PROGRESS IN STANDARDIZING FLIGHT DYNAMICS DATA EXCHANGE

David S. Berry[(1)], **Joseph Hashmall**[(2)], **Alain Lamy**[(3)], **Francisco Martinez Fadrique**[(4)], **Karen V. Richon**[(5)], **and Denise Snow**[(6)]

[(1)]*NASA Jet Propulsion Laboratory/California Institute of Technology, 4800 Oak Grove Drive, M/S 301-121, Pasadena, CA, USA 91109, +1-818-354-0764, david.s.berry@jpl.nasa.gov*

[(2)]*A.I. Solutions, Inc., 10001 Derekwood Lane, Lanham, MD, USA 20703, +1-301-306-1756, hashmall@ai-solutions.com*

[(3)]*CNES, 18 Avenue Edouard Belin, 31401 Toulouse Cedex 9, +33561273561, Alain.Lamy@cnes.fr*

[(4)]*GMV S.A.U., Isaac Newton 11, 28760 Tres Cantos, Madrid, Spain, +34 91 807 21 00, fmartinez@gmv.com*

[(5)]*NASA Goddard Space Flight Center, 8800 Green Belt Road, Green Belt, MD, USA 20771, +1-301-286-8845, karen.v.richon@nasa.gov*

[(6)]*US Air Force Space Command/A9 (Space Analysis Division) (Retired), 1774 Teller County Road 51, Divide, CO, USA 80814, 719-687-9576, denisedansnow@q.com*

Abstract: *The work of the Consultative Committee for Space Data Systems (CCSDS) Navigation Working Group was presented at the ISSFD meetings in 2004 and 2007. Since 2007, the technical program previously reported has been substantially completed, and several new work items have been started. At the time of the 2004 paper, no CCSDS flight dynamics standards had been finalized, and only one was close to being approved as a "Blue Book" international standard. By 2007, one standard had been finalized and was undergoing a semi-major revision; the other two standards were relatively close to being completed. Recognizing that the works for which it had originally been chartered were nearing completion, in 2008 the Working Group began considering further standardization relevant to flight dynamics information exchange. Active standards development has been initiated in several areas. This paper includes a brief overview of the CCSDS and its Navigation Working Group. The bulk of the paper describes the Technical Program of the Working Group, with emphasis on the standards currently in progress. The main topics include the operations infusion of the approved standards, description of the new works in progress, and the notional schedule for completing the new standards.*

Keywords: *International Standards, CCSDS, Operations.*

1. Introduction

The topic of this paper is the CCSDS Navigation Working Group (CNWG) and the international standards it has either published or are in development that relate to space flight dynamics. The primary relevance of these standards is their ability to promote interoperability between space operators. Significant results include publication of several international standards in the past nine years and the infusion of those standards into interagency operations. The status of the technical program of the Consultative Committee for Space Data Systems (CCSDS) Navigation Working Group has been presented at the ISSFD meetings in 2004 and 2007 [1], [2]. The focus of these two papers was the set of three areas of standardization that then constituted the technical program of the working group, specifically, exchanges of orbit data, attitude data, and tracking data. Since 2007, substantial progress has been made on completing the initial technical program and a number of new work items have been identified and added to the technical program. Accordingly, it is time for an update; such update is the main objective of this paper.

This paper includes a brief overview of the CCSDS and its standards development process, as well as the current composition of the CNWG. The bulk of the paper describes the Technical Program of the Working Group, both those standards that have been completed and those that are currently in progress or just starting. The main topics include things such as the current status of infusion into operations of the approved standards, brief description of the new works in progress, and the notional schedule for completion of these new standards.

2. CCSDS and ISO Overview

The Consultative Committee for Space Data Systems was founded in 1982 by a consortium of the major space agencies of the world. It is a multi-national forum for the development of communications and data systems standards for spaceflight. To date, nearly 600 space missions have chosen to use CCSDS standards in one or more aspects of the mission. Figure 1 lists the member agencies of the CCSDS as of the date of this writing.

- Agenzia Spaziale Italiana (ASI)/Italy.
- Canadian Space Agency (CSA)/Canada.
- Centre National d'Etudes Spatiales (CNES)/France.
- China National Space Administration (CNSA)/People's Republic of China.
- Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)/Germany.
- European Space Agency (ESA)/Europe.
- Federal Space Agency (FSA)/Russian Federation.
- Instituto Nacional de Pesquisas Espaciais (INPE)/Brazil.
- Japan Aerospace Exploration Agency (JAXA)/Japan.
- National Aeronautics and Space Administration (NASA)/USA.
- UK Space Agency/United Kingdom.

Figure 1. Member Agencies of the CCSDS

The CCSDS is formally affiliated with the International Organization for Standardization (ISO), an independent, non-governmental organization comprising the national standards bodies of 164 countries, about 80% of the world's countries. Within the ISO there are over 200 Technical Committees, each of which focuses on the creation of standards related to a particular area of international commerce. The CCSDS affiliation with ISO is via Technical Committee 20 (TC20, "Aircraft and Space Vehicles") Subcommittee 13 (SC13, "Space Data and Information Transfer Systems").

The CCSDS is organized into six general "Areas", each of which is partitioned into one or more related "Working Groups" (WG), "Special Interest Groups" (SIG) and "Birds of a Feather Groups" (BOF). Although the CCSDS is largely oriented towards space communication (radio frequency, command, telemetry, internetworking, etc.) standards, there are also some working groups oriented towards non-protocol domains, notably, the CCSDS Navigation Working Group (CNWG). The CNWG is organized under the Mission Operations and Information Management Services Area. The organization chart is available on the CCSDS web site [12].

3. The CCSDS Navigation Working Group

The Charter of the CCSDS Navigation Working Group (CNWG) is to provide a discipline-oriented forum for detailed discussions and development of technical flight dynamics standards, with the goal of increased possibility of flight dynamics interoperability. Historically, the CNWG has had regular participation from several of the CCSDS member space agencies, primarily CNES, DLR, ESA, JAXA, and NASA. In the case of ESA and NASA, several of the centers of the respective agencies have been involved. There are a few agencies that have either named representatives to the CNWG, but have not recently participated, or have never participated in the WG. In recent years, there has been representation from the ISO TC20/SC14/WG3 (CNWG "sister organization"), as well as commercial and military support sponsored by an agency (e.g., GMV, the United States Air Force, and Boeing/Iridium).

At the time of the 2004 paper [1], none of the three original work products of the CNWG had been finalized, and only one was close to being approved by the CCSDS Management Committee as a CCSDS international standard. By the time of the 2007 paper, one of the three standards (the Orbit Data Messages) had been finalized but was undergoing a semi-major revision and the other two standards (Attitude Data Messages and Tracking Data Message) were relatively close to being completed. The last standard in the "big three" set of standards that were part of the initial technical program was completed in 2010. Recognizing that the tasks for which it had originally been chartered were nearing completion, in the CCSDS Fall 2008 Meetings the CNWG began considering as a regular part of its agenda further opportunities for standardization of flight dynamics information exchanges. Several ideas have emerged since that time and have been added to the Charter of the Working Group, and active development has been initiated on most of them. The documents describing these new exchanges are detailed below in section 5.2, which covers the "Expanded Technical Program".

4. The CCSDS Standards Development Process

The CCSDS Standards Development Process is fully described in [3], so it will not be discussed in detail here. In general, every CCSDS standard begins as a "Concept Paper" that suggests a need for standardization. Assuming the CCSDS management agrees, a Working Group (WG) will be chartered to develop the Recommendation (or the assignment may be given to an existing

WG). Once assigned, the WG develops the material content of the recommendation via a collaborative, iterative, consensus process. CCSDS Recommendation documents go through several stages: Proposed ("White Book", internal to a WG), Draft ("Red", formally reviewed by the member Agencies over a two to three month period), and Final ("Blue"). Between the Red Book Phase and Blue Book Phase, Draft Recommendations must have a formal testing period that requires two interoperable implementations in a relevant operations environment (real or simulated). When the formal Agency Review is passed, prototyping is complete and test reports filed, promotion to Blue Book occurs. After CCSDS documents have reached the Blue Book phase, the ISO standards process is entered at an advanced stage (Draft International Standard or Final Draft International Standard) for processing to become International Standards under the "cover sheet" method, whereby ISO simply wraps the CCSDS document inside ISO boilerplate. Later, if changes are required, an existing standard enters a revision phase characterized by the book color "Pink". Even if they are not revised due to external forces, CCSDS Blue Books undergo 5-year reconfirmation review, which may result in them being reconfirmed, revised, or retired. The CCSDS also has a few categories of documents that are not on the standards track, specifically, "Green Books" are non-normative technical reports that discuss foundational aspects of technical areas related to the normative documents. The designation "Silver Book" is applied to Recommendations that are retired or historic, and thus no longer normative.

5. The Technical Program of the CNWG

5.1. Initial Technical Program

At the time of the 18th ISSFD in 2004, the CNWG was working on four documents: the Orbit Data Messages, the Attitude Data Messages, and the Tracking Data Message, as well as an update to the "Green Book" [9] that covers fundamental elements of the flight dynamics discipline. Of these documents, only the Green Book had been published. Since 2004, all of the assignments in the Navigation Working Group's original technical program have been published, and the standards documents have all achieved some level of operations infusion. The Navigation Green Book is not a standards document; rather, it is a primer on the fundamentals that relate to the messages elaborated in the set of standards. As such, it will not be discussed further here.

5.1.2. Orbit Data Messages, CCSDS 502.0-B-2, ISO 26900:2012

The Orbit Data Messages (ODM) [5] standard specifies three standard message formats for use in transferring spacecraft orbit information between spacecraft operators: the Orbit Parameter Message (OPM), the Orbit Mean-Elements Message (OMM), and the Orbit Ephemeris Message (OEM). Such exchanges are used for (a) pre-flight planning for tracking or navigation support, (b) scheduling tracking support, (c) computing antenna pointing predictions and transmit/receive frequency predictions, (d) performing orbit comparisons, (e) carrying out navigation operations such as orbit propagation and reconstruction, (f) performing orbit conjunction studies, and (g) planning and executing collaborative maneuvers to mitigate interference, enhance mutual operations, and avoid collisions. In 2009, several updates to the document that had been in work since 2005 were published in a Version 2 Blue Book. In a few notable operations implementations, (a) the CCSDS Service Management Standard [14] directly incorporates the XML representations of the OEM and OPM messages; (b) the Analytical Graphics Inc. (AGI) Orbit Determination Toolkit (ODTK) can output a CCSDS OEM; and (c) GMV's focussuite software implements the ODM in KVN and XML, being fully supported by GMV's software, and is actually used for GALILEO and others.

5.1.3. Tracking Data Message, CCSDS 503.0-B-1, ISO 13526:2010

The CCSDS Tracking Data Message (TDM) [6] Recommended Standard specifies a standard message format for use in exchanging spacecraft tracking data between space agencies. Tracking data covered by the TDM includes commonly utilized data types such as Doppler, transmit and receive frequencies, range, angles, Delta-DOR (Differential One-Way Range), media correction, weather, etc. The initial intent of the TDM was to facilitate interagency spacecraft tracking in which spacecraft managed by one agency are tracked from a ground station managed by a second agency. However, the TDM can also be used to format the data from tracking debris and other objects so independent parties can perform orbit determination and conjunction assessment utilizing the same data, in the same format. The TDM is currently in the process of undergoing a requisite 5-year update review, and it is possible that additional data types could be added during this review. For example, there have recently been requests to add some new data types specifically oriented towards the tracking of space debris, to support changes in the TDRSS Space Network ground system, and to support GPS point solutions. Operationally the TDM is produced by the deep space tracking networks of ESA, NASA, the Indian Space Research Organization (ISRO), and the China National Space Administration (CNSA). The AGI ODTK can read a TDM as input.

5.1.4. Attitude Data Messages, CCSDS 504.0-B-1, ISO 13541:2010

The CCSDS Attitude Data Messages (ADM) [7] 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 message 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; and testing to initialize sub-system simulators (communications, power, etc.).

5.1.5. Navigation Data Messages XML Specification, CCSDS 505.0-B-1, ISO 17107:2011

Based on the request of the CCSDS Management Committee (CMC), the Navigation Data Messages XML Specification (NDM/XML) specifies an Extensible Markup Language (XML) format for use in exchanging the CCSDS ADM, ODM, and TDM between space agencies. These XML message formats exist in addition to the plain ASCII Keyword Value Notation (KVN) message descriptions contained in the previously described standards. The NDM/XML specifies an integrated schema set that mirrors the underlying standards described in [5], [6], [7]. The XML schema set is suited to inter-agency exchanges of any number of Navigation Data Messages. The full schema set is available via the CCSDS Space Assigned Numbers Authority (SANA) Registry [13].

Note that in the "Expanded Technical Program" described below, the approach to the XML implementation is somewhat different. In each case, the specifics of the XML implementation are included directly in the same document with the KVN implementation. The rationale for this change of direction relates to the fact that in the prior direction, each KVN document added would require an update to the NDM/XML document, with the concomitant Agency Review and prototype testing. By including the XML implementation directly in the individual standards, the number of Agency Reviews is halved and the prototyping can focus on the new elements of the standard set.

5.1.6. Navigation Data Messages Common Structural Elements

All of the standards previously described share a few common structural elements. Specifically, all have a "header" section that provides some basic identifying information, all have a "metadata" section that provides information relevant to the data in the message, and all have a "data" section that is the primary reason for the messages to exist. There is also the notion of a "segment" that consists of a metadata section and a data section. There are some variations on this theme, for example some of the messages contain only a single segment (data + metadata), and some have an unlimited number of segments. The new messages in the expanded technical program described below preserve this structure, but one of them has exactly two segments and an additional "relative metadata" section.

5.2. Expanded Technical Program

As noted above, in the fall meetings of 2008 the CNWG began considering as a regular part of its agenda further opportunities for standardization of flight dynamics information exchanges. In the effort associated with this Extended Technical Program, the CNWG principles first described in [1] have not changed, to wit:

- Maximum commonality between recommendations: the way the documents (and messages) are organized, the notation in which parameters are specified, the formats used to present numbers;
- Clear definition of units;
- Ease of transition from a KVN specification to a common XML specification;
- Flexibility to include additional information, such as comments and optional parameters; and,
- Identification of those items that cannot or should not be standardized, so they can be addressed in an Interface Control Document (ICD).

The following sections of this paper will briefly describe each of the new standards documents being developed by the CNWG. The order in which they are presented ranges from documents that are more mature (farther along in the standards development process) to those that are less mature.

5.2.1. Conjunction Data Message (CDM, Red Book)

The CCSDS Conjunction Data Message (CDM) specifies a standard message format for use in exchanging spacecraft conjunction information between originators of conjunction assessments and spacecraft operators. Such exchanges are used to inform spacecraft operators of conjunction events between objects in space to enable consistent warning by different organizations employing diverse conjunction assessment techniques and to provide critical information to enable timely conjunction assessment decisions. The CDM is applicable to satellite operations in all environments in which close approaches and collisions among satellites are a concern. The CDM contains information about a single conjunction event between two objects. The CDM contains information about the position, velocity, miss distance and covariance of the two objects at the time of the closest approach (TCA), along with a variety of descriptive data/metadata. It optionally contains relative position, relative velocity, and probability of collision at TCA. There is also information that provides the satellite operator with an idea of the accuracy of the orbit determination, for both objects, that was used to produce the conjunction assessment. All of this information helps the satellite operator determine collision risk and enables them to perform maneuver planning if they choose to maneuver. An example of a CDM with only obligatory keywords is given in Figure 1. In addition to the obligatory keywords shown, there is a variety of optional keywords that may be implemented by conjunction assessment providers.

Current Status: The CDM recently completed the requisite CCSDS Agency Review process, and is in the process of being prototyped by several space-related organizations that currently provide conjunction assessments and notifications. It is anticipated that the CDM will become a CCSDS Recommended Standard during the first half of 2013.

Figure 2: An Example of a CDM in KVN with Only Obligatory Keywords

CCSDS_CDM_VERS	= 1.0	
CREATION_DATE	= 2010-03-12T22:31:12.000	
ORIGINATOR	= JSPOC	
MESSAGE_ID	= 201113719185	
TCA	= 2010-03-13T22:37:52.618	
MISS_DISTANCE	= 715	[m]
OBJECT	= OBJECT1	
OBJECT_DESIGNATOR	= 12345	
CATALOG_NAME	= SATCAT	
OBJECT_NAME	= SATELLITE A	
INTERNATIONAL_DESIGNATOR	= 1997-030E	
EPHEMERIS_NAME	= EPHEMERIS_SATELLITE_A_20100309	
COVARIANCE_METHOD	= CALCULATED	
MANEUVERABLE	= YES	
REF_FRAME	= EME2000	
X	= 2570.097065	[km]
Y	= 2244.654904	[km]
Z	= 6281.497978	[km]

X_DOT	= 4.418769571	[km/s]
Y_DOT	= 4.833547743	[km/s]
Z_DOT	= -3.526774282	[km/s]
CR_R	= 4.142E+01	[m**2]
CT_R	= -8.579E+00	[m**2]
CT_T	= 2.533E+03	[m**2]
CN_R	= -2.313E+01	[m**2]
CN_T	= 1.336E+01	[m**2]
CN_N	= 7.098E+01	[m**2]
CRDOT_R	= 2.520E-03	[m**2/s]
CRDOT_T	= -5.476E+00	[m**2/s]
CRDOT_N	= 8.626E-04	[m**2/s]
CRDOT_RDOT	= 5.744E-03	[m**2/s**2]
CTDOT_R	= -1.006E-02	[m**2/s]
CTDOT_T	= 4.041E-03	[m**2/s]
CTDOT_N	= -1.359E-03	[m**2/s]
CTDOT_RDOT	= -1.502E-05	[m**2/s**2]
CTDOT_TDOT	= 1.049E-05	[m**2/s**2]
CNDOT_R	= 1.053E-03	[m**2/s]
CNDOT_T	= -3.412E-03	[m**2/s]
CNDOT_N	= 1.213E-02	[m**2/s]
CNDOT_RDOT	= -3.004E-06	[m**2/s**2]
CNDOT_TDOT	= -1.091E-06	[m**2/s**2]
CNDOT_NDOT	= 5.529E-05	[m**2/s**2]
OBJECT	= OBJECT2	
OBJECT_DESIGNATOR	= 30337	
CATALOG_NAME	= SATCAT	
OBJECT_NAME	= FENGYUN 1C DEB	
INTERNATIONAL_DESIGNATOR	= 1999-025AA	
EPHEMERIS_NAME	= NONE	
COVARIANCE_METHOD	= CALCULATED	
MANEUVERABLE	= NO	
REF_FRAME	= EME2000	
X	= 2569.540800	[km]
Y	= 2245.093614	[km]
Z	= 6281.599946	[km]
X_DOT	= -2.888612500	[km/s]
Y_DOT	= -6.007247516	[km/s]
Z_DOT	= 3.328770172	[km/s]
CR_R	= 1.337E+03	[m**2]
CT_R	= -4.806E+04	[m**2]
CT_T	= 2.492E+06	[m**2]
CN_R	= -3.298E+01	[m**2]
CN_T	= -7.5888E+02	[m**2]
CN_N	= 7.105E+01	[m**2]
CRDOT_R	= 2.591E-03	[m**2/s]
CRDOT_T	= -4.152E-02	[m**2/s]
CRDOT_N	= -1.784E-06	[m**2/s]
CRDOT_RDOT	= 6.886E-05	[m**2/s**2]
CTDOT_R	= -1.016E-02	[m**2/s]
CTDOT_T	= -1.506E-04	[m**2/s]
CTDOT_N	= 1.637E-03	[m**2/s]
CTDOT_RDOT	= -2.987E-06	[m**2/s**2]

CTDOT_TDOT	= 1.059E-05	[m**2/s**2]
CNDOT_R	= 4.400E-03	[m**2/s]
CNDOT_T	= 8.482E-03	[m**2/s]
CNDOT_N	= 8.633E-05	[m**2/s]
CNDOT_RDOT	= -1.903E-06	[m**2/s**2]
CNDOT_TDOT	= -4.594E-06	[m**2/s**2]
CNDOT_NDOT	= 5.178E-05	[m**2/s**2]

5.2.2. Pointing Request Message (PRM, White Book)

The CCSDS Pointing Requests Message (PRM) specifies a standard message format for the exchange of pointing requests information between agencies. The PRM arises from the need to provide a systematic and homogeneous manner to specify the complex requests that are needed to point a satellite or an instrument on board a satellite coherently with its mission profile and pointing constraints. This becomes particularly complex when the satellite is operated by one agency but requests come from several other ones. The initial versions of the PRM are derived from the initiative by the European Space Agency (ESA) to standardize the pointing request to support the interplanetary missions Rosetta, Venus Express, and Mars Express; the PRM will also support other interplanetary and non-interplanetary missions.

The initial implementation of the PRM is based on the pointing profiles for the named missions, which properly analyzed result in a collection of pointing scenarios that are actually generic:

- Inertial pointing, either three-axis or spin stabilized
- Track pointing, using as reference the trajectory of an object in space or the ground-track on the surface of a celestial body
- Limb pointing, using as target a given grazing height over the outer edge of the apparent disk of a celestial body
- Terminator pointing, using as target a point in the light/shadow terminator on the surface of a celestial body
- Velocity pointing, where a certain axis of the satellite is aligned with the satellite velocity vector
- Nadir pointing, using as reference direction the local vertical of a celestial body surface. This pointing scheme is to be combined with yaw-steering laws around the nadir axis or off-pointing laws with respect to the reference nadir direction.

After analyzing the data structure and complexity of the expected types of requests it was decided to implement the PRM directly in an XML representation. Unlike other CNWG projects, a KVN version of the PRM is not foreseen. The PRM will in any case be integrated in the general data structure defined by NDM/XML for the other CNWG messages.

To facilitate the use of the PRM, a collection of PRM templates will accompany the standard. The complexity of the PRM can be generalized in a limited collection of template ‘containers’ where just the user data needs may be provided.

Current Status: The PRM is still relatively early in the CCSDS standards development process, however, given that there is already an operational prototype at ESA, it is at the same time relatively far into the standards development process. It is anticipated that the PRM will become a CCSDS Recommended Standard during 2014.

5.2.3. Navigation Hardware Message (NHM, White Book)

The CCSDS Navigation Hardware Message was conceived as a means of standardizing data that could be used as input in ground based determination and evaluation of spacecraft attitude. It was intended to have the same relation to the ADM as the TDM has to the ODM. Its potential use however, goes well beyond this conception and includes a standard format for transmission of any navigation hardware data, be it for attitude determination (attitude sensor data), orbit determination (Global Navigation System data), or monitoring of spacecraft health and safety.

Because the number and variety of hardware data types is enormous and constantly changing, the NHM is designed to transmit data from arbitrary hardware. It allows the use of arbitrary hardware by creating a syntax in which hardware data can be unambiguously defined. This syntax is used in the metadata section to combine fields into mnemonics that are used in the data section to specify the nature, number, and type of values that are associated with the mnemonics. When a data ingestion routine processes the metadata it can configure the routines that process the data section to input data in a specified format when each mnemonic is found. For example, in the metadata section there might be the following entry that defines the input data from an inertial reference: MNEMONIC = ACS.IRU1.RATES.V4.I3B

This mnemonic is composed of fields that indicate input of data generated in the Attitude Control System (ACS) consisting of rates measured by the first inertial reference unit (IRU1.RATES) which will contain four values (V4), the first three of which will be integers (I3, in this case representing counts) and the last representing a binary value (B, a quality flag). In the data section there might be many entries representing data with this mnemonic at different times. Examples of such data might be:

```
ACS.IRU1.RATES.V4.I3B = 2011-10-28T20:15:35.0Z   18312   62191   57637   0
ACS.IRU1.RATES.V4.I3B = 2011-10-28T20:15:35.2Z   18066   64330   58709   0
ACS.IRU1.RATES.V4.I3B = 2011-10-28T20:15:35.4Z   18687   65879   58639   0
```

Different types of data that are related and that are transmitted at the same cadence can be combined (as the IRU rate counts and quality flags in the example above) whereas related data that are transmitted at a different cadence may be separated. For example, IRU temperatures may be needed for conversion of IRU counts to meaningful rates, but may be transmitted at a much lower cadence because they vary more slowly than the rates themselves. In this case a different mnemonic definition (perhaps THM.IRU1.TEMP.V3.F3) might be specified in the metadata section to indicate data generated the spacecraft thermal system (THM) consisting of temperatures of the first inertial reference unit (IRU1.TEMP) and will contain three values (V3) which will be fixed point numbers (F3). Data records containing this mnemonic, a time value, and the temperature values will appear in the data section for the infrequent temperature data.

Because values for the fields in the mnemonic are defined and expandable, their combination in the specified syntax provides the versatility, clarity, and standardization that will improve the utility of Navigation Hardware Data.

Current Status: The NHM is still very early in the CCSDS standards development process. It is anticipated that the NHM will become a CCSDS Recommended Standard during 2015.

5.2.4. Spacecraft Maneuver Message (SMM, White Book)

The Spacecraft Maneuver Message (SMM) conveys detailed information related to intentional changes to the spacecraft trajectory state and attitude state using spacecraft hardware. The initial version of the SMM will attempt to address the most common types of spacecraft maneuvers: those performed using propulsive systems and reaction wheels. For simplicity, the term 'orbit' will be used for 'trajectory', though the SMM applies to all types of spacecraft trajectories, including escape trajectories. Environmental, or external, perturbations are not represented by the SMM.

The SMM encompasses not only basic information related to the time, magnitude and direction of the maneuver, but also summarizes the onboard hardware used to effect the change in the spacecraft orbit/attitude state. These data are exchanged between flight dynamics groups and flight operations teams for both planning and calibration of the maneuvers. Planning information for maneuvers is often provided by a flight dynamics operator to a mission operations/flight operations team for mission planning and conversion into spacecraft commands. After maneuver execution, the results of maneuver reconstruction and calibration are summarized and provided to spacecraft engineers and mission operators, who use it for evaluating spacecraft performance. While there is some overlap with the maneuver information provided in the OPM and APM, the SMM is more detailed and typically includes information related to the hardware settings needed to make the orbit or attitude change. The SMM is used for finite maneuver modeling, but is not recommended or useful for impulsive (instantaneous) maneuvers.

Examples of typical data included in an SMM include the epoch and duration of the maneuver; the magnitude and direction of the orbit/attitude change, often represented in multiple coordinate frames; the desired change in orbital parameter(s), such as delta-apogee radius, delta inclination, delta-longitude of ascending node; and/or desired change in attitude state, such as delta-pitch, roll and yaw, changes in quaternions, spin axis reorientation angle, spin rates, momentum unloaded, etc. While different spacecraft have different propulsion systems and hardware, they often can be categorized in terms of type of system, such as bipropellant or monopropellant, blowdown or pressure controlled; propellant tanks e.g. fuel, oxidizer, pressurant; thruster types and sets, thruster configurations, including duty cycles and pulse widths, and so on. Important data in the SMM needed for planning mission lifetime and troubleshooting potential problems include fuel mass used, individual thruster and propulsion system history, and momentum wheel storage and unload capacity. SMMs for attitude maneuvers effected by reaction wheels and magnetic torquer bars might also include power levels and wheel speeds.

Current Status: The SMM is currently in a very early draft form, as the first edition of the CCSDS White Book, and has not yet progressed to the point of having meaningful examples of the message. Several NASA missions are interested in implementing the SMM, notably GSFC's JWST, which will be launched in 2018, and the TDRSS Space Network, which is currently developing prototype SMMs to replace the TDRS OPM 59 and 67.

5.2.5. Events Message (EVM, Concept Paper)

One type of information used by any space mission is the notion of "events", and in particular events related to flight dynamics. An event can describe situations such as:

- when a satellite enters/leaves the Earth shadow or penumbra (i.e. start/end of eclipses),
- when the satellite becomes visible/invisible from a ground station considering a given elevation threshold (ground station visibilities AOS/LOS),
- more generally, when some geometric condition is met (in relation to the satellite's orbit, to onboard sensors, celestial bodies, possibly other satellites, etc.).

Events are usually computed and used in spacecraft control centers for operations planning for the management of onboard equipment or the scheduling of processing tasks (they are then often called "predicted events"). But they may also be exchanged between various entities that compute the events or make them available, and entities that use them. So it was natural to propose the creation of a new standard to make the exchange of events easier. The new proposed message is called the Events Message (EVM). Defining a standardized events message actually has at least two objectives:

- Clarify the meaning of the most often used events, so that everybody can share the same definitions, the same vocabulary and the same meaning for common events.
- Define a framework that simplifies the processing by a common syntax.

The EVM is intended for use in applications that already use events, but could also be used in conjunction with other navigation-related messages. For instance an EVM associated with an ephemeris file (OEM) could describe some useful events such as when propulsion has been activated, or when attitude has changed, which could be useful for processing the ephemeris file.

The abstract structure of an event is rather simple. It should contain a date/time (when the event occurred or will occur), a name (the type of event), plus any necessary additional information helpful to fully describe the event. An EVM instance would then be a collection of such blocks of information. It can be noted that some events go in pairs (e.g. beginning of something, end of something), and this feature could also be present in the description in some way.

The set of possible events (even those restricted merely to navigation) is so wide that it is impossible to define them all in a standard. The standard should give definitions and structures for the most frequently used simple events related to satellite position in the orbit, visibility, celestial bodies, etc., but should also make it possible for a particular mission to define its own.

Regarding the EVM definition and design process, the CNWG will be in charge of the definition of navigation related events (list of useful events, information associated with each of them). But given that the concept of events is much more general, the events structure (including format related aspects) will be defined by the CCSDS System Engineering Area (SEA) in cooperation with the other groups. The CNWG will then complete the EVM such that it defines flight dynamics related events within the framework defined by CCSDS Systems Engineering.

6. Operations Infusion Use Cases

There are many ways in which the products of the CNWG can be utilized in an operations environment. The following figure illustrates a notional use case showing both the existing and in progress Navigation Data Messages and a potential message flow between functions:

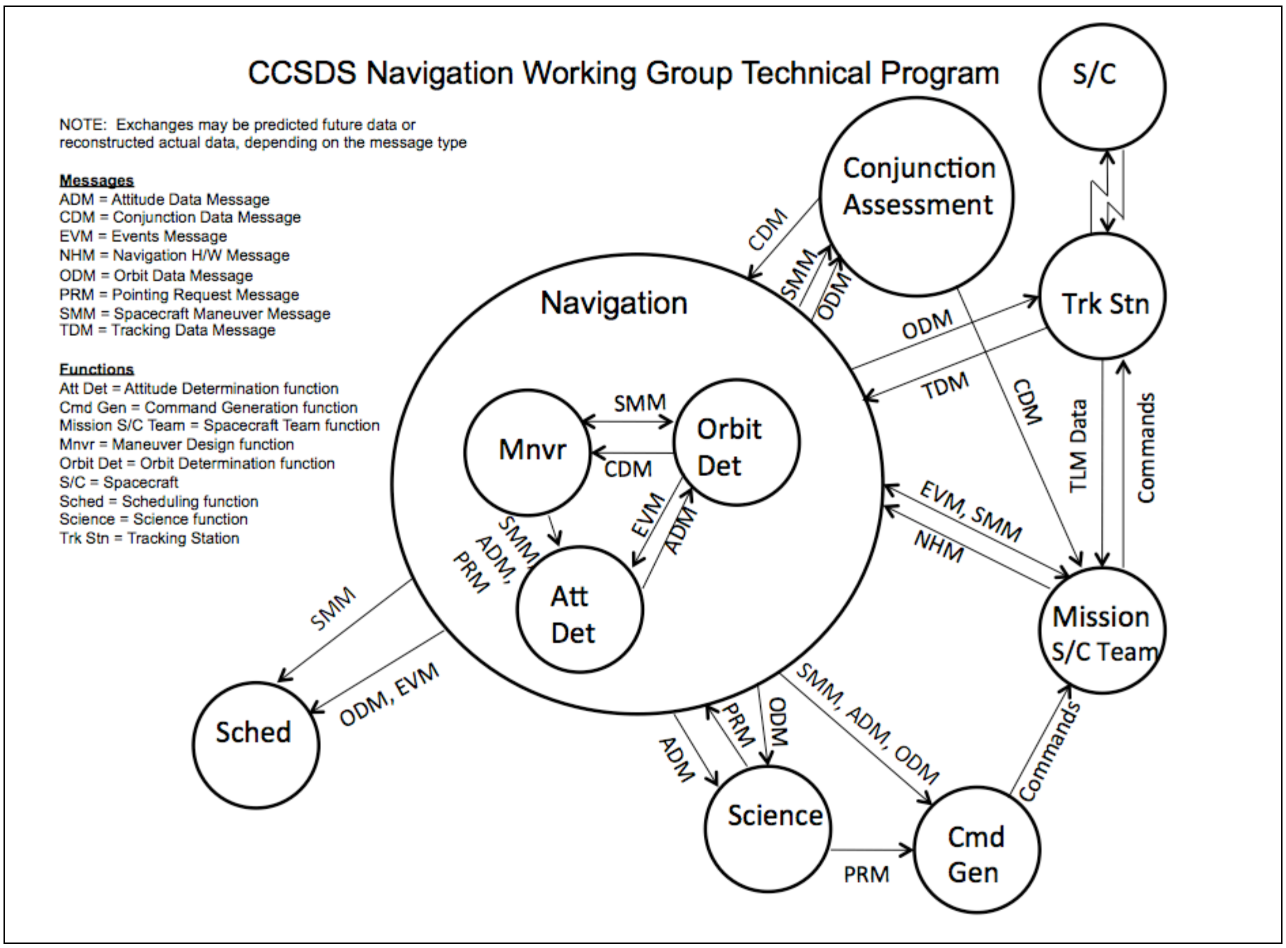

Figure 3: CCSDS Navigation Data Messages Use Case

7. Contact Information

The CCSDS maintains a general website at http://www.ccsds.org . For inquiries of a general nature, this is a good place to find out more about the CCSDS. From this website, it is possible to find the published documents of the CCSDS, documents that are currently in the review cycle (along with instructions for how to review them and the tools to provide comments), meeting schedules, and organizational information. Via the CCSDS Collaborative Work Environment (CWE) it is also possible to view documents under development. In particular, the ongoing draft documents described above in the section "Expanded Technical Program" may be found at the CWE website http://cwe.ccsds.org/moims/default.aspx . After navigating to this website, choose the “MOIMS-NAV” tab on the far left menu and then select the "Draft Documents" folder. Finally, the CNWG may be emailed at moims-nav@mailman.ccsds.org . Please send an email if you are interested in participating in the working group.

8. Conclusion

When the original charter of the CCSDS Navigation Working Group was fulfilled, it was interesting to see the number of good ideas that emerged from the group with respect to continued standardization of flight dynamics operations. For the next few years, the working group "pipeline" is full, but it is possible to envision a future day when the "extended" technical program has also been fulfilled; as that time draws near it will again be necessary to renew the effort to identify areas where further standardization of flight dynamics data exchange is desirable.

9. Acknowledgments

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