ODM P2.39 review

13 May 2020

Status

- **Review is converging**
- **Actively working on ODM 2.40; intention is to have that ready prior to Friday's meeting.**
- **ODM (OCM) Test Plan in work.**

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ODM Test Plan

- **Reminder: We're asserting that OPM, OEM and OMM are <u>not materially changed</u>; therefore, no prototype/test required**

- **Prototype/Test organizations**
  - Analytical Graphics Inc.
  - Originally, NASA/Glenn (Dale) had agreed to prototype
  - Orekit (Luc Maisonobe) <u>still supportive</u> of being the second tester

- **Recently resumed discussions with Luc.**

- **My plan to have the ODM Test Plan drafted up by end of May.**

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Achievements

- **Have globally fixed all Oxford comma issues**
- **Have now replaced many ICD references, greatly reducing the number**
- **Annex A tables (OXM Requirements Lists) now completed.**

"ICD" near-global replacement

- **I have substantially reduced references to "ICD" in the ODM. Exceptions:**
  - User-defined parameters sections
  - Definition of unique (e.g. hardware-dependent) reference frames
  - Definition of unique element sets or non-SANA content

- **Adopted verbiage:**
  - should be mutually agreed between message exchange partners
  - The OXX file-naming scheme should be mutually agreed between message exchange partners.
  - The method of exchanging OXXs should be mutually agreed between message exchange partners.
  - A section of User Defined Parameters is allowed. In principle, this provides flexibility, but also introduces complexity, non-standardization, potential ambiguity, and potential processing errors. Accordingly, if used, the keywords and their meanings must be described in an ICD. User Defined Parameters, if included, should be used as sparingly as possible; their use is not encouraged.
  - Static information should be separately shared and/or mutually agreed between message exchange partners outside of the ODM.
  - Extensive comments in an ODM are recommended in cases where that content is germane to the message and changes from message to message.
  - The specific OPM, OMM, OEM, and OCM version numbers to be used should be mutually agreed between message exchange partners.
  - Selection of KVN or XML format should be mutually agreed between message exchange partners.
  - Note that for many of these frames (particularly those that are spacecraft hardware-dependent), an ICD will likely be necessary to fully define and convey understanding of these frames.

Requiring Further Discussion (RFD)...

RFD 01: OEM Inconsistencies

- **No tabular list of ephemeris and covariance keywords**
  - **DECISION: Leave as is.**

- **OEM does not contain a User-defined parameters section – why not?**
  - **Should it be consistent with all other messages?**
  - **If so, would that require re-prototyping the OEM?**
  - **DECISION: Leave as is.**

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RFD 02: Alexandru's proposal for a clearer/better message overview

- **DECISION: Replace Table 6.1 with a new one (shown on right).**

Section			Content	Status (M/O)
OCM Header			A single header of the message	M
Segment	OCM Metadata		A single metadata section (data about data)	M
	Data	orbit data 1	metadata	One or more orbit state time histories (consisting of one or more orbit states)	O
			data lines		
		⋮			
		orbit data n	metadata		
			data lines		
		physical properties		A single space object physical characteristics secton	O
		covariance data 1	metadata	One or more covariance time histories (each consisting of one or more covariance matrices)	O
			data lines		
		⋮			
		covariance data n	metadata		
			data lines		
		STM data 1	metadata	One or more state transition matrix time histories (each consisting of one or more state transition matrices)	O
			data lines		
		⋮			
		STM data n	metadata		
			data lines		
		maneuver data 1	metadata	One or more maneuver specifications for either impulsive or finite burns or acceleration profiles	O
			data lines		
		⋮			
		maneuver data n	metadata		
			data lines		
		perturbation parameters		A single perturbations parameters section	O
		orbit determination		A single orbit determination data section	O
		user-defined parameters		A single user-defined parameters section containing data and supplemental comments (explanatory information)	O

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RFD 03: Annex B Pointers to SANA Registry

- **Based upon inputs on Monday to our discussion of the ADM Annex B, I decided to switch the ODM Annex B to match the current ADM draft format.**
  - **It's more direct and easier to follow.**

- **I propose that we standardize our approach and text regarding what to do if the user wants/needs an entry that is <u>not</u> in SANA registry**
  - **E.g., "An ICD shall be used to fully define and convey understanding of keyword values not contained in the SANA registry"**
    - B1 Message originators
    - B2 Reference Frame Center
    - B3 Time Systems
    - B4 Non-orbit-relative reference frames
    - B5 Orbit-relative reference frames
    - B6 Spacecraft and attitude reference frames
    - B7 Orbit elements
    - B8 Covariance representations
    - B9 Atmosphere models - Yellow means that these were drafted up and distributed last fall (29 Oct 2019)
    - B10 Gravity models
    - B11 Object types
    - B12 Operational status
    - B13 Orbit averaging techniques
    - B14 Orbit types

- **DECISION: Yes, this is a good approach (the new one). Follow up with Julian/Mark RE: SANA API**

RFD 04: OBJECT_NAME Considerations

- **For every tracked object, there are at least three standardized tags:**
  - International Designator (rigidly defined)
  - SSC number (or international equivalent), 5-digit or 9-digit
  - Common name (some operators have as many as 4 of these per object)
- **Published OPM and OEM define only two:**
  - **OBJECT_NAME (mandatory) – What to enter when undefined ??**
    - *Spacecraft name for which the orbit state is provided. While there is no CCSDS-based restriction on the value for this keyword, it is recommended to use names from the UN Office of Outer Space Affairs designator index (reference [2], which include Object name and international designator of the participant.*
  - **OBJECT_ID (mandatory) – What to enter when undefined ??**
    - *"... values should be the international spacecraft designator as published in the UN Office of Outer Space Affairs designator index (reference [2])."*
- **OMM additionally defines:**
  - **NORAD_CAT_ID (optional)**
    - NORAD Catalog Number ('Satellite Number') an integer of up to nine digits. This keyword is only required if MEAN_ELEMENT_THEORY=SGP/SGP4.
- ***Thus there is no "home" in the OPM, OEM and OCM for SSC number.***
  - *Since "OBJECT_ID" has now been tainted by long-standing assertion that it should be the Intl Designator, recommend switching (at least in OCM) to:*
    - OBJECT_DESIGNATOR (Optional) =SSC or other catalog ID number or block chain etc.
    - OBJECT_NAME (Optional) = *Spacecraft common name (same as before)*
    - INTERNATIONAL_DESIGNATOR (Optional) = (rigidly defined)
- **DECISION: Leave OPM, OMM and OEM as is, but make OCM consistent with RDM.**

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RFD 05: Spacecraft clock keywords

- **Can remove spacecraft clock epoch and ticks per SI second, putting it in the "should agree between message exchange partners" bin ?**

- **DECISION: Retain.**

SCLK_EPOCH	Defines the epoch corresponding to t=0 for the spacecraft clock. This is only used if the spacecraft clock (SCLK) timescale is employed by the user.	1.0	-5000.0 1980-01-06T00:00:00	No	No
SCLK_SEC_PER_SI_SEC	Defines the number of clock seconds occurring during one SI second. This is only used if the spacecraft clock (SCLK) timescale is employed by the user.	1.0	2.5 [s]	No	No

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RFD 06: Storing "lines" vs "parameters

- **David's NOTE TO DAN:** *We should discuss whether we depend on the user to parse a string delimited with spaces (e.g., an "orbitLine") based on the ORB_TYPE selected from the SANA registry, or whether we want to develop the XML tags for all of those orbit types (and the several other data lines that have complex structure). Right now in the schema I have "orbitLine", "maneuverLine", "covarianceLine", "stmLine" as a tag, after which is an unstructured string (structure supplied according to the applicable registry). It will be a huge job to break all those apart in XML. Could be done, but want to discuss before embarking on that path.*

- **Thought: OEM does not include CX_DOT_Z_DOT etc.**
  - **Instead, blocks of data are provided as KVN chunks**
  - **How are those accommodated in XML?**

- **OCM probably isn't any different (?)**

- **DECISION: David will prototype one or a few ones both ways to see how it goes.**

RFD 07: What are users to do with mandatory values that are NULL?

- **Users of our standards are asking the question: If an element is mandatory but the quantity is NULL, what should they do?**
    1. Keyword/Tag is mandatory, and you have a value -> USE THAT VALUE
    2. Keyword/Tag is mandatory, but you do not have a value (???)
    3. Keyword/Tag is optional, and you have a value -> COULD INCLUDE
    4. Keyword/Tag is optional, and you do not have a value -> OMIT
- **Can we craft some language to address their quandary?**
- **DECISION: Adopt Alexandru's text in the RDM.**
- **Is it acceptable to have KEYVALUE = <blank> ? Or "" ? Or**
- **Needs more thought.**

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- **Mandatory text entries one may not have:**
  - **OBJECT_NAME**
  - **OBJECT_ID**
- **Have now verified that there are no other <u>mandatory</u> fields in the OPM, OMM, OEM or OCM that have floating point numbers that you could reasonably not know the values of.**

RFD 08: "Multiple objects" XML schema and procedure

- "For instructions on creating a combined instantiation, e.g., one that incorporates multiple ODM/XML messages or an ODM/XML message combined with other navigation related messages, see reference [M-4]."
  - What's the correct reference? (currently pointing to Spice Files ref.)
  - Will this referenced schema allow more than one object (e.g., and entire space catalog)?

- Should we make this <u>common</u> need more obvious as to how to address?

- DECISION: Yes - - David to provide Dan with a writeup tailored to augment section 8.21 to familiarize the reader with exactly how to do this, including an OMM-based example.

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RFD 09: 9-digit SSC numbers

- **9-digit SSC numbers**

- **Some are getting ready to promote wholescale use of OMM to address 5-digit limitations of older message constructs**

- **Multi-object schema needed (?)**
  - **At a minimum, we should demonstrate its use/application**

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RFD 10: User-assigned names for User-Defined Parameters

- **Can User-Defined Parameters have User-assigned names?**
- **DECISION: Use USER_DEFINED_X.**

RFD 11: Interpolation issue

Interpolation and repeated ephemeris time tags
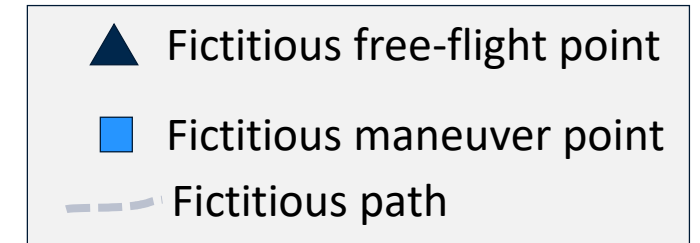
- **Multiple ephemeris formats and astrodynamics tools use duplicate time tags to designate that interpolation shall not occur across that time/event.**

- **In our previous discussions, I'd reluctantly agreed to remove the duplicate time tag representation, based on assertions that the duplicate time tag approach would introduce more work and complexity**

- **After much thought, I do not see the harm in duplicate time tags**
  - **The ability to use separate blocks to represent "interpolatable" segments is retained, so if you want to do it that way, you still can.**
    - But this method requires the operator to generate fictitious ephemeris points and is wasteful.
  - **Duplicate time tag approach requires interpolation confined to segments, just like the other method requires.**
  - **Duplicate time tag approach is most efficient for users of Hermitian two-point pos/vel/acc interpolation.**

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# Current ODM interpolation language/approach is lacking and confusing

- "The occurrence of a second (or greater) metadata block after some ephemeris data indicates that interpolation using succeeding ephemeris data with ephemeris data occurring prior to that metadata block shall not be done. This method may be used for proper modeling of propulsive maneuvers or any other source of a discontinuity such as eclipse entry or exit." – Huh?

- "Optional start and end of USEABLE time span covered by ephemeris data immediately following this metadata block. To allow for proper interpolation near the ends of the ephemeris data block it may be necessary, depending upon the interpolation method to be used, to utilize these keywords with values within the time span covered by the ephemeris data records as delimited by the START/STOP_TIME time tags. (For format specification, see 7.5.10.) These keywords are optional items, and thus may not be necessary, depending on the recommended interpolation method."

- "All data blocks must contain a sufficient number of ephemeris data records to allow the recommended interpolation method to be carried out consistently throughout the OEM."

- My interpretation of all of the above: Each segment must be padded on each end in order to prevent the well-known "ringing" effect.

- Let's see what that looks like…

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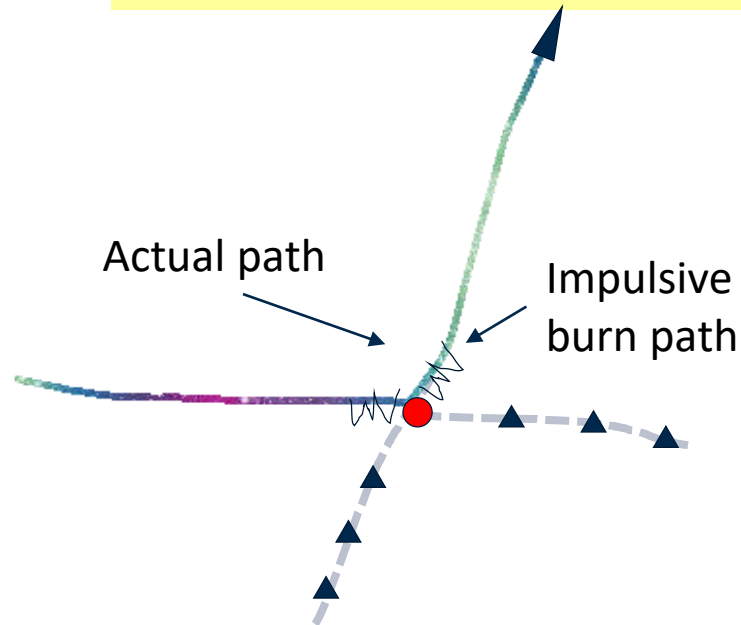STANDARDS & INNOVATION

Repeated ephemeris time tags (cont)

- **SOME interpolation methods require more than two points of data**
  - Lagrange interpolating polynomial is the polynomial P(x) of degree <=(n-1) that passes through the n points
- ***For any other interpolation method, the multi-segment method requiring fictitious points is wasteful and unnecessary.***
  - Requires "false" positions, i.e. storage, plus overhead of many segment blocks
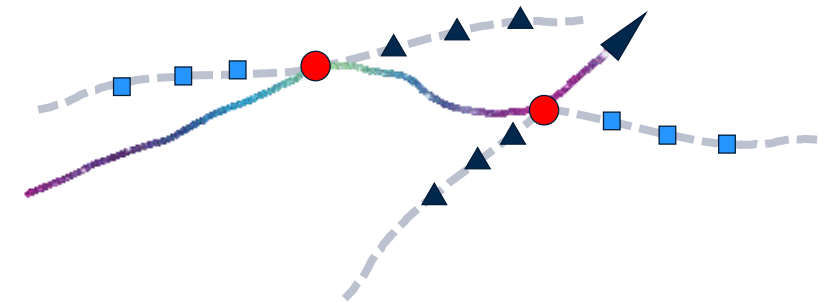- **Use cases of multiple segments:**

▲ Fictitious free-flight point

■ Fictitious maneuver point

- - - Fictitious path

Multiple OD ephem segments
(reference ephem)
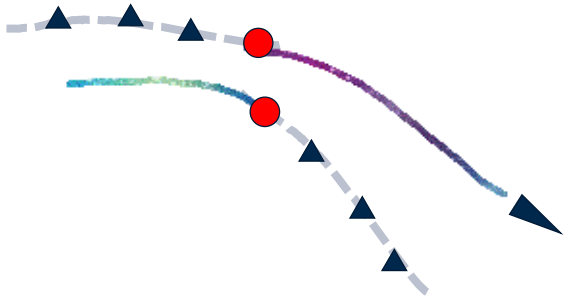
Impulsive burn modeling

Finite burn, with Isp, Thr
binary on/off, but with profiles

Actual path

Impulsive
burn path

Duplicate Time Tag additional comments

- **Primary requirement should be that discontinuities and segment boundaries must be clearly indicated and properly handled.**
- **We (Jim Woodburn and Dan) don't have a problem with allowing fictitious points, but we do not think they should be required.**
- **In our experience, most systems do not generate fictitious points and thus would require modification to meet the format if those points are required.**
- **In our experience, ringing is typically a problem when you have an unevenly spaced node at the interpolation boundary, say a 0.1 second step following a sequence of 1 second steps.**
- **In AGI STK ephemeris files:**
  - **We use duplicate time tags to designate segment boundaries**
  - **We also provide an informative list of interpolation boundaries**
  - **In AGI tools, we often use a blend of Lagrange (in the middle) and Hermitian interpolation near boundaries to avoid ringing.**
- **PROPOSE: Duplicate timetags are not allowed. Further clarify wording to expressly state that users are not forced to introduce/pad with "usable" content, but they should ensure that message exchange partners should ensure that their chosen interpolation methods can support that.**
- **DECISION:**

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RFD 12: How to specify mandatory/optional within an optional block

- *For example, "OCM Data: User-Defined Parameters" section is optional; "mandatory" in the context of Table 6-13 denotes those keywords which must be included in this section if this section is included.*
  - From Alexandru: *"This goes against the convention used in other NDMs, where all elements of optional blocks are marked as 'optional' and normative statements specify which, if any, must be present in every block. The OCM approach is also taken by one CEN/CENELEC standard, and almost every person reading the draft misses the fact that said keywords are mandatory only if the optional block is present."*

- **I think it's pretty clear, and the addition**
  of the new Annex A tables further clarifies it.

- **What do others think?**

- **DECISION: Need to research in implementation conformance statement**

A2.7   ORBIT MEAN ELEMENTS MESSAGE REQUIREMENTS LIST

Item	Feature	Keyword	Reference	Status (M/O)	Support
1	OMM Header	N/A	Table 4-1	M	
2	OMM Version	CCSDS_OMM_VERS	Table 4-1	M	
3	Comment	COMMENT	Table 4-1	O	
4	Message creation date and time	CREATION_DATE	Table 4-1	M	
5	Message originator	ORIGINATOR	Table 4-1	M	
6	Unique message identifier	MESSAGE_ID	Table 4-1	O	
7	OMM Metadata	N/A	Table 4-2	M	
8	Comment	COMMENT	Table 4-2	O	

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RFD 13: Adding thruster contributions

- Alexandru points out, "The message recipient should exercise caution whenever maneuvers are additive (MAN_IS_ADDITIVE=YES), to prevent the unintentional accumulation of maneuver contributions, for example across disparate orbit determination solutions (MAN_OD_ID). I think this will raise major alarm flags during AD or Agency Review. Would it not make more sense to add MAN_OD_ID (and any other relevant keyword) to the bolded text in 6.2.8.10, then remove this admonition?"

- Dan's response: I don't believe that the OD is the issue; in my opinion, the issue is having multiple thrusters and being able to aggregate their collective contributions into the composite thrust the spacecraft experiences.

- How should we address? Is there a better way?

- DECISION 1: Retain 6.2.8.10 language (uniqueness) as currently stated.

- DECISION 2: MAN_GROUP_ID – with all constituent maneuvers added together.

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RFD14: Maneuver Delta Mass

- **Currently have three keywords associated with mass change of maneuvers**
  - ACC_DMASS, DV_DMASS, THR_DMASS
  - Difference is that THR_DMASS only contains mass change beyond the rocket equation-prescribed mass change.
- **Reviewer pointed out that perhaps we could only have one mass change**
- **I propose DMASS as a single keyword, and the values include both the rocket equation mass change plus any associated.**
- **DECISION: Now use only a single MAN_DELTA_MASS value.**

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RFD 15:

- **Reviewer asked if there a particular reason for restricting perturbation blocks to only 1?**
  - Understanding is that the perturbations block should provide information on the propagation of the orbit state time history (ie how that data was generated).
  - What if there are two orbit time history blocks (say one predicted, one determined from OD), and different perturbations models were used in producing them?
  - What if different perturbation models associated with the same keyword have to be used (maybe two atmospheric models were used for different altitudes, or it is an interplanetary trajectory with multiple fly-bys)?
  - DECISION: At this stage, user can make multiple messages; in the future we can possibly address.

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RFD 16: Interpolation of 3D accel/thrust and eigenvectors

- **Added a section for 3D vector and eigenvalue (coordinate frame) interpolation**

C5 EULER AXIS/ANGLE INTERPOLATION (INFORMATIVE)

The Euler Axis and Angle representation of Euler's Theorem (see ANNEX M, Reference [M-12, pp. 10-14] is an effective way to interpolate a series of maneuver thrust or acceleration vector directions. The accompanying vector magnitudes (e.g. eigenvalues or thrust or acceleration magnitudes) may be interpolated using standard Lagrange polynomials or linear expressions.

As presented in [M-12] and consistent with the nomenclature of [M-1], where e_1, e_2, and e_3 represent the three vector components of the axis of rotation $\hat{e}$ and φ represents the angle of rotation, a time-based interpolation of two adjacent unit vectors $\hat{v}_A$ and $\hat{v}_B$ can be undertaken as follows:

(1) The axis of rotation $\hat{e}$ can be obtained as: $\hat{e} = \frac{\hat{v}_B \times \hat{v}_A}{|\hat{v}_B \times \hat{v}_A|}$

(2) Assuming a constant rotational rate during this interval, $\varphi(t) = \frac{(t-t_1)\cos^{-1}(\hat{v}_A \cdot \hat{v}_B)}{(t_2 - t_1)}$

(3) The orthonormal rotation matrix $[M(t)]$ is then

$$= \begin{pmatrix} (1-\cos\varphi)\hat{e}_x{}^2 + \cos\varphi & (1-\cos\varphi)\hat{e}_x\hat{e}_y + \hat{e}_z\sin\varphi & (1-\cos\varphi)\hat{e}_x\hat{e}_z - \hat{e}_y\sin\varphi \\ (1-\cos\varphi)\hat{e}_y\hat{e}_x - \hat{e}_z\sin\varphi & (1-\cos\varphi)\hat{e}_y{}^2 + \cos\varphi & (1-\cos\varphi)\hat{e}_y\hat{e}_z + \hat{e}_x\sin\varphi \\ (1-\cos\varphi)\hat{e}_z\hat{e}_x + \hat{e}_y\sin\varphi & (1-\cos\varphi)\hat{e}_z\hat{e}_y - \hat{e}_x\sin\varphi & (1-\cos\varphi)\hat{e}_z{}^2 + \cos\varphi \end{pmatrix}$$

(4) From which the interpolated vector at time t is then $\hat{v}(t) = [M(t)]\hat{v}_A$

The eigenvector matrix $[E(t)]$ contains the row-wise storage of the major, intermediate and minor eigenvectors at time t, taking care to ensure that this ordered "triad" of vectors adheres to the righthand rule. When interpolating between two eigenvector matrices $[E_1]$ and $[E_2]$ derived from two adjacent covariance matrices respectively, $[E(t)]$ can be evaluated as follows:

(5) The rotation occurring between $[E_1]$ and $[E_2]$ is: $[M_{BA}] = [E_2][E_1]^T$

(6) Compute $\sigma = (M_{BA_{11}} + M_{BA_{22}} + M_{BA_{33}})$

(7) The angle of rotation from A to B is: $\varphi_{BA} = \cos^{-1}\left[\frac{1}{2}(\sigma - 1)\right]$

(8) Exercising caution to accommodate nonunique cases (when $\sin\varphi = 0$) as described in [M-12], the axis of rotation $\hat{e} = \left[\frac{(M_{BA_{23}} - M_{BA_{32}})}{2\sin\varphi} \quad \frac{(M_{BA_{31}} - M_{BA_{13}})}{2\sin\varphi} \quad \frac{(M_{BA_{12}} - M_{BA_{21}})}{2\sin\varphi}\right]$

(9) The angle of rotation at time t is $\varphi(t) = \frac{(t-t_1)\varphi_{BA}}{(t_2 - t_1)}$

(10) $[M(t)]$ can be computed using the above expression in step (3)

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RFD 17: Should time-based duty cycle overlay pointing based?

- **I suggest it should not, unless there is an important use case.**
- **DECISION: Yes there is a valid use case; they should be allowed to overlap**

C3 MANEUVER AND DUTY CYCLE DIAGRAMS (INFORMATIVE)

This section of the informative technical annex defines time-based, phase-angle-based, and cone-based duty cycle parameters.

A "duty cycle" is a cycle of thruster operation which operates intermittently rather than continuously, having an "on" interval followed by an "off" interval.

Time-based duty cycle parameters define a window of duty cycle operations, the actual execution interval and "ON" and "OFF" intervals, as shown in Fig. C-3.
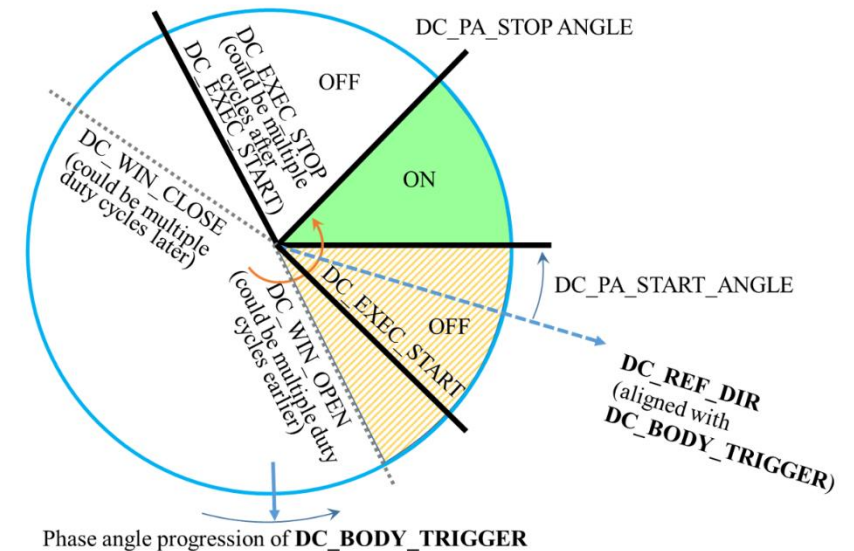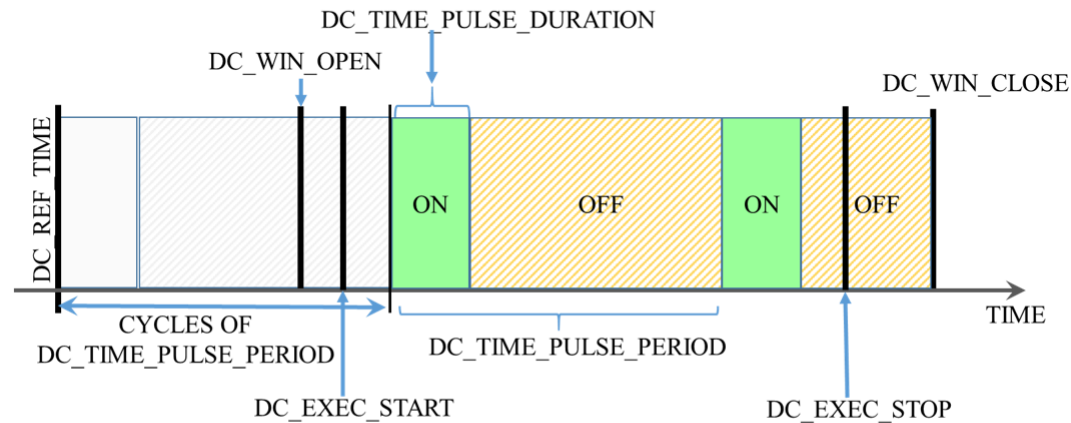

Fig. C-3 Diagram of time-based duty cycle (DUTY_CYCLE_TYPE = "TIME")

RFD 18: Use of vectors in values

- "The value for the DC_REF_DIR keyword is a triple of double precision values. The example in the table is "1.0 0.0 0.0". This is inconsistent with the other strict KVN NDM implementations and could make coding an OCM reader in legacy programming languages more challenging than it needs to be and potentially less robust."

- DECISION: The keyword is a single value that has a structure. This has been implemented in similar fashion in other standards (TDM) as a bipartite or tripartite value.

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RFD 19: Constraint on a *single* OD section

- Reviewer: "Is there a reason for this limitation? Most other blocks can be present multiple times. I can see a situation where a user would want to exchange two orbit solutions for one spacecraft, based on two different OD runs (maybe different input data, eg see what happens when a sensor track is added or removed)"

- DECISION: At this stage, user can make multiple messages; in the future we can possibly address.

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RFD 20: OCM KVN requirement?

- Reviewer: "These requirements state that OCM orbit state time history, covariance, state transition matrix, and maneuver data lines respectively are not in KVN. This is not true, as the data blocks contain plenty of KVN lines. The only mention of non-KVN lines is 7.4.1.6 (covariance), which is taken from the OEM requirement and does not mention all KVN lines in a covariance block.

- The OCM is breaking new ground in NDM development, as it allows both KVN and non-KVN data lines. Some terminology and normative paragraphs are needed to properly specify this. I am not sure what the correct terminology would be. OCM data block metadata sub-section (KVN lines are *de facto* metadata for their block) and OCM data block data subsection (for the non-KVN lines) would be one idea. This would make one OCM block an analog of one OEM segment."

- Add some clear OCM KVN structure requirements?

- DECISION: Add metadata/language normative text to OCM general description.

RFD 21: OPM and OMM n/a restriction

- *The notation '[n/a]' should not appear in an OPM or OMM.*
- Is there a reason this is a should rather than a shall?
- DECISION: In OCM, do not allow "n/a" for units.

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RFD 22: Delete TIME_SPAN?

- **Reviewer: "TIME_SPAN is defined as END_TIME minus START_TIME, so brings no new information. Do we have to keep it ?"**

- **DECISION: Retain TIME_SPAN, because START_TIME and END_TIME are not mandatory.**

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RFD 23: TCOEFF

- **TCOEFF_SOURCE : the definition does not seem completely clear to me. Which coefficients exactly ?**
- **DECISION: Delete**

RFD 24: Bolded or underlined text

- **Should that be allowed?**
- **DECISION:**

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RFD 25: Mandatory/Conditional/Optional ?

- **It would be useful to change our "Mandatory" column to be Status: M=Mandatory, C=Conditional, O=Optional**
- **DECISION:**

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RFD 26: Maneuver composition entries are alternate depictions

- I don't understand the link between "acceleration, impulsive ΔV, and thrust parameters shall not be additive" and "applied at a time tag of Tstart + ½ (MAN_DURA)"
- DECISION 1: Retain as is.

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RFD 18: Units for OCM tripartite + STM KVN values

- **In the OCM, besides single values, should [units] be allowed?**
- **DECISION 1: For single KVN values containing multiple #s, [units] are allowed**
- **DECISION 2: For orbit, covariance, STM, etc. data lines, do not allow units**
- **DECISION 3: Consider adding a mandatory free text keyword for the orbit and covariance lines containing the units.**

Summary

- My sense is that the updated ODM is converging quite rapidly (already a new version 2.40 distributed)

- Testing will begin soon.

- Please contact me if you have pressing concerns or inputs.

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