CCSDS Concept Paper: The Navigation Composite Message

Purpose

This CCSDS Concept Paper will propose a new project for the CCSDS Navigation Working Group (NavWG). Note that many of the ideas discussed in this Concept Paper were previously published in Reference [1].

Introduction

Since the publication of its first CCSDS Recommended Standard in 2004 (the Orbit Data Messages V.1), progress by the NavWG in developing international standards for use in space flight dynamics operations has been regular. New areas of flight dynamics standardization emerged in 2007, 2008, 2009, 2010, 2013, 2018, 2019, 2020, 2021, 2023, and 2024. Throughout the history of the Working Group, there have been a number of developments and some interesting future directions that will be discussed in this Concept Paper, which proposes solutions to some of the challenges that have been faced by the Working Group over the years.

Attempts to address problems associated with the interrelated concepts of inheritance, duplication, and consistency have consumed many of the NavWG resources (time and effort) over the years and have led to the notion of a "universal, modular message". The concept of this modular message has been a low-level "wish list" discussion topic within the NavWG for several years (since Fall 2014). The ability to start work on this task has been delayed by the need to prioritize a few overdue, committed works-in-progress (TDM V.2, ODM V.3, ADM V.2). Now that these documents have all been published, we can address this wish list concept. Over time, this concept has been known by several names within the NavWG, from the relatively mundane ("Navigation Functional Message", "Modular Message"), to the grandiose ("Super Message"). For the purposes of this Concept Paper, the proposed project will be called the "Navigation Composite Message" (NCM).

Acronyms

Acronym	Meaning	Standard History
ADM [4]	Attitude Data Messages CCSDS 504.0-B-n	First published 2008, revised 2024
• ACM	Attitude Comprehensive Message	One of the ADMs
• AEM	Attitude Ephemeris Message	One of the ADMs
• APM	Attitude Parameter Message	One of the ADMs
CDM [5]	Conjunction Data Messages CCSDS 508.0-B-n	First published 2013, revision well on the way
NDM/XML [10]	Navigation Data Messages/XML Specification CCSDS 505.0-B-n	First published 2010, revised 2021, 2023, revision in progress
ODM [3]	Orbit Data Messages CCSDS 502.0-B-n	First published 2004, revised 2009, 2023
• OCM	Orbit Comprehensive Message	One of the ODMs
• OEM	Orbit Ephemeris Message	One of the ODMs
• OMM	Orbit Ephemeris Message	One of the ODMs
• OPM	Orbit Parameter Message	One of the ODMs
PRM [11]	Pointing Requests Message	Published 2018, reconfirmation in progress
RDM [6]	Re-Entry Data Message CCSDS 508.1-B-n	Published 2019
SMM	Spacecraft Maneuver Message	Project Discontinued
TDM [7]	Tracking Data Message CCSDS 503.0-B-n	First published 2007, revised 2020, revision in progress

The "First Generation" Standards (ODM, TDM, ADM, NDM/XML - 2004 Through 2010)

The "First Generation" standards are the ODM, ADM, and TDM. In the beginning, there was the ODM. It consisted of two relatively simple messages, one for an orbit state (the OPM) and one for a time series of orbit states (the Orbit Ephemeris Message). The TDM project was started in late 2003. In 2004, when the ODM was nearing publication, a project for the ADM was started. Structurally like the ODM, the ADM consisted of two relatively simple messages,

one for an attitude state (the APM) and one for a time series of attitude states (the AEM). In 2009, the OMM was added to the ODM V.2. In 2010, in response to a CCSDS Management Council directive, the Navigation Data Messages XML Specification (NDM/XML) was created to provide XML formats in addition to the Keyword-Value Notation (KVN) formats used in the ODM, ADM, and TDM.

CCSDS Document 5 Year Review Requirements

Published CCSDS standards are subject to a "Five Year Review" per CCSDS operating procedures [2]. The outcomes of this review are either to reconfirm the standard (no change), retire it (no longer active), or revise it. Each of the First Generation of NavWG products (the ODM, ADM, TDM, and NDM/XML) has been through at least one such process. In every case, these periodic reviews by the NavWG led to a decision to revise the applicable standard, which can take several years. In Fall 2024, by CCSDS process rules, we are obligated to perform a Five Year Review on the RDM. Based on prior practice and the current group composition, it is likely we will opt to revise, and it is likely that there will be internal pressures to add a number of new data items and associated metadata items that are also in the ODM, CDM, and possibly ADM. It is therefore very likely that we will spend inordinate amounts of time addressing inconsistencies in the drafts compared to both the other NavWG Blue Books and the revised RDM Pink Book.

The "Second Generation" Standards (CDM, SMM, RDM, PRM - 2010 through 2018)

Work on the CDM commenced in the October 2010 and progressed at a furious pace. (This pace was the result of prioritizing the production of the CDM, and was the source of at least some of the delays identified in the Introduction of this Concept Paper.) The initial Blue Book 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. Data structures duplicated from the ODM include the spacecraft state, covariance matrix, time systems, orbit centers, and others; one prominent inconsistency is in the keywords for the covariance matrix. In 2018, the NavWG executed the CCSDS required 5 Year Review for the CDM. Given the broad usage of the standard, retirement was extremely unlikely; either reconfirmation or revision were possible. Following consultation with the United States Space Force (a principal producer of CDMs), the NavWG decided to revise the standard, and in the course of the revision, several more structures from the evolving ODM V.3 were replicated in the CDM V.2.

The PRM project was approved in late 2011 and was published in February 2018. The character of the PRM is quite different from that of most of the other NavWG standards, but it has met the needs of some missions. In Fall 2023, the NavWG elected to submit some Corrigenda for the document, and then proposed reconfirmation of the document. The final phase of the required reconfirmation polling is in progress as of this writing.

The SMM project was approved in 2012, but was discontinued in Fall 2016 without publication. For several CCSDS meeting series after the project was approved, the NavWG worked on the message, but had difficulty determining whether or not a separate document was actually required to convey information about maneuvers given that elementary maneuver descriptions were already possible in the ODM and ADM. Ultimately a decision to cancel the development of the SMM was made. **A large factor in this decision was the probable need to inherit/duplicate much of the information already included in the ODM or ADM.** Requirements that had been developed for the SMM proposed standard were refined, finalized, and then allocated to either revisions of the ODM (translational maneuvers) or the ADM (rotational maneuvers).

The RDM project was approved in 2016. It contains information related to objects re-entering the atmosphere of a celestial body and impacting on or near its surface. Primarily this message is Earth-centric, but other central bodies are not excluded, e.g., the Moon, Jupiter, Titan, etc. Several sections in the RDM are inherited from the CDM and ODM. Duplicated data structures include spacecraft state, orbit determination data, covariance matrix, time systems, orbit centers, and others.

New Use Cases: The "Third Generation" Standards" (OCM, ACM - 2014 through 2023)

New use cases have arisen on a fairly regular basis; they have often led to a project to create a new message (OCM,

ACM) or an entire new standard (e.g., CDM, RDM). These new messages have almost invariably necessitated the incorporation of data structures that have already been defined in one of the earlier standards. At the Fall 2014 CCSDS Meetings, the second ODM 5 Year Review was conducted, with an outcome of "revise". A new message, the Orbit Comprehensive Message (OCM) was proposed, designed to respond to new use cases. Structurally the OCM 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 parameters, and a great deal of 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) has been added to implement the requirements related to rotational maneuvers. Development of standards to respond to these new use cases have exposed several issues for the NavWG, specifically, the closely related topics of inheritance, duplication, and consistency.

Inheritance, Duplication, Consistency, and CCSDS Objectives

Frustrations in dealing with inheritance, duplication, and consistency led in 2014 to the still evolving notion of a "universal, modular message". Two of the most important objectives of CCSDS international standards are the enablement of interoperability and cross-support [2, Annex A], which suggests that consistency is an essential ingredient of international standards. In the achievement of the two high level objectives of interoperability and cross support, there is anecdotal evidence that consistency is expected by users of the NavWG standards. Still, for several reasons, maintaining consistency from one standard to another has been challenging for the NavWG.

Since shortly after the publication of its first completed standard in 2004 (the ODM V.1), the NavWG has increasingly struggled with issues of consistency in the development of its standards. In large part, this struggle has its roots in the fact that many astrodynamics concepts and data structures apply across the discipline. For example, in trying to develop standards related to orbits [3], attitudes [4], satellite conjunctions [5], and satellite re-entry [6], the same or similar data structures show up often; to date, this phenomenon seems less applicable to the tracking standard [7].

The need to duplicate common data structures (e.g., an orbit state) has frequently arisen in the later generation messages. Additionally, the concepts of orbit and attitude are complementary; the concepts of tracking and orbit determination/propagation are symbiotic (neither is possible without the other). 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 circa 2010 was whether or not it should be a standalone standardized message, or should be a new message added to the ODM). Parts of the information in the RDM are inherited from the CDM and ODM. This is not necessarily a problem; however, Lead Editors have often felt a technical need to slightly modify or augment existing structures that have been inherited. Such modification reduces the degree of inheritance and results in inconsistency, which could be interpreted by users of the standards as a failure to achieve the consistency they desire.

Current NavWG members have agreed that new standards should be as consistent as possible with pre-existing NavWG standards [8]; 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 has been a constant challenge. During the revisions of existing international standards, there are often pressures and desires to change things, particularly by newer members of the working group. 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. A proposed solution to the problems of duplication of data structures and the need for consistency is the proposed "universal, modular message", the Navigation Composite Message. Such a message would be a radical break from the past, but should ultimately be an improvement.

The NavWG recently had 7 standards documents in progress, with 6 different Lead Editors, and has had nearly 100% turnover of membership within the past 20 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 5 Year Review reaches a decision to "revise", NavWG 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" [8]. There is a kind of tension in the NavWG given that we have been "historically bound" to

conventions that were established during the development of the ODM V.1 standard first published in September 2004. At the Spring 2004 meetings of the NavWG 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.

In the CCSDS Meetings held in Fall 2022, the Navigation Working Group spent a great deal of time trying to resolve wording and other inconsistencies between documents. There were Header inconsistencies, Metadata inconsistencies, a variety of Data inconsistencies, and similar but not exact text. Much time was spent discussing wording trying to achieve exactitude in describing the same thing in two or more documents (this sounds easy, but it's not!). Put simply, we are spending a lot of time trying to enforce consistency between the books. Of late it has also been the case that when one of the documents in revision proposes an added feature, there is an almost automatic desire to add it to all of the related documents that are currently in revision. Almost inevitably, this leads to inconsistencies between the documents because a concept will be left out or the wording will be slightly different in the two documents. The use of SANA Registries [9] has addressed this problem to some extent, but there is still too much effort being put into making all of the standards consistent. With the proposed Navigation Composite Message (NCM) we hope to provide the ability to combine data items from multiple standards into a single standard, while also increasing the granularity of the combinations.

NavWG members are a creative bunch. "New Project" Blue Books have recently been proposed, to wit, a Launch Data Message (LDM) and a Fragmentation Data Message (FDM). Based on the history of the group, and the proposed subject matter, these new messages will likely need to re-use some of the constructs of prior Blue Books, exacerbating the effort required in the NavWG to maintain consistency across standards. It is also conceivable that the addition of future new data structures will take longer than if they could be added to a modular message construct. It is very conceivable that an LDM could inherit data structures from the ODM and CDM, and an FDM could inherit data structures from the ODM and RDM. Under the current standardization direction in the Navigation WG, there would be "opportunities" to tweak these data structures in ways that seem superficially benign, but in essence evolve into inconsistencies between the new standard and its near relative. It is conceivable that adding only the specific data structures required for an LDM or FDM to the NCM base will allow those data structures to enter operations usage in a more timely and more consistent manner, providing more rapid delivery of capability to agencies.

The SANA Registry

The NCM concept relies heavily upon the CCSDS-sponsored Space Assigned Numbers Authority (SANA). The SANA Registry 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 schemas, a glossary of terms, and other information that is used across CCSDS".

For example, most early NavWG standards have had a normative annex that specifies which Time Systems and Reference Frames may be used in messages that comply with the standard. However, these annexes have tended to vary based on when the underlying standards were published and the specific applications to which they apply. The NavWG has recently been creating normative entries in the SANA Registry that fulfill the same function in a much more dynamic way. Such an implementation would be not only more dynamic, but should contribute to greater consistency between the standards. This is because the SANA registries would reduce or 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. Already the SANA Registry is an important component towards a Navigation Composite Message.

The "Next Generation Standard" - Formal Proposal for a "Navigation Composite Message" (NCM)

In late 2014, the previously discussed concepts and pressures led to the informally, almost jokingly proposed notion of a "universal, modular message". This idea has increasingly arisen in subsequent NavWG meetings and has now gathered sufficient momentum to justify a formal proposal of the NCM. 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). One NCM challenge will be to allow the transformation of a potential jumble of trajectory, attitude, maneuver, and tracking "building blocks" into a message that is useful for flight dynamicists. One very likely 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 Navigation Data Message Generation 1 through 3 conventions that constrains, but it is one that new NavWG members often question.

Notionally it is desired to incorporate an idea that has been implemented in the NDM/XML standard [10] since its initial issue in 2010, i.e., being able to make logical combinations of data in a single "combined instantiation" message, but increase the granularity. Right now, the granularity of the NDM/XML is at the "message level", but for the NCM there is a probable need to be able to infuse granularity at the "logical block" level, or perhaps even lower. The concept of logical blocks of keywords is already present in many of the NDMs. All of the standards currently state that the logical blocks and keywords must be in a certain order. Sometimes that order is different in the different documents. But parsing can be accomplished without strict ordering. It may be desirable to remove the restrictions on ordering of elements in most cases. To some extent the NavWG has been heading in the NCM direction for a while, given the concept of the NDM/XML combined instantiation. This structural feature 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).

Other breaks from the existing NDM paradigm may relate to the number of spacecraft that can be represented in a single message. Currently each of the ODM, ADM, TDM, and RDM indicate that a message is applicable to a single spacecraft, and a single broad data type (orbit, attitude, etc.). However, the NDM/XML combined instantiations can incorporate any number of NDM messages from references [3] through [7] and many combinations of data, including:

– a constellation of spacecraft in which ephemeris data for all the spacecraft is combined in a single XML message; (multiple ODMs)

– a spacecraft attitude that depends upon a particular orbital state (an APM and its associated OPM could be conveniently conveyed in a single NDM; likewise for AEM/OEM)

– an OEM with the set of TDMs used in the orbit determination

– a CDM with OEMs of both objects

Many other potential examples exist. The above examples for combined instantiations constitute granularity at the "complete message level" (e.g., OPM, OMM, OEM, AEM, CDM). With the NCM concept, it should be possible to achieve granularity at the "subsection level" or perhaps even lower.

Navigation Composite Message Concept Basic Structure

The following suggests a rough structure for the proposed NCM. At the macro level it is similar to the current basic Navigation Data Message structure (i.e., Header, Metadata, Data, with alternating Metadata and Data sections). The proposed structure is an evolution of the structure of the third generation Orbit Comprehensive Message and Attitude Comprehensive Message:

- Header: Probably essentially the same as the existing NDMs, since this has experienced very little inconsistency and variability over the years.
- Identification Section: Identification information about the various space objects
- Metadata Section: Time span of data, time system, etc.
- Points of Contact Section: owner, operator, email addresses, etc. (could be part of Metadata Section)
- Link Section: links to other messages (e.g., ADM, CDM, ODM, RDM, TDM; necessity to be determined based on granularity of data structures and continued existence of these earlier generation standards)
- Orbit Section
- Attitude Section

- Maneuver Section
- Tracking Data Section
- Re-Entry Section
- Covariance Section(s)
- Physical Environment Section
- Orbit Determination Section
- Attitude Determination Section
- User Defined Parameters Section: same as existing in ODM, ADM, etc.

Whether or not any existing Navigation Data Messages are "standalone" or fit into the NCM Concept must be evaluated via NavWG discussions assuming the proposed project is approved by the CMC. Some existing Navigation Data Messages may remain as standalone messages (e.g., the Pointing Request Message [11]).

Advantages of the "Modular Approach"

- The Working Group spends less time trying to make the text related to common data elements (keyword descriptions) identical in each document
- Cross-consistency between messages should be improved.
- More rapid dissemination of new concepts is enabled because common aspects between the new concept and existing standards does not have to be re-developed, consistency checked, and re-tested.
- Agencies that adopt the new approach will be more resilient to future document changes.
- The biggest conceptual difference between the NDM/XML combined instantiation and the proposed "Modular Approach" is that the granularity is at the keyword level (or group of related keywords level), so the level of duplication in the message structures is reduced.

Disadvantages of the "Modular Approach"

- One potential drawback to the NCM 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 resulting standards document containing combined data structures and examples could be tremendously large (the combined page counts of the ADM, CDM, ODM, RDM, TDM is currently greater than 650 pages). Mitigation for this might be having a "common document", with smaller companion documents describing unique features that apply to specialty disciplines.
- All existing reader/writer applications in the Agencies will become obsolete if the modular approach is adopted.
- There is a risk of instantiating "nonsense messages" by combining incompatible data structures.

Conclusion

Since its origin, the CCSDS Navigation Working Group has been diligently engaged in the development of international standards that have shown broad utility in interoperable, cross-supported space flight dynamics operations. Several of the NavWG standards are widely used by space agencies, in commercial operations, and military operations. It is hoped that this Concept Paper conveys the need for the Navigation Composite Message given the continuing effort to provide useful navigation data exchange standards. It is hoped that this concept will lead to a greater degree of integration of orbit, attitude, tracking, re-entry, conjunction, and other future navigation data. In the semi-annual meetings of the NavWG, the Chair has for several years resisted active discussion on the NCM project in favor of completing existing CMC-approved projects in the Technical Program, however, now that in-progress updates to four of the major NavWG standards (TDM, ODM, ADM, and CDM) have largely been completed, it is time to open the discussion and propose a project for the "universal, modular message" concept. Recent discussion suggests that this may be the way forward. It is an opportune time to propose the new NCM approach.

References

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