

**Proposed Recommendation for
Space Data System Standards**

**NAVIGATION
HARDWARE
MESSAGE**

PROPOSED RECOMMENDED STANDARD

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FOREWORD

This document is a Proposed Standard for Navigation Hardware Messages and has been prepared by the Consultative Committee for Space Data Systems (CCSDS). The Navigation Hardware Message described in this Proposed Standard is the baseline concept for spacecraft hardware data interchange applications that are cross-supported between Agencies of the CCSDS.

This Proposed Standard establishes a common framework and provides a common basis for the format of spacecraft hardware data exchange between space agencies. 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 Proposed Standard and may incorporate features not addressed by this Proposed Standard.

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PREFACE

This document is a Proposed CCSDS Standard. Its 'White Book' status indicates that the CCSDS believes the document to be technically immature and has not released it for formal review by appropriate technical organizations. As such, its technical contents are not stable, and several iterations of it may occur in response to comments received during the review process.

Implementers are cautioned not to fabricate any final equipment in accordance with this document's technical content.

DOCUMENT CONTROL

Document	Title and Issue	Date	Status
CCSDS 510.0-W-1	Navigation Hardware Message, Draft Recommended Standard, Issue 0	November 2010	First Draft
CCSDS 510.0-W-2	Navigation Hardware Message, Proposed Recommended Standard, Issue 1	November 2011	More Complete Draft
CCSDS 510.0-W-3	Navigation Hardware Message, Proposed Recommended Standard, Issue 1	January 2012	Draft Containing Suggested Changes
CCSDS 510.0-W-4	Navigation Hardware Message, Proposed Recommended Standard, Issue 1	May 2012	Changes to Formats
CCSDS 510.0-W-5	Navigation Hardware Message, Proposed Recommended Standard, Issue 1	July 2012	Modifications of tables in Annexes and correction of errors
CCSDS 510.0-W-6	Navigation Hardware Message, Proposed Recommended Standard, Issue 1	November 2012	Addition of XML representation and changes resulting from discussions at Working Group meeting, Oct. 2012
CCSDS 510.0-W-7	Navigation Hardware Message, Proposed Recommended Standard, Issue 1	February 2013	Modification to source of mnemonic definitions and reformatting of entire document
CCSDS 510.0-W-8	Navigation Hardware Message, Proposed Recommended Standard, Issue 1	January 2014	Incorporation of suggestions from Spring and Fall 2013 technical meeting and following reviews
CCSDS 510.0-W-9	Navigation Hardware Message, Proposed Recommended Standard, Issue 1	June 2014	Addition of Frame and Calcurve keywords and incorporation of suggestions from Spring 2014 meeting

CCSDS 510.0-W-10	Navigation Hardware Message, Proposed Recommended Standard, Issue 1	November 2014	Addition of changes from reviewers comments
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CONTENTS

<u>Section</u>	<u>Page</u>
1 INTRODUCTION	1-1
1.1 PURPOSE	1-1
1.2 SCOPE.....	1-1
1.3 APPLICABILITY	1-2
1.4 RATIONALE	1-2
1.5 DOCUMENT STRUCTURE	1-2
1.6 DEFINITIONS AND CONVENTIONS	1-3
1.7 REFERENCES	1-4
2 OVERVIEW	2-1
2.1 GENERAL	2-1
2.2 THE NAVIGATION HARDWARE MESSAGE (NHM) BASIC CONTENT	2-1
3 NAVIGATION HARDWARE MESSAGE CONTENT AND STRUCTURE IN KVN	3-1
3.1 GENERAL	3-1
3.2 NHM HEADER	3-1
3.3 NHM METADATA	3-3
3.4 NHM DATA.....	3-6
4 NHM CONTENT AND STRUCTURE IN XML	4-1
4.1 GENERAL—THE NHM/XML SCHEMA.....	4-1
4.2 NHM/XML BASIC STRUCTURE.....	4-1
4.3 NHM/XML TAGS	4-2
4.4 CONSTRUCTING AN NHM/XML INSTANCE	4-2
4.5 Local Operations	4-7
5 NAVIGATION HARDWARE MESSAGE KVN SYNTAX.....	5-8
5.1 GENERAL	5-8
5.2 NHM LINES	5-8
5.3 NHM MNEMONIC KEYWORDS	5-10
5.4 NHM DATA RECORD VALUES.....	5-13
5.5 UNITS IN THE NHM.....	5-15
5.6 COMMENTS IN AN NHM	5-15
5.7 FRAME KEYWORDS IN A NHM	5-17
5.8 CALCURVE KEYWORDS IN A NHM	5-18
6 NAVIGATION HARDWARE MESSAGE XML SYNTAX	A-1
6.1 OVERVIEW	A-1
6.2 NHM LINES IN XML	A-1
6.3 NHM VALUES IN XML.....	A-1
6.4 NHM UNITS IN XML.....	A-2
NHM COMMENTS IN XML	A-2

6.5 Error! Bookmark not defined.

ANNEX A IMPLEMENTATION CONFORMANCE STATEMENT PROFORMA (NORMATIVE)	A-3
ANNEX B VALUES FOR THE TIME_SYSTEM KEYWORD (NORMATIVE)	B-4
ANNEX C SECURITY, SANA AND PATENT CONSIDERATIONS (INFORMATIVE)	C-1
ANNEX D VALUES FOR DEFINE KEYWORD (INFORMATIVE).....	D-1
ANNEX E EXAMPLE NAVIGATION HARDWARE MESSAGE MNEMONICS WITH CORRESPONDING ICD INFORMATION (INFORMATIVE).	E-4
ANNEX F EXAMPLE NAVIGATION HARDWARE MESSAGES (INFORMATIVE)	F-1
ANNEX G NHM EXAMPLE IN XML FORMAT (INFORMATIVE)	G-3
ANNEX H INFORMATIVE REFERENCES (INFORMATIVE).....	H-1
ANNEX I NAVIGATION HARDWARE MESSAGE GOALS AND REQUIREMENTS (INFORMATIVE)	I-1
ANNEX J GRAPHICAL REPRESENTATION OF NHM IN KVN (INFORMATIVE)	J-1
ANNEX K	K-1

Figure

4-1 CDM XML Basic Structure	Error! Bookmark not defined.
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Table

3-1 NMH Header	3-2
3-2 NHM Data Section Generic Format	3-7
4-1 Special NHM/XML Tags	4-7
5-1 Format of NHM Mnemonic Keywords	5-12
A-1 Normative Values for TIME_SYSTEM Metadata Keyword	B-4
B-1 Defined values for the System Field associated with the Mnemonic Keyword in the Metadata Section	D-2
B-2 Defined Values for the Hardware Type Field Associated with the Mnemonic Keyword in the Metadata Section	Error! Bookmark not defined.
B-3 Defined Values for the Data Symbols Data Format Fields Associated with the Mnemonic Keyword in the Metadata Section	Error! Bookmark not defined.
G-1 Primary Requirements	I-2
G-2 Primary Requirements	I-3

1 INTRODUCTION

1.1 PURPOSE

The Navigation Hardware message is intended to provide a uniform format for the transmission of data from a ground system functional group that receives and unpacks spacecraft telemetry to any spacecraft functional group that uses spacecraft data for determination or analysis of the spacecraft attitude or orbit. The data used, arising from onboard hardware that can be used for spacecraft navigation is called Navigation Hardware Data.

This Navigation Hardware Message (NHM) Proposed Standard specifies a standard message format for use in exchanging spacecraft hardware data used in navigation processes between space agencies. Such exchanges are used for distributing hardware data output from an agency that receives spacecraft telemetry containing hardware data to other agencies that use spacecraft hardware data. The hardware data must first be unpacked from the telemetry before distribution in the NHM format. The data is then used to monitor and analyze performance of the hardware and of the onboard use of the hardware data. The standardization of hardware data formats facilitates space agency development of software to perform the desired monitoring and analysis functions and reduces the risk of error in such software.

The spacecraft ground system telemetry processing function receives this telemetry and distributes appropriate subsets of it to corresponding spacecraft functional groups.

This document includes goals and criteria that the message format has been designed to meet. For exchanges where these requirements do not capture the needs of the participating agencies another mechanism could be selected.

1.2 SCOPE

This Proposed Standard contains the specifications for a Navigation Hardware Message designed for spacecraft navigation applications that include input of hardware data. These applications include calibration of spacecraft navigation hardware and monitoring of the performance of the spacecraft and its navigation hardware. The term “Hardware Data” is used in this document to include both data produced by navigation hardware and data that results from onboard processing of the data produced by the hardware. Similarly, the term “measurement” is used in this document to include both hardware measurements and processed hardware measurements. Although the NHM is designed for transmission of navigation hardware data the standard might be applied to spacecraft data intended for other purposes such as monitoring of functions that are not navigation related.

The Proposed Standard cannot explicitly include all types of Navigation Hardware data that exist or will exist in the future. It is intended to contain a syntax which can be used to define the transmission of those spacecraft hardware data that are not explicitly included.

Definition of the accuracy pertaining to any particular NHM is outside the scope of this Proposed Standard. An Interface Control Document (ICD) between data exchange participants is the preferred means for defining accuracies. This ICD can also be used to define any non-standard hardware data formats that might be required.

1.3 APPLICABILITY

Telemetry Data is transmitted from spacecraft to ground stations according to established standards. This document does not address the standard used for transmission from the spacecraft to ground stations. This Proposed Standard is applicable only to the message format and content, but not to its transmission. The method of transmitting the message between exchange partners is beyond the scope of this document and will generally be specified in the ICD. Message transmission could be based on a CCSDS data transfer protocol, file based transfer protocol such as SFTP, stream-oriented media, or other secure transmission mechanism. In general, the transmission mechanism will not place constraints on the technical data content of an NHM.

1.4 RATIONALE

Spacecraft hardware data are used for many required ground-processing functions but there is presently no uniform standard for their formatting.

In order for a standard to be useful it is necessary that it apply to the many thousands of types of hardware measurement data that exist and be flexible enough to be adaptable to new spacecraft hardware.

The approach taken in this proposed standard is to avoid explicitly enumerating all of the possible hardware measurement data, but instead to provide a flexible syntax through which present and future hardware data could be identified.

1.5 DOCUMENT STRUCTURE

This document consists of several sections plus annexes.

- Section 1 contains a description of the structure of this document and of the conventions and common material used in it.
- Section 2 provides a brief overview of the CCSDS-recommended Navigation Hardware Message (NHM).
- Section 3 provides details about the structure and content of the NHM in the KVN format.
- Section 4 provides details about the structure and content of the NHM in the XML format.
- Section 5 provides details about the syntax used in the NHM in the KVN format.

- Section 6 provides details about the syntax used in the NHM in the XML format. Annex A contains an Implementation Conformance Statement (ICS) pro forma that may be used by implementers to compactly describe their implementations.
- Annex BA provides a normative list of approved values for selected NHM defined keywords.
- Annex C discusses SECURITY, SANA and patent considerations.
- Annex D provides tables of allowed values for fields composing the Mnemonic Keyword along with a description of the information that would be provided in an ICD for each field.
- Annex E provides examples of navigation hardware message mnemonic keywords with corresponding ICD Information.
- Annex F shows how data from various types of spacecraft hardware can be accommodated using the NHM in KVN format, via several examples.
- Annex G contains an example of a NHM in XML format.
- Annex H contains a list of informative references.
- Annex I contains a description of the requirements and criteria that the message format has been designed to meet.
- Annex J contains a graphical representation of the NHM structure in KVN format.
- Annex K contains a information pertaining to values associated with the FRAME keyword.

1.6 DEFINITIONS AND CONVENTIONS

Conventions and definitions of navigation concepts such as reference frames, time systems, etc., are provided in references [**Error! Reference source not found.**], [H3].

1.6.1 TERMS

For the purposes of this document, the following definitions apply:

Navigation Hardware: consists of the physical parts of a spacecraft that are the source of data involved in any computations of spacecraft orbit or attitude.

Navigation Hardware data: includes all data originating from Navigation Hardware including intermediate values and results of its processing.

Keyword = Value Notation (KVN): denotes a format which associates a Measurement or group of Measurements with a keyword. The keyword designates an important property or

attribute of the subject under discussion, and the Measurement(s) represent(s) a measurement or descriptive state of that property..

eXtensible Markup Language (XML): denotes a language in which the NHM can optionally be expressed (see reference [1], [2]).

Interface Control Document (ICD): denotes a formal agreement between the data transmission and data receipt entities. It is not limited to documents with the title “Interface Control Document.”

1.6.2 NOMENCLATURE

The following conventions apply for the normative specifications in this document:

- 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;
- d) the words ‘is’, ‘are’, and ‘will’ imply statements of fact.

NOTE – These conventions do not imply constraints on diction in text that is clearly informative in nature.

1.6.3 CONVENTIONS

The term ‘n/a’ or ‘N/A’ denotes an attribute that is not applicable or not available.

In this document, the term ‘ASCII’ is used generically to refer to the text character set defined in reference [4].

CamelCase. A style of capitalization in which the initial characters of concatenated words are capitalized, as in *CamelCase*.

lowerCamelCase. A variant of CamelCase in which the first character of a character string formed from concatenated words is lowercase, as in *lowerCamelCase*. In the case of a character string consisting of only a single word, only lowercase characters are used.

1.7 REFERENCES

The following documents contain provisions which, through reference in this text, constitute provisions of this Proposed Standard. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this Proposed 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 documents.

- [1] *XML Schema Part 1: Schema*. 2nd ed. P. Biron and A. Malhotra, eds. W3C Recommendation 28. n.p.: W3C, 2004.
- [2] *XML Schema Part 2: Datatypes*. 2nd ed. P. Biron and A. Malhotra, eds. W3C Recommendation 28. n.p.: W3C, 2004.
- [3] *The International System of Units (SI)*, 8th edition, Bureau International des Poids et Mesures, Organisation Intergouvernementale de la Convention du Mètre, STEDI MEDIA, Paris, 2006.
- [4] *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.
- [5] *Time Code Formats*. Recommendation for Space Data System Standards, CCSDS 301.0-B-4. Blue Book. Issue 4. Washington, D.C.: CCSDS, November 2010.
- [6] *IEEE Standard for Binary Floating-Point Arithmetic*. IEEE Std 754-1985. New York: IEEE, 1985.
- [7] *XML Specification for Navigation Data Messages*. Recommendation for Space Data System Standards, CCSDS 505.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, December 2010.
- [8] *Spacewarn Bulletin*. Greenbelt, MD, USA: WDC-SI.
<<http://nssdc.gsfc.nasa.gov/spacewarn>>

2 OVERVIEW

2.1 GENERAL

This section provides a high-level overview of the CCSDS recommended Navigation Hardware Message.

2.2 THE NAVIGATION HARDWARE MESSAGE (NHM) BASIC CONTENT

2.2.1 The NHM in this version of the Proposed Standard is ASCII-text formatted. While binary-based Navigation Hardware Message formats are computer efficient and minimize overhead during data transfer, there are ground-segment applications for which an ASCII character-based message is more appropriate. For example, ASCII format character-based hardware data representations are useful in transferring data 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 dumps of text to displays, emails, documents or printers are possible without preprocessing. The penalty for this convenience is some measure of inefficiency (based on early tests, such penalty would be greatly reduced if the data is compressed for transmission).

2.2.2 The NHM is realized as a sequence of plain ASCII text lines (reference [4]), which can be in either a file format or a real-time stream. The content is separated into three basic types of computer data structure as described in section 3. These structures are the Header, Metadata, and Data. The NHM architecture provides flexibility by defining a syntax which can be used to define hardware data contents and consistency by defining values that correspond to commonly used hardware.

2.2.3 The ASCII text in an NHM can be exchanged in either of two formats: a 'keyword-value notation' format (KVN) or an XML format. The KVN formatted NHM is described in sections 3 and 5 of this document. Description of the message format based on XML is detailed in sections 4 and 6 of this document. It is suggested that an ICD identify which NHM ASCII format will be exchanged, the KVN or the XML format, as agreed by the exchange participants.

3 NAVIGATION HARDWARE MESSAGE CONTENT AND STRUCTURE IN KVN

3.1 GENERAL

NOTES

1 This section applies to KVN format only.

2 A graphical representation of the KVN NHM structure is presented in Annex I.

3.1.1 The NHM shall consist of digital data represented as ASCII text lines (see reference [4]) in KVN format (Keyword = Value Notation).

3.1.2 The lines constituting an NHM shall be represented as a combination of:

- a) a Header Section (see section 3.2);
- b) a Metadata Section (data about data) (see section 3.3); and
- c) a Data Section (navigation data represented as 'Hardware Data Records') (see section 3.4).

3.1.3 Optional comments may appear in specified locations in the Header, Metadata, and Data Sections (see section 0).

3.1.4 Each NHM shall have one Header Section, one Metadata Section, and one Data Section.

3.1.5 Any NHM shall contain Hardware Data for a single spacecraft.

3.1.6 The NHM shall be readable by both humans and computers.

3.1.7 It shall be possible to exchange an NHM either as a real-time stream or as a file.

3.1.8 The NHM file naming scheme should be agreed to on a case-by-case basis between the participating agencies, typically specified in an ICD.

3.1.9 The method of exchanging NHMs should be decided on a case-by-case basis by the participating agencies and documented in an ICD. The exchange method shall not constrain the data content.

3.2 NHM HEADER

3.2.1 The NHM shall include a Header that consists of information that identifies the basic parameters of the message.

3.2.2 The first Header line must be the first non-blank line in the message.

3.2.3 A description of NHM Header items and values is provided in table 3-1, which specifies for each item in the header:

- the keyword to be used;
- a short description of the item;
- examples of allowed values; and
- whether the item is obligatory or not obligatory.

3.2.4 Only those keywords shown in table 3-1 shall be used in an NHM Header. The order of occurrence of the obligatory and optional keyword assignments shall be fixed as shown in table 3-1.

Table 3-1: NHM Header

Keyword	Description	Examples	Obligatory
CCSDS_NHM_VERS	Format version in the form of 'x.y', where 'y' shall be incremented for corrections and minor changes, and 'x' shall be incremented for major changes.	0.12 (for testing) 1.0	Yes
COMMENT	See 0.	COMMENT This is a comment	No
CREATION_DATE	Data creation date/time in UTC. For format specification, see 5.4.3.7.	2001-11-06T11:17:33 2002-204T15:56:23.4 2006-001T00:00:00Z	Yes
ORIGINATOR	Creating agency. Value should be specified in the ICD.	CNES, ESOC, GSFC, GSOC, JPL, JAXA, etc.	Yes

3.2.5 Each line in the NHM Header, with the exception of COMMENTS, shall have the following generic format:

keyword = value

3.2.6 The NHM Header shall provide a CCSDS Navigation Hardware Message version number that identifies the format version; the version number is included to anticipate future changes and to provide the ability to extend the standard with no disruption to existing users.

3.2.6.1 The version keyword is CCSDS_NHM_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.

3.2.6.2 Version 1.0 shall be reserved for the initial version accepted by the CCSDS as an official Recommended Standard ('Blue Book').

3.2.6.3 Interagency testing of NHMs shall be conducted using version numbers less than 1.0 (e.g., '0.y').

3.2.6.4 Specific NHM versions that will be exchanged between agencies should be documented via the ICD.

3.2.7 The NHM Header shall include the CREATION_DATE keyword with the value set to the Coordinated Universal Time (UTC) when the data was created (file creation time if in file format, or creation time of the first data point if in stream format), as specified in Reference [5] (ASCII Time Code A or B).

3.3 NHM METADATA

3.3.1 The NHM shall include a Metadata Section that consists of information that describes the data content of the message.

3.3.2 Each line in the NHM Metadata Section, with the exception of COMMENTS, META_START and META_STOP, shall have the following generic format:

keyword = value

3.3.3 The first and last lines of a NHM Metadata Section shall consist of the META_START and META_STOP keywords, respectively. These keywords are used to facilitate parsing.

3.3.4 The NHM Metadata Section shall contain at least one Define Block.

3.3.4.1 A Define Block shall start with a line containing the DEFINE keyword.

Note: Lines containing the DEFINE keyword are referred to as Define Lines.

3.3.4.2 A Define Block may contain a multiple lines, each containing a COMMENT keyword.

Note: Lines containing the COMMENT keyword as referred to as Comment Lines.

3.3.4.3 A Define Block may contain a single line containing the FRAME keyword.

Note: Lines containing the FRAME keyword are referred to as Frame Lines.

3.3.4.4 A Define Block may contain a single line containing the CALCURVE keyword.

Note: Lines containing the CALCURVE keyword are referred to as Calcurve Lines.

3.3.5 Table 3-2 specifies for each Metadata item:

- the keyword to be used;
- a short description of the item;

- examples of allowed values; and
- whether the item is obligatory or not obligatory.

3.3.6 Only those keywords shown in table Table 3-2 shall be used in an NHM Metadata Section. The order of occurrence of the obligatory and optional keywords shall be fixed as shown in table 3-2.

Table 3-2: NHM Metadata

Keyword	Description	Examples	Obligatory
META_START	The META_START keyword shall delineate the start of the NHM Metadata Section within the message. It must appear on a line by itself; i.e., it shall have no parameters, timetags or values.	N/A	Yes
COMMENT	See 0. Comments in metadata may appear immediately after META_START or in a DEFINE BLOCK, Comments in a define block must appear after the define line and before any FRAME or CALCURVE lines.	this is a comment	No
TIME_SYSTEM	The TIME_SYSTEM keyword shall specify the time system used for timetags in the Data Section. The value associated with this keyword must be selected from the full set of allowed values enumerated in Annex B.	UTC, TAI, GPS, SCLK	Yes
OBJECT_NAME	There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the SPACEWARN Bulletin (Reference [8]), which include the Object name and international designator of the participant.	EUTELSAT W1 MARS PATHFINDER STS106	Yes

Keyword	Description	Examples	Obligatory
OBJECT_ID	<p>Spacecraft identifier of the object corresponding to the hardware 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 [3]). If this is chosen, it is recommended that values have the format YYYY-NNNP{PP}, where:</p> <ul style="list-style-type: none"> – 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. <p>In cases where the asset is not listed in the bulletin, the value should be provided in an ICD.</p>	<p>2000-052A 1996-068A 2000-053A 1996-008A</p>	Yes
START_TIME	<p>The START_TIME keyword shall specify the start time of the total time span covered by the hardware data immediately following this Metadata Section. The START_TIME value shall be relative to the time system specified by the TIME_SYSTEM keyword. For formatting rules see 5.4.3.7.</p>	<p>1996-12-18T14:28:15.1172 1996-277T07:22:54 2006-001T00:00:00Z</p>	No
STOP_TIME	<p>The STOP_TIME keyword shall specify the stop time of the total time span covered by the hardware data immediately following this Metadata Section. The STOP_TIME value shall be relative to the time system specified by the TIME_SYSTEM keyword. For formatting rules see 5.4.3.7.</p>	<p>1996-12-18T14:28:15.1172 1996-277T07:22:54 2006-001T00:00:00Z</p>	No
DEFINE	<p>There shall be one instance of the DEFINE keyword in the Metadata Section for each different set of hardware data that is to be read in the Data Section. The value associated with each DEFINE keyword shall define a single “Mnemonic Keyword” that will be used in the Data Section for a single set of hardware data. See section 5.3 for the syntax that shall be used in creating the values for the Mnemonic keyword.</p>	<p>ACS.DSS1.ANG.V3 ACS.STA2.STAR3.V4.I3B</p>	Yes

Keyword	Description	Examples	Obligatory
FRAME	<p>A FRAME keyword may be associated with any DEFINE keyword. It designates the frame(s) of the measurements of the hardware data corresponding to the DEFINE keyword. It may consists of one or (at most) two frame specifications. The frame specifications must be selected from:</p> <p>“SENSOR” “BODY” “EXTERNAL”</p> <p>Information pertaining to the values associated with the FRAME keyword is provided in Annex K.</p>	<p>SENSOR BODY EXTERNAL BODY</p>	No
CALCURVE	<p>A CALCURVE keyword may be associated with any DEFINE keyword. It specifies the coefficients of a conversion function that may be used to convert hardware data corresponding to the DEFINE keyword into units different from those in transmitted. It consists of one or more numerical values which are used as the coefficients of a polynomial conversion function with the zeroth order coefficient first and subsequent coefficients in increasing order. The units of the transmitted and converted data should be well understood by the transmitting and receiving parties. This understanding will normally be documented in an ICD.</p>	<p>1.0 0 2.5 0.112 3.456 -2.239</p>	No
META_STOP	<p>The META_STOP keyword shall delineate the end of the NHM Metadata Section within the message. It must appear on a line by itself; i.e., it shall have no parameters, timetags or values.</p>	N/A	Yes

3.4 NHM DATA

3.4.1 The Data Section of the NHM Segment shall contain one or more Hardware Data Records.

3.4.2 Each line in the Data section shall consist of a DATA_START, a DATA_STOP, a COMMENT line, or a Hardware Data record..

3.4.3 Hardware Data records shall have the following **generic** format:

mnemonic keyword = timetag measurements

NOTE – More detail on the format data records is shown in table 3-3.

3.4.4 The term “Measurement” shall be construed to include both unprocessed and processed values of hardware data.

Table 3-3: NHM Data Section DATA_START, DATA_STOP, and COMMENT line Format

Element		Description	Examples	Obligatory
<keyword >				
	"DATA_START"	First record in Data Section	DATA_START	Yes
	"DATA_STOP"	Last record in Data Section	DATA_STOP	Yes
	"COMMENT"	Comment	COMMENT	No

Table 3-4. NHM Data Section Data Record Format

Element		Description	Examples	Obligatory
<keyword >				
	one of the Mnemonic Keywords defined in the Metadata Section	Keywords for all variable	See Annex E.	Yes
=		Equals sign	=	Yes
<value>	<timetag data element>	Time associated with the hardware measurement according to the TIME_SYSTEM keyword. For format specification, see 5.4.3.7.	2003-205T18:00:01.275 2003-205T18:00:01Z	Yes

Element		Description	Examples	Obligatory
	<measurement data elements>	Data values in the group defined by the mnemonic keyword (see section 5.3)	See Annex E	Yes

3.4.5 A DATA_START line shall be the first line in the Data Section .

3.4.6 'COMMENT' keywords in the Data Section must appear after the 'DATA_START' keyword and before any Hardware Data Records.

3.4.7 Any line in the data section containing a keyword not specified in the Metadata Section shall not be processed.

NOTE The structure of the keywords defined in the Metadata Section and used in the Data section and the fields that compose the keyword are specified in Section 5.3.

3.4.8 The value in each Hardware Data record shall consist of a timetag data element and one or more measurement data elements as defined for the record's mnemonic keyword in the Metadata Section.

3.4.8.1 The data element(s) shall be separated from each other by one or more blank characters.

3.4.8.2 The number of measurement data element(s) shall be that number specified by the Measurement Count field of the keyword as defined for the record's mnemonic keyword in the Metadata Section.

3.4.8.3 If the Mnemonic Keyword contains a Data Format field the format and order of the measurement data element (s) shall correspond to that field.

3.4.8.4 Multiple instances of any Mnemonic Keyword may occur in the Data Section but their timetag data elements must differ..

3.4.9 All Hardware Data Records shall be in ascending time order.

3.4.10 The last Record in the Data Section shall be a DATA_STOP record..

4 NHM CONTENT AND STRUCTURE IN XML

4.1 GENERAL—THE NHM/XML SCHEMA

This section applies only to the XML version of the NHM.

The NHM/XML schema will be available on the SANA Web site. SANA is the registrar for the protocol registries created under CCSDS.

The NHM XML schema explicitly defines the permitted data elements and values acceptable for the XML version of the NHM message.

The NHM XML schema is composed of ASCII characters only.

The location of the NHM/XML schema will be:

<http://SANArepository.org/r/ndmxml/ndmxml-1.0-NHM-1.0.xsd>

Where possible this schema uses simple types and complex types used by the constituent schemas that make up Navigation Data Messages (see Reference [7]).

4.2 NHM/XML BASIC STRUCTURE

4.2.1 Each NHM shall consist of a <header> and a <body>.

4.2.2 The NHM <body> shall consist of a single segment construct.

4.2.3 The NHM <segment> shall consist of a <metadata>/<data> pair, as shown in figure **Error! Reference source not found..**

```
<header>
</header>
<body>
  <segment>
    <metadata>
    </metadata>
    <data>
    </data>
  </segment>
</body>
```

Figure 4-1: NHM XML Basic Structure

4.3 NHM/XML TAGS

4.3.1 An NHM XML tag shall be all uppercase if it corresponds directly to a KVN keyword from the Header or Metadata Section.

4.3.2 There is an exception where there is not a strict correspondence between keywords in the KVN and tags in the XML implementations, specifically, the 'CCSDS_NHM_VERS' keyword from the NHM Header. The 'CCSDS_NHM_VERS' keyword and its value shall appear as XML attributes rather than an XML element.

4.3.3 NHM XML tag names for the NHM Data Section shall have a special structure noted below due to the way in which the Mnemonic Keywords are dynamically constructed (see Section 5).

4.3.4 NHM 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., <defineSet>,<header>,<segment>, etc.).

4.4 CONSTRUCTING AN NHM/XML INSTANCE

4.4.1 OVERVIEW

This subsection provides more detailed instructions for the user on how to create an XML message based on the ASCII-text KVN-formatted message described in 3.2 through 3.4.

4.4.2 XML VERSION

4.4.2.1 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.

4.4.3 BEGINNING THE INSTANTIATION: ROOT DATA ELEMENT

4.4.3.1 An NHM instantiation shall be delimited with the <NHM></NHM> root element tags using the standard attributes documented in Reference [7].

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

```
xmlns:xsi = "http://www.w3.org/2001/XMLSchema-instance"
```

4.4.3.3 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://SANRegistry.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.

4.4.3.4 The final attributes of the `<NHM>` tag shall be ‘id’ and ‘version’.

4.4.3.5 The ‘id’ attribute shall be ‘id="CCSDS_NHM_VERS"’. The ‘version’ attribute shall be ‘version="1.0"’.

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

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

4.4.4 THE NHM/XML HEADER SECTION

4.4.4.1 The NHM header shall have a standard header format, with tags `<header>` and `</header>`.

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

4.4.4.3 The standard NHM header shall contain the following element tags:

- a) `<CREATION_DATE>`
- b) `<ORIGINATOR>`

NOTE – The rules for these keywords are specified in Table 3-1. The header would look like this:

```
<header>
  <COMMENT>Some comment string.</COMMENT>
  <CREATION_DATE>2010-03-12T22:31:12.000</CREATION_DATE>
  <ORIGINATOR>NASA</ORIGINATOR>
</header>
```

4.4.5 THE NHM/XML BODY SECTION

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

4.4.5.2 Inside the <body></body> tag pair must appear one <segment></segment> tag pair.

NOTE – In essence, the segment tag in the NHM XML implementation is not strictly necessary, however, it is necessary for structural symmetry with the overall NDM/XML paradigm (see Reference [7]).

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

4.4.6 THE NHM/XML METADATA SECTION

4.4.6.1 The Metadata Section shall be set off by the <metadata></metadata> tag combination.

4.4.6.2 Between the <metadata> and </metadata> tags, the keywords shall be those specified in table 3-3.

4.4.6.3

Each NHM/XML Metadata Section shall include at least one <defineSet></defineSet> construct which is used to provide a set of descriptive information about an instrument in the Data Section.

4.4.6.4 The <defineSet> shall consist of a required DEFINE Keyword, one or more optional comment statements, an optional Frames Keyword, and an optional Calcurve Keyword, as follows:).

```
<defineSet>
  <DEFINE>ACS.IRU1.RATES.V4.I3B </DEFINE>
  <COMMENT>Primary IRU Rates</COMMENT>
  <FRAME>SENSOR</FRAME>
  <CALCURVE>0 2.5</CALCURVE>
</defineSet>
```

4.4.7 THE NHM DATA SECTION

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

Between the <data> and </data> tags, the keywords shall be those specified in table 3-3.

Each NHM/XML Data Section shall include at least one `<hardwareDataRecord></hardwareDataRecord>` construct which is used to provide a set of measurements from one of the instruments described in the Metadata Section..This construct is shown in figure 4-2:

1. Basic structure of a Hardware Data Record in the Data Section:

```
<hardwareDataRecord>
  <MNEMONIC></MNEMONIC>
  <EPOCH></EPOCH>
  <measurement></measurement>
  <measurement></measurement>
  .
  .
  .
  <measurement></measurement>
</hardwareDataRecord>
```

2. Three sample NHM Hardware Data Records in KVN:

```
THM.IRU1.tempv.V7.F6B = 2011-10-28T20:15:34.4Z 3.41 4.05 1.32 3.98 5.79 5.11 0
ACS.IRU1.rates.V4.I3B = 2011-10-28T20:15:34.6Z 18312 191 57637 0
ACS.STA1.star1.V4.I3B = 2011-10-28T20:15:34.7Z 12778 -4069 82 0
```

3. The KVN sample NHM Hardware Data Records converted to XML:

```
<hardwareDataRecord>
  <MNEMONIC>THM.IRU1.TEMPV.V7.F6B</MNEMONIC>
  <EPOCH>2011-10-28T20:15:34.4Z</EPOCH>
  <measurement>3.41</measurement>
  <measurement>4.05</measurement>
  <measurement>1.32</measurement>
  <measurement>3.98</measurement>
  <measurement>5.79</measurement>
  <measurement>5.11</measurement>
  <measurement>0</measurement>
</hardwareDataRecord>

<hardwareDataRecord>
  <MNEMONIC>ACS.IRU1.RATES.V4.I3B</MNEMONIC>
  <EPOCH>2011-10-28T20:15:34.6Z</EPOCH>
  <measurement>18312</measurement>
  <measurement>191</measurement>
  <measurement>57637</measurement>
  <measurement>0</measurement>
</hardwareDataRecord>

<hardwareDataRecord>
  <MNEMONIC>ACS.STA1.STAR1.V4.I3B</MNEMONIC>
  <EPOCH>2011-10-28T20:15:34.7Z</EPOCH>
  <measurement>12778</measurement>
  <measurement>-4069</measurement>
  <measurement>82</measurement>
  <measurement>0</measurement>
</hardwareDataRecord>
```

Figure 4-2: NHM XML Data Section Basic Structure/Correspondence to KVN Data

4.4.8 SPECIAL NHM/XML TAGS

Special tags in the NHM shall be used to encapsulate the information in the XML implementation of the NHM that are not necessary in the KVN implementation. The special tags indicating logical block divisions shall be those defined in table 4-1.

Table 4-1: Special NHM/XML Tags

Special Tag	Definition
<defineSet>	Defines a Mnemonic Keyword, an optional reference frame, and an optional calibration curve. May also include descriptive comments.
<hardwareDataRecord>	Distinguishes one Hardware Data Record from the next.
<measurement>	Contains a number received from telemetry data.

4.5 LOCAL OPERATIONS

4.5.1 For use in a local operations environment, the schema set may be downloaded from the SANA web site to a local server that meets local requirements for operations robustness.

4.5.2 If a local version is used, the value associated with the xsi:nonamespacechemalocation attribute must be changed to a url that is accessible to the local server.

5 NAVIGATION HARDWARE MESSAGE KVN SYNTAX

5.1 GENERAL

5.1.1 The NHM shall observe the syntax described in sections 5.2 through 0.

5.2 NHM LINES

5.2.1 The NHM shall consist of a set of NHM lines.

5.2.2 The NHM line shall contain only printable ASCII characters and blanks.

5.2.3 ASCII control characters (such as TAB, etc.) shall not be used, except as indicated below for the termination of the NHM record.

5.2.4 An NHM line shall not exceed 254 ASCII characters and spaces (excluding line termination character[s]).

5.2.5 Each NHM line shall be one of the following:

- Header Section line;
- Metadata Section line;
- Data Section line;
- blank line.

5.2.6 All Header Section, Metadata Section, and Data Section lines, with exceptions as noted below, shall use ‘keyword = value’ syntax, abbreviated as KVN.

5.2.7 Only a single ‘keyword = value’ assignment shall be made on an NHM line.

5.2.8 Keywords must not contain blanks.

5.2.9 The following distinctions in KVN syntax shall apply for NHM KVN lines.

5.2.9.1 NHM KVN lines in the Header and Metadata Section, with exceptions as noted below, shall consist of a keyword, followed by an equals sign '=', followed by a single value assignment.

5.2.9.2 NHM KVN lines in the Data Section shall be COMMENT lines, DATA_START lines, DATA_STOP lines or DATA RECORD lines.

5.2.9.3 NHM KVN Data Records shall consist of a Mnemonic Keyword, followed by an equals sign '=', followed a value.

5.2.9.4 Mnemonic Keywords in Data Records must be defined in the Metadata Section.

NOTE – The keywords defined with a DEFINE line in the Metadata Section and used in the Data Records are referred to as “Mnemonic Keywords”.

5.2.9.5 The value that follows the Mnemonic Keyword in Data Records shall consist of at least two elements.

5.2.9.5.1 The first element after the equals sign shall be a timetag.

5.2.9.5.2 Elements after the timetag shall consist of one or more measurements or calculated values associated with that timetag.

5.2.9.6 An arbitrary number of instances of any Mnemonic Keyword (see Section 5.3) may appear as separate Data Records in the Data Section.

5.2.9.7

5.2.9.8 The timetag and measurements/calculated elements in the value must be separated by at least one blank character (white space).

5.2.10 The keywords COMMENT, META_START, META_STOP, DATA_START, and DATA_STOP are exceptions to the KVN syntax.

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

5.2.12 Any white space immediately preceding or following the equals sign '=' shall not be significant.

5.2.13 Any white space immediately preceding the end of a record shall not be significant.

5.2.14 Blank lines may be used at any position within the NHM.

5.2.15 NHM records shall be terminated by a single Carriage Return or a single Line Feed or a Carriage Return/Line Feed pair or a Line Feed/Carriage Return pair.

5.3 NHM MNEMONIC KEYWORDS

5.3.1 The Values associated with the “DEFINE” keyword shall specify the Mnemonic Keywords that are used in Data Records in the Data Section.

5.3.1.1 There shall be a Mnemonic Keyword defined for each type of Hardware Data that is to be read in the Data Section.

5.3.1.2 The Mnemonic Keyword shall be an alphanumeric string created according to the syntax defined in table 5-1. The Mnemonics shall contain four mandatory fields and an optional field separated by the period (“.”) symbol (ASCII value decimal 46).

5.3.1.3 System Field

5.3.1.3.1 The first field of a Mnemonic Keyword definition shall specify the spacecraft system from which the data comes.

NOTE – This field is referred to as the System Field.

5.3.1.3.2 The System Field shall consist of an alphanumeric string.

5.3.1.3.3 The string contained in the System field shall be one of the strings specified in a SANA registry (see Annex C) or shall be specified in an ICD.

5.3.1.4 NOTE – An ICD should be used only if the appropriate designator is not in the SANA registry. In that event, if the designator is not considered unique, addition of the designator to the SANA registry is preferred.

5.3.1.5 Hardware Type Field

5.3.1.5.1 The second field of a Mnemonic Keyword definition shall specify the type of hardware from which the data that is associated with this Mnemonic Keyword originates.

NOTE – This field is referred to as the Hardware Type field.

5.3.1.5.2 The Hardware Type Field shall consist of an alphanumeric string.

5.3.1.5.3 The string contained in the Hardware Type field shall be one of the strings specified in a SANA registry (see Annex C) or shall be specified in an ICD.

NOTE – An ICD should be used only if the appropriate designator is not in the SANA registry. In that event, if the designator is not considered unique, addition of the designator to the SANA registry is preferred.

5.3.1.6 Data Group Field

5.3.1.6.1 The third field of a Mnemonic Keyword shall specify the group of data that is associated with this Mnemonic Keyword.

NOTE – This field is referred to as the Data Group field.

5.3.1.6.2 The Data Group Field shall consist of an alphanumeric string.

5.3.1.6.3 The string contained in the Hardware Type field shall be one of the strings specified in a SANA registry (see Annex C) or shall be specified in an ICD.

NOTE – An ICD should be used only if the appropriate designator is not in the SANA registry. In that event, if the designator is not considered unique, addition of the designator to the SANA registry is preferred. Because individual users may require different groupings of data from the same hardware, ICDs will generally be necessary.

5.3.1.7 Measurement Count Field

5.3.1.7.1 The fourth field of a Mnemonic Keyword shall specify the number of measurements that will appear in each record of the Data Section that begins with the Mnemonic Keyword.

NOTE – This field is referred to as the Measurement Count field.

5.3.1.7.2 The Measurement Count field shall consist of an alphanumeric string consisting of the character “V” followed by an integer specifying the number of values that will be in Hardware Data Records.

5.3.1.8 MEASUREMENT Type Field

5.3.1.8.1 The fifth field of the Mnemonic Keyword may optionally be included to specify the form of the measurements associated with the Mnemonic Keyword.

NOTE – This field is referred to as the Measurement Type field.

5.3.1.8.2 The Measurement Type field shall consist of and alphanumeric string.

5.3.1.8.3 The string of the Measurement Type field shall consist of one or more alphabetic characters, each of which may be followed by an integer.

5.3.1.8.4 The alphabetic characters in the Measurement Type field shall be one of the values of Measurement Types specified in a SANA registry (see Annex C) or shall be specified in an ICD.

5.3.1.9 NOTE – An ICD should be used only if the appropriate designator is not in the SANA registry. In that event, if the designator is not considered unique, addition of the designator to the SANA registry is preferred.

5.3.1.9.1 The integers following any alphabetic character in the Measurement Type field shall be the number of contiguous measurements of that Measurement Type that that will be in Data Records associated with the Mnemonic Keyword.

5.3.1.9.2 If an integer is not present following an alphabetic character in the Measurement Type field the number of contiguous measurements of that Measurement Type shall be construed to be 1.

5.3.1.9.3 The sum of the number of measurements with types specified in the Measurement Type field shall equal the number of measurements specified in the Measurement Count field.

5.3.1.9.4 The order of the types specified in the Measurement Type field shall be the same as the order of the measurements that will be in Data Records containing the Mnemonic Keyword.

Table 5-1: Format of NHM Mnemonic Keywords

Field	Description	Examples	Obligatory
SYSTEM	A code representing the spacecraft system from which the data comes. <ul style="list-style-type: none"> – The values of this field shall be selected from those in a SANA registry (see annex C) or specified in an ICD. Every effort should be made to select a value from the SANA registry. 	ACS PRP THM	Yes
HARDWARE TYPE	The hardware type field shall start with an upper case alphabetic string containing exactly three characters followed by an integer that specifies the instance of this hardware. <ul style="list-style-type: none"> – If only one instance exists, the value (1) must be used. – The three character code must be either selected from those in a SANA registry (see annex D) or specified in an ICD. Every effort should be made to select a value from the SANA registry. 	STA3 OBC1 GPS2	Yes

Field	Description	Examples	Obligatory
DATA GROUP	An arbitrary string of alphanumeric characters that identifies the set of data arising from the hardware. <ul style="list-style-type: none"> - This string should be specified in an ICD. - The first character in this field shall be alphabetical. - If more than one instance of a data group is possible, a numerical designator of the instance referred to shall be the last character(s) in the field. 	STAR1 A PSR	Yes
MEASUREMENT COUNT	The Measurement Count field shall be a string consisting of the upper case letter "V" followed by an integer that indicates the number of data fields on each data record with this string as its Mnemonic Keyword.	V4	Yes
MEASUREMENT TYPE	The Measurement Type field shall be a string consisting of a series of ASCII characters representing the type of the data of each of the Measurement Fields, each optionally followed by an integer. <ul style="list-style-type: none"> - There must be one character for each of the measurements in the Data Record containing the Mnemonic Keyword except that if the same measurement types are repeated, a single character followed by an integer representing the number of repetitions may be used. - The Data type symbols shall be in the same order that the data elements associated with this Mnemonic Keyword will appear on records in the Data Section - The data types shall be either selected from those in a SANA registry (see annex D) or specified in an ICD. Every effort should be made to select a value from the SANA registry. 	I B2 F3 C	No

5.4 NHM DATA RECORD VALUES

5.4.1 All Data Records containing a Mnemonic Keyword shall also contain a time and a Measurement Field for each of the Measurements specified by the Mnemonic Keyword.

5.4.2 The number of Measurement Fields for each Mnemonic Keyword provided must equal the number in the "Measurement Count" field of the Mnemonic Keyword.

5.4.3 If the Measurement Type field exists in the Mnemonic the format of the measurements in each Measurement Field for each Mnemonic Keyword provided shall be the same as the format specified in the "Measurement Type field of the Mnemonic Keyword.

5.4.3.1 Integer values shall consist of a sequence of decimal digits with an optional leading sign ('+' or '-'). If the sign is omitted, '+' shall be assumed. Leading zeros may be used.

NOTE - The range of values that may be expressed as an integer is:

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

5.4.3.2 Fields expressed in floating point notation shall consist of a mantissa and an optional exponent.

5.4.3.2.1 The mantissa shall consist of a sequence of decimal digits separated by a period as a decimal point indicator, with an optional leading sign ('+' or '-').

5.4.3.2.1.1 At least one digit shall be used before and after a decimal point.

5.4.3.2.1.2 The number of digits shall be 16 or fewer.

5.4.3.2.2 The optional exponent shall follow the last digit of the mantissa.

5.4.3.2.2.1 The exponent shall start with the character 'E' or 'e' .

NOTE - The character 'E' or 'e' separates the mantissa value from the exponent value.

5.4.3.2.2.2 An optional sign character '+' (ASCII character 43) or '-' (ASCII character 45) may follow first character in the exponent.

5.4.3.2.2.3 Following the separator character or the optional sign character the exponent shall contain an integer.

5.4.3.3 Any omitted sign characters in numeric fields shall be construed to mean a positive sign.

5.4.3.4 NOTES - The maximum positive floating-point value is approximately 1.798E+308, with 16 significant decimal digits precision. The minimum positive floating-point value is approximately 4.94E-324, with 16 significant decimal digits precision. -

These specifications for integer and floating-point values conform to the XML specifications for the data types four-byte integer 'xsd:int', 'decimal', and 'double', respectively (see References [1] and [2]). The specifications for floating-point values conform to the IEEE 754 double precision type (see Reference [6]). Floating-point numbers in IEEE extended-single or IEEE extended-double precision may be represented, but do require an ICD between participating agencies because of their implementation specific attributes. The special values 'NaN', '-Inf', '+Inf', and '-0' are not supported in the NHM.

5.4.3.5 Character Measurement fields shall contain only printable characters (ASCII characters 32 through 126) .

5.4.3.5.1 Character Measurement fields must start and end with a single quotation symbol (' ASCII Character 39).

NOTE - The purpose of the quotations is to separate Character Measurement fields from each other and from other data fields.

5.4.3.5.2 Single quotation symbols (‘ which is ASCII Character 39) within Character Measurement fields shall be represented by two adjacent single quotation symbols.

NOTE - The use of single quotation symbols within Character Measurement fields should be avoided because it could cause confusion.

5.4.3.6 Binary fields shall consist a single digit; either zero (“0”) or one (“1”).

5.4.3.7 In Measurement fields that represent a time tag 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 represented by as many 'd' characters to the right of the period as required may be used to obtain the required precision, up to the maximum allowed for a fixed point number.;

5.4.3.7.1 All fields shall have leading zeros.

5.4.3.7.2 ‘Z’ is an optional time code terminator (the only permitted value is ‘Z’ for Zulu, i.e., UTC).

NOTE - See Reference [5], ASCII Time Code A and B.

5.4.4 The time system for the CREATION_DATE shall be UTC.

5.4.5 The time system for the timetags in the NHM Data Section and the START_TIME, and STOP_TIME shall be determined by the TIME_SYSTEM metadata keyword.

5.5 UNITS IN THE NHM

Units of data associated with each Mnemonic Keyword in the NHM should be taken from the appropriate SANA registry (see Annex D) or defined in an ICD.

5.6 COMMENTS IN AN NHM

5.6.1 Comments may be used to provide any pertinent information associated with the data that is not covered via one of the keywords. This additional information is intended to aid in consistency checks and elaboration where needed. Comments shall not be required for successful processing of a NHM; i.e., comment lines shall be optional.

NOTES -

The principal use of comments will be in the METADATA section where they can be used to explain the Mnemonic Keywords defined in that section.

Given that NHMs may consist of large amounts of data, and are generally produced via automation, using the COMMENT feature of the NHM may have limited usefulness. On the other hand, a simple utility could be developed to search for and extract all the comments in a NHM to make them easily reviewable. Existing built-in utilities (e.g., UNIX 'grep') or 'freeware' utilities could also be used for this purpose.

5.6.2 Comment lines, if used, shall only occur in one of the contexts described below

5.6.2.1 In the NHM header immediately following the CCSDS_NHM_VERS line, as shown in table 3-1.

5.6.2.2 In the NHM metadata section immediately following the META_START line as shown in table 3-2.

5.6.2.3 In a DEFINE BLOCK the NHM metadata section immediately following the DEFINE line as shown in table 3-2.

5.6.2.4 At the beginning of the NHM DATA SECTION (i.e., between the 'DATA_START' line and the first Hardware Data Record as shown in table 3-3).

5.6.3 All comment lines shall begin with the 'COMMENT' Keyword followed by at least one space (note: may also be preceded by spaces). The 'COMMENT' Keyword must appear on every comment line, not just the first comment line. After the keyword, the remainder of the line shall be the comment value. White space shall be retained (is significant) in comment values.

5.6.4 Conventions for particular comments in the NHM that may be required between any two participating agencies should be specified in the ICD.

5.6.5 Descriptions of any ancillary data in the NHM may have to be specified via comments, and should be outlined in the ICD.

5.7 FRAME KEYWORDS IN A NHM

5.7.1 FRAME keywords in a NHM may occur only in lines immediately following COMMENT lines or, if no COMMENT lines are present, immediately following a DEFINE lines in the metadata section of the NHM as shown in table 3-2.

5.7.2 The value in a line containing the FRAME keyword may only consist of either one or two alphanumeric strings.

5.7.3 The strings in a line containing the FRAME keyword shall be limited to: "SENSOR", "BODY", or "EXTERNAL".

5.7.4 If a line containing the FRAME keyword has a single string, that string must be "SENSOR" or "BODY".

5.7.5 If a line containing the FRAME keyword has two strings one of those strings must be "EXTERNAL".

NOTES

1. The use of the FRAME keyword is to define the frame in which the hardware measurement is represented.
2. Hardware that produce data representing directional measurements have a single frame associated with them.
3. Hardware that produce a relative orientation have two frames associated with them, one of which is an external frame.
4. If two frames are designated in a frame line the measurements associated with the Mnemonic Keyword defined in the corresponding Define Block represents a rotation from the frame specified by the first string to the frame specified by the second string.
5. Additional information on the meaning and selection of the values associated with the FRAME keyword is provided in Annex K.

5.8 CALCURVE KEYWORDS IN A NHM

5.8.1 CALCURVE keywords in a NHM may occur only in lines immediately following a line containing a FRAME keyword or, if no such line exists, immediately following a COMMENT line, or if no such line exists, immediately following a DEFINE line in the metadata section of the NHM.

5.8.2 The Value in a CALCURVE line shall contain an arbitrary number of integer or floating point numbers separated by spaces.

NOTES

1. The “n” numbers in a line containing a CALCURVE keyword represent the coefficients in a polynomial of (n-1) order that is used to convert the transmitted measurement values into desired units.
2. The order of the coefficients is lowest first and highest last so that for a line:

CALCURVE = val1 val2 val3 ... valn
and a measurement M

The converted Measurement will be given by:

$$val1 + val2 \cdot M + val3 \cdot M^2 + val4 \cdot M^3 + \dots valn \cdot M^{(n-1)}$$

6 NAVIGATION HARDWARE MESSAGE XML SYNTAX

6.1 OVERVIEW

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

6.2 NHM LINES IN XML

6.2.1 Each NHM file shall consist of a set of NHM lines. Each NHM line shall be one of the following:

- XML version line;
- an XML-formatted line; or
- a blank line.

6.2.2 Each NHM line must not exceed 254 ASCII characters and spaces (excluding line termination character[s]).

6.2.3 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.

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

6.2.5 The first line in the instantiation shall specify the XML version.

6.2.6 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.

6.3 NHM VALUES IN XML

6.3.1 Each obligatory XML tag must be present and contain a valid value.

6.3.2 Integer values shall follow the conventions of the integer data type per Reference [2]. Additional restrictions on the allowable range or values permitted for any integer data element may also be defined in the NHM 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.

6.3.3 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 [2]. Additional restrictions on the allowable range or values permitted for any numeric data element may also be defined in the NHM 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.

6.3.4 Text value data shall follow the conventions of the string data type per Reference [2]. Additional restrictions on the allowable range or values permitted for any data element may also be defined in the NHM 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.

6.3.5 Text values in NHM/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, mixing of uppercase and lowercase characters is prohibited.

6.4 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.NHM UNITS IN XML

6.4.1 Units are not explicitly displayed in the NHM. The units associated with values in the NHM should be taken from the appropriate SANA registry (see Annex C) or defined in an icd.NHM comments in xml

6.5 NHM COMMENTS IN XML

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 PRO FORMA
(NORMATIVE)

ANNEX B

VALUES FOR THE TIME_SYSTEM KEYWORD

(NORMATIVE)

The values in this annex represent the set of acceptable values for the TIME_SYSTEM keyword. For details and description of these time systems, see Reference H2. If exchange partners wish to use different settings, they should be documented in the ICD.

Table 6-1: Normative Values for TIME_SYSTEM Metadata Keyword

Time System Value	Meaning
GMST	Greenwich Mean Sidereal Time
GPS	Global Positioning System
MET	Mission Elapsed Time
	Note: Mission Elapsed time is the time in normal time unites since the mission start.
SCLK	Spacecraft Clock
	Note: Spacecraft Clock time is the number of counts that have occurred on a spacecraft clock (with each count representing a specific time increment) since the clock was last reset.
TAI	International Atomic Time
TT	Terrestrial Time
UT1	Universal Time
UTC	Coordinated Universal Time

ANNEX C

SECURITY, SANA AND PATENT CONSIDERATIONS

(INFORMATIVE)

C1 SECURITY CONSIDERATIONS

C1.1 ANALYSIS OF SECURITY CONSIDERATIONS

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

C1.2 CONSEQUENCES OF NOT APPLYING SECURITY TO THE TECHNOLOGY

The consequences of not applying security to the systems and networks on which this Proposed Standard is implemented could include potential loss, corruption, and theft of data. Because these messages are used in orbit determination and attitude determination, the consequences of not applying security to the systems and networks on which this Proposed Standard is implemented could include compromise or loss of the mission if malicious tampering of a particularly severe nature occurs.

C1.3 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 Proposed Standard. It is strongly recommended that potential threats or attack scenarios applicable to the systems and networks on which this Proposed Standard is implemented be addressed by the management of those systems and networks.

C1.4 DATA PRIVACY

Privacy of data formatted in compliance with the specifications of this Proposed Standard should be assured by the systems and networks on which this Proposed Standard is implemented.

C1.5 DATA INTEGRITY

Integrity of data formatted in compliance with the specifications of this Proposed Standard should be assured by the systems and networks on which this Proposed Standard is implemented.

C1.6 AUTHENTICATION OF COMMUNICATING ENTITIES

Authentication of communicating entities involved in the transport of data which complies with the specifications of this Proposed Standard should be provided by the systems and networks on which this Proposed Standard is implemented.

C1.7 DATA TRANSFER BETWEEN COMMUNICATING ENTITIES

The transfer of data formatted in compliance with this Proposed Standard between communicating entities should be accomplished via secure mechanisms approved by the Information Technology Security functionaries of exchange participants.

C1.8 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.

C1.9 AUDITING OF RESOURCE USAGE

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

C1.10 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.

C1.11 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 Proposed Standard should be specified in an ICD.

C2 SANA CONSIDERATIONS

The following NHM-related items will be registered with the SANA operator. The registration rule for new entries is the approval of new requests by the CCSDS Navigation Working Group chair.

C2.1 XML

The NHM XML schema will be registered with the SANA. New requests for this registry should be sent to SANA (<mailto:info@sanaregistry.org>).

C2.2 HARDWARE TYPES AND UNITS

A description of hardware types and units will be registered with SANA. New requests for this registry should be sent to SANA (<mailto:info@sanaregistry.org>).

Note: See Table D-1

C3 PATENT CONSIDERATIONS

The recommendations of this document have no patent issues.

ANNEX D

VALUES FOR DEFINE KEYWORD

(INFORMATIVE)

The values in this annex represent examples of values associated with three fields of the Mnemonic Keywords defined in the records of the Metadata Section with the DEFINE keyword. The complete list of normative values will be contained in a SANA registry.

The SANA register will consist of a table. Each entry (row) of the table will contain the following columns:

The Value column will contain strings with either a System Field Value, a Hardware Type Value, or a Data Type Value.

The Type column will contain strings indicating the type (System Field, Hardware Type, or Data Symbol) contained in the corresponding entry.

The Meaning column will contain a brief description of the meaning of the corresponding entry.

The Measurement Type column will contain the physical quantity represented by the data. This column will be populated only for Hardware Type entries.

The Units column will contain a list of common units in which this data is measured and/or supplied. SI units should be used wherever possible. Note that hardware measurements may be supplied in “counts” and if they are transfer functions must be included in an ICD that describe the conversion of the counts to physical units.

An example of this table in the SANA registry is given as Table D-1 below.

In table D-1 the first column (“Value”) contains values that would appear in the SANA registry table.

The second column (“Type and Field Within Value of DEFINE Lines “) identifies the type or field for the value as described in Table 5-1. The different types or fields are:

1. System: Entries marked “System Field” contain the values that will be used in the System Field of a Mnemonic defined with the Define line in the Metadata section. It indicates the spacecraft system concerned with the data on Data Lines in the Data Section. Because different spacecraft systems may be concerned with the same hardware the same data, in different messages, may be associated with different systems, depending on the intended use of the message.
2. Hardware: Entries marked “Hardware Type” indicate the particular spacecraft hardware associated with particular data. The values of Hardware Types will appear in the Hardware Type Field of a Mnemonic defined with the Define line in the

Metadata section. Since there are often several instances of a particular type of hardware on a spacecraft the Hardware Type Field in the Mnemonic will also include a numeric designator of the instance of the hardware. Some “Hardware Types” do not correspond to actual hardware but represent combinations of processed hardware data such as output from the Onboard Computer (Type is “OBC”).

3. Measurement: Entries marked “Measurement Type” indicate one of the few forms in which measurements will appear. The values of Measurement Types may appear in the optional Measurement Type Field of a Mnemonic defined with the Define line in the Metadata section.

The third column of Table D-1 (“Meaning”) contains a brief description of the significance of the Value. The fourth column of Table D-1 (“Measurement Type”) shows (where relevant) the type of physical quantity represented by the measurement .

The fifth and last column of Table D-1 (“Examples of Units”) shows typical units in which measurements of a particular type are represented. An ICD should be used to specify which of the units are used in any message.

Table D-1: Example of a SANA Registry Table Containing Values Associated with the DEFINE Keyword in the Metadata Section

Value	Type and Field Within Value of DEFINE Lines	Meaning	Measurement Type	Examples of Units
ACS	System Field	Attitude Control System (Attitude Determination and Control)		
CDH	System Field	Command and Data Handling System		
COM	System Field	Communications		
NAV	System Field	Navigation		
PWR	System Field	Power		
PRP	System Field	Propulsion		
THM	System Field	Thermal		
STA	Hardware Type	Star Tracker	star direction (and intensity)	counts, deg, rad (magnitude units)
AST	Hardware Type	Autonomous Star Tracker	star tracker attitude	no units
DSS	Hardware Type	Digital Sun Sensor	Sun position	counts, deg, rad
IRU	Hardware Type	Inertial Reference Unit	attitude rates. accumulated angles	counts, deg, rad, deg/s, rad/s, arcsec/s
ACC	Hardware Type	Accelerometer	accelerations	m/s ²

GNS	Hardware Type	Global Navigation System Receiver	Pseudorange to GNSS satellite, position, velocity	km, km/s, m, m/s
THR	Hardware Type	Thruster	Pulse count, tank pressure	counts
OBC	Hardware Type	On Board Computer	Any values that are computed onboard from hardware data such as attitude, position, velocity, etc,	various
ANT	Hardware Type	Antenna	Receiver Power	dB
I	Measurement Type	Integer		
F	Measurement Type	Fixed Point Number		
E	Measurement Type	Exponential Notation Number		
B	Measurement Type	Binary Value		
C	Measurement Type	Character String		

ANNEX E

EXAMPLE NAVIGATION HARDWARE MESSAGE MNEMONIC KEYWORDS WITH CORRESPONDING ICD INFORMATION

(INFORMATIVE)

Table D-1: Example of Information Used in Creating an NHM that Should Be Included in an ICD

Mnemonic Keyword	Information in ICD	Required
ACS.CSS1.EYECURRENT.V5.I4B	Definitions of "eyecurrent"	Yes
	Conversion factors for converting counts to engineering units	No
	Mounting vector for each eye	No

EXAMPLE NAVIGATION HARDWARE MESSAGES (CONTINUED)

ANNEX F

**EXAMPLE NAVIGATION HARDWARE
MESSAGES**

(INFORMATIVE)

```

CCSDS_NHM_VERS = 0.20
COMMENT This is fictitious data for a very simple spacecraft
CREATION_DATE = 2012-11-27T09:55:31
ORIGINATOR = NASA

META_START
TIME_SYSTEM = UTC
OBJECT_NAME = STS106OBJECT_ID = 2000-053A
START_TIME = 2009-06-49T4.:00:00ZDEFINE = ACS.TAM1.FIELD.V4.I3B
COMMENT Three axis magnetometer detected field in counts and a quality flag
COMMENT Three axis magnetometer data is expressed in the TAM1 Frame (see ICD)
COMMENT Three axis magnetometer data is in counts that may be converted to milligauss by a linear transfer function
FRAME = SENSOR
CALCURVE = -301.5 0.00724
DEFINE = ACS.STA2.STAR1.V4.I3B
COMMENT Star tracker 1, First Star. Horizontal and Vertical positions and Intensity in counts and a quality flag
DEFINE = ACS.STA2.STAR2.V4.I3B
COMMENT Star tracker 1, Second Star. Horizontal and Vertical positions and Intensity in counts and a quality flag
DEFINE = ACS.IRU1.RATES.V4.I3B
COMMENT Gyro rates for IRU assembly-1 3 axes in counts and a quality flag in the Body Frame
FRAME = BODY
DEFINE = THM.IRU1.TEMPV.V4.F6B

DEFINE = ACS.OBC1.QUAT.V4.F4B
COMMENT Onboard computed Quaternions as EME2000 inertial frame to body frame and a quality flag
FRAME = EXTERNAL BODY
META_STOP
DATA_START
COMMENT The data values are not real in this example
ACS.IRU1.RATES.V4.I3B = 2009-06-49T07:15:00.6Z 18312 191 57637 0
ACS.STA1.STAR1.V4.I3B = 2009-06-49T07:15:00.7Z 12778 -4069 82 0
ACS.STA1.STAR2.V4.I3B = 2009-06-49T07:15:00.7Z 9200 4565 81 0
ACS.IRU1.RATES.V4.I3B = 2009-06-49T07:15:01.0Z 18767 29 57295 0
ACS.STA2.STAR1.V4.I3B = 2009-06-49T07:15:01.1Z 4495 4834 78 0
ACS.STA2.STAR2.V4.I3B = 2009-06-49T07:15:01.1Z 27180 6367 89 0
ACS.OBC1.QUAT.V4.F4B = 2009-06-49T07:15:01.4Z 0.8619094 0.5002867 0.0472852 0.0677461 0
ACS.IRU1.RATES.V4.I3B = 2009-06-49T07:15:01.6Z 18704 64126 56639 0
    
```

EXAMPLE NAVIGATION HARDWARE MESSAGES (CONTINUED)

```
ACS.STA2.STAR1.V4.I3B = 2009-06-49T07:15:01.9Z 4663 5257 78 0  
ACS.STA2.STAR2.V4.I3B = 2009-06-49T07:15:01.9Z 25079 6678 89 0  
ACS.TAM1.FIELD.V4.I3B = 2009-06-49T07:15:02.6Z 5527 -1596 -21298 0  
DATA_STOP
```

EXAMPLE NAVIGATION HARDWARE MESSAGES (CONTINUED)

ANNEX G

NHM EXAMPLE IN XML FORMAT

(INFORMATIVE)

The following is a sample of an NHM in XML format:

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

  <header>
    <CREATION_DATE>2011-10-30T12:32:58</CREATION_DATE>
    <ORIGINATOR>NASA</ORIGINATOR>
  </header>
  <body>
    <segment>
      <metadata>
        <TIME_SYSTEM>UTC</TIME_SYSTEM>
        <OBJECT_NAME>BOGUS</OBJECT_NAME>
        <OBJECT_ID>2010-999A</OBJECT_ID>
        <START_TIME>2011-10-28T20:15:34.4Z</START_TIME>
        <STOP_TIME>2011-10-28T20:15:36.7Z</STOP_TIME>
        <defineSet>
          <DEFINE>THM.HTR1.TEMP.V4.F3B</DEFINE>
          <COMMENT>first instrument: no FRAME, no CALCURVE</COMMENT>
        </defineSet>
        <defineSet>
          <DEFINE>ACS.IRU1.RATES.V4.I3B</DEFINE>
          <COMMENT>second instrument: FRAME, but no CALCURVE</COMMENT>
          <FRAME>SENSOR</FRAME>
        </defineSet>
        <defineSet>
          <DEFINE>ACS.STA1.STAR1.V4.I3B</DEFINE>
          <COMMENT>third instrument: no FRAME, CALCURVE</COMMENT>
          <CALCURVE>7.8 5.6 3.4 1.2</CALCURVE>
        </defineSet>
        <defineSet>
```

EXAMPLE NAVIGATION HARDWARE MESSAGES (CONTINUED)

```

    <DEFINE>ACS.STA2.STAR1.V4.I3B</DEFINE>
    <COMMENT>fourth instrument: FRAME, CALCURVE</COMMENT>
    <FRAME>SENSOR</FRAME>
    <CALCURVE>7.8 5.6 3.4 1.2</CALCURVE>
</defineSet>
<defineSet>
    <DEFINE>ACS.STA3.STAR1.V.4.I3B</DEFINE>
    <COMMENT>fifth instrument: 2 FRAMES, CALCURVE</COMMENT>
    <FRAME>SENSOR</FRAME>
    <FRAME>EXTERNAL BODY</FRAME>
    <CALCURVE>7.8 5.6 3.4 1.2</CALCURVE>
</defineSet>

</metadata>
<data>
    <hardwareDataRecord>
        <MNEMONIC>THM.HTR1.TEMP.V4.F3B</MNEMONIC>
        <EPOCH>2011-10-28T20:15:34.4Z</EPOCH>
        <measurement>3.41</measurement>
        <measurement>4.05</measurement>
        <measurement>1.32</measurement>
        <measurement>0</measurement>
    </hardwareDataRecord>

    <hardwareDataRecord>
        <MNEMONIC>ACS.IRU1.RATES.V4.I3B</MNEMONIC>
        <EPOCH>2011-10-28T20:15:34.6Z</EPOCH>
        <measurement>18312</measurement>
        <measurement>191</measurement>
        <measurement>57637</measurement>
        <measurement>0</measurement>
    </hardwareDataRecord>

    <hardwareDataRecord>
        <MNEMONIC>ACS.STA1.STAR1.V4.I3B</MNEMONIC>
        <EPOCH>2011-10-28T20:15:34.7Z</EPOCH>
        <measurement>12778</measurement>
        <measurement>-4069</measurement>
        <measurement>82</measurement>
        <measurement>0</measurement>

```

EXAMPLE NAVIGATION HARDWARE MESSAGES (CONTINUED)

```
    </hardwareDataRecord>

    <hardwareDataRecord>
      <MNEMONIC>ACS.STA2.STAR1.V4.I3B</MNEMONIC>
      <EPOCH>2011-10-28T20:15:35.7Z</EPOCH>
      <measurement>12778</measurement>
      <measurement>-4069</measurement>
      <measurement>82</measurement>
      <measurement>0</measurement>
    </hardwareDataRecord>

    <hardwareDataRecord>
      <MNEMONIC>ACS.STA3.STAR1.V4.I3B</MNEMONIC>
      <EPOCH>2011-10-28T20:15:36.7Z</EPOCH>
      <measurement>12778</measurement>
      <measurement>-4069</measurement>
      <measurement>82</measurement>
      <measurement>0</measurement>
    </hardwareDataRecord>

  </data>
</segment>
</body>
</nhm>
```


ANNEX H

INFORMATIVE REFERENCES

(INFORMATIVE)

NOTE – Normative References are provided in section 1.7.

- [H1] *Organization and Processes for the Consultative Committee for Space Data Systems*. CCSDS A02.1-Y-3. Yellow Book. Issue 3. Washington, D.C.: CCSDS, July 2011.
- [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, November 2010.
- [H3] *Astrodynamics – Propagation Specifications, Technical Definitions, and Recommended Practices*, ANSI/AIAA S-131-2010, Reston, VA: American Institute of Aeronautics and Astronautics, 2010, http://astrodynamicstandards.com/Resources/ANSI_AIAA_S-131-2010.pdf

ANNEX I

NAVIGATION HARDWARE MESSAGE GOALS AND REQUIREMENTS

(INFORMATIVE)

The Navigation Hardware Message is intended to facilitate the use of navigation hardware data in ground monitoring, validation, and analysis of spacecraft navigation performance. Its use is expected to reduce from mission to mission the amount of software modification necessary to transmit and receive navigation hardware data. It is also expected to allow visual examination of the text of the message to provide easy understanding of the nature of any data in the message.

For a single mission, multiple Navigation Hardware Messages may be desired for different users. For example:

- An Attitude NHM containing the output of attitude sensors and the results of their onboard processing (such as onboard attitude estimates, rate biases, etc.) sent to the attitude validation team.
- An Orbit NHM containing output of orbit determination hardware (e.g. GPS receivers, accelerometers, thrusters, etc) and the results of any onboard orbit processing sent to the orbit determination team.
- A Health and Safety Monitoring NHM containing output of any onboard hardware or results of hardware processing that are needed for monitoring the spacecraft navigation systems health and safety (e.g. temperatures, pressures, battery charge, hardware status) sent to the mission operations Team.

It is expected that the data in various messages not be exclusive. For example, both the Attitude NHM and the Health and Safety Monitoring NHM could contain data on the status of attitude hardware.

For each NHM it is expected that:

- identical (or at least similar) forms will be used for corresponding data from different missions.
- Mnemonic Keywords will be constructed to be as clear as possible.
- ICDs will be used to describe the contents of each type of data record.

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 and satellite operators. 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 section the requirements are organized into two categories:

- **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, its Member Agencies, or other independent users.
- **Desirable Characteristics:** These are not requirements, but they are felt to be important or useful features of the Recommended Standard.

Table 6-2: Primary Requirements

ID	Requirement	Rationale	Trace
NHM-P01	The NHM data shall be provided in digital form (computer file or stream).	Facilitates computerized processing of NHMs	3.1.1
NHM-P02	The NHM shall be provided in data structures (e.g., files) that are readily ported between, and useable within, 'all' computing environments in use by Member Agencies.	The CCSDS objective of promoting interoperability is not met if messages are produced using esoteric or proprietary data structures.	3.1.6
NHM-P03	The NHM shall provide a mechanism by which messages may be uniquely identified and clearly annotated. The file name alone is considered insufficient for this purpose.	Facilitates discussion between a message recipient and the originator should it become necessary.	Table 3-1
NHM-P04	The NHM shall provide time measurements (time stamps, or epochs) in commonly used, clearly specified systems.	The CCSDS objective of promoting interoperability is not met if time measurements are produced in esoteric or proprietary time systems	Table 3-2, Annex A
NHM-P05	The NHM shall be provided in, or shall include, an ASCII format.	ASCII character-based messages promote interoperability. ASCII messages are useful in transferring data 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 dumps of text to displays, emails, documents or printers are possible without preprocessing.	3.1.1, 4.1, 6.2.3
NHM-P06	The NHM shall not require software supplied by other	This principle was agreed upon early in the history of the CCSDS	n/a

ID	Requirement	Rationale	Trace
	Agencies.	Navigation Working Group.	
NHM-P07	The NHM shall provide data for a single spacecraft.	Data from multiple spacecraft would be confusing and the specific hardware from which the data arises will be on a single spacecraft.	3.1.5
NHM-P08	The single spacecraft to which an NHM applies shall be clearly identified.	Identifies the spacecraft from which the data originated.	Table 3-2 OBJECT_NAME and OBJECT_ID
NHM-P09	The source (hardware) from which data in lines in the NHM Data Section originate shall be clearly identified.	Identifies the spacecraft from which the data originated.	Table 3-2 OBJECT_NAME and OBJECT_ID
NHM-P10	The NHM shall have an XML representation.	CCSDS CMC requires such a representation for Navigation WG standards	Sections 4 and 6
NHM-P11	The NHM shall have the ability to dynamically configure the input.	The large number and constantly varying types of navigation hardware data require a dynamic configuration to prevent constant updating of the standard as hardware changes.	5.3

Table 6-3: Desirable Characteristics

ID	Requirement	Rationale	Trace
NHM-D01	An ICD should be agreed upon between participants in NHM exchanges.	Issues such as naming conventions, units, and specification of hardware types and characteristics are too diverse to be specified in a standard. Use of an ICD allows flexibility within the standard.	3.1.8, 3.1.9, Annex E
NHM-D02	The NHM should be extensible with no disruption to existing users/uses.	Space agencies and operators upgrade systems and processes on schedules that make sense for their organizations. In practice, some organizations will be early adopters but others will opt to wait until performance of a new version of the NHM has been proven in other	Table 3-1 (CCSDS_NHM_VERS keyword)

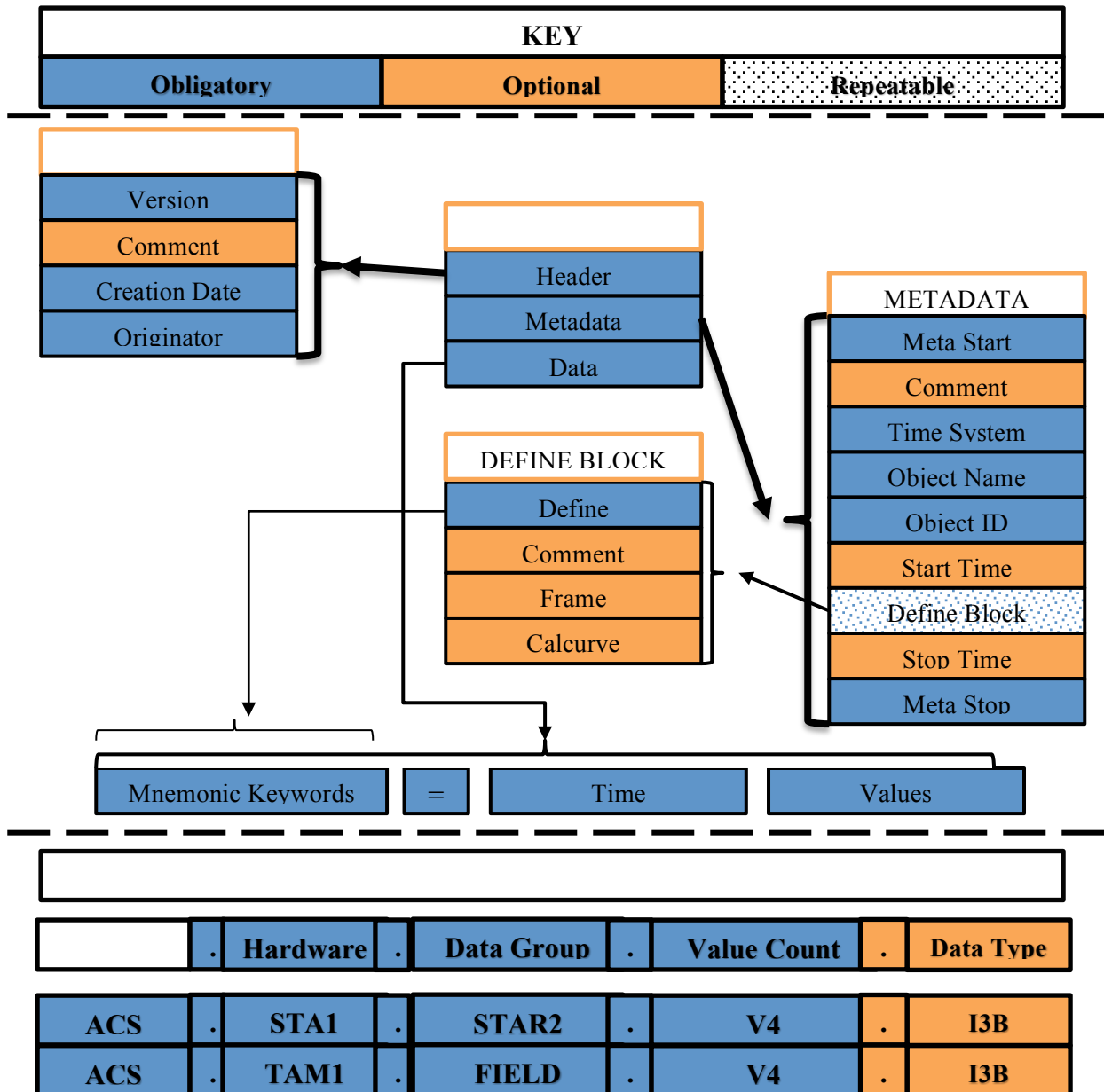
PROPOSED CCSDS RECOMMENDED STANDARD FOR NAVIGATION HARDWARE MESSAGE

ID	Requirement	Rationale	Trace
		operations facilities.	
NHM-D03	The NHM should be as consistent as reasonable with any related CCSDS Recommended Standards used for spacecraft-to-earth applications.	Ideally, the set of Recommended Standards developed by a given CCSDS Working Group will be consistent.	n/a
NHM-D04	The NHM should have the capability to specify reference frames for the data.	Some hardware measurements are linked to specific reference frames and it is desirable to be able to specify the reference frame to which the data is linked.	Table 3-2 and Section 5.7
NHM-D05	The NHM should have the capability to specify calibration curves for the data.	Some hardware measurements will be received in units that are different from thos in which it will be displayed or used. The conversion can be performed using a calibration curve. It is desirable to be able to specify the calibration curve to which the data is linked.	Table 3-2 and Section 5.8

ANNEX J

GRAPHICAL REPRESENTATION OF
NHM IN KVN

(INFORMATIVE)



ANNEX K

DESIGNATION OF FRAME VALUES

(INFORMATIVE)

The FRAMES keyword is associated with three types of coordinate frames: External Frames, Body Frames, and Instrument Frames. The definition of the frames used should be well understood by the transmitting and receiving parties. This understanding will normally be documented in an ICD.

K1 BODY FRAME

Spacecraft Body frames are defined by the physical construction of the spacecraft and are defined by the spacecraft metrology. They are generally fixed by time of spacecraft launch and are not changed throughout a mission. In some cases the body frame is defined relative to one or more specific instrument frames in which case the relation of the body frame to the instrument frame(s) is generally not changed throughout a mission.

Hardware data that represents a direction in the body frame or that can be converted to a direction in the body frame should have the value BODY on the frame line (if one exists) in the define block representing the data.

Example of a body frame definition:

The body frame is defined with the XY plane parallel to the spacecraft baseplate with the XZ plane containing the point of attachment of Thrusters A and B to the baseplate and containing the spacecraft prelaunch fueled center of mass. The Z-axis forms a right handed coordinate system with the X and Y axes.

Example of a define block using a Frame line with the value BODY.

```
DEFINE = ACS.ESA.ANGS.V2.F2  
COMMENT Earth Sensor Earth In/Earth Out angles in radians  
FRAME = BODY
```

K2 SENSOR FRAME

A separate frame may be defined for each sensor (instrument) that measures a directional quantity. The instrument frames are determined before launch by spacecraft metrology but may be redefined on orbit due to changes detected after launch. If one or more instrument frames are used to define the body frame then the relation between the instrument frame and the body frame is not changed even if the relation between the instruments defining the body frame changes.

Hardware data that represents a direction in a sensor frame or that can be converted to a direction in the sensor frame should have the value SENSOR on the frame line (if one exists) in the define block representing the data.

Example: The star tracker 1 frame is defined by a 321 Euler Rotation series of 89.231, 0, 1.502 degrees from the body frame with the star tracker boresight in the Z-direction.

Example of a define block using a Frame line with the value SENSOR.

DEFINE = ACS.STA1.STAR2.V4.I3B

COMMENT Star tracker 1, First Star. Horizontal and Vertical positions and Intensity in counts and a quality flag

COMMENT Star Direction is in ST1 Frame. See ICD for ST1 orientation.

FRAME = SENSOR

K3 EXTERNAL FRAME

Frames defined externally to the spacecraft are external frames. They can be defined based on celestial properties (for example the International Celestial Reference Frame) or based on the spacecraft orbit parameters (for example as a Local Vertical, Local Horizontal Frame). A description of common external frames appears in Section 4.3 of Reference H2.

Example: The LVLH is defined with its origin at the spacecraft center of gravity and its Z axis vector collinear and opposite in sign to the geocentric satellite position (planet center to spacecraft gravity center), its Y axis collinear and opposite sign of the orbital kinetic momentum (normal to orbit plane), and its X axis forming a right handed orthogonal coordinate system with its Y and Z axes.

The designation and precise definition of external coordinate frames should be well understood and agreed upon by the transmitting and receiving entities. Definitions that might be used are given in section 4.2 of Reference H2 and section 5.5 of Reference H3.