Keyword	Description	Units	Default (if any)	Examples of Values	M/O/C
PREVIOUS_MESSAGE_EPOCH	Creation epoch of the previous message from this originator for this space object. For format specification, see Section 7.5.10. NOTE – One may provide the previous message epoch without supplying the PREVIOUS_MESSAGE_ID, and vice versa.			2001-11-06T11:17:33	O
NEXT_MESSAGE_EPOCH	Anticipated (or actual) epoch of the next message from this originator for this space object. For format specification, see Section 7.5.10. NOTE – One may provide the next message epoch without supplying the NEXT_MESSAGE_ID, and vice versa.			2001-11-07T11:17:33	O
START_TIME	Time of the earliest data contained in the OCM, specified as either a relative or absolute time tag.			0.0 2001-11-06T00:00:00	O
STOP_TIME	Time of the latest data contained in the OCM, specified as either a relative or absolute time tag.			86400.0 2001-11-08T00:00:00	O
TIME_SPAN	Span of time that the OCM covers, measured in days. TIME_SPAN is defined as (STOP_TIME-START_TIME), measured in days, irrespective of whether START_TIME or STOP_TIME are provided by the message creator.	d		20.0	O
TAIMUTC_AT_TZERO	Difference (TAI – UTC) in seconds (i.e., total number of leap seconds elapsed since 1958) as modeled by the message originator at epoch “EPOCH_TZERO”.	s		36	O
NEXT_LEAP_EPOCH	Epoch of next leap second, specified as either a relative or absolute time tag.	s		86400.0 2016-12-31T23:59:60	O
NEXT_LEAP_TAIMUTC	Difference (TAI – UTC) in seconds (i.e., total number of leap seconds elapsed since 1958) incorporated by the message originator at epoch “NEXT_LEAP_EPOCH”.	s		37	O
UT1MUTC_AT_TZERO	Difference (UT1 – UTC) in seconds, as modeled by the originator at epoch “EPOCH_TZERO”.	s		0.357	O
EOP_SOURCE	Free-text field specifying the source and version of the message originator’s Earth Orientation Parameters (EOP) used in the creation of this message, including leap seconds, TAI-UT1, etc.			CELESTRAK_20201028	O
INTERP_METHOD_EOP	Free-text field specifying the method used to select or interpolate sequential EOP data.		LINEAR	PRECEDING_VALUE NEAREST_NEIGHBOR LINEAR LAGRANGE_ORDER_5	O

Keyword	Description	Units	Default (if any)	Examples of Values	M/O/C
ORB_REVNUM	The integer orbit revolution number associated with first orbit state in this orbit state time history block. NOTE – The first ascending node crossing that occurs AFTER launch or deployment is designated to be the beginning of orbit revolution number = one ("1").		0	1500 30007	O
ORB_REVNUM_BASIS	The integer orbit revolution number associated with first orbit state in this orbit state time history block. NOTE – The first ascending node crossing that occurs AFTER launch or deployment is designated to be the beginning of orbit revolution number = one ("1").		0	1500 30007	O
ORB_TYPE	Specifies the orbit element set type; selected per ANNEX B, Section B7.		CARTPV	CARTP	O
ORB_UNITS	A comma-delimited set of SI unit designations for each element of the orbit state time history **following the orbit state time tag** solely for informational purposes, provided as an free-text field enclosed in square brackets. When provided, each orbit state element shall have a corresponding units entry, with non-dimensional values (such as orbit eccentricity) denoted by "n/a". **NOTE – The listing of units via the ORB_UNITS keyword does not override the mandatory units specified for the selected ORB_TYPE** (links to the relevant SANA registries provided in ANNEX B, Section B7).			[km,km,km,km/s,km/s,km/s] [km,n/a,deg, deg, deg, deg]	O
… < Insert orbit state time history here >	Orbit state time history line(s) shall be formatted as specified in 6.2.4.11, containing time and orbit elements formatted as specified in 7.4.1.5 and corresponding to the selected ORB_TYPE in the SANA Orbital Elements registry (ANNEX B, Section B7). Units are as specified in this registry.				M
ORB_STOP	End of an orbit state vector or time history section.			n/a	M

6.2.5 OCM DATA: SPACE OBJECT PHYSICAL CHARACTERISTICS

6.2.5.1 Table 6-5 gives an overview of the OCM space object physical characteristics section. Only those keywords shown in Table 6-5 shall be used in OCM space object physical characteristics data.

6.2.5.2 At most, only one space object physical characteristics section shall appear in an OCM.

6.2.5.3 The space object physical characteristics data section in the OCM shall be indicated by two keywords: PHYS_START and PHYS_STOP.

6.2.5.4 The Space Object Optimally Encompassing Box (OEB) parameters are defined in further detail in Informative ANNEX F, Section F1.

6.2.6.11.1 The composition of the covariance matrix shall be commensurate with the specified COV_TYPE value.

6.2.6.11.2 Directly following the time tag specification on the same line as the time tag, all elements of the "NxN" covariance shall be presented in row wise fashion.

6.2.6.11.3 On each covariance line, the ordering of the covariance values is governed by the "COV_ORDERING" keyword. Acceptable values are:

6.2.6.11.3.1 **LTM:** Lower Triangular Matrix (LTM) beginning with element [1,1], followed by [2,1], [2,2], [3,1], [3,2] and so on, until all $\sum_{i=1}^{N} \boldsymbol{i}$ of the LTM entries have been provided as shown and ordered in Figure 6-1.

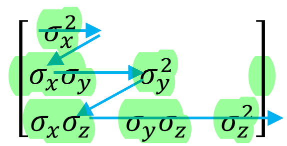

Figure 6-1: LTM covariance element ordering following time tag.

6.2.6.11.3.2 **UTM:** Upper Triangular Matrix (UTM) beginning with element [1,1], followed by [1,2], [1,3], [2,2], [2,3] and so on, until all $\sum_{i=1}^{N} \boldsymbol{i}$ of the UTM entries have been provided as shown and ordered in **Figure 6-2**.

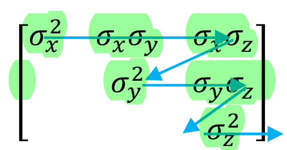

Figure 6-2: UTM covariance element ordering following time tag.

6.2.6.11.3.3 **FULL:** The full, symmetric covariance matrix, beginning with element [1,1], followed by [1,2], [1,3], [2,1], [2,2], [2,3], [3,1], [3,2] [3,3] and so on, until all covariance entries (there are $\boldsymbol{N^2}$ entries in total) have been provided as shown and ordered in **Figure 6-3**.

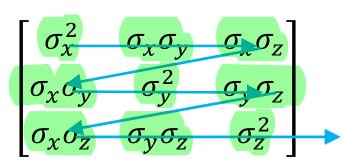

Figure 6-3: Full covariance element ordering following time tag.

6.2.6.11.3.4 LTMWCC: Lower Triangular Matrix conflated with cross-correlation terms, where correlation is obtained by dividing the covariance of the two variables by the product of their standard deviations. This combined matrix shall be provided beginning with covariance element [1,1], followed by $correlation_{xy}$, $correlation_{xz}$, covariance [2,1], [2,2], $correlation_{yz}$, and covariance [3,1], [3,2] [3,3] and so on, until all covariance entries (there are $\boldsymbol{N^2}$ entries in total) have been provided as shown and ordered in **Figure 6-4**.

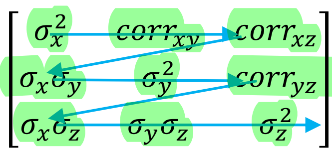

Figure 6-4: LTM covariance/correlation element ordering following time tag.

6.2.6.11.3.5 UTMWCC: Upper Triangular Matrix conflated with cross-correlation terms, provided beginning with covariance element [1,1], followed by [1,2] and [1,3], then $correlation_{xy}$, covariance [2,2], and [2,3], then $correlation_{xz}$, $correlation_{yz}$, and covariance [3,3] and so on, until all covariance entries (there are $\boldsymbol{N^2}$ entries in total) have been provided as shown and ordered in **Figure 6-5**.

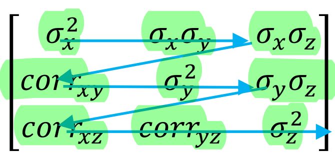

Figure 6-5: UTM covariance/correlation element ordering following time tag.

6.2.6.11.4 At least one space character must be used to separate the items in each covariance matrix data line as related in Section 7.4.1.6.

6.2.6.12 Variance and covariance values shall be expressed in floating point or scientific notation as related in Section 7.5. The number of significant figures and time steps suitable for interpolation of a covariance time history should be chosen according to best practice to avoid covariance interpolation loss of precision ANNEX H, References [H-6] and [H-13]).

NOTE – It is strongly recommended that covariance matrix time history interpolation be done by either (1) using orbit-dynamics-aware numerical methods as provided in [H-9] or (2) eigenvalue/vector decomposition, linear (or higher-order) interpolation of neighboring eigenvalues; Euler axis/angle rotation of eigenvectors at intermediate time(s) of interest; and re-composition of attained eigenvalues and eigenvectors into covariances at time(s) of interest (see ANNEX F, Section F5 and ANNEX H, References [H-10, H-11, and H-12]). Direct interpolation of covariance matrix components or failure to incorporate enough significant figures on the interpolated covariance elements can produce invalid (non-positive-semidefinite) covariances.

6.2.7.16.9 Maneuver elements of information shall be drawn from Table 6-8 or Table 6-9.

NOTE – Each set of data has practical benefits when applied to maneuver scenarios:

- Specification of a time history of acceleration parameters ACC_X, ACC_Y, and ACC_Z allows the OCM originator to portray and share the net effects of maneuvers without the OCM recipient needing to do complex finite burn modeling.
- Specification of ΔV parameters allows simplified modeling assuming impulsive (instantaneous velocity change) maneuvers.
- Specification of thrust parameters provides a finite burn capability. In the case of low-thrust and/or long-duration burns, sequential low-thrust interval maneuver lines may be used to reflect the evolution of the low-thrust maneuver thrust parameters.

Table 6-8: OCM Data: Selectable propulsive (i.e., non-deployment) maneuver fields in the maneuver time history data

Keyword	Description	Units	Examples of Values
TIME_ABSOLUTE	Absolute epoch time as formatted in Section 7.5.10.	n/a	2018-11-13T11:13:20.5Z
TIME_RELATIVE	Relative epoch time measured in SI seconds with respect to the epoch time specified via the EPOCH_TZERO keyword.	s	20157.26
MAN_DURA	The maneuver duration associated with this impulsive ΔV, thrust, and/or acceleration-imparted event.	s	200.0
DELTA_MASS	Mass change (where a negative number denotes a mass decrement/loss to the host) associated with this portion ("time slice") of the maneuver. For "thrust" specification, this mass change shall include the mass change prescribed by the rocket equation.	kg	-5.0
ACC_X	Acceleration component A_X in the selected maneuver frame.	km/s**2	0.000734092785
ACC_Y	Acceleration component A_Y in the selected maneuver frame.	km/s**2	0.000189779834
ACC_Z	Acceleration component A_Z in the selected maneuver frame.	km/s**2	0.0000794872502
ACC_INTERP	Acceleration vector Euler axis/angle interpolation mode between current and next acceleration line.	n/a	OFF ON
ACC_MAG_SIGMA	One-sigma percent error on acceleration magnitude.	%	1.0
ACC_DIR_SIGMA	One-sigma angular off-nominal acceleration vector direction.	deg	5.0
DV_X	Velocity increment ΔV_X in the selected maneuver reference frame. The actual ΔV should be impulsively applied at a time of <time tag> + ½ (MAN_DURA).	km/s	0.025
DV_Y	Velocity increment ΔV_Y in the selected maneuver reference frame. The actual ΔV should be impulsively applied at a time of <time tag> + ½ (MAN_DURA).	km/s	0.0015
DV_Z	Velocity increment ΔV_Z in the selected maneuver reference frame. The actual ΔV should be impulsively applied at a time of <time tag> + ½ (MAN_DURA).	km/s	0.00029
DV_MAG_SIGMA	One-sigma percent error on ΔV magnitude.	%	2.0
DV_DIR_SIGMA	One-sigma angular off-nominal ΔV vector direction.	deg	5.0

Keyword	Description	Units	Examples of Values
THR_X	Thrust component T_X measured in the selected maneuver reference frame.	N	1.0
THR_Y	Thrust component T_Y measured in the selected maneuver reference frame.	N	2.0
THR_Z	Thrust component T_Z measured in the selected maneuver reference frame.	N	3.0
THR_EFFIC	Thrust efficiency "η," typically ranging between 0.0 and 1.0, that must be applied to the nominal thrust X, Y, and Z constituents to obtain the net resultant thrust applied to the vehicle.	n/a	0.95
THR_INTERP	Thrust vector Euler axis/angle interpolation mode between current and next thrust line; values shall be selected as either "OFF" or "ON".	n/a	OFF ON
THR_ISP	Thrust specific impulse.	s	330.0
THR_MAG_SIGMA	One-sigma percent error on thrust magnitude.	%	2.0
THR_DIR_SIGMA	One-sigma angular off-nominal thrust vector direction.	deg	5.0

Keyword	Description	Units	Default (if any)	Examples of Values	M/O/C
CONSIDER_PARAMS	Free-text comma-delimited description of the consider parameters used in the orbit determination.			DRAG, SRP	O
SEDR	The Specific Energy Dissipation Rate, which is the amount of energy being removed from the object's orbit by atmospheric drag. This value is an average calculated during the OD. (See ANNEX F, Section F7 for definition.)	W/kg		4.54570E-05	O
SENSORS_N	The number of sensors used in the orbit determination.			3	O
SENSORS	Free-text comma-delimited description of the sensors used in the orbit determination.			EGLIN, FYLINGDALES	O
WEIGHTED_RMS	***(Useful / valid only for Batch OD systems).*** The weighted RMS residual ratio, defined as: $Weighted\ RMS = \sqrt{\frac{\sum_{i=1}^{N} w_i (y_i - \hat{y}_i)^2}{N}}$ Where y_i is the ith observation measurement $\hat{y}_i$ is the current estimate of y_i, $w_i = \frac{1}{\sigma_i^2}$ is the weight (sigma) associated with the measurement at the ith time and N is the number of observations. This is a value that can generally identify the quality of the most recent vector update and is used by the analyst in evaluating the OD process. A value of 1.00 is ideal.	(measurement units)		1.3	O
DATA_TYPES	Comma-separated list of observation data types utilized in this orbit determination. Although this is a free-text field, it is recommended at a minimum to use data type descriptor(s) as provided in Table 3-5 of the TDM standard [9] (excluding the DATA_START, DATA_STOP, and COMMENT keywords). Additional descriptors/detail is encouraged if the descriptors of Table 3-5 are not sufficiently clear, e.g., could replace ANGLE_1 and ANGLE_2 with RADEC (e.g., from a telescope), AZEL (e.g., from a ground radar), RANGE (whether from radar or laser ranging), etc.			ANGLE_1, ANGLE_2	O
OD_STOP	End of the orbit determination data section.			n/a	M

Sample Regular Expression for "Keyword = Multipartite CCSDS Numerical Values"

For orbit, covariance, and/or maneuver lines providing a multipartite sequence of numerical values, the Regex pattern provided in Fig. F-10 may be used (in this example, to capture and set value1, value2 and value3 for a 3-element set of numbers):

```
^(?:\s*)(?<value1>(?:[-+]?)(?:[0-9]*)(?:\.\d*)?(?:[eE][+-
]?\d+)?)(?:\s+)(?<value2>(?:[-+]?)(?:[0-
9]*)(?:\.\d*)?(?:[eE][+-]?\d+)?)(?:\s+)(?<value3>(?:[-
+]?)(?:[0-9]*)(?:\.\d*)?(?:[eE][+-]?\d+)?)(?:\s*)$
```

Fig. F- 10 Regex for string containing numerical value with optional units

F7 SPECIFIC ENERGY DISSIPATION RATE (SEDR) FORMULATION

An orbit's Specific Energy Dissipation Rate (SEDR) represents the amount of energy (W/kg) being removed from a satellite's orbit by atmospheric drag. It is a very useful metric for characterizing satellites since it accounts for both the drag environment (atmospheric density) and the 'area to mass ratio' of the specific object. It does this by including *drag acceleration* in the computation. Drag acceleration is proportional to atmospheric density and to satellite area to mass.

SEDR is computed as follows:

Instantaneous SEDR at time t is given by

$$SEDR(t) = -\vec{A}_D \bullet \vec{V}$$

where,

$\vec{A}_D$ = drag acceleration vector (inertial)

$\vec{V}$ = velocity vector (inertial)

Average SEDR over the orbit determination interval is given by

$$\frac{1}{T}\int_0^T SEDR(t)\,dt$$

where, to correctly average over a complete orbital revolution, *T* is an integer multiple of the satellite period. This consideration is primarily for eccentric orbits. Aside from this consideration, *T* is the orbit determination interval.