# ATTITUDE Comprehensive Message (ACM)

## General

Comprehensive attitude information may be exchanged between two participants by sending attitude data/content for one or more epochs 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.

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.

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.

Attitude information may be exchanged between two participants by sending an attitude ephemeris in the form of one or more time series of attitude states using an Atittude Comprehensive Message (ACM). 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 TBD.

## ACM content/STRUCTURE

### General

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. a single mandatory header;
2. a single mandatory metadata section (data about data);
3. optional data section(s), comprised of one or more data constituent types:
	1. a single, optional space object physical characteristics section
	2. optional estimator description section
	3. optional sensor description section
	4. optional maneuver data section(s)
	5. optional attitude state time histories
	6. optional covariance time histories
	7. optional sensor data time histories
	8. optional actuator/torque description and data section
	9. a single, optional, user-defined data and supplemental comments (explanatory information).

Table 5‑1 : ACM File Layout and Ordering Specification

|  |  |
| --- | --- |
| **Section** | **Content** |
| Mandatory Header | Header of message |
| Mandatory Metadata | Metadata(Informational comments recommended but not required.) |
| Optional Space Object Physical Description | Optional space object physical characteristics, if known. |
| Optional Estimator Description Section | Type of estimator used in attitude determination, states estimated, sensors used in estimation |
| Optional Sensor Description Section | Sensor Types on the spacecraft, calibration, alignment parameters for each sensor listed |
| Optional Maneuver Section(s) | Optional maneuver specifications  |
| Optional Attitude Section(s) | Optional: attitude state time histories (each consisting of one or more attitude states), each time history corresponds to the estimator specified in the Estimator Description Section |
| Optional Covariance Data Section(s) | Optional: covariance time histories, each time history corresponds to the estimator specified in the Estimator Description Section |
| Optional Sensor Data Section(s) | Optional: One or more sensor data history sections, each block containing data from a single sensor type, sensor descriptions are as provided in the Sensor Description Section |
| Optional Actuator/Torque Section(s) | Optional: Actuators, external torques. NOT YET INCLUDED. |
| Optional User Defined Data | User-defined |

### ACM Header

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

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

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. | 1.0 | **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 7.5.9.) | 2001-11-06T11:17:332002-204T15:56:23Z | **Yes** |
| ORIGINATOR | Creating agency. Value should be an entry in the Abbreviation column in the Organizations registry of the SANA registry. http://sanaregistry.org/r/organizations/organizations.html | 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. | 201113719185ABC-12\_34 | **No** |

### ACM Metadata

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

May 2012

CCSDS 502.0-B-2 Cor. 1

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

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

The TIME\_SYSTEM value must remain fixed within an ACM.

Any spacecraft physical characteristics, maneuver, attitude states, covariance values, sensor and/or actuator values in the ACM data which require time-tagging shall be time-tagged by a relative time value in seconds measured with respect to the epoch time specified via the EPOCH\_TZERO keyword.

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 0 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 data, 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 ?** |
| --- | --- | --- | --- | --- |
| 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 EngineerACS 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. | SPOT, ENVISAT, IRIDIUM, INTELSAT | Yes | No |
| OBJECT\_ID | Spacecraft identifier of the object corresponding to the attitude data to be given. Wile there is no CCSDS-based restriction on the value for this keyword, it is recommended to use names from the UN Office of Outer Space Affairs. | 2000-052A | Yes | No |
| CENTER\_NAME | Origin of reference frame, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this the value for ‘CENTER\_NAME’ is subject to the same rules as ‘OBJECT\_NAME’). There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the Orbit Centers SANA Registry (link TBS). | EARTHEARTH BARYCENTERMOON | No | No |
| TIME\_SYSTEM | Time system used for metadata, attitude data, covariance data, sensor data, torque/actuator data. The full set of allowed values is enumerated in TBD SANA Registry(link TBS).  | UTCTAI | Yes | No |
| EPOCH\_TZERO | Epoch from which all ACM relative times are referenced. (For format specification, see 7.5.9.). The time scale for EPOCH\_TZERO is the one specified by "TIME\_SYSTEM" keyword in the metadata section. | 2001-11-06T00:00:00 | Yes | MNVR, COVAR,SENSOR |
| INCL\_DATA\_BLOCKS | Comma-delimited list of data blocks included in this message. | MAN, ATT, COV, AD, PHYS, SENSOR | No | No |
| START\_TIME | Relative time of the earliest of all time tags corresponding to maneuver, attitude state, covariance, sensor and/or actuator data. 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, sensor and/or actuator data 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 |

### ACM DATA: Space Object Physical Characteristics

Table 5-4 provides an overview of the ACM space object physical characteristics section. Only those keywords shown in table 5-4 shall be used in ACM space object physical characteristics data.

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

The order of occurrence of these ACM Space Objects Physical Characteristics keywords shall be fixed as shown in table 5-4.

The “ACM Data: Space Object Physical Characteristics” 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.

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

The space object physical characteristics data section in the ACM shall be indicated by two keywords: PHYS\_START and PHYS\_STOP.

Further definition of Space Object Physical Characteristics parameters is provided in ANNEX X.

Table 5-4 : 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 |  | 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 |  |
| FUEL\_MASS | Fuel mass | kg | 750.0 |  |
| PHYS\_STOP | End of a Space Object Physical Characteristics specification | n/a |  | Yes |

### ACM Data: ESTIMATOR DEscription section

Table 5-5 provides an overview of the ACM Estimator Description section. Only those keywords shown in table 5-5 shall be used in ACM Estimator Description.

Keyword values shall be provided in the units specified in the Units column of table 5-5.

The order of occurrence of these ACM Estimator Description keywords shall be fixed as shown in table 5-5.

The ACM Estimator Description 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.

The ACM Estimator Description section shall be indicated by two keywords: EST\_START and EST\_STOP.

Table 5-5 : ACM Data: Estimator Description

| **Keyword** | **Description** | **Units** | **Examples of Values** | **Mandatory** |
| --- | --- | --- | --- | --- |
| EST\_START | Start of Estimator Description  |  |  |  |
| COMMENT | Comments allowed only immediately after the EST\_START keyword  | n/a | COMMENT This is a comment | No |
| ESTIMATOR\_TYPE | Type of estimator used. For further description see Annex C7. | 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 |
| NUMBER\_COV\_STATES | Number of covariance states if EKF, BATCH, or FILTER SMOOTHER is specified  | n/q | 3, 6 | No |
| ATTITUDE\_STATES | Type of attitude state included in the estimator. Attitude states must always be listed before RATE\_STATES. | n/a, rad | QUATERNIONEULER ANGLES | No |
| COV\_ATT\_STATES | Type of attitude error state included in the estimator covariance. Attitude error states must always be listed before COV\_RATE\_STATES | rad, n/a | ANGLES, DELTAQUAT | 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. | 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. | 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 | rad/s | ANGVELGYRO\_BIAS | No |
| COV\_RATE\_STATES | Type of rate error state included in the estimator, if COV\_RATE\_STATES are included NUMBER\_COV\_STATES must be at least 6 to include both COV\_ATT\_STATES and COV\_RATE\_STATES | rad/sec | ANGVEL\_ERRORGYRO\_BIAS\_ERROR |  |
| SIGMA\_U | Rate random walk if RATE\_STATES=GYRO\_BIAS | rad/sec\*\*1.5 | 6.5e-9 | No |
| SIGMA\_V | Angle random walk if RATE\_STATES=GYRO\_BIAS | rad/sec\*\*0.5 | 2.3e-7 | 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, IMU | 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 | rad | 0.00017, 0.00017 | 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 | rad/sec\*\*1.5 | 9.0E-08 | No |
| EST\_STOP | End of the estimator description | n/a |  | Yes |

### ACM Data: sensor DEscription section

Table 5-6 provides an overview of the ACM Sensor Description section. Only those keywords shown in table 5-6 shall be used in ACM Sensor Description.

Keyword values shall be provided in the units specified in the Units column of table 5-6.

The order of occurrence of these ACM Sensor Description keywords shall be fixed as shown in table 5-6.

The ACM Sensor Description section is optional; “mandatory” in the context of Table 5-6 denotes those keywords which must be included in this section if this section is included.

The ACM Sensor Description section shall be indicated by two keywords: SENSOR\_START and SENSOR\_STOP.

Table 5-6 : ACM Data: Sensor Description

| **Keyword** | **Description** | **Units** | **Examples of Values** | **Mandatory** |
| --- | --- | --- | --- | --- |
| SENSOR\_START | Start of sensor description |  |  | Yes |
| COMMENT | Comments allowed only immediately after the SENSOR\_START keyword | n/a | COMMENT This is a comment | No |
| SENSOR\_TYPE | Type of sensor  | n/a | AST, CSS, DSS, IMU | No |
| DATA\_TYPE | Sensor data included or residual data included | n/a | SENSOR, RESIDUAL | Yes |
| NUMBER\_ELEMENTS | Number of data points for SENSOR\_TYPE | n/a | 1, 2, 3, 4 | No |
| SENSOR\_UNITS | Units of sensor data or sensor residual | n/a  | n/a, rad, mG, rad/sec | No |
| MEASUREMENT\_FRAME | Frame of measurement for SENSOR\_TYPE | n/a | AST, SC\_BODY | No |
| DATA\_ADJUSTMENT | Calibration or transformation parameters includ | n/a | Yes, No | No |
| NUMBER\_ADJUSTMENTS | Number of adjustments included for SENSOR\_TYPE | n/a  | 2 | No |
| ADJUSTMENT\_TYPE | What calibration or transformation is included | n/a | ALIGNMENT, BIAS, etc | No |
| ALIGNMENT\_FRAME\_A | Name of the reference frame that defines the starting point of the sensor alignment | n/a | SC\_BODY | No |
| ALIGNMENT\_FRAME\_B | Name of the reference frame that defines the end of the sensor alignment |  n/a | AST\_i | No |
| ALIGNMENT\_QUAT | Quaternion representing the alignment from ALIGNMENT\_FRAME\_A to ALIGNMENT\_FRAME\_B |  | 0,0,0,1 | No |
| BIAS | Bias for SENSOR\_TYPE, must be in the same frame as MEASUREMENT\_FRAME | rad/sec, mG | 1.0E-4 | No |
| SENSOR\_STOP | End of the sensor specification | n/a |  | Yes |

###  ACM Data: Maneuver specification

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.

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.

The “ACM Data: Maneuver Specification” section is optional; “mandatory” in the context of Table 5-7 denotes those keywords which must be included in this section if this section is included.

One or more ACM Maneuver Specification sections may appear in an ACM.

Maneuver data in the ACM shall be indicated by two keywords: MAN\_START and MAN\_STOP.

The ‘MAN\_TYPE’ keyword must appear before the first line of any maneuver time history data.

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 |  | 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 can specify the intention(s) of the maneuver. Multiple maneuver purposes can 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 | sec | 100.0 | No |
| MAN\_ END | End time of actual maneuver, measured as a relative time with respect to EPOCH\_TZERO | sec | 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 | THR, 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 | rad/sec | 0.31 | No |
| MAN\_STOP | End maneuver data interval specification | n/a |  | Yes |

### ACM Data: ATTITUDE State Time History

Table 5-8 provides an overview of the ACM attitude state time history section. Only those keywords shown in table 5-8 shall be used in ACM attitude state time history data specification.

Keyword values shall be provided in the units specified in the Units column of table 5-8.

The order of occurrence of these ACM Attitude State Time History keywords shall be fixed as shown in table 5-8.

The “ACM Data: Attitude State Time History” section is optional; “mandatory” in the context of table 5-8 denotes those keywords which must be included in this section if this section is included.

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

##### They are delimited by separate ATT\_START and ATT\_STOP keywords;

##### Each data block is clearly differentiated from the others by one or more precluding comment(s) or by ICD agreement

##### Each data block is 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)

One or more ACM Attitude State Time History sections may appear in an ACM. Each ACM Attitude State Time History shall be paired, and immediately preceeded with an Estimator Description block that describes the type of estimator used to generate the Attitude State Time History.

Attitude state time history data intervals in the ACM shall be indicated by two keywords: ATT\_START and ATT\_STOP.

The states and reference frames included shall be specfied in in the estimator description, as described in Table 5-8.

The ATT\_STOP keyword must appear after the last line of attitude state data and metadata. Each of these keywords shall appear on a line by itself.

All orbit 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.

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.

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 preceding descriptive comment line.

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

Attitude state time tags may or may not match those of maneuver, covariance and/or sensor time histories.

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.

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

Table 5-8 : ACM Data: Attitude State Time History

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Keyword** | **Description** | **Units** | **Examples of Values** | **Mandatory** |
| ATT\_START | Start of an attitude state vector or 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 |
|  … < Insert attitude lines here> |  |  |  | Yes |
| ATT\_STOP | End of an attitude state vector or time history section | n/a | n/a | Yes |

### ACM Data: SENSOR Data

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

Keyword values shall be provided in the units specified in the Units column of table 5-9.

The order of occurrence of these ACM Sensor Data keywords shall be fixed as shown in table 5-9.

The ACM Data: Sensor Data 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.

One or more ACM Sensor Data sections may appear in an ACM. Each ACM Sensor Data sections shall be paired, and immediately preceeded with a Sensor Description block that describes the type of sensor data provided in the Sensor Data section.

Sensor data shall be indicated by two keywords: DATA\_START and DATA\_STOP.

All sensor data values in the ACM sensor data shall be time-tageed by a relative time value measured with respect to the epoch time specified via the EPOCH\_TZERO keyword.

**Table 5-9** **: ACM Data: Sensor Data**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Keyword** | **Description** | **Units** | **Examples of Values** | **Mandatory** |
| DATA\_START | Start of a sensor data section | n/a | n/a | Yes |
| COMMENT | Comments allowed only immediately after the DATA\_START keyword | n/a | COMMENT This is a comment | No |
| AD\_ID | Optional alphanumeric free-text string containing the identification number for this attitude state time history. | n/a | MissionX\_SENSORDATA\_20160402 | No |
| <insert sensor data lines here> |   |  |  | No |
| DATA\_STOP |  End of a Sensor Data section |  |  | No |

### ACM Data: ATtitude State Covariance Time History

Table 5-10 provides an overview of the ACM attitude state covariance time history section. Only those keywords shown in table 5-10 shall be used in ACM covariance time history data specification.

Keyword values shall be provided in the units specified in the Units column of table 5-10.

The order of occurrence of these ACM Attitude State Covariance Time History keywords shall be fixed as shown in table 5-10.

The “ACM Data: Attitude State Covariance Time History” section is optional; “mandatory” in the context of table 5-10 denotes those keywords which must be included in this section if this section is included.

One or more ACM Attitude State Covariance Time Histories may appear in an ACM. Each ACM Attitude State Covariance Time History shall be paired, and immediately preceeded with an Estimator Description block that describes the type of estimator used to generate the Attitude State Covariance Time History.

Attitude State Covariance Time History data shall be indicated by two keywords: COV\_START and COV\_STOP

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.

Each covariance 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 covariance data blocks containing a duplicate timestamp (e.g. following application of an impulsive 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 covariance matrices, and interpolation or propagation after the duplicate timestamp shall use the second of the two.

If the user includes covariances at key mission event times, it is recommended that those mission event covariances be annotated as such by a preceding descriptive comment line.

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

 Covariance time tags may or may not match those of maneuver, attitude state, and/or sensor data time histories.

 Values in the covariance matrix shall be only main diagonal elements provided on a single line. Off-diagonal elements could be defined in a USER defined block.

**Table 5-10** **: ACM Data: Covariance Time History**

| **Keyword** | **Description** | **Units** | **Examples of Vaes** | **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 |
|  …< Insert covariance data here> |  |  |  | Yes |
| COV\_STOP | End of a covariance time history section | n/a | n/a | Yes |

### ACM DATA: ACTUATOR/TORQUE DESCRIPTION and DATA Section TBD

### ACM Data: User-Defined Parameters

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.

The “ACM Data: User-Defined Parameters” section is optional; “mandatory” in the context of table 5-11 denotes those keywords which must be included in this section if this section is included.

Table 5-11 provides an overview of the ACM user-defined data section. Only those keywords shown in table 5-11 shall be used in ACM user-defined data specification.

Table 5-11 : ACM Data: User-Defined Parameters

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Keyword** | **Description** | **Units** | **Examples of Values** | **Mandatory** |
| COMMENT | Comments (allowed at any point(s) throughout the ACM User-Defined Data section). (See 7.7 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\_TEMPERATURE = 273.15 [K] | No |

## 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

OBJECT\_NAME = GODZILLA 5

OBJECT\_ID = 2000-052A

TIME\_SYSTEM = UTC

EPOCH\_TZERO = 1998-12-18T14:28:15.1172

EST\_START

TYPE\_OF\_ESTIMATOR = QUEST

ATTITUDE\_STATES= QUATERNION

REF\_FRAME\_A = J2000

REF\_FRAME\_B = SC\_BODY

EST\_STOP

ATT\_START

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‑ : Simple/Succinct ACM File example

CCSDS\_ACM\_VERS = 2.0

CREATION\_DATE = 2017-12-01T00:00:00

ORIGINATOR = NASA

OBJECT\_NAME = SDO

OBJECT\_ID = 2010-005A

TIME\_SYSTEM = UTC

EPOCH\_TZERO = 2017-12-26T19:40:00.000

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

EST\_START

COMMENT SDO Onboard Filter

TYPE\_OF\_ESTIMATOR= EKF

ATTITUDE\_SOURCE = OBC

NUMBER\_OF\_STATES = 7

ATTITUDE\_STATES = QUATERNION

REF\_FRAME\_A = J2000

REF\_FRAME\_B = SC\_BODY

OTHER\_STATES = GYRO\_BIAS

NUMBER\_SENSORS\_USED = 4

SENSORS\_USED\_1 = AST1

SENSORS\_USED\_2 = AST2

SENSORS\_USED\_3 = DSS

SENSORS\_USED\_4 = IMU

EST\_STOP

ATT\_START

COMMENT OBC Attitude and Bias during momentum management maneuver

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

Figure 5-2: ACM example with Momentum Management Maneuver, Estimator Description, and Attitude State History During Manuever

CCSDS\_ACM\_VERS = 2.0

CREATION\_DATE = 1998-11-06T09:23:57

ORIGINATOR = JAXA

ORIGINATOR\_POC = Ms. Rodgers, (719)555-5555, email@email.XXX

TIME\_SYSTEM = TAI

EPOCH\_TZERO = 1998-12-18T14:28:15.1172

OBJECT\_NAME = GODZILLA 5

OBJECT\_ID = 1998-999ZZZ

TAIMUTC\_TZERO = 36 [s]

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]

CM = 0.04 -0.78 -0.023 [m]

PHYS\_STOP

Figure 5-3: Example Spacecraft Physical Characteristics

CCSDS\_ACM\_VERS = 2.0

CREATION\_DATE = 2017-12-30T10:00:00

ORIGINATOR = NASA

OBJECT\_NAME = LRO

OBJECT\_ID = 2009-031A

TIME\_SYSTEM = UTC

EPOCH\_TZERO = 2017-12-17T00:00:00.0

SENSOR\_START

COMMENT Sensor description for AST1

SENSOR\_TYPE = AST

DATA\_TYPE = RESIDUAL

NUMBER\_OF\_ELEMENTS = 3

SENSOR\_UNITS = RAD

MEASUREMENT\_FRAME = AST

ALIGNMENT\_FRAME\_A = SC\_BODY

ALIGNMENT\_FRAME\_B = AST1

ALIGNMENT\_QUAT = -0.1294 0.8365 0.2241 0.4830

SENSOR\_STOP

DATA\_START

COMMENT Sensor residuals for AST1

1. 6.28e-06 1.09e-04 -1.23e-04

1.09669 -8.38e-05 4.32e-05 -5.86e-05

< intervening data records omitted here >

59.89669 -2.96e-04 -4.12e-05 -1.07e-05

DATA\_STOP

SENSOR\_START

COMMENT Sensor description for AST2

SENSOR\_TYPE = AST

DATA\_TYPE = RESIDUAL

NUMBER\_OF\_ELEMENTS = 3

SENSOR\_UNITS = RAD

MEASUREMENT\_FRAME = AST

ALIGNMENT\_FRAME\_A = SC\_BODY

ALIGNMENT\_FRAME\_B = AST2

ALIGNMENT\_QUAT = 0 0.9659 0.2588 0

SENSOR\_STOP

DATA\_START

COMMENT Sensor residuals for AST2

0.0 1.35e-05 -6.33e-05 2.79e-04

1.09669 1.67e-05 3.03e-05 1.28e-04

< intervening data records omitted here >

59.89669 5.05e-05 6.60e-05 6.93e-06

DATA\_STOP

Figure 5-4: Sensor Data Description and Sensor Data

CCSDS\_ACM\_VERS = 1.0

CREATION\_DATE = 2017-12-30T00:00:00

ORIGINATOR = NASA

OBJECT\_NAME = LRO

OBJECT\_ID = 2009-031A

EPOCH\_TZERO = 2017-12-30T00:00:00.0

TIME\_SYSTEM = UTC

COMMENT LRO Onboard Filter, A Multiplicative Extended Kalman Filter

EST\_START

TYPE\_OF\_ESTIMATOR = EKF

ATTITUDE\_SOURCE = OBC

NUMBER\_STATES = 7

NUMBER\_COV\_STATES = 6

ATTITUDE\_STATES = QUATERNION

COV\_ATT\_STATES = ANGLES

REF\_FRAME\_A = EME2000

REF\_FRAME\_B = SC\_BODY

RATE\_STATES = GYRO\_BIAS

COV\_RATE\_STATES = GYRO\_BIAS\_ERROR

NUMBER\_SENSORS\_USED = 3

SENSORS\_USED\_1 = AST1

SENSORS\_USED\_2 = AST2

SENSORS\_USED\_3 = IMU

EST\_END

COV\_START

COMMENT Diagonal Covariance for LRO Onboard Kalman Filter

1. 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

Figure 6-4: ACM example with Covariance Elements

[Addition to Current ANNEX C]

C7 ESTIMATORS

|  |  |
| --- | --- |
| EKF | Extended Kalman Filter, a sequential estimation algorithm applied to spacecraft attitude determination. Often additional state vector components are included, such as gyro biases. |
| 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.  |

ANNEX G

ACM Attitude Comp

AST Autonomous Star Tracker

CP Center of Pressure

CSS Coarse Sun Sensor

DSS Digital Sun Sensor

EKF Extended Kalman Filter

IMU Inertial Measurement Unit

RWA Reaction Wheel Assembly