Presented in London CCSDS meeting (2014).

Some corrections / clarifications / complements included since then.

27 jan 2015 – A. Lamy (CNES)

Draft 1.

# Main issues (already presented / discussed)

1. The type of quaternion is not clearly defined:

Is it a quaternion representing a rotation or a frame transformation matrix ?

(what some call “active” or “passive” rotation)

1. “frames”, “rotation direction”: unclear

Specifying “A2B” for FRAME\_A to FRAME\_B does not mean ambiguity disappears.

And quaternions, frame transformation matrices: often a source of ambiguity: it’s usually not clear enough.

=> the standard should set an example.

=> if originator and recipient conform to the standard => they should understand the contents in the same way (so that no confusion is possible).

1. Angular velocity vector or Euler angles derivatives: unclear (what it is is undecidable just looking at the standard).
2. Ambiguity in referencing the Euler angles X\_ANGLES, Y\_ANGLES… (the same keywords appear several times in KVN). The description is different (better) in XML.
3. Angular velocity vector is said to be A/B whereas B/A (object / reference) would be more expected.

# Consequences

Small adjustments to the document are difficult because there are implicit conventions (supposedly) that are not well defined. There are also ambiguities.

Proposal to the group:

* “Drastic” changes to make the standard clearer and easier to use.
* Reduce the number of keywords to increase simplicity if this does not restrict the use of the standard.
* The primary objective for version 2 is to propose a renewed standard, simpler, and not ambiguous … putting aside (for now) upward compatibility considerations with version 1.

Note: there are very few real applications using ADM. They should not be neglected. But the possibility of improving the standard and increasing the number of users should be considered too.

# Redesign proposals

1. Frames

It would be chosen once (in the metadata) which reference frame is considered (the frame with respect to which the object’s attitude is defined).

The object’s frame would be implicit by default.

An explicit name for the object’s frame could be allowed in case of ambiguity (that is if several different objet’s frames can be defined for a given object).

There is some analogy with to what is done in ODM for instance: a reference frame is defined in the metadata and the state vector refers to the object specified by a name in the metadata section.

Consequences:

* + The keywords: frameA, frameB, DIR => removed
  + Replaced by ref\_frame in metadata + (optionally) obj\_frame.

The notion of “direction” is not necessary :

The attitude that is defined in the message always is that of the object and it is relative to the reference frame.

1. Quaternions

The type of quaternion in the message should be clearly defined in the standard.

Only one definition is allowed to simplify the use of the standard.

Proposal: quaternion of the rotation from the reference frame to the object’s frame.

R = rotation which transforms the reference frame axes into the object’s frame axes.

R ⬄ angle  and axis u

q = (cos(/2), sin(/2) \* ux, sin(/2) \* uy, sin(/2) \* uz)

with u = (ux, uy, uz): components in either reference frame or object’s frame (same quaternion)

*Note: This convention of for instance consistent with the type of quaternion sent to CNES by ESA for Rosetta or the type of quaternion defined in SPICELIB.*

*It is also consistent with:*

*http://en.wikipedia.org/wiki/Quaternions\_and\_spatial\_rotation*

For simplicity, only one convention is adoted for the order of the real and imaginary parts : the most widely used: real part first or last. The presence of keywords (QC, Q1, Q2, Q3) makes the contents unambiguous anyway.

*Remark: ADM is for data exchange only. The conventions chosen for the ADM need not be the same as in user applications (and should not be the union of the conventions found in all user applications to keep the standard simple).*

1. Euler angles: 3 successive rotations around 3 axes equivalent to the rotation R (see above).

The rotation sequence would be described by the letters (e.g. : ZXZ) = successive rotation axis names from left to right.

The rotation angles would be : ANGLE\_1, ANGLE\_2, ANGLE\_3 = rotation angles for rotation 1 (first), 2 (second), 3 respectively.

Applying the rotation R is equivalent to applying: rotation 1, then rotation 2, and then rotation 3. The numbers are not related to the multiplication order of rotation matrices (for instance).

Note: that enables consistency with XML (3 different names for the 3 angles).

The “rates” (Euler rates) are the time derivatives of the Euler angles.

* No need for a frame for the definition of derivatives.

1. Spin: unchanged (TBC : depends on how clear the contents is)

But requires better definition of contents, e.g.

SPIN\_ANGLE = phase of satellite axis around spin axis : what origin for the angle ?

NUTATION\_PHASE = inertial nutation phase : exact definition ? what origin the the angle ?

1. New section for the “angular velocity vector”

= angular velocity vector of object’s frame / ref frame

The components are given a the specified frame (object’s frame, ref frame, or any other frame)

Note: the “spin” data block could do the job, but it seems more complicated this way as the spin data are primarily designed for a spinning spacecraft.

1. New keyword for DATA\_TYPES = QUATERNION, EULER, …

Enables easier parsing: what is in the message is “declared” in the header.

1. Other sections (maneuvers…) : unchanged

# New APM (proposal)

The description that follows is as independent as possible from the format used.

It may not be the same as the description used in the standard.

## Structure:

Conventions:

+ => one or more (one or more line in KVN)

{ } => grouping (things rhat appear together in the message)

// => comment

:: => means “is by definition”

*// Entire message*

APM ::

HEADER

{

METADATA

DATA

}+

HEADER ::

CCSDS\_APM\_VERS

COMMENT+

CREATION\_DATE

ORIGINATOR

METADATA ::

COMMENT+

OBJECT\_NAME

OBJECT\_ID

REF\_FRAME

OBJ\_FRAME

CENTER\_NAME [OPT]

TIME\_SYSTEM

DATA ::

COMMENT+

EPOCH

BLOCK+

BLOCK ::

COMMENT+

SPECIALISED\_BLOCK

SPECIALISED\_BLOCK ::

SPECIALISED\_BLOCK\_HEADER

SPECIALISED\_BLOCK\_DATA

## CONTENTS in DETAIL (only data, comments not included)

NB: The description, examples are not the final ones.

APM Header

|  |  |  |  |
| --- | --- | --- | --- |
| **Keyword** | **Description** | **Examples of Values** | **Obligatory** |
| CCSDS\_APM\_VERS | Format version in the form of ‘x.y’, where ‘y’ is incremented for corrections and minor changes, and ‘x’ is incremented for major changes. | 1.0 | Yes |
| CREATION\_DATE | File creation date/time in one of the following formats:  YYYY-MM-DDThh:mm:ss[.d→d] or  YYYY-DDDThh:mm:ss[.d→d]  where ‘YYYY’ is the year, ‘MM’ is the two-digit month, ‘DD’ is the two-digit day, ‘DDD’ is the three-digit day of year, ‘T’ is constant, ‘hh:mm:ss[.d→d]’ is the UTC time in hours, minutes, seconds, and optional fractional seconds. As many ‘d’ characters to the right of the period as required may be used to obtain the required precision. All fields require leading zeros. | 2001-11-06T11:17:33  2002-204T15:56:23  1996-12-18T14:28:15.1172 | Yes |
| ORIGINATOR | Originator of message. | CNES, ESOC, GSFC, GSOC, JPL, JAXA, etc. | Yes |

APM Metadata

|  |  |  |  |
| --- | --- | --- | --- |
| **Keyword** | **Description** | **Normative Values / Examples** | **Obligatory** |
| OBJECT\_NAME | Spacecraft name of the object corresponding to the attitude data to be given. There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the SPACEWARN Bulletin (reference [2]), which include the Object name and international designator of the participant. | EUTELSAT W1  MARS PATHFINDER  STS106  NEAR | Yes |
| OBJECT\_ID | Spacecraft identifier of the object corresponding to the attitude data to be given. While there is no CCSDS-based restriction on the value for this keyword, the names could be drawn from the SPACEWARN Bulletin (reference [2]). If this is chosen, it is recommended that values have the format YYYY-NNNP{PP}, where:   * YYYY = year of launch; * NNN = three-digit serial number of launch in year YYYY (with leading zeros); * P{PP} = at least one capital letter for the identification of the part brought into space by the launch.   In cases where the asset is not listed in the bulletin, the value should be provided in an ICD. | 2000-052A  1996-068A  2000-053A  1996-008A | Yes |
| REF\_FRAME | Reference frame relative to which the attitude of the object is to be given.  See annex for list. | EME2000 | Yes |
| OBJ\_FRAME | Reference frame describing the object | BODY\_FRAME | 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 for ‘OBJECT\_NAME’). There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the NASA/JPL Solar System Dynamics Group (reference [3]).  If not present: implied by REF\_FRAME.  See annex for list. | EARTH | No  (Not absolutely necessary) |
| TIME\_SYSTEM | Time system used for attitude and maneuver data (also see table 3‑3).  See annex for list. | UTC | Yes |

Note1 : center name : could be removed as useless (no impact on attitude definition)

Note2 : information describing the contents should be added in the metadata section. It is not clear yet what information should be added

APM Data

| **Keyword** | **Description** | **Normative Units/Values** | **Obligatory** |
| --- | --- | --- | --- |
| EPOCH | Epoch of the attitude elements and other data included in the data block. | n/a | Yes |

Block “Quaternion”

|  |  |  |  |
| --- | --- | --- | --- |
| QC | cos(/2)  = rotation angle | n/a | Yes |
| Q1 | e1 \* sin(/2)  = rotation angle | n/a | Yes |
| Q2 | e2 \* sin(/2)  = rotation angle | n/a | Yes |
| Q3 | e3 \* sin(/2)  = rotation angle | n/a | Yes |
| QC\_DOT | Derivative of QC | 1/s | No |
| Q1\_DOT | Time derivative of Q1 | 1/s | No |
| Q2\_DOT | Derivative of Q2 | 1/s | No |
| Q3\_DOT | Derivative of Q3 | 1/s | No |

Note: Order of components: TBC

Block “Euler”

|  |  |  |  |
| --- | --- | --- | --- |
| EULER\_ROT\_SEQ | Rotation sequence (X=X-axis, Y = Y-axis …) | XYZ  ZXZ | No |
| ANGLE\_1 | Angle of first rotation in the sequence (= leftmost letter) | deg | No |
| ANGLE\_2 | … | deg | No |
| ANGLE\_3 | … | deg | No |
| ANGLE\_1\_DOT | Time derivative of ANGLE\_1 | deg/s | No |
| ANGLE\_2\_DOT | … | deg/s | No |
| ANGLE\_3\_DOT | … | deg/s | No |

Block “Angular velocity”

|  |  |  |  |
| --- | --- | --- | --- |
| ANGVEL\_FRAME | Coordinates frame where the components are given | OBJECT  REF  QSW | No |
| ANGVEL\_X | Angle of first rotation | deg | No |
| ANGVEL\_Y | … | deg | No |
| ANGVEL\_Z | … | deg | No |

Block “Spin”

|  |  |  |  |
| --- | --- | --- | --- |
| SPIN\_ALPHA | Right ascension of spin axis vector | deg | No |
| SPIN\_DELTA | Declination of the spin axis vector | deg | No |
| SPIN\_ANGLE | Phase of the satellite about the spin axis | deg | No |
| SPIN\_ANGLE\_VEL | Angular velocity of satellite around spin axis | deg/s | No |
| NUTATION | Nutation angle of spin axis | deg | No |
| NUTATION\_PER | Body nutation period of the spin axis | s | No |
| NUTATION\_PHASE | Inertial nutation phase | deg | No |

Note : changes could be necessary if contents cannot be made clear enough.

Block “Inertia”

|  |  |  |  |
| --- | --- | --- | --- |
| INERTIA\_REF\_FRAME | Coordinate system for the inertia tensor | n/a | No |
| I11 | Moment of Inertia about the 1-axis | kg\*m\*\*2 | No |
| I22 | Moment of Inertia about the 2-axis | kg\*m\*\*2 | No |
| I33 | Moment of Inertia about the 3-axis | kg\*m\*\*2 | No |
| I12 | Inertia Cross Product of the 1 & 2 axes | kg\*m\*\*2 | No |
| I13 | Inertia Cross Product of the 1 & 3 axes | kg\*m\*\*2 | No |
| I23 | Inertia Cross Product of the 2 & 3 axes | kg\*m\*\*2 | No |

Block “Maneuver”

|  |  |  |  |
| --- | --- | --- | --- |
| MAN\_EPOCH\_START | Epoch of start of maneuver – see remark 3.1.5.1.2 | n/a | No |
| MAN\_DURATION | Maneuver duration | s | No |
| MAN\_REF\_FRAME | Coordinate system for the torque vector | n/a | No |
| MAN\_TOR\_1 | 1st component of the torque vector | N\*m | No |
| MAN\_TOR\_2 | 2nd component of the torque vector | N\*m | No |
| MAN\_TOR\_3 | 3rd component of the torque vector | N\*m | No |

Other data blocks : unchanged (except may : for the SPIN TBC)

# New AEM (proposal)

Should be as consistent as possible with the new APM.

Below : the ADM version 1 description with some remarks added below each table.

Changes in yellow.

## AEM Header

Table 4‑2 : AEM Header

| **Keyword** | **Description** | **Normative Values / Examples** | **Obligatory** |
| --- | --- | --- | --- |
| CCSDS\_AEM\_VERS | Format version in the form of ‘x.y’, where ‘y’ is incremented for corrections and minor changes, and ‘x’ is incremented for major changes. | 1.0 | Yes |
| COMMENT | Comments (allowed after AEM version number and META\_START and before a data block of ephemeris lines). Each comment line shall begin with this keyword. | This is a comment. | No |
| CREATION\_DATE | File creation date/time in one of the following formats:  YYYY-MM-DDThh:mm:ss[.d→d] or  YYYY-DDDThh:mm:ss[.d→d]  where ‘YYYY’ is the year, ‘MM’ is the two-digit month, ‘DD’ is the two-digit day, ‘DDD’ is the three-digit day of year, ‘T’ is constant, ‘hh:mm:ss[.d→d]’ is the UTC time in hours, minutes, seconds, and optional fractional seconds. As many ‘d’ characters to the right of the period as required may be used to obtain the required precision. All fields require leading zeros. | 2001-11-06T11:17:33  2002-204T15:56:23  1996-12-18T14:28:15.1172 | Yes |
| ORIGINATOR | Creating agency (value should be specified in an ICD). | CNES, ESOC, GSFC, GSOC, JPL, JAXA, etc. | Yes |

## AEM metadata

Table 4‑3 : AEM Metadata

| **Keyword** | **Description** | **Normative Values / Examples** | **Obligatory** |
| --- | --- | --- | --- |
| META\_START | The AEM message contains both metadata and attitude ephemeris data; this keyword is used to delineate the start of a metadata block within the message (metadata are provided in a block, surrounded by ‘META\_START’ and ‘META\_STOP’ markers to facilitate file parsing). This keyword must appear on a line by itself. | n/a | Yes |
| COMMENT | Comments allowed only at the beginning of the Metadata section. Each comment line shall begin with this keyword. | COMMENT This is a comment. | No |
| OBJECT\_NAME | Spacecraft name of the object corresponding to the attitude data to be given. There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the SPACEWARN Bulletin (reference [2]), which include the Object name and international designator of the participant. | EUTELSAT W1  MARS PATHFINDER  STS106  NEAR | Yes |
| OBJECT\_ID | Spacecraft identifier of the object corresponding to the attitude data to be given. While there is no CCSDS-based restriction on the value for this keyword, the names could be drawn from the SPACEWARN Bulletin (reference [2]). If this is chosen, it is recommended that values have the format YYYY-NNNP{PP}, where:   * YYYY = year of launch; * NNN = three-digit serial number of launch in year YYYY (with leading zeros); * P{PP} = At least one capital letter for the identification of the part brought into space by the launch.   In cases where the asset is not listed in the bulletin, the value should be provided in an ICD. | 2000-052A  1996-068A  2000-053A  1996-008A | Yes |
| CENTER\_NAME | Origin of reference frame, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this the value for ‘CENTER\_NAME’ is subject to the same rules as for ‘OBJECT\_NAME’). There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the NASA/JPL Solar System Dynamics Group (reference [3]). | EARTH  EARTH BARYCENTER  MOON  SOLAR SYSTEM BARYCENTER  SUN  JUPITER BARYCENTER  STS 106  EROS | No |
| REF\_FRAME | Reference frame relative to which the attitude of the object is to be given.  See annex for list. | EME2000 | Yes |
| OBJ\_FRAME | Reference frame describing the object | BODY\_FRAME | No |
| ~~REF\_FRAME\_A~~ | ~~The name of the reference frame specifying one frame of the transformation, whose direction is specified using the keyword ATTITUDE\_DIR. The full set of values is enumerated in annex A, with an excerpt provided in the ‘Values / Examples’ column. For a definition of these various frames, the reader is directed to~~ *~~Navigation Definitions and Conventions~~* ~~(reference [E4]).~~  ~~Note that if a reference frame is to be used that does not appear in [E4], a description should be placed in an ICD.~~ | ~~ICRF~~  ~~ITRF-93~~  ~~ITRF-97~~  ~~ITRF2000~~  ~~ITRFxxxx~~  ~~TOD~~  ~~EME2000~~  ~~LVLH~~  ~~NTW~~  ~~SC\_BODY\_1~~  ~~INSTRUMENT\_A~~ | ~~Yes~~ |
| ~~REF\_FRAME\_B~~ | ~~Name of the reference frame specifying the second portion of the transformation, whose direction is specified using the keyword ATTITUDE\_DIR. The full set of values is enumerated in annex A, with an excerpt provided in the ‘Values / Examples’ column. For a definition of these various frames, the reader is directed to reference [E4]. Note that if a frame is used that does not appear in [E4], a description should be placed in an ICD.~~ | ~~SC\_BODY\_1~~  ~~STARTRACKER\_1~~  ~~INSTRUMENT\_A~~  ~~ICRF~~  ~~ITRF2000~~  ~~EME2000~~ | ~~Yes~~ |
| ~~ATTITUDE\_DIR~~ | ~~Rotation direction of the attitude specifying from which frame the transformation is to:~~  ~~- A2B specifies a transformation from the REF\_FRAME\_A to the REF\_FRAME\_B~~  ~~- B2A specifies a transformation from the REF\_FRAME\_B to the REF\_FRAME\_A.~~ | ~~A2B~~  ~~B2A~~ | ~~Yes~~ |
| TIME\_SYSTEM | Time system used for both attitude ephemeris data and metadata (also see tables 4‑3 and 4‑4). The full set of allowed values is enumerated in annex A, with an excerpt provided in the ‘Values/Examples’ column. Explanations of these time systems can be found in *Navigation Definitions and Conventions* (reference [E4]). | UTC  TAI  TT  GPS  TDB  UTC | Yes |
| START\_TIME | Start of TOTAL time span covered by attitude ephemeris data immediately following this metadata block. The START\_TIME time tag at a new block of attitude ephemeris data must be equal to or greater than the STOP\_TIME time tag of the previous block. | 1996-12-18T14:28:15.1172  2001-277T07:22:54 | Yes |
| USEABLE\_  START\_TIME,  USEABLE\_  STOP\_TIME | Optional start and end of USEABLE time span covered by attitude ephemeris data immediately following this metadata block. To allow for proper interpolation near the ends of the attitude ephemeris data block, it may be necessary, depending upon the interpolation method to be used, to utilize these keywords with values within the time span covered by the attitude ephemeris data records as denoted by the START/STOP\_TIME time tags. | 1996-12-18T14:28:15.1172  2001-277T07:22:54 | No |
| STOP\_TIME | End of TOTAL time span covered by the attitude ephemeris data immediately following this metadata block. The STOP\_TIME time tag for the block of attitude ephemeris data must be equal to or less than the START\_TIME time tag of the next block. | 1996-12-18T14:28:15.1172  2001-277T07:22:54 | Yes |
| ATTITUDE\_TYPE |  | QUATERNION  QUATERNION/DERIVATIVE  QUATERNION/RATE  EULER\_ANGLE  EULER\_ANGLE/DERIVATIVE  EULER\_ANGLE/RATE  SPIN  SPIN/NUTATION | Yes |
| ~~QUATERNION\_~~  ~~TYPE~~ | ~~The placement of the scalar portion of the quaternion (QC) in the attitude data. This keyword shall be provided if the ATTITUDE\_TYPE used in the message denotes quaternions.~~ | ~~FIRST~~  ~~LAST~~ | ~~No~~ |
| EULER\_ROT\_SEQ | Rotation sequence (X=X-axis, Y = Y-axis …) | XYZ  ZXZ | No |
| RATE\_FRAME | The frame of reference in which Anguler velocity vector components are given | TBD  … | No |
| INTERPOLATION\_METHOD | Recommended interpolation method for attitude ephemeris data in the block immediately following this metadata block. | LINEAR  HERMITE  lagrange | No |
| INTERPOLATION\_DEGREE | Recommended interpolation degree for attitude ephemeris data in the block immediately following this metadata block. It must be an integer value. This keyword must be used if the ‘INTERPOLATION\_METHOD’ keyword is used. | 5  1 | No |
| META\_STOP | The end of a metadata block within the message. The AEM message contains both metadata and attitude ephemeris data; this keyword is used to delineate the end of a metadata block within the message (metadata are provided in a block, surrounded by ‘META\_START’ and ‘META\_STOP’ markers to facilitate file parsing). This keyword must appear on a line by itself. | n/a | Yes |

## AEM Data

### Attitude ephemeris data lines

Table 4‑4 : Types of Attitude Ephemeris Data Lines

| **Keyword** | **Value** | **Ephemeris Data Line** |
| --- | --- | --- |
| Quaternion Options (note that keywords and values appear only in Metadata) | | |
| ~~QUATERNION\_TYPE~~ | ~~FIRST~~ | ~~N/A~~ |
| ATTITUDE\_TYPE | QUATERNION | Epoch, QC, Q1, Q2, Q3  (QUATERNION ORDER : TBC) |
| QUATERNION/DERIVATIVE | Epoch, QC, Q1, Q2, Q3, QC\_DOT, Q1\_DOT, Q2\_DOT, Q3\_DOT  (QUATERNION ORDER : TBC) |
| QUATERNION/RATE | Epoch, QC, Q1, Q2, Q3, X\_RATE, Y\_RATE, Z\_RATE  (QUATERNION ORDER : TBC) |
| ~~QUATERNION\_TYPE~~ | ~~LAST~~ | ~~N/A~~ |
| ~~ATTITUDE\_TYPE~~ | ~~QUATERNION~~ | ~~Epoch, Q1, Q2, Q3, QC~~ |
| ~~QUATERNION/DERIVATIVE~~ | ~~Epoch, Q1, Q2, Q3, QC, Q1\_DOT, Q2\_DOT, Q3\_DOT, QC\_DOT~~ |
| ~~QUATERNION/RATE~~ | ~~Epoch, Q1, Q2, Q3, QC, X\_RATE, Y\_RATE, Z\_RATE~~ |
| Euler Angle Options (note that keywords and values appear only in Metadata) | | |
| ATTITUDE\_TYPE | EULER\_ANGLE | Epoch,  ANGLE\_1, ANGLE\_2, ANGLE\_3 |
| EULER\_ANGLE/DERIVATIVE | Epoch,  ANGLE\_1\_DOT, ANGLE\_2\_DOT, ANGLE\_3\_DOT |
| EULER\_ANGLE/RATE | Epoch,  ANGLE\_1, ANGLE\_2, ANGLE\_3, X\_RATE, Y\_RATE, Z\_RATE |
| Spin Axis Options (note that keywords and values appear only in Metadata) | | |
| ATTITUDE\_TYPE | SPIN | Epoch,  SPIN\_ALPHA, SPIN\_DELTA, SPIN\_ANGLE, SPIN\_ANGLE\_VEL  (TBC) |
| SPIN/NUTATION | Epoch,  SPIN\_ALPHA, SPIN\_DELTA, SPIN\_ANGLE, SPIN\_ANGLE\_VEL, NUTATION, NUTATION\_PER, NUTATION\_PHASE  (TBC) |