicated by two keywords: PHYS_START and PHYS_STOP.

5.2.5.7 Further definition of Space Object Physical Characteristics parameters is provided in [H2].

Table 5-5: ACM Data: Space Object Physical Characteristics

Keyword	Description	Units	Examples of Values	Mandatory
PHYS_START	Start of a Space Object Physical Characteristics specification	n/a	n/a	Yes
COMMENT	Comments allowed only immediately after the PHYS_START keyword.	n/a	COMMENT This is a comment	No
MASS	Total S/C Mass at the reference epoch "EPOCH_TZERO"	kg	500.0	No
IXX	Moment of Inertia about the X-axis of the spacecraft's primary body frame (e.g. SC_Body_1)	kg*m**2	1000.0	No
IYY	Moment of Inertia about the Y-axis	kg*m**2	800.0	No
IZZ	Moment of Inertia about the Z-axis	kg*m**2	400.0	No
IXY	Inertia Cross Product of the X & Y axes	kg*m**2	20.0	No
IXZ	Inertia Cross Product of the X & Z axes	kg*m**2	40.0	No
IYZ	Inertia Cross Product of the Y & Z axes	kg*m**2	60.0	No
CP	Vector location of spacecraft center of pressure for determining solar pressure torque, measured from the spacecraft center of mass in the spacecraft's primary body frame (e.g. SC_Body_1).	m	[0.02, 0.01, 0.2]	No
DRAG_COEF	Drag coefficient	n/a	2	No
FUEL_MASS	Fuel mass	kg	750.0	No
PHYS_STOP	End of a Space Object Physical Characteristics specification	n/a	n/a	Yes

5.2.6 ACM DATA: ATTITUDE STATE COVARIANCE TIME HISTORY

5.2.6.1 Table 5-6 provides an overview of the ACM attitude state covariance time history section. Only those keywords shown in Table 5-6 shall be used in ACM covariance time history data specification.

5.2.6.2 Each attitude state covariance time history data block must begin with keyword COV_START and end with keyword COV_STOP.

5.2.6.3 Multiple covariance data blocks may appear in an ACM only if they are delimited by separate COV_START and COV_STOP keywords.

5.2.6.4 Each ATTITUDE state covariance data block should be unique from all others in at least one of the following respects:

1) the covariance time history basis (PREDICTED, DETERMINED, SIMULATION, OTHER)
2) the covariance time history is based upon a unique attitude determination solution or simulation
3) the data interval timespan is unique (i.e., has no overlap with any other data interval(s))

5.2.6.5 All covariance matrices in the ACM data shall be time-tagged by a relative time value measured with respect to the epoch time specified via the EPOCH_TZERO keyword.

5.2.6.6 Each attitude state covariance time history shall be time-ordered to be monotonically increasing.

5.2.6.7 If the user includes attitude state covariances at key mission events or times, it may be useful to provide times, names, and significance for such mission events in descriptive comment line(s) immediately following the COV_START keyword.

5.2.6.8 Values in the covariance matrix shall be only main diagonal elements provided on a single line directly following the time tag specification. Off-diagonal elements may be defined in a user-defined block.

5.2.6.9 Values in the attitude state covariance matrix shall be expressed in the applicable reference frame specified via the 'COV_REF_FRAME' keyword.

Table 5-6: ACM Data: Covariance Time History

Keyword	Description	Units	Examples of Values	Mandatory
COV_START	Start of a covariance time history section	n/a	n/a	Yes
COMMENT	Comments allowed only immediately after the COV_START keyword	n/a	COMMENT This is a comment	No
ATT_ID	Optional alphanumeric free-text string containing the identification number for this attitude covariance time history block	n/a	ATT_20160402_XYZ	No

Keyword	Description	Units	Examples of Values	Mandatory
ATT_BASIS	Basis of this covariance time history data, this is a text field with the following suggested values: 1. “PREDICTED” 2. “DETERMINED_GND” when estimated by post-processing attitude sensor data on the ground 3. “DETERMINED_OBC” when estimated onboard using onboard sensor data 4. “Simulated” for future mission design or other testing purposes	n/a	PREDICTED	No
COV_REF_FRAME	Reference frame of the covariance time history. The full set of values is enumerated in annex B, Section B3.	n/a	SC_BODY	No
COV_TYPE	Indicates covariance composition. Select from ANNEX B, Section B6.	deg, deg/sec	ANGLE ANGLE_GYROBIAS	Yes
…< Insert covariance data here>				Yes
COV_STOP	End of a covariance time history section	n/a	n/a	Yes

5.2.7 ACM DATA: MANEUVER SPECIFICATION

5.2.7.1 Table 5-7 provides an overview of the ACM maneuver specification section. Only those keywords shown in table 5-7 shall be used in the ACM maneuver specification.

5.2.7.2 Keyword values shall be provided in the units specified in the Units column of Table 5-7.

The order of occurrence of these ACM Maneuver Specification keywords shall be fixed as shown in Table 5-7.

5.2.7.3 Maneuver data in the ACM shall be indicated by two keywords: MAN_START and MAN_STOP.

5.2.7.4 Multiple maneuver data blocks shall appear in an ACM only when delimited by separate MAN_START and MAN_STOP keywords.

5.2.7.5 The ‘MAN_PURPOSE’ keyword must appear before the first line of any maneuver time history data.

5.2.7.6 Attitude maneuver data in the ACM data shall be time-tagged by a relative time value measured with respect to the epoch time specified via the EPOCH_TZERO keyword.

Table 5-7: ACM Data: Maneuver Specification

Keyword	Description	Units	Examples of Values	Mandatory
MAN_START	Start of a maneuver data interval specification	n/a	n/a	Yes
COMMENT	Comments allowed only immediately after the MAN_START keyword.	n/a	COMMENT This is a comment	No
MAN_ID	Optional alphanumeric free-text string containing the identification number for this maneuver	n/a	DH2018172	No

MAN_PURPOSE	The user may specify the intention(s) of the maneuver. Multiple maneuver purposes may be provided as a comma-delimited list. While there is no CCSDS-based restriction on the value for this keyword, it is suggested to use: Attitude adjust (ATT_ADJUST) Momentum desaturation (MOM_DESAT) Pointing Request Message (PRM_ID_xxxx) Science objective (SCI_OBJ) Spin rate adjust (SPIN_RATE_ADJUST)	n/a	ATT_ADJUST	No
MAN_ BEGIN	Start time of actual maneuver, measured as a relative time with respect to EPOCH_TZERO	s	100.0	No
MAN_ END	End time of actual maneuver, measured as a relative time with respect to EPOCH_TZERO	s	120.0	No
MAN_DURATION	Length of maneuver, should only specify MAN_END or MAN_DURATION, not both	s	20.0	No
ACTUATOR_USED	Specifies the type of actuator used for the maneuver	n/a	THRUSTER RWA	No
TARGET_MOMENTUM	If MAN_PURPOSE=MOM_DESAT, TARGET_MOMENTUM in SC_BODY	N m s	[0, -10, 0]	No
TARGET_ATTITUDE	If MAN_PURPOSE=ATT_ADJUST, target quaternion	n/a	[0, 0, 0, 1]	No
TARGET_SPINRATE	If MAN_PURPOSE=SPIN_RATE_ADJUST, target spin rate	deg/s	0.31	No
MAN_STOP	End maneuver data interval specification	n/a	n/a	Yes

5.2.8 ACM DATA: ATTITUDE DETERMINATION DATA

5.2.8.1 Table 5-8 provides an overview of the ACM attitude determination data section. Only those keywords shown in Table 5-8 shall be used in ACM attitude determination data specification.

5.2.8.2 At most, only one Attitude Determination Data section shall appear in an ACM.

5.2.8.3 Attitude determination data in the ACM shall be indicated by two keywords: AD_START and AD_STOP.

5.2.8.4 The attitude determination specification shall apply to all ACM attitude and covariance time history data sections that are based upon "determined” attitude solutions.

Table 5-8: ACM Data: Attitude Determination Data

Keyword	Description	Units	Examples of Values	Mandatory
AD_START	Start of an attitude determination data section	n/a	n/a	Yes
COMMENT	Comments allowed only immediately after the AD_START keyword	n/a	COMMENT This is a comment	No

Keyword	Description	Units	Examples of Values	Mandatory
AD_ID	Optional identification number for this attitude determination.	n/a	AD_20190101	No
AD_METHOD	Type of estimator used. For further description see Annex B5.	n/a	EKF, TRIAD, QUEST, BATCH,Q METHOD, FILTER SMOOTHER	No
ATTITUDE_SOURCE	Source of attitude estimate, whether from a ground based estimator or onboard estimator	n/a	GND,OBC	No
NUMBER_STATES	Number of states if EKF, BATCH, or FILTER SMOOTHER is specified.	n/a	3 6 7	No
ATTITUDE_STATES	Type of attitude data, selected per ANNEX B, section B4. Attitude states must always be listed before RATE_STATES.	n/a	QUATERNION	Yes
COV_TYPE	Type of attitude error state included in the estimator. Select from ANNEX B, Section B6.	n/a	ANGLE ANGLE_GYROBIAS NONE	No
REF_FRAME_A	Name of the reference frame that defines the starting point of the transformation described by the attitude state in the estimator. The set of allowed values is described in ANNEX B, section B3.	n/a	J2000	Yes
REF_FRAME_B	Name of the reference frame that defines the ending point of the transformation described by the attitude state in the estimator. The set of allowed values is described in ANNEX B, section B3.	n/a	SC_BODY	Yes
RATE_STATES	Type of rate state included in the estimator, if RATE_STATES are included NUMBER_STATES must be at least 6 to include both ATTITUDE_STATES and RATE_STATES	deg/s	ANGVEL GYRO_BIAS	No
SIGMA_U	Rate random walk if RATE_STATES=GYRO_BIAS	deg/s**1.5	3.7e-7	No
SIGMA_V	Angle random walk if RATE_STATES=GYRO_BIAS	deg/s**0.5	1.3e-5	No
NUMBER_SENSORS_USED	Number of sensors used to provide estimator measurements	n/a	2 3	No
SENSORS_USED_I	Types of sensors used in estimation, I = 1 to NUMBER_SENSORS_USED	n/a	AST, DSS GYRO	No
NUMBER_SENSOR_NOISE_COVARIANCE_I	Number of noise elements for sensor I. For example, noise along horizontal and vertical directions of a CCD, or noise along x, y, and z axes of a sensor.	n/a	2 3	No
SENSOR_NOISE_STDDEV_I	Standard deviation of sensor noise, size will be the same as NUMBER_SENSOR_NOISE_COVARIANCE_I	deg	0.0097, 0.0097	No
SENSOR_FREQUENCY_I	Frequency of sensor I data	Hz	5	No
RATE_PROCESS_NOISE_STDDEV	Process noise standard deviation if RATE_STATES=ANG_VEL	deg/s**1.5	5.1E-06	No
AD_STOP	End of an attitude determination data section	n/a	n/a	Yes

5.2.9 ACM DATA: USER-DEFINED PARAMETERS

5.2.9.1 A section of user-defined parameters may be provided if necessary. In principle, this provides flexibility, but also introduces complexity, non-standardization, potential ambiguity, and potential processing errors. Accordingly, if used, the keywords and their meanings must be described in an ICD. User-Defined Parameters, if included in an ACM, should be used as sparingly as possible; their use is not encouraged.

5.2.9.2 The "ACM data: User-Defined Parameters" section is optional; "mandatory" in the context of Table 5-9 denotes those keywords which must be included in this section if this section is included.

5.2.9.3 At most, only one User-Defined Parameters section shall appear in an ACM.

5.2.9.4 Each user-defined parameter line may be preceded by one or more comment lines.

5.2.9.5 Table 5-9 provides an overview of the ACM user-defined data section. Only those keywords shown in Table 5-9 shall be used in ACM user-defined data specification.

Table 5-9: ACM Data: User-Defined Parameters

Keyword	Description	Units	Examples of Values	Mandatory
USER_START	Start of a user-defined parameters data block	n/a	n/a	Yes
COMMENT	Comments allowed only immediately after the USER_START keyword. See 7.9 for formatting rules.	n/a	COMMENT This is a comment	No
USER_DEFINED_x	User-defined parameter, where 'x' is replaced by a variable length user specified character string. Any number of user-defined parameters may be included, if necessary to provide essential information that cannot be conveyed in standard ACM keywords or in COMMENT statements	n/a	USER_DEFINED_SENSOR = FINE_GUIDANCE_SENSOR	No
USER_STOP	End of a user-defined parameters data block	n/a	n/a	Yes

5.3 ACM EXAMPLES

Figures 5.1 through figure 5-5 are examples of Attitude Comprehensive Messages. The first has only a time history of attitude states and constitutes a minimal content ACM. The second includes space object characteristics, the third includes a maneuver with associated attitude history, the fourth contains an example sensor description block followed by sensor data, and the fifth includes a time series of covariance elements.

```
CCSDS_ACM_VERS  = 2.0
CREATION_DATE   = 1998-11-06T09:23:57
ORIGINATOR      = JAXA
MESSAGE_ID = A7015Z

OBJECT_NAME     = GODZILLA 5
OBJECT_ID       = 2000-052A
TIME_SYSTEM     = UTC
EPOCH_TZERO     = 1998-12-18T14:28:15.1172

ATT_START
REF_FRAME_A    = J2000
REF_FRAME_B    = SC_BODY
NUMBER_STATES = 4
ATT_TYPE = QUATERNION

0.0    0.73566        -0.50547       0.41309        0.180707
0.25   0.73529        -0.50531       0.41375        0.181158
0.50   0.73492        -0.50515       0.41441        0.181610

< additional data records omitted here >
ATT_STOP
```

Figure 5-1: Simple/Succinct ACM File example

```
CCSDS_ACM_VERS   = 2.0

CREATION_DATE    = 2017-12-01T00:00:00
ORIGINATOR       = NASA
MESSAGE_ID = A7015Z

META_START
OBJECT_NAME      = SDO
OBJECT_ID        = 2010-005A
TIME_SYSTEM      = UTC
EPOCH_TZERO      = 2017-12-26T19:40:00.000
META_START


ATT_START
COMMENT           OBC Attitude and Bias during momentum management maneuver
REF_FRAME_A      = J2000
REF_FRAME_B      = SC_BODY
NUMBER_OF_STATES = 7
ATT_TYPE         = QUATERNION
RATE_TYPE        = GYRO_BIAS

0.000000 0.1153 -0.1424 0.8704 0.4571 2.271e-06 -4.405e-06 -3.785e-06
2.000000 0.1153 -0.1424 0.8704 0.4571 2.271e-06 -4.405e-06 -3.785e-06
< intervening data records omitted here >
99.80183  0.1017 -0.1332 0.8806 0.4433 2.587e-06 8.769e-06 5.436e-06
< intervening data records omitted here >
599.80275 0.1152 -0.1423 0.8704 0.4571 2.48e-06 -4.350e-06 -3.779e-06
ATT_STOP


MAN_START
COMMENT            Momentum management maneuver
MAN_PURPOSE      = MOM_DESAT
MAN_BEGIN        = 100.0
MAN_DURATION     = 450.0
ACTUATOR_USED    = THR
TARGET_MOMENTUM  = [1.30, -16.400, -11.350]
MAN_STOP


AD_START
COMMENT            SDO Onboard Filter
AD_METHOD        = EKF
ATTITUDE_SOURCE  = OBC
NUMBER_SENSORS_USED = 4
SENSORS_USED_1   = AST1
SENSORS_USED_2   = AST2
SENSORS_USED_3   = DSS
SENSORS_USED_4   = IMU
AD_STOP
```

Figure 5-2: ACM example with Attitude State Time History, Maneuver Specification, and Attitude Determination Data

```
CCSDS_ACM_VERS  = 2.0

CREATION_DATE         = 1998-11-06T09:23:57
ORIGINATOR            = JAXA
MESSAGE_ID = A7015Z
ORIGINATOR_POC        = Ms. Rodgers, (719)555-5555, email@email.XXX

META_START
OBJECT_NAME           = GODZILLA 5
OBJECT_ID             = 1998-999Z
TIME_SYSTEM           = TAI
EPOCH_TZERO           = 1998-12-18T14:28:15.1172
TAIMUTC_TZERO         = 36      [s]
META_STOP

PHYS_START
COMMENT                 Spacecraft Physical Parameters
MASS                = 1916   [kg]
IXX                 = 752    [kg*m**2]
IYY                 = 1305   [kg*m**2]
IZZ                 = 1490   [kg*m**2]
IXY                 = 81.1   [kg*m**2]
IXZ                 = -25.7  [kg*m**2]
IYZ                 = 74.1   [kg*m**2]
CP                   = 0.04  -0.78  -0.023  [m]
PHYS_STOP
```

Figure 5-3: Example Space Object Physical Characteristics

```
CCSDS_ACM_VERS   = 2.0

CREATION_DATE   = 2017-12-30T00:00:00
ORIGINATOR      = NASA
MESSAGE_ID = A7015Z

META_START
OBJECT_NAME     = LRO
OBJECT_ID       = 2009-031A
TIME_SYSTEM     = UTC
EPOCH_TZERO     = 2017-12-30T00:00:00.0
META_STOP

COV_START
COMMENT  Diagonal Covariance for LRO Onboard Kalman Filter
ATT_BASIS      = DETERMINED_OBC
COV_REF_FRAME  = SC_BODY
COV_TYPE       = ANGLE_GYROBIAS

0.0     6.74E-11 8.10E-11 9.22E-11 1.11E-15 1.11E-15 1.12E-15
1.096694  6.74E-11 8.10E-11 9.22E-11  1.11E-15 1.11E-15 1.12E-15
< intervening data records omitted here >
59.896697 6.74E-11 8.10E-11 9.22E-11  1.11E-15 1.11E-15 1.12E-15
COV_STOP


COMMENT  LRO Onboard Filter, A Multiplicative Extended Kalman Filter
AD_START
AD_METHOD         = EKF
ATTITUDE_SOURCE   = OBC
NUMBER_STATES     = 7
ATTITUDE_STATES   = QUATERNION
COV_TYPE          = ANGLE_GYROBIAS
REF_FRAME_A       = EME2000
REF_FRAME_B       = SC_BODY
RATE_STATES       = GYRO_BIAS
NUMBER_SENSORS_USED = 3
SENSORS_USED_1    = AST1
SENSORS_USED_2    = AST2
SENSORS_USED_3    = IMU
AD_END
```

Figure 5-4: ACM example with Attitude State Covariance Time History and Attitude Determination Data

6. CONSTRUCTING AN ADM/XML INSTANCE

6.1 OVERVIEW

6.1.1 This section provides more detailed instructions for the user on how to create an XML message based on one of the ASCII-text KVN-formatted messages described in Sections 3 through 5 of this document.

6.1.2 This section applies only to the XML representation of the ADM messages. The ADM/XML schemas are available on the SANA Web site. SANA is the registrar for the protocol registries created under CCSDS. The ADM XML schemas explicitly define the permitted data elements and values acceptable for the XML versions of the ADM messages. The location of the ADM/XML schemas is:

APM: https://sanaregistry.org/r/ndmxml/ndmxml-1.0-apm-2.0.xsd

AEM: https://sanaregistry.org/r/ndmxml/ndmxml-1.0-aem-2.0.xsd

ACM: https://sanaregistry.org/r/ndmxml/ndmxml-1.0-acm-2.0.xsd

6.1.3 Where possible these schemas use simple types and complex types used by the constituent schemas that make up Navigation Data Messages (see Reference [5]).

6.2 ADM/XML BASIC STRUCTURE

6.2.1 Each ADM shall consist of a `<header>` and a `<body>`.

6.2.2 The `<body>` shall consist of one or more `<segment>` constructs (one for the APM, one or more for the AEM, one for the ACM).

6.2.3 Each `<segment>` shall consist of one `<metadata>/<data>` pair, as shown in Figure 6-1.

NOTE: An AEM may have more than one segment, in which case the metadata/data pair is repeated in each segment.

```
<header>
</header>
<body>
      &lt;segment&gt;
            <metadata>
            </metadata>
            <data>
            </data>
      &lt;/segment&gt;
</body>
```

Figure 6-1: ADM XML Basic Structure

6.3 ADM/XML TAGS

6.3.1 An ADM XML tag shall be all uppercase if it corresponds directly to a KVN keyword from the Header, Metadata, or Data sections.

6.3.2 The 'CCSDS_A*M_VERS' keyword and value shall appear as XML attributes of the root element rather than as XML elements. This is an exception where there is not a strict correspondence between keywords in the KVN and tags in the XML implementations, specifically, the ‘CCSDS_A*M_VERS’ keywords from the Headers for the APM, AEM, and ACM respectively.

6.3.3 ADM XML tags related to the XML message structure (i.e., that do not correspond directly to a KVN keyword) shall be in ‘lowerCamelCase’ (e.g., <header>, <segment>, <metadata>, <attitudeStateType>, etc.).

6.4 CONSTRUCTING AN ADM/XML INSTANCE

6.4.1 OVERVIEW

This subsection provides more detailed instructions for the user on how to create an XML message based on the ASCII-text KVN-formatted messages described in Sections 1 through 5.

6.4.2 XML VERSION

6.4.2.1 The first line in the instantiation shall specify the XML version:

```
<?xml version="1.0" encoding="UTF-8"?>
```

This line must appear on the first line of each instantiation, exactly as shown.

6.4.3 BEGINNING THE INSTANTIATION: ROOT ELEMENT TAG

6.4.3.1 Each instantiation shall have a 'root element tag' that identifies the message type and other information such as where to find the applicable schema, required attributes, etc.

6.4.3.2 The root element tag in an ADM/XML instantiation shall be one of those listed in Table 6-1.

Table 6-1: ADM/XML Root Element Tags

Root Element Tag	Message Type
`<apm></apm>`	Attitude Parameter Message
`<aem></aem>`	Attitude Ephemeris Message
`<acm></acm>`	Attitude Comprehensive Message

6.4.3.3 The XML Schema Instance namespace attribute must appear in the root element tag of all ADM/XML instantiations, exactly as shown:

```
XMLNS:XSI="HTTP://WWW.W3.ORG/2001/XMLSCHEMA-INSTANCE"
```

6.4.3.4 If it is desired to validate an instantiation against the CCSDS Web-based schema, the xsi:noNamespaceSchemaLocation attribute must be coded as a single string of non-blank characters, with no line breaks, exactly as shown:

```
xsi:noNamespaceSchemaLocation="http://sanaregistry.org/r/ndmxml/ndmxml-
1.0-master.xsd"
```

NOTE – The length of the value associated with the xsi:noNamespaceSchemaLocation attribute can cause the string to wrap to a new line; however, the string itself contains no breaks.

6.4.3.5 There are two attributes that are required in the root element tag of an ADM/XML single message instantiation, specifically, the CCSDS_xxx_VERS keyword that is also part of the standard KVN header, and the Blue Book version number.

6.4.3.6 The final attributes of the root element tag shall be ‘id’ and ‘version’.

6.4.3.7 The ‘id’ attribute shall be ‘id="CCSDS_xxx_VERS"’, where xxx = AEM, APM, or ACM.

6.4.3.8 The ‘version’ attribute shall be ‘version="2.0"’.

NOTE – The following example root element tag for an APM instantiation combines all the directions in the preceding several subsections:

```
<?xml version="1.0" encoding="UTF-8"?>
<apm  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation=
"http://sanaregistry.org/r/ndmxml/ndmxml-1.0-master.xsd"
id="CCSDS_APM_VERS" version="2.0">
```

6.4.4 THE ADM/XML HEADER SECTION

6.4.4.1 The ADMs (APM, AEM, ACM) shall share a standard header format, with tags `<header>` and `</header>` (see [5]).

6.4.4.2 Immediately following the <header> tag the message may have any number of `<COMMENT></COMMENT>` tag pairs.

6.4.4.3 The standard ADM header shall contain the following element tags:

a) `<CREATION_DATE>`

b) `<ORIGINATOR>`

c) <MESSAGE_ID>

NOTE – The rules for these keywords are specified in Table 3-1, Table 4-2 and Table 5-2. An example <header> section is shown immediately below:

```
<header>
   <COMMENT>This is the common ADM/XML Header.</COMMENT>
   <COMMENT>I can put as many comments here as I want,</COMMENT>
   <COMMENT>including none.</COMMENT>
   <CREATION_DATE>2010-03-12T22:31:12.000</CREATION_DATE>
   <ORIGINATOR>AGENCYX</ORIGINATOR>
   <MESSAGE_ID>AGENCYX-1234</MESSAGE_ID>
</header>
```

6.4.5 THE ADM/XML BODY SECTION

6.4.5.1 After coding the <header>, the instantiation must include a <body></body> tag pair.

6.4.5.2 Inside the <body></body> tag pair must appear at least one <segment></segment> tag pair, depending on the particular ADM (APM, AEM, ACM).

6.4.5.3 Each <segment> must be made up of one <metadata></metadata> tag pair and one <data></data> tag pair.

6.4.6 THE ADM/XML METADATA SECTION

6.4.6.1 All ADMs must have at least one metadata section.

6.4.6.2 The Metadata section shall be set off by the <metadata></metadata> tag combination.

6.4.6.3 Immediately following the <metadata> tag, the message may have any number of <COMMENT></COMMENT> tag pairs.

NOTE: The <COMMENT></COMMENT> placement is regulated by the XML schema. Standard XML comments, i.e. of the form <!-- comment content --> may be placed anywhere in the Metadata Section because they are ignored by the XML schema validator.

6.4.6.4 Between the <metadata> and </metadata> tags, the keywords shall be the same as those in the Metadata sections in Sections 3 through 5 of this document, with exceptions as noted in the subsections that discuss creating instantiations of the specific messages.

6.4.7 THE ADM/XML DATA SECTION

6.4.7.1 All ADMs must have at least one data section.

6.4.7.2 The Data Section shall follow the Metadata Section and shall be set off by the `<data></data>` tag combination.

6.4.7.3 Immediately following the `<data>` tag, the message may have any number of `<COMMENT></COMMENT>` tag pairs.

NOTE: The `<COMMENT></COMMENT>` placement is regulated by the XML schema. Standard XML comments, i.e. of the form `<!-- comment content -->` may be placed anywhere in the Data Section because they are ignored by the XML schema validator.

6.4.7.4 Between the `<data>` and </data> tags, the keywords shall be the same as those in the data sections in Sections 3 through 5 of this document, with exceptions as noted in the subsections that discuss creating instantiations of the specific messages.

6.5 LOCAL OPERATIONS

6.5.1 For use in a local operations environment, the NDM/XML schema set (which includes the ADM schemas) may be downloaded from the SANA web site to a local server that meets local requirements for operations robustness. See Reference [5].

6.5.2 If a local version is used, the value associated with the xsi:noNamespaceSchemaLocation attribute must be changed to a URL that is accessible to the local server.

6.6 CREATING AN APM INSTANTIATION

6.6.1 An APM instantiation shall be delimited by the `<apm></apm>` root element tags using the standard attributes documented in 6.4.3.

NOTE – Figures <<TBD>> provide example APM instantiations.

6.6.2 The final attributes of the `<apm>` tag shall be 'id' and 'version'; the order in which these attributes are specified is not significant.

6.6.3 The 'id' attribute shall be '`id="CCSDS_APM_VERS"`'.

6.6.4 The '`version`' attribute for the version of the APM shall be '`version="2.0"`'.

6.6.5 The standard ADM/XML header shall follow the `<apm>` tag (see 6.4.4).

6.6.6 The APM `<body>` shall consist of a single `<segment>`.

6.6.7 The keywords in the `<metadata>` and `<data>` sections shall be those specified in Section 3.2.

6.6.8 Tags for keywords shall be all uppercase, as in Section 3.2.

6.6.9 Several of the APM/XML keywords may have a unit attribute, if desired by the APM producer, as illustrated in the following table:

Table 6-2: APM XML Units

Keyword	Units	Example
Q1_DOT	1/s	<Q1_DOT units="1/s">numeric-value</Q1_DOT>
Q2_DOT	1/s	<Q2_DOT units="1/s">numeric-value</Q2_DOT>
Q3_DOT	1/s	<Q3_DOT units="1/s">numeric-value</Q3_DOT>
QC_DOT	1/s	<QC_DOT units="1/s">numeric-value</QC_DOT>
ANGLE_1	deg	<ANGLE_1 units="deg">numeric-value</ANGLE_1>
ANGLE_2	deg	<ANGLE_2 units="deg">numeric-value</ANGLE_2>
ANGLE_3	deg	<ANGLE_3 units="deg">numeric-value</ANGLE_3>
ANGLE_1_DOT	deg/s	<ANGLE_1_DOT units="deg/s">numeric-value</ANGLE_1_DOT>
ANGLE_2_DOT	deg/s	<ANGLE_2_DOT units="deg/s">numeric-value</ANGLE_2_DOT>
ANGLE_3_DOT	deg/s	<ANGLE_3_DOT units="deg/s">numeric-value</ANGLE_3_DOT>
ANGVEL_X	deg/s	<ANGVEL_X units="deg/s">numeric-value</ANGVEL_X>
ANGVEL_Y	deg/s	<ANGVEL_Y units="deg/s">numeric-value</ANGVEL_Y>
ANGVEL_Z	deg/s	<ANGVEL_Z units="deg/s">numeric-value</ANGVEL_Z>
SPIN_ALPHA	deg	<SPIN_ALPHA units="deg">numeric-value</SPIN_ALPHA>
SPIN_DELTA	deg	<SPIN_DELTA units="deg">numeric-value</SPIN_DELTA>
SPIN_ANGLE	deg	<SPIN_ANGLE units="deg">numeric-value</SPIN_ANGLE>
SPIN_ANGLE_VEL	deg/s	<SPIN_ANGLE_VEL units="deg/s">numeric-value</SPIN_ANGLE_VEL>
NUTATION	deg	<NUTATION units="deg">numeric-value</NUTATION>
NUTATION_PER	s	<NUTATION_PER units="s">numeric-value</NUTATION_PER>
NUTATION_PHASE	deg	<NUTATION_PHASE units="deg">numeric-value</NUTATION_PHASE>
IXX	kg*m**2	<IXX units="kg*m**2">numeric-value</IXX>
IYY	kg*m**2	<IYY units="kg*m**2">numeric-value</IYY>
IZZ	kg*m**2	<IZZ units="kg*m**2">numeric-value</IZZ>
IXY	kg*m**2	<IXY units="kg*m**2">numeric-value</IXY>
IXZ	kg*m**2	<IXZ units="kg*m**2">numeric-value</IXZ>
IYZ	kg*m**2	<IYZ units="kg*m**2">numeric-value</IYZ>
MAN_DURATION	s	<MAN_DURATION units="s">numeric-value</MAN_DURATION>
MAN_TOR_X	N*m	<MAN_TOR_X units="N*m">numeric-value</MAN_TOR_X>
MAN_TOR_Y	N*m	<MAN_TOR_Y units="N*m">numeric-value</MAN_TOR_Y>
MAN_TOR_Z	N*m	<MAN_TOR_Z units="N*m">numeric-value</MAN_TOR_Z>

6.6.10 SPECIAL TAGS IN THE APM/XML BODY

NOTE – In addition to the APM keywords specified in Section 3, there are several special tags associated with the APM body as described in the next few subsections. The information content in the APM is separated into constructs referred to as 'logical blocks'. Special tags in the APM are used to encapsulate the information in the logical blocks of the APM.

6.6.10.1 The APM/XML tags used to delimit the logical blocks of the APM shall be drawn from the following table:

Table 6-3: Special Tags in the APM/XML Body

APM Logical Block	Associated APM/XML Tag

Attitude Quaternion	`<quaternionState>`
	  `<quaternion>`
	  `<quaternionDerivative>`
	
	The <quaternionState> consists of the <quaternion> tag that contains the components of the quaternion itself, and the <quaternionDerivative> tag that contains the rate of change of the quaternion components

Euler Angle Elements	<eulerAngleElements>
Angular Velocity Vector	<angularVelocity>
Spin	<spin>
Inertia	<inertia>
Maneuver Parameters	<maneuverParameters>

6.6.10.2 Between the begin tag and end tag (e.g., between <eulerAngleElements> and </eulerAngleElements>), the user shall place the keywords required by the specific logical block as specified in Section 3.

6.6.11 DISCUSSION

This non-normative subsection discusses and provides examples of the use of quaternion tags in the APM.

The XML representations of quaternions in the ADM constituent messages share a common quaternion definition. However, there are some differences in those definitions in the underlying KVN definitions of the APM and AEM. The following examples are meant to illustrate the standard for representing quaternions in the APM.

Here is an example APM quaternion construct:

```
<quaternionState>
  <EPOCH>2004-100T00:00:00Z</EPOCH>
  <REF_FRAME_A>ICRF</REF_FRAME_A>
  <REF_FRAME_B>ICRF</REF_FRAME_B>
  <quaternion>
   <Q1>0.00005</Q1>
   <Q2>0.87543</Q2>
   <Q3>0.40949</Q3>
   <QC>0.25678</QC>
  </quaternion>
</quaternionState>
```

Here is an example APM quaternion construct with the optional derivative:

```
<quaternionState>
  <EPOCH>2004-100T00:00:00Z</EPOCH>
  <REF_FRAME_A>ICRF</REF_FRAME_A>
  <REF_FRAME_B>ICRF</REF_FRAME_B>
  <quaternion>
```

```
     <Q1>0.00005</Q1>
     <Q2>0.87543</Q2>
     <Q3>0.40949</Q3>
     <QC>0.25678</QC>
    </quaternion>
    <quaternionDerivative>
     <Q1_DOT>0.002</Q1_DOT>
     <Q2_DOT>0.003</Q2_DOT>
     <Q3_DOT>0.004</Q3_DOT>
     <QC_DOT>0.001</QC_DOT>
    </quaternionDerivative>
  </quaternionState>
```

6.7 CREATING AN AEM INSTANTIATION

6.7.1 An AEM instantiation shall be delimited with the `<aem></aem>` root element tags using the standard attributes documented in 6.4.3.

NOTE – Figures <<TBD>> provide example AEM instantiations.

6.7.2 The final attributes of the `<aem>` tag shall be ‘id’ and ‘version’; the order in which these attributes are specified is not significant.

6.7.3 The ‘id’ attribute shall be ‘id="CCSDS_AEM_VERS"’.

6.7.4 The ‘version’ attribute for the version of the AEM shall be ‘version="2.0"’.

6.7.5 The standard ADM/XML header shall follow the `<aem>` tag (see 6.4.4).

6.7.6 The AEM `<body>` shall consist of one or more `<segment>` constructs (see [5], section 3.4).

6.7.7 The keywords in the `<metadata>` and `<data>` sections shall be those specified in Section 4.2.

6.7.8 Tags for keywords shall be all uppercase as in Section 4.2.

6.7.9 Although units are not specified in the KVN representation of the AEM, several of the AEM/XML keywords may have a unit attribute, if desired by the AEM producer, as illustrated in the following table:

Table 6-4: AEM XML Units

Keyword	Units	Example
Q1_DOT	1/s	<Q1_DOT units="1/s">numeric-value</Q1_DOT>
Q2_DOT	1/s	<Q2_DOT units="1/s">numeric-value</Q2_DOT>
Q3_DOT	1/s	<Q3_DOT units="1/s">numeric-value</Q3_DOT>
QC_DOT	1/s	<QC_DOT units="1/s">numeric-value</QC_DOT>
ANGLE_1	deg	<ANGLE_1 units="deg">numeric-value</ANGLE_1>
ANGLE_2	deg	<ANGLE_2 units="deg">numeric-value</ANGLE_2>
ANGLE_3	deg	<ANGLE_3 units="deg">numeric-value</ANGLE_3>
ANGLE_1_DOT	deg/s	<ANGLE_1_DOT units="deg/s">numeric-value</ANGLE_1_DOT>
ANGLE_2_DOT	deg/s	<ANGLE_2_DOT units="deg/s">numeric-value</ANGLE_2_DOT>
ANGLE_3_DOT	deg/s	<ANGLE_3_DOT units="deg/s">numeric-value</ANGLE_3_DOT>
ANGVEL_X	deg/s	<ANGVEL_X units="deg/s">numeric-value</ANGVEL_X>
ANGVEL_Y	deg/s	<ANGVEL_Y units="deg/s">numeric-value</ANGVEL_Y>
ANGVEL_Z	deg/s	<ANGVEL_Z units="deg/s">numeric-value</ANGVEL_Z>
SPIN_ALPHA	deg	<SPIN_ALPHA units="deg">numeric-value</SPIN_ALPHA>
SPIN_DELTA	deg	<SPIN_DELTA units="deg">numeric-value</SPIN_DELTA>
SPIN_ANGLE	deg	<SPIN_ANGLE units="deg">numeric-value</SPIN_ANGLE>
SPIN_ANGLE_VEL	deg/s	<SPIN_ANGLE_VEL units="deg/s">numeric-value</SPIN_ANGLE_VEL>
NUTATION	deg	<NUTATION units="deg">numeric-value</NUTATION>
NUTATION_PER	s	<NUTATION_PER units="s">numeric-value</NUTATION_PER>
NUTATION_PHASE	deg	<NUTATION_PHASE units="deg">numeric-value</NUTATION_PHASE>

6.7.10 SPECIAL TAGS IN THE AEM BODY

NOTE – In addition to the AEM keywords specified in Section 4.2, there are several special tags associated with the AEM body as described in the next few subsections.

6.7.10.1 The <attitudeState> tag shall be used to encapsulate the keywords associated with the structure of one of the attitude ephemeris data line types.

6.7.10.2 The ADM/XML tags used within the `<attitudeState>` structure shall be drawn from the following table:

Table 6-5: Special Tags in the AEM/XML Body

AEM 'ATTITUDE_TYPE' Metadata Value	Associated ADM/XML Tag in the <attitudeState>
QUATERNION	<quaternionState>
QUATERNION/DERIVATIVE	<quaternionDerivative>
QUATERNION/ANGVEL	<quaternionAngvel>
EULER_ANGLE	<eulerAngle>
EULER_ANGLE/DERIVATIVE	<eulerAngleDerivative>
EULER_ANGLE/ANGVEL	<eulerAngleAngvel>
SPIN	<spin>
SPIN/NUTATION	<spinNutation>

6.7.10.3 Between the begin tag and end tag (e.g., between `<quaternionState>` and `</quaternionState>`), the user shall place the values required by the specific ephemeris data line type as specified in Section 4.2.5, Table 4-4.

6.7.10.4 In the XML representation of the AEM, the components of the `<attitudeState>` ephemeris data line must be represented with keywords (i.e., a tag).

6.7.10.5 The `<attitudeState>` keywords shall be the same as those defined for the same construct in the APM.

NOTE – In the KVN representations of the ephemeris data lines, keywords are not used. Rather, the components of the ephemeris data line appear in an order defined by the specific ephemeris data line type. In the XML representation, the tags described are fundamental to the format.

6.7.11 DISCUSSION

This non-normative subsection discusses and provides examples of the use of quaternion tags in the AEM.

The XML representations of quaternions in the ADM constituent messages share a common quaternion definition. However, there are some differences in those definitions in the underlying KVN definitions of the APM and AEM. As in the KVN representation of the quaternion, it is possible to code the tags for the individual components of the quaternion (Q1, Q2, Q3, QC) in either of the standard orders (i.e., scalar component first or last). The following examples are meant to illustrate the standard for representing quaternions in the AEM.

Here is an example AEM quaternion for a 'QUATERNION' ephemeris data line:

```
<attitudeState>
  <quaternionState>
   <EPOCH>2004-100T00:00:00</EPOCH>
   <quaternion>
     <Q1>0.00005</Q1>
     <Q2>0.87543</Q2>
     <Q3>0.40949</Q3>
     <QC>0.25678</QC>
   </quaternion>
  </quaternionState>
</attitudeState>
```

Here is an example AEM quaternion for a ‘QUATERNION/DERIVATIVE’ ephemeris data line:

```
<attitudeState>
  <quaternionDerivative>
   <EPOCH>2004-100T00:00:00</EPOCH>
   <quaternion>
     <Q1>0.00005</Q1>
     <Q2>0.87543</Q2>
     <Q3>0.40949</Q3>
     <QC>0.25678</QC>
   </quaternion>
   <quaternionDerivative>
     <Q1_DOT>0.002</Q1_DOT>
     <Q2_DOT>0.003</Q2_DOT>
     <Q3_DOT>0.004</Q3_DOT>
     <QC_DOT>0.001</QC_DOT>
   </quaternionDerivative>
  </quaternionDerivative>
</attitudeState>
```

6.8 CREATING AN ACM INSTANTIATION

6.8.1 SECTION FORTHCOMING AS THE ACM IS DEFINED... NOTHING TO ADD AT THIS TIME.

7. ATTITUDE DATA MESSAGES KVN SYNTAX

7.1 INTRODUCTION

This section details the syntactic requirements for attitude messages. All APM, AEM and ACM messages shall observe the syntax described in subsections 7.2 through 7.9.

7.2 APM

7.2.1 The APM shall be a plain text file, using keyword descriptions given in 3.2.2 through 3.2.4.

7.3 AEM

7.3.1 The AEM shall be a plain text file, using the keyword descriptions given in 4.2.2 through 4.2.5.

7.4 ACM

7.4.1 The ACM shall be a plain text file, using the keywords given in 5.2.2 through 5.2.9.

7.5 LINES

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

7.5.2 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.

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

7.5.4 Comment lines shall be optional. See 7.9.2 for details regarding the placement of comment lines in an APM. See 7.9.3 for details regarding the placement of comment lines in an AEM. See 7.9.4 for details regarding the placement of comment lines in an ACM.

7.5.5 APM, AEM, and ACM 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.

7.6 KEYWORDS

7.6.1 All header, metadata, and data lines, with exceptions as noted in 7.6.9, shall use ‘keyword = value’ notation, abbreviated as KVN.

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

7.6.3 Keywords must be uppercase and must not contain blanks.

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

7.6.5 Any white space immediately preceding or following the ‘equals’ sign shall not be significant.

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

7.6.7 Any white space immediately preceding or following the units shall not be significant.

7.6.8 The order of occurrence of mandatory and optional KVN assignments shall be fixed as shown in tables 3-1, 3-2, and 3-3 for the APM, as shown in tables 4-2 and 4-3 for the AEM, and as shown in tables 5-2 through 5-9 for the ACM.

7.6.9 The keywords COMMENT, *_START (where * is different from "MANEUVER_EPOCH"), *_STOP, and AEM data lines are exceptions to the KVN syntax.

7.7 VALUES

7.7.1 Angle measurements shall be given in degrees, with values between -360 and 360 degrees. If agencies wish to exchange using radians, this must be specified in an ICD because it is nominally outside the standard.

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

7.7.3 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 zeroes may be used. The range of values that may be expressed as an integer is:

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

NOTE – The commas in the range of values above are thousands separators and are used only for readability. They should not appear in an actual message.

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

7.7.4.1 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.

7.7.4.2 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.

7.7.5 These specifications for integer, fixed-point, and floating-point values conform to the XML specifications for the data types four-byte integer 'xsd:int', 'xsd:decimal' and 'xsd:double' respectively. The specifications for floating-point values conform to the IEEE double precision type (reference [5]). 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 [5]). Note that NaN, +Inf, -Inf, and -0 are not supported values.

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

7.7.7 A non-empty value field must be specified for each keyword provided, except as noted in 7.6.9.

7.7.8 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.

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

YYYY-MM-DDThh: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 [3], ASCII Time Code A and B.

7.8 UNITS

7.8.1 APM RESTRICTIONS

7.8.1.1 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) division of units shall be denoted with a forward slash '/' (e.g., '[deg/s]');

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

7.8.2 AEM RESTRICTIONS

7.8.2.1 Units shall not be displayed; the applicable units are determined by the value set for the ATTITUDE_TYPE keyword. See 4.2.5.3.

7.8.3 ACM RESTRICTIONS

7.8.3.1 Units for ACM keyword values shall not be displayed; applicable units are specified in the "Units" column of Tables 5-4 through 5-9.

7.9 COMMENTS

7.9.1 GENERAL

7.9.1.1 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.

7.9.1.2 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.

7.9.1.3 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, AEM or ACM producer convey key elements of that information in comments and use an ICD to provide further details.

7.9.2 APM SPECIFIC

7.9.2.1 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.

7.9.3 AEM SPECIFIC

7.9.3.1 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. See Table 4-2, Table 4-3 and Table 4-4.

7.9.4 ACM SPECIFIC

7.9.4.1 Comments are optional and may appear at the beginning of the ACM Header, ACM Metadata section, and after the start of each included ACM Data block as shown in tables 5-4 through 5-9.

8. ATTITUDE DATA MESSAGES XML SYNTAX

NOTE: Could be put in Section 7 also (i.e., one syntax section, divided between KVN and XML.

8.1 OVERVIEW

8.1.1 XML instantiations of an ADM shall observe the syntax described in this chapter.

8.2 ADM LINES IN XML

8.2.1 Each ADM file shall consist of a set of ADM lines. Each ADM line shall be one of the following:

– XML version line;

– an XML-formatted line; or

– a blank line.

8.2.2 Each ADM line must not exceed 254 ASCII characters and spaces (excluding line termination character[s]). [Question: Different limit for ACM?]

8.2.3 Only printable ASCII characters and blanks shall be used. Control characters (such as TAB, etc.) shall not be used, with the exception of the line termination characters specified below. [Note: Frank has recommended as statement/requirement regarding XML "escaped" characters such as & < > " ', but it is not yet clear what the statement/requirement should be.]

8.2.4 Blank lines may be used at any position within the file. Blank lines shall have no assignable meaning, and may be ignored.

8.2.5 All 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.

8.3 VALUES IN THE ADM/XML

8.3.1 Each mandatory XML tag must be present and contain a valid value.

8.3.2 Integer values shall follow the conventions of the integer data type per Reference [reference here to XML datatypes document [9] (see above)]. Additional restrictions on the allowable range of values permitted for any integer data element may also be defined in the ADM XML Schema.

NOTE – Examples of such restrictions may include a defined range (e.g., 0 - 100, 1 - 10, etc.), a set of enumerated values (e.g., 0,1,2,4,8), a pre-defined specific variation such as positiveInteger, or a user-defined data type variation.

8.3.3 Non-integer numeric values may be expressed in either fixed-point or floating-point notation. Numeric values shall follow the conventions of the double data type per Reference [reference here to XML datatypes document [9] (see above)]. Additional restrictions on the allowable range of values permitted for any numeric data element may also be defined in the ADM XML Schema.

NOTE – Examples of such restrictions may include a defined range (e.g., 0.0-100.0, etc.), or a user-defined data type variation.

8.3.4 Text values shall follow the conventions of the string data type per Reference [reference here to XML datatypes document [9] (see above)]. Additional restrictions on the allowable range or values permitted for any data element may also be defined in the ADM XML Schema.

NOTE – Examples of such restrictions may include a set of enumerated values (e.g., ‘YES’/‘NO’) or other user-defined data type variation.

8.3.5 Text values in ADM/XML instantiations (i.e., the values between the opening and closing tags), shall consist of either all uppercase or all lowercase characters; an exception is made for values between the `<COMMENT>` and `</COMMENT>` tags, which may be in any case desired by the user. Otherwise, instantiations shall not mix uppercase and lowercase characters in values.

8.3.6 In value fields that represent a time tag, values shall follow the conventions of the ndm:epochType data type used in all CCSDS NDM/XML schemas (see 7.7).

8.4 UNITS IN THE ADM/XML

8.4.1 The units in the ADM/XML shall be the same units used in the KVN-formatted ADM described in Sections 3 through 5. XML attributes shall be used to explicitly define the units or other important information associated with the given data element (see Annex C for examples).

8.5 COMMENTS IN ADM/XML

8.5.1 Comments are optional and must be displayed as values between the `<COMMENT>` and `</COMMENT>` tags. Comments may be in any case desired by the user.

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 the Attitude Data Message. 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.

Item Column

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

Feature Column

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

Status Column

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 THE ATTITUDE DATA MESSAGE

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

504.0-B-2	
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 [H2]. If exchange partners wish to use different settings, they should be documented in an ICD.

B2 TIME_SYSTEM METADATA KEYWORD

The value associated with this keyword must be selected from the full set of allowed values enumerated in the SANA Registry:

- https://sanaregistry.org/r/time_systems.

B3 REF_FRAME KEYWORD VALUES

This section describes the allowable keywords for reference frames that can be used by ADM messages. They are valid for keywords REF_FRAME_* in the APM, AEM and ACM messages, where '*' denotes 'A' or 'B' and for the keyword MAN_REF_FRAME.

The value associated with these keywords must be selected from the full set of allowed values enumerated in one of the following SANA Registries:

- https://sanaregistry.org/r/celestial_body_reference_frames
- https://sanaregistry.org/r/orbit_relative_reference_frames
- https://sanaregistry.org/r/spacecraft_body_reference_frames

B4 ATTITUDE AND RATE TYPES

The following table enumerates the allowed values for the keywords associated with ATT_TYPE and RATE_TYPE in the ACM.

Keyword Value	Meaning/Description
QUATERNION	Coordinate transformation represented as a quaternion
EULER_ANGLES	Coordinate transformation represented with three successive rotations

DCM	Coordinate transformation represented as a 3x3 matrix
ANGVEL	Angular velocity vector
Q_DOT	Rate of change of the quaternion
EULER_RATE	Time derivative of the Euler angles
GYRO_BIAS	Correction to gyro estimated angular velocity

B5 ESTIMATOR TYPES

The following table enumerates the allowed values for the keyword AD_METHOD in the ACM:

Keyword Value	Meaning/Description
EKF	Extended Kalman Filter, a sequential estimation algorithm applied to spacecraft attitude determination. Often additional state vector components are included, such as gyro biases or angular velocity.
TRIAD	TRIAxial Attitude Determination, an algebraic method for determination of spacecraft attitude from a set of two vector observations.
QUEST	Quaternion ESTimator, an efficient, deterministic algorithm to estimate a spacecraft attitude quaternion.
BATCH	A batch least squares algorithm to estimate spacecraft attitude, and optionally additional sensor parameters such as alignments, biases, scale factors.
Q_METHOD	Considered the best deterministic algorithm to estimate a spacecraft attitude quaternion. Requires use of an eigenvalue decomposition algorithm.
FILTER_SMOOTHER	A method to smooth noisy processes. Several smoothing approaches exist such as fixed-point, fixed-lag, and fixed-interval. Used in ground applications to produce fine attitude estimates for post-processing applications.

B6 COVARIANCE MATRIX TYPES

This section describes the allowable keywords for covariance matrix types that can be used by ACM messages.

Name	**Description and Reference**	**Nomenclature**	**Default Units/Type**
ANGLE	3x3: Angular errors about each spacecraft axis	dθ_1, dθ_2, dθ_3	deg
ANGLE_GYROBIAS	6x6: Angular errors about each spacecraft axis and gyro bias errors	dθ_1, dθ_2, dθ_3, db_1, db_2, db_3	deg, deg/sec
ANGLE_ANGVEL	6x6: Angular errors about each spacecraft axis and angular velocity errors	dθ_1, dθ_2, dθ_3, dω_1, dω_2, dω_3	deg, deg/sec
QUATERNION	4x4: Quaternion errors	dQ_1, dQ_2, dQ_3, dQ_4	unitless
QUATERNION_GYROBIAS	7x7: Quaternion errors and gyro bias errors	dQ_1, dQ_2, dQ_3, dQ_4, db_1, db_2, db_3	unitless, deg/sec
QUATERNION_ANGVEL	7x7: Quaternion errors and angular velocity errors	dQ_1, dQ_2, dQ_3, dQ_4, dω_1, dω_2, dω_3	unitless, deg/sec

B7 NORMATIVE REFERENCES FOR ATTITUDE AND SPACECRAFT CONVENTIONS

[B-1] SANA Registry of Attitude and Spacecraft Conventions: https://sanaregistry.org/r/attitude_and_spacecraft_conventions

ANNEX C

CONVENTIONS FOR ADM DATA

(INFORMATIVE)

C1 OVERVIEW

This annex 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:

$Q_1 = \sin(\phi/2) * e_1$
$Q_2 = \sin(\phi/2) * e_2$
$Q_3 = \sin(\phi/2) * e_3$
$Q_C = \cos(\phi/2)$

where:

- ϕ is the rotation angle,
- e_1, e_2 and e_3 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:

$$M_{BA} = \begin{bmatrix} Q_1^2 - Q_2^2 - Q_3^2 + Q_c^2 & 2\,(Q_1\,Q_2 + Q_3\,Q_c) & 2\,(Q_1\,Q_3 - Q_2\,Q_c) \\ 2\,(Q_1\,Q_2 - Q_3\,Q_c) & -Q_1^2 + Q_2^2 - Q_3^2 + Q_c^2 & 2\,(Q_2\,Q_3 + Q_1\,Q_c) \\ 2\,(Q_1\,Q_3 + Q_2\,Q_c) & 2\,(Q_2\,Q_3 - Q_c\,Q_c) & -Q_1^2 - Q_2^2 + Q_3^2 + Q_c^2 \end{bmatrix}$$

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 θ_1, θ_2, θ_3 the 3 rotation angles, and a_1, a_2, a_3 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 θ_1 and axis a_1, angle θ_2 and axis a_2, angle θ_3 and axis a_3 are the respective basis vectors of frame B.

Example:

Let's consider the 3 successive rotations around axes a_1=X, a_2=Y, a_3=Z of respective angles θ_1, θ_2, θ_3.

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

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

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:

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

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

The components of the angular momentum vector in frame B are:

- 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)

$$I = \begin{bmatrix} I_{XX} & -I_{XY} & -I_{XZ} \\ -I_{XY} & I_{YY} & -I_{YZ} \\ -I_{XZ} & -I_{YZ} & I_{ZZ} \end{bmatrix}$$

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 2.0

Changes relative to APM:

Number	Description	Rationale for change	See section
1	The "*_DIR" keywords have been removed	Simplification of the standard.	
2	The quaternion block is now optional.	Enable more flexibility if other data need to be exchanged.	
3	Any block can now be present as many times as necessary.	Increased flexibility.	
4	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.	Avoid misuse of exchange data.	
5	Euler rotation sequences ("EULER_ROT_SEQ" keyword) are specified by letter (X, Y, Z) instead of number, e.g. XYX instead of 121.	Improvement as version 1 led to repeated keyword as X_ANGLE, Y_ANGLE, X_ANGLE.	
6	The logical block "Euler angles" now contains angle derivatives rather than components of the angular velocity vector.	Better design of the standard.	
7	A new block for the angular velocity vector has been added: ANGVEL.	Better design of the standard.	
8	The keywords for the moments of inertia have changed: IXY instead of I12, etc...	Consistency with other changes	
9	Data blocks have been added. Data types such as quaternion, Euler angles... are explicitly enclosed between QUAT_START ... QUAT_STOP,	Make the data easier to process, and the standard easier to extend in the future	

	EULER_START … EULER_STOP, etc delimiters.		
10	A new keyword: “MESSAGE_ID” has been added.	Consistency with other standards	
11	Frame related keywords have changed in APM version 2: keywords in version 1 such as Q_FRAME_*, SPIN_FRAME_*, etc… (where * denotes “A” or “B”) have been removed. The keywords in version 2 are REF_FRAME_*.	Increased simplicity	
12	The keywords defining attitude direction (Q_DIR, EULER_DIR, SPIN_DIR) have been removed. The direction is always from A to B.	Simplicity of the standard	

Changes relative to AEM:

Number	Description	Rationale for change	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.	Consistency with ADM	
2	A new value has been introduced for the "ATTITUDE_TYPE" keyword: EULER_ANGLE/DERIVATIVE	Consistency with ADM	
3	The order for quaternion components (real part first or last) is now imposed by the standard.	More Consistency between KVN and XML formats	
4	The ATTITUDE_DIR keyword has been removed.	Consistency with ADM	
5	A new keyword: “MESSAGE_ID” has been added.	Consistency with ADM / Other standards	
6	The keyword “QUATERNION_TYPE” has been removed. The order in the AEM is the same as in the APM: Q1, Q2, Q3, QC by convention. This change also makes the KVN and XML versions more consistent.	More Consistency between ADM and AEM, and also KVN and XML formats	

7	Values for the “ATTITUDE_TYPE” keyword have changed: - QUATERNION/RATE and EULER_ANGLE/RATE have been removed - QUATERNION/ANGVEL and EULER_ANGLE/ANGVEL have been added	More consistency between ADM and AEM (naming conventions)	

Changes relative to ACM:

The Attitude Comprehensive Message (ACM) was added to provide symmetry with the Orbit Comprehensive Message (OCM) being added to the Orbit Data Messages standard.

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?	Accepted for ACM?
Data must be provided in digital form (computer file).	Y	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	Y
The interface must facilitate the receiver of the message to generate an attitude state at any required epoch.	Y	Y	Y
Attitude state information must be provided in a reference frame that is clearly identified and unambiguous.	Y	Y	Y
Identification of the object must be clearly identified and unambiguous.	Y	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	N
Time measurements (time stamps, time tags, or epochs) must be provided in a commonly used, clearly specified system.	Y	Y	Y
The time bounds of the attitude ephemeris must be unambiguously specified.	N	Y	Y
The standard must provide for clear specification of units of measure.	Y	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	Y
Files must have means of being uniquely identified and clearly annotated. The file name alone is considered insufficient for this purpose.	Y	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	Y

Table E-2: Heritage Requirements

Requirement	Accepted for APM?	Accepted for AEM?	Accepted for ACM?
A complete attitude ephemeris, not subject to integration or propagation by the customer, must be provided.	N	Y	Y
The standard is, or includes, an ASCII format.	Y	Y	Y
The standard does not require software supplied by other agencies.	Y	Y	Y

Table E-3: Desirable Characteristics

Requirement	Accepted for APM?	Accepted for AEM?	Accepted for ACM?
The standard applies to non-traditional objects, such as landers, rovers, balloons, and natural bodies (asteroids, comets).	Y	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	Y
The standard is extensible with no disruption to existing users or uses.	Y	Y	Y
The standard is consistent with, and ideally a part of, attitude products and processes used for other space science purposes.	N	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	Y
The standard allows for the specification of the accuracy of the attitude solution.	Y	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 three 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?	Applicable to ACM?
Modeling Fidelity	Permits modeling of any dynamic perturbation to the attitude.	N	Y	Y
Human Readability	Provides easily readable message corresponding to widely used attitude representations.	Y	Y	Y
Remote Body Extensibility	Permits use for assets on remote solar system bodies.	Y	Y	Y
Lander/Rover Compatibility	Permits exchange of non-orbit attitudes.	Y	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?	Applicable to ACM?
Absolute Attitude Interpretation	State availability at specific times for use in additional computations (geometry, event detection, etc.).	Y	Y	Y
Relative Attitude Interpretation	Trajectory comparison and differencing for events based on the same time source.	Only at time specified at Epoch	Y	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, AEM, and ACM file naming conventions.	3.1.4 4.1.2
2	Method of exchanging ADMs (transmission).	1.2.2 3.1.4 4.1.2
3	Definition of attitude accuracy requirements pertaining to data in an ADM as well as attitude dynamics modeling.	1.2.1
4	Specific APM, AEM and/or ACM version numbers that will be exchanged.	3.2.2.1 4.2.2.1 5.2.2.1
5	Values used for the 'OBJECT_ID' or 'OBJECT_NAME' 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 Table 5-3
6	If floating-point numbers in extended-single or extended-double precision are to be used, then discussion of implementation-specific attributes is required.	7.7.5
7	Information which must appear in comments for any given ADM exchange.	7.9.1.3
8	Whether the format of the ADM will be KVN or XML.	1.2.3
9	If the chosen angle units are radians (which is outside the standard).	
10	Provisions that are made to ensure information security.	ANNEX I
11	Values used for those keywords listed in annex B when those values are different from those given in annex B.	B
12	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

[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).

ANNEX G

ABBREVIATIONS AND ACRONYMS

(INFORMATIVE)

ASCII	American Standard Code for Information Interchange
ACM	Attitude Comprehensive Message
ADM	Attitude Data Message
AEM	Attitude Ephemeris Message
APM	Attitude Parameter Message
AST	Autonomous Star Tracker
CCSDS	Consultative Committee for Space Data Systems
CP	Center of Pressure
CSS	Coarse Sun Sensor
DSS	Digital Sun Sensor
EKF	Extended Kalman Filter
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
IMU	Inertial Measurement Unit
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
RWA	Reaction Wheel Assembly
TAI	International Atomic Time
TCB	Barycentric Coordinated Time
TDB	Barycentric Dynamical Time

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] *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.

[H2] *Navigation Data—Definitions and Conventions*. Report Concerning Space Data System Standards, CCSDS 500.0-G-3. 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)

I1 SECURITY CONSIDERATIONS

I1.1 ANALYSIS OF SECURITY CONSIDERATIONS

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

I1.2 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 spacecraft attitude 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.

I1.3 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.

I1.4 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.

I1.5 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.

I1.6 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.

I1.7 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.

I1.8 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.

I1.9 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.

I1.10 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.

I1.11 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.

I2 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 Area or Working Group responsible for maintenance of the ADM at the time of the request. 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

- Values for various keywords or conventions from the following SANA registries:
  - https://sanaregistry.org/r/time_systems
  - https://sanaregistry.org/r/orbit_centers
  - https://sanaregistry.org/r/celestial_body_reference_frames
  - https://sanaregistry.org/r/orbit_relative_reference_frames
  - https://sanaregistry.org/r/spacecraft_body_reference_frames
  - https://sanaregistry.org/r/attitude_and_spacecraft_conventions

I3 PATENT CONSIDERATIONS

The recommendations of this document have no patent issues.