

Recent Developments and Future Directions in CCSDS Flight Dynamics Standards

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Progress by the Consultative Committee for Space Data Standards (CCSDS) Navigation Working Group in developing international standards for use in space flight dynamics operations has been regularly presented at the ISSFD. Since the last update in 2012, the status of several standards has changed relative to previous reports: the Conjunction Data Message has been published and is widely used, the Pointing Request Message is in final prototyping, the Navigation Hardware Message may be cancelled, the Spacecraft Maneuver Message has been discontinued, a new Re-Entry Data Message standard has been started, the Events Message is about to start, and the "first generation" standards (Orbit Data Messages, Attitude Data Messages, Tracking Data Message, NDM/XML Specification) are being revised. Future directions have primarily arisen in the context of "second generation" standards that supplement first generation standards. The need to duplicate common data structures (e.g., an orbit state) commonly arises. Two important objectives of CCSDS international standards are interoperability and cross-support, which makes consistency essential. Still, maintaining consistency from one standard to another is challenging. The related concepts of duplication and consistency have led to the still evolving notion of a "universal, modular message". Recent discussion suggests this concept may be the way forward.

Key Words: International Standards, CCSDS, Operations, Interoperability

1. Introduction

Starting in 2004, the progress of the Consultative Committee for Space Data Standards (CCSDS) Navigation Working Group (CNWG) in developing international standards for use in space flight dynamics operations has been regularly presented at the ISSFD.¹⁻³⁾ Since the most recent status update in 2012, there have been a number of developments and some interesting future directions that will be discussed in this paper.

2. Recent Developments

Recent developments include changes in the status of several works in progress relative to previous reports. The next few sections of the paper provide specific developments for each of the CNWG standards; details about most of the referenced standards are described in Ref. 3). For documents that have not yet reached the CCSDS Recommended Standard state (aka "Blue Book"), there is no reference listed.

2.1. The Conjunction Data Message

The Conjunction Data Message (CDM)⁴⁾ was published in June 2013, and is now in wide usage. The CDM specifies a standard message format for use in exchanging spacecraft conjunction information between originators of conjunction assessments, satellite owner/operators, and other authorized parties. Such exchanges are used to inform affected satellite operator(s) of conjunctions between space objects to facilitate development of an effective response should one be necessary. The USSTRATCOM Joint Space Operations Center (JSpOC),⁵⁾ the organization responsible for the orbit

determination required to maintain the United States space catalogue, publishes CDMs for all detected conjunctions of catalogued objects. NASA's Conjunction Assessment Risk Analysis team (CARA)⁶⁾ also uses the JSpOC-produced CDMs extensively as input to their processing, and recently announced that they would be starting to produce CDMs of their own that include the 3D probability of collision.⁷⁾ In 2018, the CDM will be eligible for the CCSDS required 5-year review, for which the possible outcomes are to reconfirm, revise, or retire the standard. Given the wide usage of the standard, retirement seems extremely unlikely; either reconfirmation or revision is possible.

2.2. The Pointing Request Message

There are numerous circumstances in spacecraft operations, when pointing requests must be transmitted from a user, e.g., of an instrument or of a relay service, to the operator of a spacecraft. For clarity of intent, particularly in interagency operations, it is desirable to exchange the specifics of these pointing requests in a standardized format. Such is the purpose of the Pointing Request Message (PRM). Development of the PRM document was completed in mid-2016, and the draft standard is in the final prototyping phase prior to publication. As specified in the Organization and Processes for the CCSDS,⁸⁾ the CCSDS requires that "at least two independent and interoperable prototypes or implementations must have been developed and demonstrated in an operationally relevant environment, either real or simulated" before a standard can be approved for publication. We anticipate that the PRM will be published in mid-2017.

2.3. The Navigation Hardware Message

The proposed Navigation Hardware Message (NHM) is a proposed standard intended to specify a message format for

use in exchanging data from onboard sensor measurements or onboard calculations that are involved in attitude or orbit determination. The hardware data must first be unpacked from telemetry before distribution in the NHM format. The NHM standard has been the subject of significant effort over the past several years, but it has not matured to the point where an Agency Review is feasible. It has reached a decisive point (essentially a roadblock) in its development. Consequently, it may be subject to cancellation based on CCSDS rules. Specifically, there is a relatively new requirement to have the two required prototypes committed at the time a new project is approved by the CCSDS Engineering Steering Group (CESG). As yet a second prototyping agency has not yet stepped forward for the NHM. Additionally, and perhaps more serious, the NHM as currently designed essentially requires the use of an Interface Control Document (ICD) for effective use, a requirement which has recently fallen into disfavor. CESG policy doesn't prohibit the use of ICDs to supplement CCSDS standards, however, limiting the dependency on ICDs as much as possible is clearly favored. The CNWG is still debating the future of the NHM, and exploring options for continuing its development. A decision as to the direction for the NHM is anticipated at the Spring 2017 CCSDS Meetings.

2.4. The Spacecraft Maneuver Message

Development of the Spacecraft Maneuver Message (SMM) has recently been discontinued. This proposed standard was intended to establish the content and format for exchanging predicted and reconstructed information related to intentional actuator induced changes to spacecraft orbit and/or attitude. Requirements that were developed for the SMM have been refined and re-allocated to the in-progress revisions of the Orbit Data Messages (ODM)⁹⁾ and Attitude Data Messages (ADM)¹⁰⁾ (see Section 2.7 below). For a long time, the CNWG had been evaluating whether or not a separate document was actually required to convey information about maneuvers given that elementary maneuver descriptions are already possible in the ODM and ADM. Ultimately the decision to cancel the development of the SMM was made. A large factor in this decision was the probable need to inherit/duplicate in a consistent manner much of the information included in the ODM and/or ADM. Issues associated with the inheritance/duplication and consistency topics will be addressed more thoroughly later in this paper.

2.5. The Re-Entry Data Message

A new standard has been started (the Re-Entry Data Message, RDM). The proposed RDM standard will contain information related to objects re-entering the atmosphere of a celestial body and impacting on its surface. Primarily this is Earth-centric, but other objects are not excluded, e.g., Jupiter, Titan, etc. The RDM is not intended to contain detailed orbit/attitude ephemerides, possible break-up data, or even conjunction information. The aforementioned information can to a large extent be better covered by Orbit Ephemeris Messages (OEM),⁹⁾ Attitude Ephemeris Messages (AEM),¹⁰⁾ and CDMs. Much of the information in the RDM is inherited from the CDM. The RDM is very early in its development; however, for various reasons it may progress quickly.

2.6. The Events Message

The "Events Message" (EVM) was introduced and discussed in the 2012 progress report,³⁾ but it has not yet started, primarily due to CCSDS internal priorities. Orbital events describe when and possibly how some situations (generally related to a satellite) occur. Predicted orbital events constitute a major data type used in control centers for operations; however, no standard exists yet. Due to cooperative work between the CNWG and another CCSDS working group in the Cross Support Services Area that is also interested in orbital events, we seem poised to commence this development. A decision as to the direction for the EVM is anticipated at the Spring 2017 CCSDS Meetings.

2.7. "First Generation" standards

Several other standards are in the process of revision, per standard CCSDS operating procedures that require a review every 5 years, as noted in section 2.1. These documents "the first generation" of CNWG products (the ODM, ADM, and Tracking Data Message (TDM)).¹¹⁾ In each of these cases, the periodic review led to a decision to revise the documents.

As noted in section 2.4, the requirements for conveying information about maneuvers have been refined, finalized, and allocated to either the ODM (translational maneuvers) or the ADM (rotational maneuvers). As part of the ODM revisions, a new message, the Orbit Comprehensive Message (OCM) is being added; it responds to new use cases and is very different in several respects from the other three messages documented in the standard. The OCM aggregates and extends the content of the three existing constituent messages in the ODM into a single hybrid message, and adds the ability to describe force models, orbit determination description, state transition matrices, and other information. In particular, the OCM will allow the exchange of more detailed information about translational maneuvers than can be conveyed in the simpler Orbit Parameter Message (OPM). During the ADM revisions, an analogous "Attitude Comprehensive Message" (ACM) is contemplated to implement the requirements related to rotational maneuvers. A decision as to whether or not to embark on the ACM is anticipated at the Spring 2017 CCSDS Meetings.

A revised TDM will be out for Agency Review in late 2017 or early 2018; the revision includes a few new data types and XML formatting material, but is otherwise largely unchanged. A second revision of the TDM will be started almost immediately upon publication of the Version 2 TDM in order to capture a number of new ideas that were proposed late in its development.

The Navigation Data Messages XML Specification (NDM/XML),¹²⁾ which captures the ODM, ADM, and TDM in XML format, is also considered one of the first generation documents. It too is being revised, and much of its content is being partitioned across the underlying standards. The reason for this is that if we did NOT do this, every time a Blue Book is published we would need to update TWO Blue Books; one for the keyword-value notation (KVN) description of the standard, and one for the XML document. So as part of the process of revising the first generation ODM, ADM, and TDM standards, the instructions for preparing the messages in

XML format are being included with the baseline text and the corresponding material is being removed from the NDM/XML document. The CDM document was the first to implement this new direction, and all new CNWG standards will follow.

3. Future Directions

Future directions of the CNWG focus on a few topics that have arisen in the context of the "second generation" standards that supplement the first generation ODM, TDM, and ADM. Additionally, new use cases have been arising on a fairly regular basis. There are also some policy changes in the CCSDS that have affected decisions made by the working group. Together, these discussions have exposed several issues for the CNWG, specifically, the closely related topics of *inheritance, duplication, and consistency*.

3.1 Inheritance and duplication

The need to duplicate common data structures (e.g., an orbit state) commonly arises. For example, many of the data items that appear in the ODM are also relevant to the CDM (in fact, one of the early design decisions for the CDM was whether or not it was a standalone standardized message, or should be a new message added to the ODM). Much of the information in the RDM is inherited from the CDM. This is not necessarily a problem; however, Lead Editors have sometimes been tempted to slightly modify structures that have been inherited. This modification could be interpreted by users of the standards as a failure to achieve the desired consistency.

3.2 Consistency and CCSDS objectives

Two of the most important objectives of CCSDS standards are the enablement of interoperability and cross-support. In the achievement of these two high level objectives, the author argues that consistency is essential. There is anecdotal evidence that this consistency is expected by users of the CNWG standards. Current CNWG members have agreed that new standards should be as consistent as possible with pre-existing CNWG standards; and, that avoiding duplication of material wherever possible is desirable. Also, where data structures must be duplicated they should be consistent unless there is a very good reason to diverge. Still, the effort to maintain consistency from one standard to another is a constant challenge. During the revisions of existing international standards, there are often pressures and desires by newer members of the working group to change things. However, we have at least an implied commitment to existing users of earlier versions of the standard based on the objectives of interoperability and cross-support.

There's a famous quote attributed to the American philosopher, essayist, and poet Ralph Waldo Emerson that "a foolish consistency is the hobgoblin of little minds...". The operative word here is "foolish", and in the process of developing international standards consistency between related standards is not foolish! The CNWG now has 7 standards documents in progress, with 6 different Lead Editors, and has had 100% turnover of membership within the past 15 years. Thus, consistency is a frequent challenge. Membership turnover brings fresh ideas into the group, but

also complicates the effort to maintain consistency with past products. This effort is particularly evident in the standards revision process. When the CCSDS periodic review reaches a decision to "revise", CNWG members have agreed to the following guideline: if it's wrong, fix it; if it's unclear, clarify it; if it's a new requirement, add or subtract as needed; if it's stylistic or opinion or alternative technically valid formulation, leave it alone. There is a kind of tension in the CNWG given that we have been "historically bound" to conventions that were established during the development of the ODM Version 1 standard first published in September 2004. At the Spring 2004 meetings of the CNWG in Montreal, there was an agreement among attendees that the ODM document design would be the model for future standards developed by the group, and successive standards would be consistent with it. This model, with a few exceptions, has generally been observed. However, the group turnover brings in members who understandably may not feel bound by this convention. For these group members, the 2004 ODM convention represents an uncomfortable constraint and block to progress.

3.3 The "Navigation Functional Message"

In late 2014, these previously discussed concepts and pressures led to the informally proposed notion of a "universal, modular message". This idea has increasingly arisen in subsequent meetings and has gathered some momentum. It is tentatively called the "Navigation Functional Message" or NFM. One might characterize this notion as related to "The Lego[®] System" (i.e., standardized message blocks defined in one document that can be systematically and easily combined in many ways to meet specific needs). The NFM challenge will be to allow the transformation of a jumble of trajectory, attitude, maneuver, and tracking "building blocks" into a message that is useful for flight dynamicists. One consequence of this "building blocks" approach is that it will necessarily result in a relaxation of the current fixed formats in which sections and keywords must appear in a prescribed, fixed order. This is not necessarily bad, since programmers can generally deal relatively easily with parameters that appear in varying order. This is only one of a few ODM Version 1 conventions that constrains, but it is one that new CNWG members often question.

The NFM is envisioned as potentially providing a creative vehicle for flight dynamicists, but the concept raises the potential issue of how to control the creativity so that the outcome of the process remains technically valid and useful. It is not too difficult to imagine that a nonsensical, technically invalid message could be created using the NFM approach. To some extent the CNWG has been heading in this direction for a while, given the concept of the "combined instantiation" that was incorporated in the NDM/XML specifications document. The combined instantiation allows a variety of what might be termed "scenarios" to be exchanged in a single flight dynamics data message (e.g., an OEM and an associated AEM, or a CDM with an OEM for each of the objects, in the same XML message).

One potential drawback to the NFM idea is that it might make more difficult the process of developing converters from

the international exchange format to the internal formats used by message recipients in their Agency processing.

The concept of this modular Navigation Functional Message is still in its early formative stages, and the CNWG is not in a position to be able to act on this idea immediately due to ongoing obligations, but recent work suggests that it may be the way forward. Additional discussion on the topic is scheduled for the Spring 2017 CCSDS meetings.

3.4 The SANA Registry

The CCSDS Space Assigned Numbers Authority (SANA) is intended to provide a single, CCSDS-wide, central location to register "a variety of standards-related information, such as protocol identifiers, agencies, service and data providers, XML schema, a glossary of terms, and other information that is used across CCSDS".¹³⁾ In February 2011, the CNWG successfully created the first formal registry within the new (at the time) SANA. This first registry for Navigation contains the XML schemas documented in the NDM/XML standard.

Most CNWG standards have a normative annex that specifies which Time Systems and Reference Frames may be used in messages that comply with the standard. However, these annexes tend to vary based on when the underlying standards were published and the specific applications to which they apply. The CNWG has recently been considering creating normative entries in the SANA Registry that fulfill the same function in a much more dynamic way. It is felt that such an implementation would be not only more dynamic, but would contribute to greater consistency between the standards. This is because the SANA registries would eliminate the need for the associated document annexes, and hence would eliminate inconsistencies between them. The SANA Registry is also more flexibly modified than a document in the event that something needs to be corrected, clarified, added, or deleted based on ongoing research or new use cases.

3.5 Draft projects

Whereas the *Organization and Processes for the CCSDS* specifies that that Working Groups "are chartered to produce specific standards on a specific schedule and within specific resource envelopes, and then go out of business",⁸⁾ there has recently been a greater emphasis on a longer view. Working group chairs are encouraged at each CCSDS face-to-face plenary to "update your 5 year plans", and have recently been asked to create "draft projects" in conjunction with the creation of a CCSDS Strategic Plan. Draft projects are essentially proposals for future work to be undertaken by working groups, and thus represent something of a contradiction with the notion of going out of business stated in the official documentation. Currently, 18 of the 23 CCSDS working groups have at least one draft project in the project framework. The CNWG has three such draft projects, a "Launch Data Message", "Fragmentation Data Message", and the previously mentioned "Events Message". The RDM began its existence as a draft project, and had that status for a couple of years. It has now been commenced as an active project, and we anticipate that the Events Message may start soon. The NFM concept is too new and as yet too ill-defined to become a draft project, but a draft project could be an outcome of the Spring 2017 CCSDS Meetings.

4. Conclusion

This paper has described a few recent developments and future directions of the CCSDS Navigation Working Group. In addition to the future directions discussed in sections 3.3 through 3.5, a few other less mature future ideas have been proposed/suggested. At each semi-annual CCSDS Meeting series, some agenda time is allocated to these future topics as we continue to evaluate them; some mature further and may find their way into an international standard, and some do not survive. Since the last ISSFD status update in 2012, the CCSDS Navigation Working Group has been diligently engaged in the development of international standards that we hope are useful in interoperable, cross-supported space flight dynamics operations. It is hoped that this status update adequately conveys the continuing effort to provide useful navigation data exchange vehicles and the seriousness with which this charter is being pursued.

Acknowledgments

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, under contract to the National Aeronautics and Space Administration. The author gratefully acknowledges the ideas and contributions of past and present members of the CCSDS Navigation Working Group that have been stated in face-to-face working meetings, telecons, and correspondence. © 2017 California Institute of Technology. Government sponsorship acknowledged.

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