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Space data and information transfer systems — Attitude data messages

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National foreword

This British Standard is the UK implementation of ISO 13541:2021. It supersedes BS ISO 13541:2010, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee ACE/68, Space systems and operations.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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INTERNATIONAL STANDARD

ISO 13541

Second edition
2021-06

Space data and information transfer systems — Attitude data messages

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

Reference number
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Foreword

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

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

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

— adds clarifying text to 1.3, Conventions and Definitions.

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1 INTRODUCTION

1.1 PURPOSE

1.1.1 This Attitude Data Message (ADM) Recommended Standard specifies two standard message formats for use in transferring spacecraft attitude information between space agencies: the Attitude Parameter Message (APM) and the Attitude Ephemeris Message (AEM). Such exchanges are used for:

- preflight planning for tracking or attitude estimation support;
- scheduling attitude and data processing support;
- carrying out attitude operations;
- performing attitude comparisons;
- carrying out attitude propagations and/or sensor predictions;
- testing to initialize sub-system simulators (communications, power, etc.).

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

1.2 SCOPE AND APPLICABILITY

1.2.1 This document contains two attitude data messages designed for applications involving data interchange in space data systems. The rationale behind the design of each message is described in annex B and may help the application engineer to select a suitable message. Definition of the attitude accuracy underlying a particular attitude message is outside of the scope of this Recommended Standard and should be specified via Interface Control Document (ICD) between data exchange participants. Applicability information specific to each Attitude Data Message format appears in sections 3 and 4, as well as in annex subsection B3.

1.2.2 This Recommended Standard is applicable only to the message format and content, but not to its transmission. The transmission of the message between agencies is outside the scope of this document and should be specified in an ICD or by following a CCSDS standard on transmission.

1.2.3 Description of the message formats based on the use of the eXtensible Markup Language (XML) will be available. An XML schema is defined by the CCSDS Recommended Standard titled 'XML Specification for Navigation Data Messages' (reference [5]). Agencies should specify, via ICD, the ASCII file format to be exchanged (Keyword Value Notation [KVN] or XML).

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1.3 CONVENTIONS AND DEFINITIONS

The following conventions apply throughout this Recommended Standard:

a) the words 'shall' and 'must' imply a binding and verifiable specification;

b) the word 'should' implies an optional, but desirable, specification;

c) the word 'may' implies an optional specification; and

d) the words 'is', 'are', and 'will' imply statements of fact.

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

1.4 STRUCTURE OF THIS DOCUMENT

1.4.1 Section 2 provides a brief overview of the CCSDS-recommended Attitude Data Message types, the Attitude Parameter Message (APM) and Attitude Ephemeris Message (AEM).

1.4.2 Section 3 provides details about the structure and content of the APM.

1.4.3 Section 4 provides details about the structure and content of the AEM.

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

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

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

1.4.7 Annex B lists a set of requirements that were taken into consideration in the design of the APM and AEM, along with tables and discussion regarding the applicability of the two message types to various attitude estimation tasks and functions.

1.4.8 Annex C lists a number of items that should be covered in ICDs prior to exchanging ADMs on a regular basis. There are several statements throughout the document that refer to the desirability or necessity of such a document; this annex lists all the suggested ICD items in a single place in the document.

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

1.4.10 Annex E is a list of informative references.

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1.5 REFERENCES

The following documents contain provisions which, through reference in this text, constitute provisions of this Recommended Standard. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this Recommended Standard are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS Recommended Standards.

[1] *Information Technology—8-Bit Single-Byte Coded Graphic Character Sets—Part 1: Latin Alphabet No. 1*. International Standard, ISO/IEC 8859-1:1998. Geneva: ISO, 1998.

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

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

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

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

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

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

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

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2 OVERVIEW

2.1 ATTITUDE DATA MESSAGE TYPES

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

2.1.2 The recommended attitude data messages are ASCII text format. While binary-based attitude data message formats are computer efficient and minimize overhead on uplinked/downlinked data streams, there are ground-segment applications for which an ASCII character-based message is more appropriate. For example, when files or data objects are created using text editors or word processors, ASCII character-based attitude data format representations are necessary. They are also useful in transferring text files between heterogeneous computing systems, because the ASCII character set is nearly universally used and is interpretable by all popular systems. In addition, direct human-readable downloads of text files or objects to displays or printers are possible without preprocessing. The penalty for this convenience is inefficiency.

2.1.3 As currently specified, an APM or AEM file is to represent attitude data for a single vehicle. It is possible that the architecture may support multiple vehicles per file; this could be considered in the future.

2.2 ATTITUDE PARAMETER MESSAGE (APM)

2.2.1 An APM specifies the attitude state of a single object at a specified epoch. This message is suited to inter-agency exchanges that (1) involve automated interaction and/or human interaction, and (2) do not require high-fidelity dynamic modeling (for high-fidelity dynamic modeling, see 2.3, Attitude Ephemeris Message).

2.2.2 The APM requires the use of a propagation technique to determine the attitude state at times different from the specified epoch, leading to a higher level of effort for software implementation than for the AEM. When inertial frames are specified, the APM is fully self-contained and no additional information is required to specify the attitude; if local orbital frames are specified, then an APM must be used in conjunction with an Orbit Parameter Message (reference [7]).

2.2.3 The APM allows for modeling of any number of finite maneuvers and simple modeling of solar radiation pressure and atmospheric torque. Note that an Orbit Parameter Message (OPM) is needed for proper solar radiation pressure modeling. The attributes of the APM also make it suitable for applications such as exchanges by FAX or voice, or applications where the message is to be frequently interpreted by humans.

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2.3 ATTITUDE EPHEMERIS MESSAGE (AEM)

2.3.1 An AEM specifies the attitude state of a single object at multiple epochs, contained within a specified time range. The AEM is suited to inter-agency exchanges that (1) involve automated interaction (e.g., computer-to-computer communication where frequent, fast, automated time interpretation and processing are required), and (2) require higher fidelity or higher precision dynamic modeling than is possible with the APM (e.g., flexible structures, more complex attitude movement, etc.).

2.3.2 The AEM allows for dynamic modeling of any number of torques (solar pressure, atmospheric torques, magnetics, etc.). The AEM requires the use of an interpolation technique to interpret the attitude state at times different from the tabular epochs.

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

2.4 EXCHANGE OF MULTIPLE MESSAGES

For a given object, multiple APM or AEM messages may be provided in a message exchange session to achieve attitude fidelity requirements. If attitude information for multiple objects is to be exchanged, then multiple APM or AEM files must be used.

2.5 DEFINITIONS

Definitions of time systems, reference frames, attitude estimation and prediction methods and models are provided in reference [E4].

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3 ATTITUDE PARAMETER MESSAGE (APM)

3.1 OVERVIEW

3.1.1 Attitude information may be exchanged between two participants by sending the attitude state (see reference [E4]) for a specified epoch using an Attitude Parameter Message (APM). The message recipient must have an attitude propagator available that is able to propagate the APM state to compute the estimated attitude at other desired epochs. For this propagation, additional ancillary information (spacecraft properties such as inertia matrix, torque vectors, and maneuver planning data, if applicable) shall be included with the message.

3.1.2 The use of the APM shall be applicable under the following conditions:

– an attitude propagator shall be available at the receiver's location;

– the receiver's modeling of satellite attitude dynamics, atmospheric torque, other internal and external torques (e.g., magnetic, gravitational, etc.), thrust maneuvers, and attitude control (see reference [E4]) must fulfill accuracy requirements established via an ICD between the agencies.

3.1.3 The APM shall be a text file consisting of attitude data for a single object. It shall be easily readable by both humans and computers.

3.1.4 The APM file naming scheme shall be agreed to on a case-by-case basis between the participating agencies, and should be documented in an Interface Control Document (ICD). The method of exchanging APMs shall be decided on a case-by-case basis by the participating agencies and documented in an ICD.

3.2 APM CONTENT

3.2.1 GENERAL

The APM shall be represented as a combination of the following:

a) a header;

b) metadata (data about the data);

c) optional comments (explanatory information); and

d) data.

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3.2.2 APM HEADER

3.2.2.1 Table 3-1 specifies for each header item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

3.2.2.2 Only those keywords shown in table 3-1 shall be used in an APM header.

Table 3-1: APM Header

Keyword	Description	Examples of Values	Obligatory
`CCSDS_APM_VERS`	Format version in the form of 'x.y', where 'y' is incremented for corrections and minor changes, and 'x' is incremented for major changes.	`1.0`	Yes
`COMMENT`	Comments (allowed at the beginning of the APM Header after the APM version number). Each comment line shall begin with this keyword.	`This is a comment`	No

`CREATION_DATE`	File creation date/time in one of the following formats: YYYY-MM-DDThh:mm:ss[.d→d] or YYYY-DDDThh:mm:ss[.d→d] where 'YYYY' is the year, 'MM' is the two-digit month, 'DD' is the two-digit day, 'DDD' is the three-digit day of year, 'T' is constant, 'hh:mm:ss[.d→d]' is the UTC time in hours, minutes, seconds, and optional fractional seconds. As many 'd' characters to the right of the period as required may be used to obtain the required precision. All fields require leading zeros.	`2001-11-06T11:17:33`
		`2002-204T15:56:23`
		`1996-12-18T14:28:15.1172`
			Yes

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

3.2.3 APM METADATA

3.2.3.1 Table 3-2 specifies for each metadata item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is obligatory or optional.

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3.2.3.2 Only those keywords shown in table 3-2 shall be used in APM metadata. For some keywords (OBJECT_NAME, OBJECT_ID, CENTER_NAME) there are no definitive lists of authorized values maintained by a control authority; the references listed in 1.5 and annex E are the best known sources for authorized values to date.

Table 3-2: APM Metadata

Keyword	Description	Normative Values / Examples	Obligatory
COMMENT	Comments (allowed only at the beginning of the APM Metadata before OBJECT_NAME). Each comment line shall begin with this keyword.	COMMENT This is a comment	No
OBJECT_NAME	Spacecraft name of the object corresponding to the attitude data to be given. There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the SPACEWARN Bulletin (reference [2]), which include the Object name and international designator of the participant.	EUTELSAT W1 MARS PATHFINDER STS106 NEAR	Yes
OBJECT_ID	Spacecraft identifier of the object corresponding to the attitude data to be given. While there is no CCSDS-based restriction on the value for this keyword, the names could be drawn from the SPACEWARN Bulletin (reference [2]). If this is chosen, it is recommended that values have the format YYYY-NNNP{PP}, where: – YYYY = year of launch; – NNN = three-digit serial number of launch in year YYYY (with leading zeros); – P{PP} = at least one capital letter for the identification of the part brought into space by the launch. In cases where the asset is not listed in the bulletin, the value should be provided in an ICD.	2000-052A 1996-068A 2000-053A 1996-008A	Yes
CENTER_NAME	Origin of reference frame, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this the value for 'CENTER_NAME' is subject to the same rules as for 'OBJECT_NAME'). There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the NASA/JPL Solar System Dynamics Group (reference [3]).	EARTH EARTH BARYCENTER MOON SOLAR SYSTEM BARYCENTER SUN JUPITER BARYCENTER STS 106 EROS	No
TIME_SYSTEM	Time system used for attitude and maneuver data (also see table 3-3). The full set of allowed values is enumerated in annex A, with an excerpt provided in the 'Normative Values/Examples' column. Explanations of these time systems can be found in *Navigation Definitions and Conventions* (reference [E4]).	UTC, TAI, TT, GPS, TDB, TCB	Yes

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3.2.4 APM DATA

3.2.4.1 Table 3-3 provides an overview of the five logical blocks in the APM Data section (attitude Quaternion, attitude Euler angles (three-axis), spin axis types, Spacecraft Parameters, Maneuver Parameters), and specifies for each data item:

a) the keyword to be used;

b) a short description of the item;

c) the units to be used;

d) whether the item is obligatory or optional.

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

Table 3-3: APM Data

Keyword	Description	Normative Units/Values	Obligatory
Comments (Shall appear only at the beginning of the logical blocks, but not between components of the logical blocks.)			
COMMENT	Each comment line shall begin with this keyword.	n/a	No
EPOCH	Epoch of the attitude elements & optional logical blocks and denotes a spacecraft event time.	n/a	Yes
Attitude Quaternion Components in the Specified Coordinate System (All obligatory elements of the logical block are to be provided.)			
Q_FRAME_A	The name of the reference frame specifying one frame of the transformation, whose direction is specified using the keyword Q_DIR. The full set of values is enumerated in annex A, with an excerpt provided in the 'Units/Values' column. For a definition of these various frames, the reader is directed to reference [E4]. Note that if a frame is used that does not appear in annex A, a description should be placed in an ICD.	SC_BODY_1 STARTRACKER_1 INSTRUMENT_A LVLH ICRF	Yes
Q_FRAME_B	Name of the reference frame specifying the second portion of the transformation, whose direction is specified using the keyword Q_DIR. The full set of values is enumerated in annex A, with an excerpt provided in the 'Units/Values' column. For a definition of these various frames, the reader is directed to *Navigation Definitions and Conventions* (reference [E4]). Note that if a reference frame is to be used that does not appear in annex A, a description should be placed in an ICD.	ICRF ITRF-97 ITRF2000 ITRFxxxx TOD EME2000 LVLH RTN SC_BODY_1 INSTRUMENT_A	Yes
Q_DIR	Rotation direction of the attitude quaternion, specifying from which frame the transformation is to: - A2B specifies an attitude transforming from the Q_FRAME_A to the Q_FRAME_B - B2A specifies an attitude transforming from the Q_FRAME_B to the Q_FRAME_A	A2B B2A	Yes
Q1	$e_1 * \sin(\phi/2)$ ϕ = rotation angle	n/a	Yes
Q2	$e_2 * \sin(\phi/2)$ ϕ = rotation angle	n/a	Yes
Q3	$e_3 * \sin(\phi/2)$ ϕ = rotation angle	n/a	Yes

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

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Keyword	Description	Normative Units/Values	Obligatory
Attitude parameters in the Specified Reference Frame for a Spin Stabilized Satellite (The sender shall give parameters from this logical block that are necessary to uniquely specify the attitude.)			
COMMENT	Each comment line shall begin with this keyword.	n/a	No
SPIN_FRAME_A	The name of the reference frame specifying one frame of the transformation, whose direction is specified using the keyword SPIN_DIR. The full set of values is enumerated in annex A, with an excerpt provided in the 'Units/Values' column. For a definition of these various frames, the reader is directed to reference [E4]. Note that if a frame is used that does not appear in annex A, a description should be placed in an ICD.	SC_BODY_1 STARTRACKER_1 INSTRUMENT_A ICRF LVLH	No
SPIN_FRAME_B	Name of the reference frame specifying the second portion of the transformation, whose direction is specified using the keyword SPIN_DIR. The full set of values is enumerated in annex A, with an excerpt provided in the 'Units/Values' column. Note that if a reference frame is to be used that does not appear in annex A, a description should be placed in an ICD.	ICRF ITRF-93 ITRF-97 ITRF2000 SC_BODY_1 INSTRUMENT_A	No
SPIN_DIR	Rotation direction of the Spin angles, specifying from which frame the transformation is to: - A2B specifies an attitude transforming from the SPIN_FRAME_A to the SPIN_FRAME_B - B2A specifies an attitude transforming from the SPIN_FRAME_B to the SPIN_FRAME_A	A2B B2A	No
SPIN_ALPHA	Right ascension of spin axis vector	deg	No
SPIN_DELTA	Declination of the spin axis vector	deg	No
SPIN_ANGLE	Phase of the satellite about the spin axis	deg	No
SPIN_ANGLE_VEL	Angular velocity of satellite around spin axis	deg/s	No
NUTATION	Nutation angle of spin axis	deg	No
NUTATION_PER	Body nutation period of the spin axis	s	No
NUTATION_PHASE	Inertial nutation phase	deg	No
Spacecraft Parameters (1, 2, 3 are a set of orthogonal axes. None or all parameters of this block are to be given.)			
COMMENT	Each comment line shall begin with this keyword.	n/a	No
INERTIA_REF_FRAME	Coordinate system for the inertia tensor	n/a	No
I11	Moment of Inertia about the 1-axis	kg*m**2	No
I22	Moment of Inertia about the 2-axis	kg*m**2	No
I33	Moment of Inertia about the 3-axis	kg*m**2	No
I12	Inertia Cross Product of the 1 & 2 axes	kg*m**2	No
I13	Inertia Cross Product of the 1 & 3 axes	kg*m**2	No
I23	Inertia Cross Product of the 2 & 3 axes	kg*m**2	No
Maneuver Parameters (Repeat for each maneuver. None or all parameters of this block are to be given.)			
COMMENT	Each comment line shall begin with this keyword.	n/a	No
MAN_EPOCH_START	Epoch of start of maneuver	n/a	No
MAN_DURATION	Maneuver duration	s	No
MAN_REF_FRAME	Coordinate system for the torque vector	n/a	No
MAN_TOR_1	1st component of the torque vector	N*m	No
MAN_TOR_2	2nd component of the torque vector	N*m	No
MAN_TOR_3	3rd component of the torque vector	N*m	No

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