The Consultative Committee for Space Data Systems

Recommendation for Space Data System Standards

# CONJUNCTION DATA MESSAGE

RECOMMENDED STANDARD

CCSDS 508.0-P-1.0.1

PINK BOOK

December 2020

# AUTHORITY


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# FOREWORD

This document is a Recommended Standard for Conjunction Data Messages (CDMs) and has been prepared by the CCSDS. The CDM described in this Recommended Standard is the baseline concept for conjunction information interchange applications between interested parties.

This Recommended Standard establishes a common framework and provides a common basis for the format of conjunction information exchange between originators of conjunction assessment data and satellite owner/operators. It allows implementing organizations within each conjunction assessment originator to proceed coherently with the development of compatible derived standards for the flight and ground systems that are within their cognizance. Derived Agency standards can implement only a subset of the optional features allowed by the Recommended Standard and can incorporate features not addressed by this Recommended Standard.

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- Space and Upper Atmosphere Research Commission (SUPARCO)/Pakistan.
- Swedish Space Corporation (SSC)/Sweden.
- United States Geological Survey (USGS)/USA.

# DOCUMENT CONTROL

| Document | Title | Date | Status |
|---|---|---|---|
| CCSDS 508.0-B-1 | Conjunction Data Message, Recommended Standard, Issue 1 | June 2013 | Previous issue, superseded |
| CCSDS 508.0-B-1<br><br>CCSDS 508.0-B-1 EC 1 | Editorial change 1 | March 2014 | – corrects broken hyperlinks;<br>– updates references to superseded documents;<br>– updates obsolete style elements. |
| CCSDS 508.0-B-1 EC 2 | Editorial change 2 | February 2018 | – addresses minor typographical and layout issues. |
| CCSDS 508.0-B-1 Cor. 1 | Technical Corrigendum 1 | June 2018 | – adds direction to use Space Assigned Numbers Authority (SANA) registry values. |
| CCSDS 508.0-P-1.0.1 | Conjunction Data Message, Recommended Standard, Issue 1 | December 2020 | Updates from 5 year systematic review |

# CONTENTS

# CONTENTS (CONTINUED)

Section Page



Figures



Tables

# 1 INTRODUCTION

## 1.1 PURPOSE AND SCOPE

This Conjunction Data Message (CDM) Recommended Standard specifies a standard message format for use in exchanging spacecraft conjunction information between originators of Conjunction Assessments (CAs) and satellite owner/operators and other authorized parties. Such exchanges are used to inform satellite owner/operators of conjunctions between objects in space to enable consistent warning by different organizations employing diverse CA techniques.

This Recommended Standard will:

a) facilitate interoperability and enable consistent warning between data originators who supply CA and the satellite owner/operators who use it;

b) facilitate automation for the CA processes; and

c) provide critical information to enable timely CA decisions.

This document includes requirements and criteria that the message format has been designed to meet (see annex E). Also included are informative descriptions of conjunction information pertinent to performing CA (see annex F).

## 1.2 APPLICABILITY

This Recommended Standard is applicable to satellite operations in all environments in which close approaches and collisions among satellites are concerns. It contains the specification for a CDM designed for applications involving conjunction information interchange between originators of CAs and recipients. Conjunction information includes data types such as miss distance, probability of collision, Time of Closest Approach (TCA), and closest approach relative position and velocity. Further information describing the conjunction information contained in this message can be found in section 3 and annex F.

This message is suited for exchanges that involve manual or automated interaction. The attributes of a CDM make it suitable for use in machine-to-machine interfaces because of the large amount of data typically present. The CDM is self-contained. However, the presence of user defined keywords allows other information to be exchanged after being specified in an Interface Control Document (ICD) written jointly by the service originator and recipients. The CCSDS Navigation Working Group should be notified of new optional keywords for possible inclusion in future revisions of the standard.

It is desirable that CDM originators maintain consistency with respect to the optional keywords provided in their implementations; i.e., it is desirable that the composition of the CDMs provided not change on a frequent basis.

This Recommended Standard is applicable only to the message format and content, but not to its transmission nor to the algorithms used to produce the data within. The method of transmitting the message between exchange partners is beyond the scope of this document and could be specified in an ICD.

The methods used to predict conjunctions and calculate the probability of collision, and the definition of the conjunction assessment accuracy underlying a particular CDM, are also outside the scope of this Recommended Standard (the interested reader can consult references in annex G).

## 1.3 DOCUMENT STRUCTURE

Section 2 provides a brief overview of the CCSDS-recommended CDM.

Section 3 provides details about the structure and content of the CDM in 'Keyword = Value Notation' (KVN).

Section 4 provides details about the structure and content of the CDM in eXtensible Markup Language (XML).

Section 5 addresses the CDM data in general.

Section 6 discusses the syntax considerations of the CDM.

Annex A contains an Implementation Conformance Statement (ICS) proforma that may be used by implementers to compactly describe their implementations.

Annex B provides information on security, the Space Assigned Numbers Authority (SANA), and patent-related information.

Annex C provides CDM examples in both KVN and XML formats.

Annex D is a list of abbreviations and acronyms applicable to the CDM.

Annex E provides rationale and requirements for the CDM Recommended Standard.

Annex F provides a description of the CA information contained in the CDM.

Annex G provides informative references.

## 1.4 CONVENTIONS AND DEFINITIONS

### 1.4.1 NOTATION

#### 1.4.1.1 Unit Notations

The following conventions for unit notations apply throughout this Recommended Standard. Insofar as possible, an effort has been made to use units that are part of the International System of Units (SI); units are either SI base units, SI derived units, or units outside the SI that are accepted for use with the SI (see reference [1]). The units used within this document are as follows:

– km: kilometers;

– m: meters;

– d: days, 86400 SI seconds;

– s: SI seconds;

– kg: kilograms;

– W: watts;

– %: percent.

#### 1.4.1.2 General

The following notational conventions are used in this document:

a) multiplication of units is denoted with a single asterisk '*' (e.g., 'kg*s');

b) exponents of units are denoted with a double asterisk '**' (e.g., $m^2$ = m**2);

c) division of units is denoted with a single forward slash '/' (e.g., m/s).

### 1.4.2 NOMENCLATURE

#### 1.4.2.1 General

The CDM contains information about a conjunction between two space objects (hereafter referred to as 'Object1' and 'Object2').

#### 1.4.2.2 Normative Text

The following conventions apply for the normative specifications in this Recommended Standard:

a) the words 'shall' and 'must' imply a binding and verifiable specification;

b) the word ‘should’ implies an optional, but desirable, specification;

c) the word ‘may’ implies an optional specification;

d) the words ‘is’, ‘are’, and ‘will’ imply statements of fact.

NOTE – These conventions do not imply constraints on diction in text that is clearly informative in nature.

#### 1.4.2.3 Informative Text

In the normative sections of this document (sections 3-6), informative text is set off from the normative specifications either in notes or under one of the following subsection headings:

– Overview;

– Discussion.

### 1.4.3 OTHER CONVENTIONS

#### 1.4.3.1 Terminology

In this document, the term ‘ASCII’ is used generically to refer to the text character set defined in reference [2]. The terms ‘N/A’ and ‘n/a’ are defined to mean ‘not available’ or ‘not applicable’.

#### 1.4.3.2 Orthography

The following terms define orthographic conventions for XML notation in this Recommended Standard:

**CamelCase**. A style of capitalization in which the initial characters of concatenated words are capitalized, as in *CamelCase*.

**lowerCamelCase**. A variant of CamelCase in which the first character of a character string formed from concatenated words is lowercase, as in *lowerCamelCase*. In the case of a character string consisting of only a single word, only lowercase characters are used.

## 1.5 REFERENCES

The following publications contain provisions which, through reference in this text, constitute provisions of this Recommended Standard. At the time of publication, the editions indicated were valid. All publications are subject to revision, and users of this Recommended Standard are encouraged to investigate the possibility of applying the most recent editions of the publications indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS publications.

[1] *The International System of Units (SI)*. 8th ed. Sèvres, France: BIPM, 2006.

[2] *Information Technology—8-Bit Single-Byte Coded Graphic Character Sets—Part 1: Latin Alphabet No. 1*. International Standard, ISO/IEC 8859-1:1998. Geneva: ISO, 1998.

[3] Henry S. Thompson, et al., eds. *XML Schema Part 1: Structures*. 2nd ed. W3C Recommendation. N.p.: W3C, October 2004.

[4] Paul V. Biron and Ashok Malhotra, eds. *XML Schema Part 2: Datatypes*. 2nd ed. W3C Recommendation. N.p.: W3C, October 2004.

[5] *Time Code Formats*. Issue 4. Recommendation for Space Data System Standards (Blue Book), CCSDS 301.0-B-4. Washington, D.C.: CCSDS, November 2010.

[6] *XML Specification for Navigation Data Messages*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 505.0-B-1. Washington, D.C.: CCSDS, December 2010.

# 2 OVERVIEW

## 2.1 GENERAL

This section provides a high-level overview of the CCSDS-recommended CDM, a message format designed to facilitate standardized exchange of conjunction information between originators of CA data and satellite owner/operators.

## 2.2 CDM BASIC CONTENT

The CDM is ASCII format encoded either in plain text or XML (see references [2], [3], and [4]). This CDM document describes a KVN-formatted message as well as an XML-formatted message (it is desirable that an ICD specify which of these formats will be exchanged).

The CDM contains information about a single conjunction between Object1 and Object2. It contains

– Object1/Object2 positions/velocities at TCA with respect to one of a set of widely used reference frames.;

– Object1/Object2 covariances at TCA with respect to an object centered reference frame;

– the relative position/velocity of Object2 with respect to an Object1 centered reference frame;

– information relevant to how all the above data was determined.

This information is used by satellite owner/operators to evaluate the risk of a conjunction and plan maneuvers if warranted by that agency/organization. Where possible, the CDM is consistent with other CCSDS Navigation Data Messages (NDMs). Similar tables have been used to describe header, metadata, and data information. Common keywords have been used in order to minimize duplication and confusion (e.g., CREATION_DATE, ORIGINATOR, OBJECT_NAME, INTERNATIONAL_DESIGNATOR, etc.).

# 3 CDM CONTENT/STRUCTURE IN KVN

## 3.1 GENERAL

**3.1.1** The CDM in KVN shall consist of digital data represented as ASCII text lines. As depicted in Table 3-1, the lines constituting a CDM shall be represented as a combination of the following:

a) a header;

b) relative motion metadata/data;

c) metadata;

d) data for Object1;

e) data for Object2; and

f) user defined parameters.

**Table 3-1: CDM File Layout and Ordering Specification**

| Section | | Content |
|---|---|---|
| CDM Header | | A single header of the message |
| CDM Relative Motion Metadata | | Metadata/data describing relative motion of Object2 with respect to Object1 |
| Object1 | Metadata | Metadata about Object1 |
| | Data | Data for Object1 |
| Object2 | Metadata | Metadata about Object2 |
| | Data | Data for Object2 |
| User Defined Parameters (Optional) | | A user-defined parameters section containing data the existing CDM keywords do not accommodate |

NOTES

1 KVN messages contain one keyword per line (see 6.3.1.4).

2 The order of keywords in the KVN representation is fixed by this Recommended Standard (see 6.3.1.9).

**3.1.2** The CDM shall be plain text consisting of CA data for a single conjunction event. It shall be easily readable by both humans and computers.

**3.1.3** The method of exchanging CDMs shall be decided on a case-by-case basis by the participating parties and should be documented in an ICD.

## 3.2 CDM HEADER

The CDM header shall consist of the KVN elements defined in table 3-2, which specifies for each KVN header item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values; and

d) whether the item is mandatory (M), optional (O) or conditional (C). Combinations of flags may also be used to indicate mandatory if condition met (MC) and optional if condition met (OC). Optional keywords should be omitted if they have no assigned value.

**Table 3-2: CDM KVN Header**

| Keyword | Description | Example of Values | MOC |
|---|---|---|---|
| CCSDS_CDM_VERS | Format version in the form of ‘x.y’, where ‘y’ is incremented for corrections and minor changes, and ‘x’ is incremented for major changes. | 1.0<br>2.0 | M |
| COMMENT | (See 6.3.4 for formatting rules.) | COMMENT This is a comment | O |
| CREATION_DATE | Message creation date/time in Coordinated Universal Time (UTC). (See 6.3.2.6 for formatting rules.) | 2010-03-12T22:31:12.000<br>2010-071T22:31:12.000 | M |
| ORIGINATOR | Creating agency or owner/operator. Value should be the ‘Abbreviation’ value from the SANA ‘Organizations’ registry (https://sanaregistry.org/r/organizations) for an organization that has the Role of ‘Conjunction Data Message Originator’. (See 5.2.10 for formatting rules.) | JSPOC, ESA SST, CAESAR, JPL, SDC | M |
| CLASSIFICATION | User-defined free-text message classification/caveats of this CDM. It is recommended that selected values be pre-coordinated between exchanging entities by mutual agreement. | SBU<br>“Operator-proprietary data; secondary distribution not permitted” | O |
| MESSAGE_FOR | Spacecraft name(s) for which the CDM is provided. | SPOT, ENVISAT, IRIDIUM, INTELSAT | O |
| MESSAGE_ID | ID that uniquely identifies a message from a given originator. The format and content of the message identifier value are at the discretion of the originator. (See 5.2.10 for formatting rules.) | 201113719185<br>ABC-12_34 | M |

| Keyword | Description | Example of Values | MOC |
|---|---|---|---|
| CONJUNCTION_ID | Originator's ID that uniquely identifies the conjunction to which the message refers. (See 5.2.10 for formatting rules). | 20200610T10hz_SKYNET_5B_GORIZONT_9 | O |

## 3.3 CDM RELATIVE METADATA/DATA

The CDM relative metadata/data shall consist of the KVN elements defined in table 3-3, which specifies for each KVN relative metadata/data item:

a) the keyword to be used;

b) a short description of the item;

c) the units to be used if applicable; and

d) whether the item is mandatory (M), optional (O) or conditional (C). Combinations of flags may also be used to indicate mandatory if condition met (MC) and optional if condition met (OC). Optional keywords should be omitted if they have no assigned value.

**Table 3-3: CDM KVN Relative Motion Metadata/Data**

| Keyword | Description | Units | MOC |
|---|---|---|---|
| COMMENT | (See 6.3.4 for formatting rules.) | n/a | O |
| TCA | The date and time in UTC of the closest approach. (See 6.3.2.6 for formatting rules.) | n/a | M |
| MISS_DISTANCE | The length of the relative position vector. It indicates how close the two objects are at TCA. Data type = double. | m | M |
| MAHALANOBIS_DISTANCE | The length of the relative position vector, normalized to one-sigma dispersions of the combined error covariance in the direction of the relative position vector, as defined in informative Annex F1. Data type = double. | n/a | O |
| RELATIVE_SPEED | The length of the relative velocity vector. It indicates how fast the two objects are moving relative to each other at TCA. Data type = double. | m/s | O |
| RELATIVE_POSITION_R | The R component of Object2's position relative to Object1's position in the Radial, Transverse, and Normal (RTN) coordinate frame. (See annex F for definition.) Data type = double. | m | O |
| RELATIVE_POSITION_T | The T component of Object2's position relative to Object1's position in the RTN coordinate frame. (See annex F for definition.) Data type = double. | m | O |
| RELATIVE_POSITION_N | The N component of Object2's position relative to Object1's position in the RTN coordinate frame. (See annex F for definition.) Data type = double. | m | O |

| Keyword | Description | Units | MOC |
|---|---|---|---|
| RELATIVE_VELOCITY_R | The R component of Object2's velocity relative to Object1's velocity in the RTN coordinate frame. (See annex F for definition.) Data type = double. | m/s | O |
| RELATIVE_VELOCITY_T | The T component of Object2's velocity relative to Object1's velocity in the RTN coordinate frame. (See annex F for definition.) Data type = double. | m/s | O |
| RELATIVE_VELOCITY_N | The N component of Object2's velocity relative to Object1's velocity in the RTN coordinate frame. (See annex F for definition.) Data type = double. | m/s | O |
| START_SCREEN_PERIOD | The start time in UTC of the screening period for the conjunction assessment. (See 6.3.2.6 for formatting rules.) | n/a | O |
| STOP_SCREEN_PERIOD | The stop time in UTC of the screening period for the conjunction assessment. (See 6.3.2.6 for formatting rules.) | n/a | O |
| SCREEN_VOLUME_FRAME | Name of the Object1 centered reference frame in which the screening volume data are given. Available options are RTN and Transverse, Velocity, and Normal (TVN). (See annex F for definition.) | n/a | O |
| SCREEN_VOLUME_SHAPE | The type of screening metric or algorithm used, to include SPHERE, PC, PC_MAX, ELLIPSOID, or BOX | n/a | O |
| SCREEN_VOLUME_RADIUS | The radius of the screening volume (SCREEN_VOLUME_SHAPE = SPHERE). Data type = double. | M | O |
| SCREEN_PC_THRESHOLD | The collision probability screening threshold used to identify this conjunction. Data type = double. | n/a | O |
| SCREEN_VOLUME_X | The R or T (depending on if RTN or TVN is selected) component size of the screening volume (SCREEN_VOLUME_SHAPE = ELLIPSOID or BOX) in the SCREEN_VOLUME_FRAME. Data type = double. | m | O |
| SCREEN_VOLUME_Y | The T or V (depending on if RTN or TVN is selected) component size of the screening volume (SCREEN_VOLUME_SHAPE = ELLIPSOID or BOX) in the SCREEN_VOLUME_FRAME. Data type = double. | m | O |
| SCREEN_VOLUME_Z | The N component size of the screening volume (SCREEN_VOLUME_SHAPE = ELLIPSOID or BOX) in the SCREEN_VOLUME_FRAME. Data type = double. | m | O |
| SCREEN_ENTRY_TIME | The time in UTC when Object2 enters the screening volume (only relevant when SCREEN_VOLUME_SHAPE = SPHERE, ELLIPSOID or BOX). (See 6.3.2.6 for formatting rules.) | n/a | O |

| Keyword | Description | Units | MOC |
|---|---|---|---|
| SCREEN_EXIT_TIME | The time in UTC when Object2 exits the screening volume (only relevant when SCREEN_VOLUME_SHAPE = SPHERE, ELLIPSOID or BOX). (See 6.3.2.6 for formatting rules.) | n/a | O |
| COLLISION_PERCENTILE | An array of 1 to n elements indicating the percentile(s) for which estimates of the collision probability are provided in the COLLISION_PROBABILITY variable. Data type = integer array. | | O |
| COLLISION_PROBABILITY | If COLLISION_PERCENTILE present, an array of 1 to n elements specifying the estimate of collision probability that Object1 and Object2 will collide, accounting for estimated uncertainties in covariance realism and variability in Object1 and Object2 orientation at TCA with respect to the encounter plane for each percentile specified in COLLISION_PERCENTILE. Data type = double array.<br><br>If COLLISION_PERCENTILE not present, the best estimate (median) probability (denoted ‘p’ where 0.0<=p<=1.0), that Object1 and Object2 will collide, accounting for estimated uncertainties in covariance realism and variability in Object1 and Object2 orientation at TCA with respect to the encounter plane. Data type = double. | n/a | O |
| COLLISION_PROBABILITY_METHOD | The method that was used to calculate the collision probability. (See annex F for definition.) | n/a | O |
| COLLISION_MAX_PROBABILITY | The maximum collision probability that Object1 and Object2 will collide, as assessed via COLLISION_ MAX_PC_METHOD. Data type = double. | n/a | O |
| COLLISION_ MAX_PC_METHOD | The method that was used to calculate the collision probability. (See Annex F1 for definition.) | n/a | O |

| Keyword | Description | Units | MOC |
|---|---|---|---|
| SEFI_COLLISION_PROBABILITY | If COLLISION_PERCENTILE present, an array of 1 to n elements specifying the space environment fragmentation impact adjusted estimate of collision probability that Object1 and Object2 will collide, accounting for estimated uncertainties in covariance realism and variability in Object1 and Object2 orientation at TCA with respect to the encounter plane for each percentile specified in COLLISION_PERCENTILE. Data type = double array.<br><br>If COLLISION_PERCENTILE not present, the best estimate (median) space environment fragmentation impact adjusted probability (denoted 'p' where 0.0<=p<=1.0), that Object1 and Object2 will collide, accounting for estimated uncertainties in covariance realism and variability in Object1 and Object2 orientation at TCA with respect to the encounter plane.<br>Data type = double.<br><br>See Annex F1 for definition of space environment fragmentation impact adjustment. | n/a | O |
| **Information about the previous and next messages to be issued** | | | |
| PREVIOUS_MESSAGE_ID | ID of previous CDM issued for event identified by CONJUNCTION_ID. | n/a | O |
| PREVIOUS_MESSAGE_EPOCH | UTC epoch of the previous CDM issued for the event identified by CONJUNCTION_ID. | n/a | O |
| NEXT_MESSAGE_EPOCH | Scheduled UTC epoch of the next CDM associated with the event identified by CONJUNCTION_ID. | n/a | O |

## 3.4 CDM OBJECT1 AND OBJECT2 METADATA

The CDM metadata shall consist of the KVN elements defined in table 3-4, which specifies for each KVN metadata item:

a) the keyword to be used;

b) a short description of the item;

c) normative values or examples of allowed values;

d) whether the 'Normative Values/Examples' column contains normative values (N) or examples of allowed values (E) for the item; and

e) whether the item is mandatory (M), optional (O) or conditional (C). Combinations of flags may also be used to indicate mandatory if condition met (MC) and optional if condition met (OC). Optional keywords should be omitted if they have no assigned value.

NOTE – Table 3-4 and table 3-5 will be used to define both Object1 and Object2 depending on the value of the keyword OBJECT which is specified in table 3-4.

**Table 3-4: CDM KVN Metadata**

| Keyword | Description | Normative Values/ Examples | N/E | MOC |
|---|---|---|---|---|
| COMMENT | (See 6.3.4 for formatting rules.) | COMMENT This is a comment | E | O |
| OBJECT | The object to which the metadata and data apply (Object1 or Object2). | OBJECT1<br>OBJECT2 | N | M |
| OBJECT_DESIGNATOR | Free text field specification of the unique satellite identification designator for the object, as reflected in the catalog whose name is "CATALOG_NAME". If the ID is not known (uncorrelated object), "UNKNOWN" may be used. (see 5.2.10 for formatting rules). | 22444<br>18SPCS 18571<br>2147483648_04ae[…]d84c<br>UNKNOWN | E | M |
| CATALOG_NAME | The satellite catalog used for the object. Value should be taken from the SANA 'Conjunction Data Message CATALOG_NAME' registry (https://sanaregistry.org/r/cdm_catalog). (See 5.2.10 for formatting rules.) | SATCAT | E | M |
| OBJECT_NAME | Free text field containing the name of the object (formatting rules specified in 5.2.10). There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the UN Office of Outer Space Affairs designator index —reference [7], which include Object name and international designator of the participant. If the object name is not known (uncorrelated object), "UNKNOWN" may be used. | SPOT-7<br>ENVISAT<br>IRIDIUM NEXT-8<br>INTELSAT G-15<br>UNKNOWN | E | M |

| Keyword | Description | Normative Values/ Examples | N/E | MOC |
|---|---|---|---|---|
| INTERNATIONAL_DESIGNATOR | Free text field containing an international designator for the object as assigned by the UN Committee on Space Research (COSPAR) and the US National Space Science Data Center (NSSDC). Such designator values have the following COSPAR format: YYYY-NNNP{PP}, where:<br>YYYY = Year of launch.<br>NNN = Three-digit serial number of launch in year YYYY (with leading zeros).<br>P{PP} = At least one capital letter for the identification of the part brought into space by the launch.<br>In cases where the object has no international designator, the value UNKNOWN may be used. (See 5.2.10 for further formatting rules.) | 2002-021A<br>2002-009A<br>1997-020AA<br>1998-037ABC<br>2001-049PE<br>UNKNOWN | E | M |
| OBJECT_TYPE | Specification of the type of object. Select from the accepted set of values enumerated in the SANA Registry of Object Types, located at: https://sanaregistry.org/r/orbject_types | PAYLOAD<br>ROCKET BODY<br>DEBRIS<br>UNKNOWN<br>OTHER | N | O |
| OPERATOR_CONTACT_POSITION | Contact position of the owner/operator of the object. | ORBITAL SAFETY ANALYST (OSA), NETWORK CONTROLLER | E | O |
| OPERATOR_ORGANIZATION | Contact organization of the object. | EUMETSAT, ESA, INTELSAT, IRIDIUM | E | O |
| OPERATOR_PHONE | Phone number of the contact position or organization for the object. | +49615130312 | E | O |
| OPERATOR_EMAIL | Email address of the contact position or organization of the object. | JOHN.DOE@ SOMEWHERE.NET | E | O |
| ODM_MSG_LINK | Free text field containing a unique identifier of Orbit Data Message(s) that are linked (relevant) to this Conjunction Data Message. | ODM_MSG_35132.txt<br>ODM_ID_0572 | E | O |
| ADM_MSG_LINK | Free text field containing a unique identifier of Attitude Data Message(s) that are linked (relevant) to this Conjunction Data Message. | ATT_MSG_35132.txt<br>ATT_ID_0572 | E | O |

| Keyword | Description | Normative Values/ Examples | N/E | MOC |
|---|---|---|---|---|
| TDM_MSG_LINK | Free text field containing a unique identifier of Tracking Data Message(s) that are linked (relevant) to this Conjunction Data Message. | TDM_MSG_35132.txt<br>TDM_ID_0572 | E | O |
| EPHEMERIS_NAME | Unique name of the external ephemeris file used for the object or NONE. This is used to indicate whether an external (i.e., Owner/Operator [O/O] provided) ephemeris file was used to calculate the CA. If 'NONE' is specified, then the output of the most current Orbit Determination (OD) of the CDM originator was used in the CA. | EPHEMERIS SATELLITE A,<br>NONE | E | M |
| OBS_BEFORE_NEXT_MESSGSE | Flag indicating whether new tracking observations are anticipated prior to the issue of the next CDM associated with the event specified by CONJUNCTION_ID. N/A if no other message is specified. | YES<br>NO<br>N/A | N | O |
| COVARIANCE_METHOD | Method used to calculate the covariance during the OD that produced the state vector, or whether an arbitrary, non-calculated default value was used. Caution should be used when using the default value for calculating collision probability. | CALCULATED<br>DEFAULT | N | M |
| MANEUVERABLE | The maneuver capacity of the object. (See 1.4.3.1 for definition of 'N/A'.) | YES<br>NO<br>N/A | N | M |
| ORBIT_CENTER | Origin of the CDM reference frame about which Object1 and Object2 orbit, which shall be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter. Natural bodies shall be selected from the accepted set of values enumerated in the SANA Registry of Orbit Centers, located at: https://sanaregistry.org/r/orbit_centers.<br><br>If not specified, the center is assumed to be Earth. | EARTH<br>SUN<br>MOON<br>MARS | E | O |

| Keyword | Description | Normative Values/ Examples | N/E | MOC |
|---|---|---|---|---|
| REF_FRAME | Name of the reference frame in which the state vector data are provided. Value must be selected from the list of reference frame values for *_REF_FRAME keywords as enumerated in the SANA Registry of Celestial Body Reference Frames, located at: https://sanaregistry.org/r/celestial_body_reference_frames.<br><br>The selected reference frame is the same for both Object1 and Object2. | ICRF3<br>ITRF | N | M |
| COV_TYPE | Flag indicating the type of covariance information provided. Value must be one of those listed to the right. If not included RTN is assumed. | RTN<br>XYZ<br>CSIG3EIGVEC3 | N | O |
| COV_REF_FRAME | Name of the reference frame in which the xyz covariance data are given. Value must be selected from the list of reference frame values for *_REF_FRAME keywords as enumerated in the SANA Registry of Celestial Body Reference Frames, located at: The selected reference frame is the same for both Object 1 and Object 2 covariances.<br><br>(Conditional on COV_TYPE present and = XYZ) | ITRF3<br>ITRF | N | MC |
| GRAVITY_MODEL | The gravity model (selected from the accepted set of gravity model names enumerated in the SANA Registry of Gravity Models, located at: https://sanaregistry.org/r/gravity_models, followed by the degree (D) and order (O) of the applied spherical harmonic coefficients used in the simulation.<br><br>NOTE: Specifying a zero value for “order” (e.g., 2D 0O) denotes zonals (J2 … JD) | EGM-96: 36D 36O<br>WGS-84: 8D 0O<br>GGM-01: 36D 36O<br>TEG-4: 36D 36O | E | O |
| ATMOSPHERIC_MODEL | Name of atmosphere model, which shall be selected from the accepted set of values enumerated in the SANA Registry of Atmosphere Models, located at: https://sanaregistry.org/r/atmosphere_models | MSISE90<br>NRLMSIS00<br>J70<br>J71<br>JROBERTS<br>DTM<br>JB2008 | E | O |

| Keyword | Description | Normative Values/ Examples | N/E | MOC |
|---|---|---|---|---|
| N_BODY_PERTURBATIONS | One OR MORE (N-body) gravitational perturbations bodies used. Values, listed serially in comma-delimited fashion, denote a natural solar or extra-solar system body (stars, planets, asteroids, comets, and natural satellites). Note that only those entries denoted as an “Attracting Body” enumerated in the SANA Registry of Orbit Centers, located at: https://sanaregistry.org/r/orbit_centers are acceptable values. | MOON, SUN, JUPITER | E | O |
| SOLAR_RAD_PRESSURE | Indication of whether solar radiation pressure perturbations were used for the OD of the object. | YES<br>NO | N | O |
| EARTH_TIDES | Indication of whether solid Earth and ocean tides were used for the OD of the object. | YES<br>NO | N | O |
| INTRACK_THRUST | Indication of whether in-track thrust modeling was used for the OD of the object. | YES<br>NO | N | O |

## 3.5 CDM OBJECT1 AND OBJECT2 DATA

**3.5.1** The CDM Data section shall consist of two separate data blocks (one for “Object1” and the second for “Object2”), each of which will consist of the following logical blocks:

- OD Parameters;
- Additional Parameters;
- State Vector; and
- Covariance Matrix.

**3.5.2** The covariance may be specified in one of three formats, these being RTN, XYZ and the eigenvector decomposition format, as indicated by the COV_TYPE keyword. If the COV_TYPE keyword is not present then RTN formulation is assumed in order to ensure backwards compatibility with previous message formats. If COV_TYPE is specified as XYZ, then the reference frame used for the covariance must be specified using the COV_REF_FRAME parameter.

NOTE: If covariance data for Object1 and Object2 are obtained by interpolation of neighboring relative time points within a covariance matrix time history, such interpolation shall be accomplished by the following process: (1) eigenvalue/vector decomposition; (2) linear (or higher-order) interpolation of neighboring eigenvalues; (3) Euler axis/angle rotation of eigenvectors at intermediate time(s) of interest; and (4) Re-composition of attained eigenvalues and eigenvectors into covariances at time(s) of interest [G12]. Direct interpolation of covariance matrix components or failure to incorporate sufficient digits of precision on the interpolated covariance elements can produce invalid (non-positive-semidefinite) covariances.

**3.5.2.1** The digits of precision provided for orbit and covariance data should be chosen according to best practice to avoid positional and error dispersion loss of precision [G14 and G15], with covariance data being supplied with at least seven significant figures**.**

**3.5.3** The logical blocks of the CDM Data section shall consist of KVN elements as defined in table 3-5, which specifies for each data item:

a) the keyword to be used;

b) a short description of the item;

c) the units to be used if applicable; and

d) whether the item is mandatory (M), optional (O) or conditional (C). Combinations of flags may also be used to indicate mandatory if condition met (MC) and optional if condition met (OC). Optional keywords should be omitted if they have no assigned value.

**Table 3-5: CDM KVN Data**

| Keyword | Description | Units | MOC |
|---|---|---|---|
| COMMENT | (See 6.3.4 for formatting rules.) | n/a | O |
| **OD Parameters** | | | |
| COMMENT | (See 6.3.4 for formatting rules.) | n/a | O |
| TIME_LASTOB_START | The start of a time interval (UTC) that contains the time of the last accepted observation. (See 6.3.2.6 for formatting rules.) For an exact time, the time interval is of zero duration (i.e., same value as that of TIME_LASTOB_END). | n/a | O |
| TIME_LASTOB_END | The end of a time interval (UTC) that contains the time of the last accepted observation. (See 6.3.2.6 for formatting rules.) For an exact time, the time interval is of zero duration (i.e., same value as that of TIME_LASTOB_START). | n/a | O |
| RECOMMENDED_OD_SPAN | The recommended OD time span calculated for the object. (See annex F for definition.) Data type = double. | d | O |
| ACTUAL_OD_SPAN | Based on the observations available and the RECOMMENDED_OD_SPAN, the actual time span used for the OD of the object. (See annex F for definition.) Data type = double. | d | O |
| OBS_AVAILABLE | The number of observations available for the OD of the object. (See annex F for definition.) Data type = integer. | n/a | O |

| Keyword | Description | Units | MOC |
|---|---|---|---|
| OBS_USED | The number of observations accepted for the OD of the object. (See annex F for definition.) Data type = integer. | n/a | O |
| TRACKS_AVAILABLE | The number of sensor tracks available for the OD of the object. (See annex F for definition.) Data type = integer. | n/a | O |
| TRACKS_USED | The number of sensor tracks accepted for the OD of the object. (See annex F for definition.) Data type = integer. | n/a | O |
| RESIDUALS_ACCEPTED | The percentage of residuals accepted in the OD of the object. Data type = double, range = 0.0 to 100.0. | % | O |
| WEIGHTED_RMS | The weighted Root Mean Square (RMS) of the residuals from a batch least squares OD. (See annex F for definition.) Data type = double. | n/a | O |
| **Additional Parameters** | | | |
| COMMENT | (See 6.3.4 for formatting rules.) | n/a | O |
| AREA_PC | Typical area (or cross-section) of the object to be used in the calculation of the probability of collision. (See annex F for definition.) Data type = double. | m**2 | O |
| AREA_PC_MIN | Minimum area (or cross-section) of the object to be used in the calculation of the probability of collision. Data type = double. | m**2 | O |
| AREA_PC_MAX | Maximum area (or cross-section) of the object to be used in the calculation of the probability of collision. Data type = double. | m**2 | O |
| AREA_DRG | The effective area of the object exposed to atmospheric drag. (See annex F for definition.) Data type = double. | m**2 | O |
| AREA_SRP | The effective area of the object exposed to solar radiation pressure. (See annex F for definition.) Data type = double. | m**2 | O |
| OEB_PARENT_FRAME | Reference frame which maps to the Optimally Enclosing Box (OEB) frame via the Euler sequence OEB_ROLL and OEB_YAW. | n/a | O |
| OEB_PARENT_FRAME_EPOCH | Epoch of the OEB reference frame if not intrinsic to the definition of the reference frame. | n/a | O |
| OEB_Q1 | q1 = e1 * sin(θ/2), where θ = Euler rotation angle and e1 = 1st component of Euler rotation axis for the rotation that maps from the OEB_PARENT_FRAME (defined above) to the frame aligned with the OEB (defined in ANNEX F, Section F4). A value of “-999” denotes a tumbling space object. Data type = double. | n/a | O |

| Keyword | Description | Units | MOC |
|---|---|---|---|
| OEB_Q2 | q2 = e2 * sin(θ/2), where θ = Euler rotation angle and e2 = 2nd component of Euler rotation axis for the rotation that maps from the OEB_PARENT_FRAME (defined above) to the frame aligned with the OEB (defined in ANNEX F, Section F4). A value of "-999" denotes a tumbling space object. Data type = double. | n/a | O |
| OEB_Q3 | q3 = e3 * sin(θ/2), where θ = Euler rotation angle and e3 = 3rd component of Euler rotation axis for the rotation that maps from the OEB_PARENT_FRAME (defined above) to the frame aligned with the OEB (defined in ANNEX F, Section F4). A value of "-999" denotes a tumbling space object. Data type = double. | n/a | O |
| OEB_QC | qc = cos(θ/2), where θ = Euler axis/angle rotation angle for the rotation that maps from the OEB_PARENT_FRAME (defined above) to the frame aligned with the OEB (defined in ANNEX F, Section F4). qc shall be made non-negative by convention. A value of "-999" denotes a tumbling space object. Data type = double. | n/a | O |
| OEM_MAX | Maximum physical dimension of the OEB. Data type = double. | m | O |
| OEB_MED | Medium physical dimension of the OEB. Data type = double. | m | O |
| OEB_MIN | Minimum physical dimension of the OEB. Data type = double. | m | O |
| AREA_ALONG_OEB_MAX | Cross-sectional area of the object when viewed along maximum OEB direction as defined in Annex F, Section F4. Data type = double. | m**2 | O |
| AREA_ALONG_OEB_MED | Cross-sectional area of the object when viewed along medium OEB direction as defined in Annex F, Section F4. Data type = double. | m**2 | O |
| AREA_ALONG_OEB_MIN | Cross-sectional area of the object when viewed along minimum OEB direction as defined in Annex F, Section F4. Data type = double. | m**2 | O |
| RCS | Typical (50th percentile) effective Radar Cross Section of the space object sampled over all possible viewing angles. Data type = double. | m**2 | O |
| RCS_MIN | Minimum Radar Cross Section observed for this object. Data type = double. | m**2 | O |
| RCS_MAX | Maximum Radar Cross Section observed for this object. Data type = double. | m**2 | O |

| Keyword | Description | Units | MOC |
|---|---|---|---|
| VM_ABSOLUTE | Typical (50th percentile) absolute Visual Magnitude of the space object sampled over all possible viewing angles and “normalized” as discussed in Annex F, Section F4, to a 1 AU Sun-to-target distance, a phase angle of 0° and a 40,000 km target-to-sensor distance (equivalent of GEO satellite tracked at 15.6° above local horizon). Data type = double. | n/a | O |
| VM_APPARENT_MIN | Minimum apparent Visual Magnitude observed for this space object. Data type = double. | n/a | O |
| VM_APPARENT | Typical (50th percentile) apparent Visual Magnitude observed for this space object. Data type = double. | n/a | O |
| VM_APPARENT_MAX | Maximum apparent Visual Magnitude observed for this space object (NOTE: The “MAX” value represents the brightest observation, which associates with a lower Vmag). Data type = double. | n/a | O |
| REFLECTIVITY | Typical (50th percentile) coefficient of reflectivity of the space object over all possible viewing angles, ranging from -1.0 to +1.0. Data type = double. | n/a | O |
| MASS | The mass of the object. Data type = double. | kg | O |
| HBR | Object hard body radius, the radius of the sphere used to represent the physical dimensions of this individual space object (Object 1 or Object2), for use in calculating the probability of collision. Data type = double. | m | O |
| CD_AREA_OVER_MASS | The object’s $C_D$•*A/m* used to propagate the state vector and covariance to TCA. (See annex F for definition.) Data type = double. | m**2/kg | O |
| CR_AREA_OVER_MASS | The object’s $C_r$ •*A/m* used to propagate the state vector and covariance to TCA. (See annex F for definition.) Data type = double. | m**2/kg | O |
| THRUST_ACCELERATION | The object’s acceleration due to in-track thrust used to propagate the state vector and covariance to TCA. (See annex F for definition.) Data type = double. | m/s**2 | O |
| SEDR | 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 for definition.) Data type = double. | W/kg | O |
| APOAPSIS_HEIGHT | The distance of the furthest point in the objects orbit above the equatorial radius of the central body about which the object is orbiting. Data type = double. | km | O |

| Keyword | Description | Units | MOC |
|---|---|---|---|
| PERIAPSIS_HEIGHT | The distance of the closest point in the objects orbit above the central body about which the object is orbiting. Data type = double. | km | O |
| INCLINATION | The angle between the objects orbit plane and the orbit center equatorial plane. Data type = double. | deg | O |
| COV_CONFIDENCE | A measure of the confidence in the covariance errors matching reality, as characterized via a Wald test, a Chi-squared test, the log of likelihood, or a numerical representation per mutual agreement. Data type = double. | n/a | O |
| COV_CONFIDENCE_METHOD | A free text field indicating the method used for the calculation of COV_CONFIDENCE. (Condition COV_CONFIDENCE present) | n/a | MC |
| **State Vector (all values have data type=double)** | | | |
| COMMENT | (See 6.3.4 for formatting rules.) | n/a | O |
| X | Object Position Vector X component. | km | M |
| Y | Object Position Vector Y component. | km | M |
| Z | Object Position Vector Z component. | km | M |
| X_DOT | Object Velocity Vector X component. | km/s | M |
| Y_DOT | Object Velocity Vector Y component. | km/s | M |
| Z_DOT | Object Velocity Vector Z component. | km/s | M |
| **Covariance Matrix in the RTN Coordinate Frame** (see annex F for definition) (Covariance Matrix 9×9 Lower Triangular Form. All parameters of the 6×6 position/velocity submatrix must be given. All data type=double.) **Conditional on COV_TYPE either not present or = RTN** | | | |
| COMMENT | (See 6.3.4 for formatting rules.) | n/a | OC |
| CR_R | Object covariance matrix [1,1]. | m**2 | MC |
| CT_R | Object covariance matrix [2,1]. | m**2 | MC |
| CT_T | Object covariance matrix [2,2]. | m**2 | MC |
| CN_R | Object covariance matrix [3,1]. | m**2 | MC |
| CN_T | Object covariance matrix [3,2]. | m**2 | MC |
| CN_N | Object covariance matrix [3,3]. | m**2 | MC |
| CRDOT_R | Object covariance matrix [4,1]. | m**2/s | MC |
| CRDOT_T | Object covariance matrix [4,2]. | m**2/s | MC |
| CRDOT_N | Object covariance matrix [4,3]. | m**2/s | MC |
| CRDOT_RDOT | Object covariance matrix [4,4]. | m**2/s**2 | MC |
| CTDOT_R | Object covariance matrix [5,1]. | m**2/s | MC |
| CTDOT_T | Object covariance matrix [5,2]. | m**2/s | MC |
| CTDOT_N | Object covariance matrix [5,3]. | m**2/s | MC |
| CTDOT_RDOT | Object covariance matrix [5,4]. | m**2/s**2 | MC |
| CTDOT_TDOT | Object covariance matrix [5,5]. | m**2/s**2 | MC |
| CNDOT_R | Object covariance matrix [6,1]. | m**2/s | MC |
| CNDOT_T | Object covariance matrix [6,2]. | m**2/s | MC |
| CNDOT_N | Object covariance matrix [6,3]. | m**2/s | MC |
| CNDOT_RDOT | Object covariance matrix [6,4]. | m**2/s**2 | MC |
| CNDOT_TDOT | Object covariance matrix [6,5]. | m**2/s**2 | MC |

| Keyword | Description | Units | MOC |
|---|---|---|---|
| CNDOT_NDOT | Object covariance matrix [6,6]. | m**2/s**2 | MC |
| CDRG_R | Object covariance matrix [7,1]. | m**3/kg | OC |
| CDRG_T | Object covariance matrix [7,2]. | m**3/kg | OC |
| CDRG_N | Object covariance matrix [7,3]. | m**3/kg | OC |
| CDRG_RDOT | Object covariance matrix [7,4]. | m**3/(kg*s) | OC |
| CDRG_TDOT | Object covariance matrix [7,5]. | m**3/(kg*s) | OC |
| CDRG_NDOT | Object covariance matrix [7,6]. | m**3/(kg*s) | OC |
| CDRG_DRG | Object covariance matrix [7,7]. | m**4/kg**2 | OC |
| CSRP_R | Object covariance matrix [8,1]. | m**3/kg | OC |
| CSRP_T | Object covariance matrix [8,2]. | m**3/kg | OC |
| CSRP_N | Object covariance matrix [8,3]. | m**3/kg | OC |
| CSRP_RDOT | Object covariance matrix [8,4]. | m**3/(kg*s) | OC |
| CSRP_TDOT | Object covariance matrix [8,5]. | m**3/(kg*s) | OC |
| CSRP_NDOT | Object covariance matrix [8,6]. | m**3/(kg*s) | OC |
| CSRP_DRG | Object covariance matrix [8,7]. | m**4/kg**2 | OC |
| CSRP_SRP | Object covariance matrix [8,8]. | m**4/kg**2 | OC |
| CTHR_R | Object covariance matrix [9,1]. | m**2/s**2 | OC |
| CTHR_T | Object covariance matrix [9,2]. | m**2/s**2 | OC |
| CTHR_N | Object covariance matrix [9,3]. | m**2/s**2 | OC |
| CTHR_RDOT | Object covariance matrix [9,4]. | m**2/s**3 | OC |
| CTHR_TDOT | Object covariance matrix [9,5]. | m**2/s**3 | OC |
| CTHR_NDOT | Object covariance matrix [9,6]. | m**2/s**3 | OC |
| CTHR_DRG | Object covariance matrix [9,7]. | m**3/(kg*s**2) | OC |
| CTHR_SRP | Object covariance matrix [9,8]. | m**3/(kg*s**2) | OC |
| CTHR_THR | Object covariance matrix [9,9]. | m**2/s**4 | OC |
| **Covariance Matrix in the XYZ Coordinate Frame** (defined by value of COV_REF_FRAME)<br>(Covariance Matrix 9×9 Lower Triangular Form. All parameters of the 6×6 position/velocity submatrix must be given. All data type=double.)<br>**Conditional on COV_TYPE = XYZ** | | | |
| COMMENT | (See 6.3.4 for formatting rules.) | n/a | OC |
| CX_X | Object covariance matrix [1,1]. | m**2 | MC |
| CY_X | Object covariance matrix [2,1]. | m**2 | MC |
| CY_Y | Object covariance matrix [2,2]. | m**2 | MC |
| CZ_X | Object covariance matrix [3,1]. | m**2 | MC |
| CZ_Y | Object covariance matrix [3,2]. | m**2 | MC |
| CZ_Z | Object covariance matrix [3,3]. | m**2 | MC |
| CXDOT_X | Object covariance matrix [4,1]. | m**2/s | MC |
| CXDOT_Y | Object covariance matrix [4,2]. | m**2/s | MC |
| CXDOT_Z | Object covariance matrix [4,3]. | m**2/s | MC |
| CXDOT_XDOT | Object covariance matrix [4,4]. | m**2/s**2 | MC |
| CYDOT_X | Object covariance matrix [5,1]. | m**2/s | MC |
| CYDOT_Y | Object covariance matrix [5,2]. | m**2/s | MC |
| CYDOT_Z | Object covariance matrix [5,3]. | m**2/s | MC |
| CYDOT_XDOT | Object covariance matrix [5,4]. | m**2/s**2 | MC |
| CYDOT_YDOT | Object covariance matrix [5,5]. | m**2/s**2 | MC |
| CZDOT_X | Object covariance matrix [6,1]. | m**2/s | MC |

| Keyword | Description | Units | MOC |
|---|---|---|---|
| CZDOT_Y | Object covariance matrix [6,2]. | m**2/s | MC |
| CZDOT_Z | Object covariance matrix [6,3]. | m**2/s | MC |
| CZDOT_XDOT | Object covariance matrix [6,4]. | m**2/s**2 | MC |
| CZDOT_YDOT | Object covariance matrix [6,5]. | m**2/s**2 | MC |
| CZDOT_ZDOT | Object covariance matrix [6,6]. | m**2/s**2 | MC |
| CDRG_X | Object covariance matrix [7,1]. | m**3/kg | OC |
| CDRG_Y | Object covariance matrix [7,2]. | m**3/kg | OC |
| CDRG_Z | Object covariance matrix [7,3]. | m**3/kg | OC |
| CDRG_XDOT | Object covariance matrix [7,4]. | m**3/(kg*s) | OC |
| CDRG_YDOT | Object covariance matrix [7,5]. | m**3/(kg*s) | OC |
| CDRG_ZDOT | Object covariance matrix [7,6]. | m**3/(kg*s) | OC |
| CDRG_DRG | Object covariance matrix [7,7]. | m**4/kg**2 | OC |
| CSRP_X | Object covariance matrix [8,1]. | m**3/kg | OC |
| CSRP_Y | Object covariance matrix [8,2]. | m**3/kg | OC |
| CSRP_Z | Object covariance matrix [8,3]. | m**3/kg | OC |
| CSRP_XDOT | Object covariance matrix [8,4]. | m**3/(kg*s) | OC |
| CSRP_YDOT | Object covariance matrix [8,5]. | m**3/(kg*s) | OC |
| CSRP_ZDOT | Object covariance matrix [8,6]. | m**3/(kg*s) | OC |
| CSRP_DRG | Object covariance matrix [8,7]. | m**4/kg**2 | OC |
| CSRP_SRP | Object covariance matrix [8,8]. | m**4/kg**2 | OC |
| CTHR_X | Object covariance matrix [9,1]. | m**2/s**2 | OC |
| CTHR_Y | Object covariance matrix [9,2]. | m**2/s**2 | OC |
| CTHR_Z | Object covariance matrix [9,3]. | m**2/s**2 | OC |
| CTHR_XDOT | Object covariance matrix [9,4]. | m**2/s**3 | OC |
| CTHR_YDOT | Object covariance matrix [9,5]. | m**2/s**3 | OC |
| CTHR_ZDOT | Object covariance matrix [9,6]. | m**2/s**3 | OC |
| CTHR_DRG | Object covariance matrix [9,7]. | m**3/(kg*s**2) | OC |
| CTHR_SRP | Object covariance matrix [9,8]. | m**3/(kg*s**2) | OC |
| CTHR_THR | Object covariance matrix [9,9]. | m**2/s**4 | OC |
| **Covariance Matrix in Sigmas/Eigenvector format**<br>(Covariance sigmas and eigenvectors for major, intermediate and minor eigenvalues and associated eigenvectors. All data type=double.)<br>**Conditional on COV_TYPE = CSIG3EIGVEC3** | | | |
| COMMENT | (See 6.3.4 for formatting rules.) | n/a | OC |
| CSIG3EIGVEC3 | The 3x3 positional covariance one-sigma dispersions corresponding to the major, intermediate and minor eigenvalues, followed by the associated eigenvectors, shall all be presented on a single line (12 values separated by spaces) | n/a | MC |
| **Additional covariance meta data (Optional)** | | | |
| COMMENT | (See 6.3.4 for formatting rules.) | n/a | O |
| DENSITY_FORECAST_UNCERTAINTY | The atmospheric density forecast error is a compensation factor that is added to the drag variance in the covariance matrix to reflect expected errors in predicting the future atmospheric density. Data type = double. | n/a | O |

| Keyword | Description | Units | MOC |
|---|---|---|---|
| CSCALE_FACTOR_MIN | The minimum suggested covariance scale factor, used to improve covariance realism in the provided covariance for this object. Data type = double.<br><br>NOTE 1: The supplied one-sigma deviations get multiplied by $\mathrm{CSCALE\_FACTOR}$, while the covariance matrix must be multiplied by $\mathrm{CSCALE\_FACTOR}^2$ to scale the covariance appropriately.<br><br>NOTE 2: If COLLISION_MAX_PC_METHOD = 'SCALE_COMBINED_COVAR, this scale factor is used when included with OBJECT1, and disregarded when included with OBJECT2. | n/a | O |
| CSCALE_FACTOR | The suggested (median) covariance scale factor, used to improve covariance realism in the provided covariance for this object. $\mathrm{CSCALE\_FACTOR}^2$. Data type = double.<br><br>NOTE 1: The supplied one-sigma deviations get multiplied by $\mathrm{CSCALE\_FACTOR}$, while the covariance matrix must be multiplied by $\mathrm{CSCALE\_FACTOR}^2$ to scale the covariance appropriately.<br><br>NOTE 2: If COLLISION_MAX_PC_METHOD = 'SCALE_COMBINED_COVAR, this scale factor is used when included with OBJECT1, and disregarded when included with OBJECT2. | n/a | O |
| CSCALE_FACTOR_MAX | The maximum suggested covariance scale factor, used to improve covariance realism in the provided covariance for this object. $\mathrm{CSCALE\_FACTOR}^2$. Data type = double.<br><br>NOTE 1: The supplied one-sigma deviations get multiplied by $\mathrm{CSCALE\_FACTOR}$, while the covariance matrix must be multiplied by $\mathrm{CSCALE\_FACTOR}^2$ to scale the covariance appropriately.<br><br>NOTE 2: If COLLISION_MAX_PC_METHOD = 'SCALE_COMBINED_COVAR, this scale factor is used when included with OBJECT1, and disregarded when included with OBJECT2. | n/a | O |
| SCREENING_DATA_SOURCE | Free-text string specifying the source (or origin) of the specific orbital data for this object that was used in this screening. | n/a | O |

| Keyword | Description | Units | MOC |
|---|---|---|---|
| DCP_SENSITIVITY_VECTOR_POSITION | The drag consider parameter (DCP) sensitivity vectors map forward expected error in the drag acceleration to actual componentized position errors at TCA. Data type = double(3). | n/a | O |
| DCP_SENSITIVITY_VECTOR_VELOCITY | The drag consider parameter (DCP) sensitivity vectors map forward expected error in the drag acceleration to actual componentized velocity errors at TCA. Data type = double(3). | n/a | O |

## 3.6 CDM USER-DEFINED PARAMETERS

A section of user-defined parameters may be provided if necessary. In principle, this provides flexibility, but also introduces complexity; non-standardisation, potential ambiguity and potential processing errors. Accordingly, if used, the keywords and their meanings must be described in an Interface Control Document (ICD). The use of User-Defined Parameters is not encouraged. The CDM metadata shall consist of the KVN elements defined in table 3-6, which specifies for each KVN metadata item:

f) the keyword to be used;

g) a short description of the item;

h) normative values or examples of allowed values;

i) whether the 'Normative Values/Examples' column contains normative values (N) or examples of allowed values (E) for the item; and

j) whether the item is mandatory (M), optional (O) or conditional (C). Combinations of flags may also be used to indicate mandatory if condition met (MC) and optional if condition met (OC). Optional keywords should be omitted if they have no assigned value.

**Table 3-6: CDM KVN User-Defined Parameters**

| Keyword | Description | Normative Values/Examples | N/E | MOC |
|---|---|---|---|---|
| COMMENT | (See 6.3.4 for formatting rules.) | COMMENT This is a comment | E | O |
| USER_DEFINED_x | User-defined parameter where 'x' is replaced by a variable length user specified character string. Any number of user defined parameters may be included if necessary to provide essential information that cannot be conveyed in standard CDM keywords. | USER_DEFINED_OBJ1_TIME_LASTOB_START=2020-01-29T13:30:00 | E | O |

# 4 CDM CONTENT/STRUCTURE IN XML

## 4.1 DISCUSSION—THE CDM/XML SCHEMA

The CDM/XML schema is available on the SANA Web site. SANA is the registrar for the protocol registries created under CCSDS.

The CDM XML schema explicitly defines the permitted data elements and values acceptable for the XML version of the CDM message.

The location of the CDM/XML schema is:

http://sanaregistry.org/r/ndmxml/ndmxml-1.0-cdm-1.0.xsd

Where possible this schema uses simple types and complex types used by the constituent schemas that make up NDMs (see reference [6]).

An Extensible Stylesheet Language Transformations (XSLT) converter is available on the SANA Web site to transform an XML CDM to a KVN CDM if desired by the CDM recipient. The location of the CDM/XML XSLT converter is http://sanaregistry.org/r/ndmxml/ndmxml-1.0-cdm-1.0.xsl.

## 4.2 CDM/XML BASIC STRUCTURE

**4.2.1** Each CDM shall consist of a <header> and a <body>.

**4.2.2** The CDM body shall consist of one relative metadata/data and two segment constructs.

**4.2.3** Each <segment> shall consist of a <metadata>/<data> pair, as shown in figure 4-1.

<header><br>
</header><br>
<body><br>
  <relativeMetadataData><br>
  </relativeMetadataData><br>
  <segment><br>
    <metadata><br>
    </metadata><br>
    <data><br>
    </data><br>
  </segment><br>
  <segment><br>
    <metadata><br>
    </metadata><br>
    <data><br>
    </data><br>
  </segment><br>
</body>

**Figure 4-1: CDM XML Basic Structure**

**4.2.4** XML tags shall be uppercase and correspond with the KVN keywords in 3.2 through 3.5 (uppercase with '_' [the underscore character] as separators). The XML logical tags related to message structure shall be in lowerCamelCase.

## 4.3 CONSTRUCTING A CDM/XML INSTANCE

### 4.3.1 OVERVIEW

This subsection provides more detailed instructions for the user on how to create an XML message based on the ASCII-text KVN-formatted message described in Annex C Sections C1.2 through 3.6C1.4 (see reference [6]).

### 4.3.2 XML VERSION

The first line in the instantiation shall specify the XML version:

```
<?xml version="1.0" encoding="UTF-8"?>
```

This line must appear on the first line of each instantiation, exactly as shown.

### 4.3.3 BEGINNING THE INSTANTIATION: ROOT DATA ELEMENT

**4.3.3.1** A CDM instantiation shall be delimited with the <cdm></cdm> root element tags using the standard attributes documented in reference [3].

**4.3.3.2** The XML Schema Instance namespace attribute must appear in the root element tag of all CDM/XML instantiations, exactly as shown:

xmlns:xsi = "http://www.w3.org/2001/XMLSchema-instance"

**4.3.3.3** If it is desired to validate an instantiation against the CCSDS Web-based schema, the xsi:noNamespaceSchemaLocation attribute must be coded as a single string of non-blank characters, with no line breaks, exactly as shown:

xsi:noNamespaceSchemaLocation="http://sanaregistry.org/r/ndmxml/ndmxml-1.0-master.xsd"

NOTE – The length of the value associated with the xsi:noNamespaceSchemaLocation attribute can cause the string to wrap to a new line; however, the string itself contains no breaks.

**4.3.3.4** For use in a local operations environment, the schema set may be downloaded from the SANA Web site to a local server that meets local requirements for operations robustness.

**4.3.3.5** If a local version is used, the value associated with the xsi:noNamespaceSchemaLocation attribute must be changed to a URL that is accessible to the local server.

**4.3.3.6** The final attributes of the <cdm> tag shall be ‘id’ and ‘version’.

**4.3.3.7** The ‘id’ attribute shall be ‘id="CCSDS_CDM_VERS"’.

**4.3.3.8** The ‘version’ attribute shall be ‘version="1.0"’.

NOTE – The following example root element tag for a CDM instantiation combines all the directions in the preceding several subsections:

```
<?xml   version="1.0" encoding="UTF-8"?>
<cdm    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
        xsi:noNamespaceSchemaLocation="http://sanaregistry.org/r/ndmxml/ndmx
        ml-1.0-master.xsd"
        id="CCSDS_CDM_VERS" version="1.0">
```

### 4.3.4 THE CDM/XML HEADER SECTION

**4.3.4.1** The CDM header shall have a standard header format, with tags <header> and </header>.

**4.3.4.2** Immediately following the <header> tag, the message may have any number of <COMMENT></COMMENT> tag pairs.

**4.3.4.3** The standard CDM header shall contain the following element tags:

a) <CREATION_DATE>;

b) <ORIGINATOR>;

c) optional <MESSAGE_FOR>;

d) <MESSAGE_ID>,

e) optional <CONJUNCTION_ID>.

NOTE – The rules for these keywords are specified in 3.2. The header would look like this:

```
<header>
  <COMMENT>Some comment string.</COMMENT>
  <CREATION_DATE>2010-03-12T22:31:12.000</CREATION_DATE>
  <ORIGINATOR>JSPOC</ORIGINATOR>
  <MESSAGE_FOR>SATELLITE A</MESSAGE_FOR>
  <MESSAGE_ID>201113719185</MESSAGE_ID>
  <CONJUNCTION_ID>04JUN101608</CONJUNCTION_ID>
</header>
```

### 4.3.5 THE CDM/XML BODY SECTION

**4.3.5.1** After coding the <header>, the instantiation must include a <body></body> tag pair.

**4.3.5.2** Inside the <body></body> tag pair, there must appear one <relativeMetadataData></relativeMetadataData> tag pair.

**4.3.5.3** Following the <relativeMetadataData></relativeMetadataData> tag pair, there must appear two <segment></segment> tag pairs, one for Object1 and one for Object2.

**4.3.5.4** Each segment must be made up of one <metadata></metadata> tag pair and one <data></data> tag pair.

### 4.3.6 THE CDM/XML RELATIVE METADATA/DATA SECTION

**4.3.6.1** The relative metadata/data section shall be set off by the <relativeMetadataData></relativeMetadataData> tag combination.

**4.3.6.2** Immediately following the <relativeMetadataData> tag, the message may have any number of <COMMENT></COMMENT> tag pairs.

**4.3.6.3** Between the <relativeMetadataData> and </relativeMetadataData> tags, the keywords shall be those specified in table 3-3.

### 4.3.7 THE CDM/XML METADATA SECTION

**4.3.7.1** All CDMs must have two metadata sections, one for Object1 and one for Object2.

**4.3.7.2** The metadata section for Object1 shall follow the relative metadata/data section and shall be set off by the <metadata></metadata> tag combination. The metadata section for Object2 shall follow the Object1 data section and shall be set off by the <metadata></metadata> tag combination.

**4.3.7.3** Immediately following the <metadata> tag, the message may have any number of <COMMENT></COMMENT> tag pairs.

**4.3.7.4** Between the <metadata> and </metadata> tags for both Object1 and Object2, the keywords shall be those specified in table 3-4. The value of the keyword OBJECT shall be used to define whether the metadata defines Object1 or Object2.

### 4.3.8 THE CDM DATA SECTION

**4.3.8.1** All CDMs must have two data sections, one for Object1 and one for Object2.

**4.3.8.2** Each data section shall follow the corresponding metadata section and shall be set off by the <data></data> tag combination.

**4.3.8.3** Immediately following the <data> tag, the message may have any number of <COMMENT></COMMENT> tag pairs.

**4.3.8.4** Between the <data> and </data> tags, the keywords shall be those specified in table 3-5. The value of the keyword OBJECT, referenced in table 3-4, shall be used to define whether the data defines Object1 or Object2.

### 4.3.9 SPECIAL CDM/XML TAGS

**4.3.9.1** The information content in the CDM shall be separated into constructs described in 3.5 as ‘logical blocks’. Special tags in the CDM shall be used to encapsulate the information in the logical blocks of the CDM. Immediately following the special tags for logical blocks, the message may have any number of <COMMENT></COMMENT> tag pairs.

**4.3.9.2** The special tags indicating logical block divisions shall be those defined in table 4-1.

**Table 4-1: Relation of KVN Logical Blocks to Special CDM/XML Tags**

| CDM Logical Block | Associated CDM/XML Tag |
|---|---|
| **OD Parameters** | <odParameters> |
| **Additional Parameters** | <additionalParameters> |
| **State Vector** | <stateVector> |
| **Covariance Matrix** | <covarianceMatrix> |

**4.3.9.3** Another special tag that shall be used is defined in table 4-2.

**Table 4-2: Another Special CDM/XML Tag**

| Special Tag | Definition |
|---|---|
| <relativeStateVector> | Includes the relative state vector keywords: RELATIVE_POSITION_R, RELATIVE_POSITION_T, RELATIVE_POSITION_N, RELATIVE_VELOCITY_R, RELATIVE_VELOCITY_T, and RELATIVE_VELOCITY_N. |

#### 4.3.10 UNITS IN THE CDM/XML

The units in the CDM/XML shall be the same units used in the KVN-formatted CDM described in 3.3 and 3.5. XML attributes shall be used to explicitly define the units or other important information associated with the given data element (see 6.4.3 for examples).

CDM/XML examples are provided at Annex C Section 0.

# 5 CDM DATA IN GENERAL

## 5.1 OVERVIEW

The following rules apply for both KVN- and XML-formatted CDMs.

## 5.2 RULES THAT APPLY IN KVN AND XML

**5.2.1** Some keywords represent mandatory items and some are optional. KVN and XML assignments representing optional items may be omitted.

**5.2.2** The objects' state vectors and covariance shall be given 'at the time of closest approach', i.e., at the time specified in the TCA keyword.

**5.2.3** Table 3-5 is broken into four logical blocks, each of which has a descriptive heading. These descriptive headings shall not be included in a CDM, unless they appear in a properly formatted COMMENT statement for the KVN implementation and with values between the <COMMENT> and </COMMENT> tags for the XML implementation.

**5.2.4** For $C_D$•*A/m*, CD_AREA_OVER_MASS, a value of zero shall indicate no atmospheric drag was modelled in the orbit determination process.

**5.2.5** For $C_R$•*A/m*, CR_AREA_OVER_MASS, a value of zero shall indicate no solar radiation pressure was modelled in the orbit determination process.

**5.2.6** For acceleration due to in-track thrust, THRUST_ACCELERATION, a value of zero shall indicate no in-track thrust acceleration was modelled in the orbit determination process.

**5.2.7** For covariance matrix type, COV_TYPE, if omitted, a lower triangular RTN formatted covariance will be mandatory. If XYZ is specified, COV_REF_FRAME becomes mandatory specifying the reference frame of the mandatory XYZ covariance.

**5.2.8** For the Optimally-Encompassing Box quaternion, a value of -999 denotes a tumbling object.

**5.2.9** For this specification covariance information is mandatory. The object covariance may be specified as either a lower triangular matrix or in Eigenvalue/Eigenvector format as specified by the COV_TYPE keyword:

- Lower Triangular Format: Values in the covariance matrix shall be presented sequentially from upper left [1,1] to lower right [9,9], lower triangular form, row by row, left to right. Variance and covariance values shall be expressed in standard double precision as related in 6.3.2.3.

  The covariance matrix shall be provided for the position and velocity terms, given in the lower triangular form of a 6×6 matrix. If any of the diagonal terms are zero, the entire row and column of the matrix related to that term should be discounted. Optional terms for CD_AREA_OVER_MASS (denoted ‘DRG’), CR_AREA_OVER_MASS (denoted ‘SRP’), and THRUST_ACCELERATION (denoted ‘THR’) may be added to the 6×6 matrix, in the lower triangular form, to complete a 9×9 matrix. If any element in any of these rows (7, 8, or 9) is provided, then all of the elements for that row and all preceding rows shall be provided (i.e., a subset of the terms for any of these rows is not allowed). (See annex F for definition.)

- Sigma/Eigenvector Format: This format comprises the one-sigma dispersions of the combined error covariance matrix along the major, intermediate and minor eigenvector directions, followed by the associated major, intermediate and minor eigenvectors, provided as a single line of twelve white space-delimited quantities.

**5.2.10** In the value fields for the keywords ORIGINATOR, MESSAGE_ID, CONJUNCTION_ID, OBJECT_DESIGNATOR, CATALOG_NAME and INTERNATIONAL_DESIGNATOR, values shall be given as alphanumeric text. The underscore ‘_’ and dash ‘-’ may also be used.

# 6 CDM SYNTAX

## 6.1 OVERVIEW

This section details the syntax requirements for the CDM using both KVN and XML formats.

## 6.2 COMMON CDM SYNTAX

### 6.2.1 OVERVIEW

This subsection details the syntax requirements that are common to both KVN and XML formats.

### 6.2.2 COMMON CDM LINES

**6.2.2.1** Each CDM line must not exceed 254 ASCII characters and spaces (excluding line termination character[s]).

**6.2.2.2** Only printable ASCII characters and blanks shall be used. Control characters (such as TAB, etc.) shall not be used, with the exception of the line termination characters specified below.

**6.2.2.3** Blank lines may be used at any position within the file. Blank lines shall have no assignable meaning, and may be ignored.

**6.2.2.4** All lines shall be terminated by a single Carriage Return, a single Line Feed, a Carriage Return/Line Feed pair, or a Line Feed/Carriage Return pair.

### 6.2.3 COMMON CDM VALUES

**6.2.3.1** A nonempty, valid value must be specified for each mandatory keyword.

**6.2.3.2** Non-integer numeric values may be expressed in either fixed-point or floating-point notation.

**6.2.3.3** Text value fields must be constructed using only all uppercase. An exception is made for comment values (see 6.2.5 for formatting rules).

**6.2.3.4** All time tags in the CDM shall be in UTC.

### 6.2.4 COMMON CDM UNITS

**6.2.4.1** If units are applicable, as specified in table 3-3 and/or table 3-5, they must be displayed and must exactly match the units specified in each table (including case). (See 1.4.1.1 and 1.4.1.2 for units conventions and operations.)

**6.2.4.2** The notation '[n/a]' shall not appear in a CDM as a units designator.

NOTE – Some of the items in the applicable tables are dimensionless. For such items, the table shows a unit value of 'n/a', which in this case means that there is no applicable units designator for those items (e.g., for COLLISION_PROBABILITY, WEIGHTED_RMS).

### 6.2.5 COMMON CDM COMMENTS

**6.2.5.1** For the CDM, comment lines shall be optional.

**6.2.5.2** Placement of comments shall be as specified in the tables in section 3 that describe the CDM keywords. In places where comments are permitted any number of comments may appear.

**6.2.5.3** Comment text may be in any case desired by the user.

## 6.3 THE CDM IN KVN

### 6.3.1 CDM LINES IN KVN

**6.3.1.1** Each CDM file shall consist of a set of CDM lines. Each CDM line shall be one of the following:

– Header line;

– Relative Metadata/Data line;

– Metadata line;

– Data line; or

– Blank line.

**6.3.1.2** The first header line must be the first non-blank line in the file.

**6.3.1.3** All header, relative metadata/data, metadata, and data lines shall use 'keyword = value' notation. For this purpose, only those keywords shown in table 3-2, table 3-3, table 3-4, and table 3-5 shall be used in a CDM.

**6.3.1.4** Only a single 'keyword = value' assignment shall be made on a line.

**6.3.1.5** Keywords must be uppercase and must not contain blanks.

**6.3.1.6** Any white space immediately preceding or following the keyword shall not be significant.

**6.3.1.7** Any white space immediately preceding or following the ‘equals’ sign shall not be significant.

**6.3.1.8** Any white space immediately preceding the end of line shall not be significant.

**6.3.1.9** The order of occurrence of mandatory and optional KVN assignments shall be fixed as shown in the tables in section 3 that describe the CDM keywords.

### 6.3.2 CDM VALUES IN KVN

**6.3.2.1** Integer values shall consist of a sequence of decimal digits with an optional leading sign (‘+’ or ‘-’). If the sign is omitted, ‘+’ shall be assumed. Leading zeroes may be used. The range of values that may be expressed as an integer is:

$$-2{,}147{,}483{,}648 \leq x \leq +2{,}147{,}483{,}647 \text{ (i.e., } -2^{31} \leq x \leq 2^{31}-1\text{).}$$

NOTE – The commas in the range of values above are thousands separators and are used only for readability.

**6.3.2.2** Non-integer numeric values expressed in fixed-point notation shall consist of a sequence of decimal digits separated by a period as a decimal point indicator, with an optional leading sign (‘+’ or ‘-’). If the sign is omitted, ‘+’ shall be assumed. Leading and trailing zeroes may be used. At least one digit shall appear before and after a decimal point. The number of digits shall be 16 or fewer.

**6.3.2.3** Non-integer numeric values expressed in floating point notation shall consist of a sign, a mantissa, an alphabetic character indicating the division between the mantissa and exponent, and an exponent, constructed according to the following rules:

a) The sign may be ‘+’ or ‘-’. If the sign is omitted, ‘+’ shall be assumed.

b) The mantissa must be a string of no more than 16 decimal digits with a decimal point (‘.’) in the second position of the ASCII string, separating the integer portion of the mantissa from the fractional part of the mantissa.

c) The character used to denote exponentiation shall be ‘E’ or ‘e’. If the character indicating the exponent and the following exponent are omitted, an exponent value of zero shall be assumed (essentially yielding a fixed-point value).

d) The exponent must be an integer, and may have either a ‘+’ or ‘-’ sign; if the sign is omitted, then ‘+’ shall be assumed.

e) The maximum positive floating-point value is approximately 1.798E+308, with 16 significant decimal digits precision. The minimum positive floating-point value is approximately 4.94E-324, with 16 significant decimal digits precision.

**6.3.2.4** Blanks shall not be used within numeric values.

**6.3.2.5** In value fields that are text, an underscore shall be equivalent to a single blank. Individual blanks shall be retained (shall be significant), but multiple contiguous blanks shall be equivalent to a single blank.

**6.3.2.6** In value fields that represent a time tag, times shall be given in one of the following two formats:

*yyyy-mm-dd***T***hh:mm:ss*[*.d→d*][Z]

or

*yyyy-ddd***T***hh:mm:ss*[*.d→d*][Z]

where '*yyyy*' is the year, '*mm*' is the two-digit month, '*dd*' is the two-digit day of the month, and '*ddd*' is the three-digit day of the year, separated by hyphens; '**T**' is a fixed separator between the date and time portions of the string; and '*hh:mm:ss*[*.d→d*]' is the time in hours, minutes, seconds, and fractional seconds, separated by colons. As many 'd' characters to the right of the period as required may be used to obtain the required precision, up to the maximum allowed for a fixed-point number. Because all times in the CDM are UTC, the 'Z' indicator allowed by the CCSDS Time Code Formats Recommended Standard should be omitted. All fields require leading zeros. (See reference [5], ASCII Time Code A or B.)

### 6.3.3 CDM UNITS IN KVN

When units are displayed, then:

a) there must be at least one blank character between the value and the units;

b) the units must be enclosed within square brackets (e.g., '[km]').

### 6.3.4 CDM COMMENTS IN KVN

All comment lines shall begin with the 'COMMENT' keyword followed by at least one space. This keyword must appear on every comment line, not just the first such line. The remainder of the line shall be the comment value. White space shall be retained (shall be significant) in comment values.

## 6.4 THE CDM IN XML

### 6.4.1 CDM LINES IN XML

**6.4.1.1** Each CDM file shall consist of a set of CDM lines. Each CDM line shall be one of the following:

– XML version line;

– an XML-formatted line; or

– a blank line.

**6.4.1.2** The first line in the instantiation shall specify the XML version.

**6.4.1.3** While specific formatting of an XML message is not critical, and white space and line breaks are not significant, the message should be organized and formatted to facilitate human comprehension.

### 6.4.2 CDM VALUES IN XML

**6.4.2.1** Integer values shall follow the conventions of the *integer* data type per reference [4]. Additional restrictions on the values permitted for any integer data element may also be defined in the CDM XML Schema.

NOTE – Examples of such restrictions may include a defined range (e.g., 0 - 100, 1 - 10, etc.), a set of enumerated values (e.g., 0, 1, 2, 4, 8), a predefined specific variation such as *positiveInteger*, or a user-defined data type variation.

**6.4.2.2** Non-integer numeric values shall follow the conventions of the *double* data type per reference [4]. Additional restrictions on the allowable range or values permitted for any non-integer numeric data element may also be defined in the CDM XML Schema.

NOTE – Examples of such restrictions may include a defined range (e.g., 0.0 - 100.0, etc.), or a user-defined data type variation.

**6.4.2.3** Text value data shall follow the conventions of the *string* data type per reference [4]. Additional restrictions on the values permitted for any data element may also be defined in the CDM XML Schema.

NOTE – Examples of such restrictions may include a set of enumerated values (e.g., 'YES'/'NO', or 'RTN'/'TVN'), or other user-defined data type variation.

**6.4.2.4** In value fields that represent a time tag, values shall follow the conventions of the *ndm:epochType* data type used in all CCSDS NDM/XML schemas. This data type supports the options specified in 6.3.2.6.

### 6.4.3 CDM UNITS IN XML

CDM units shall be expressed as attributes in XML keyword tags in the form 'units="*unit-notation*"', where *unit-notation* conforms to the convention stated in 1.4.1.1.

NOTE – Table 6-1 gives examples of XML keyword tags with specified units.

**Table 6-1: Example XML Keyword Tags with Specified Units**

| Tag | Units | Example |
|---|---|---|
| MISS_DISTANCE | m | <MISS_DISTANCE units="m">715</MISS_DISTANCE> |
| RELATIVE_SPEED | m/s | <RELATIVE_SPEED units="m/s">14762</RELATIVE_SPEED> |
| ACTUAL_OD_SPAN | d | <ACTUAL_OD_SPAN units="d">5.50</ACTUAL_OD_SPAN> |

### 6.4.4 CDM COMMENTS IN XML

Comments must be displayed as values between the <COMMENT> and </COMMENT> tags.

# ANNEX A

# IMPLEMENTATION CONFORMANCE STATEMENT PROFORMA

# (NORMATIVE)

## A1 INTRODUCTION

### A1.1 OVERVIEW

This annex provides the Implementation Conformance Statement (ICS) Requirements List (RL) for an implementation of *Conjunction Data Message* (CCSDS 508.0). The ICS for an implementation is generated by completing the RL in accordance with the instructions below. An implementation shall satisfy the mandatory conformance requirements referenced in the RL.

The RL in this annex is blank. An implementation's completed RL is called the ICS. The ICS states which capabilities and options have been implemented. The following can use the ICS:

– the implementer, as a checklist to reduce the risk of failure to conform to the standard through oversight;

– a supplier or potential acquirer of the implementation, as a detailed indication of the capabilities of the implementation, stated relative to the common basis for understanding provided by the standard ICS proforma;

– a user or potential user of the implementation, as a basis for initially checking the possibility of interworking with another implementation (it should be noted that, while interworking can never be guaranteed, failure to interwork can often be predicted from incompatible ICSes);

– a tester, as the basis for selecting appropriate tests against which to assess the claim for conformance of the implementation.

### A1.2 ABBREVIATIONS AND CONVENTIONS

The RL consists of information in tabular form. The status of features is indicated using the abbreviations and conventions described below.

Item Column

The item column contains sequential numbers for items in the table.

Feature Column

The feature column contains a brief descriptive name for a feature. It implicitly means 'Is this feature supported by the implementation?'

NOTE – The features itemized in the RL are elements of a CDM. Therefore support for a mandatory feature indicates that generated messages will include that feature, and support for an optional feature indicates that generated messages can include that feature.

Keyword Column

The keyword column contains, where applicable, the CDM keyword associated with the feature.

Reference Column

The reference column indicates the relevant subsection or table in *Conjunction Data Message* (CCSDS 508.0) (this document).

Status Column

The status column uses the following notations:

M mandatory.

O optional.

C conditional.

MC mandatory if condition met

OC optional if condition met

Support Column Symbols

The support column is to be used by the implementer to state whether a feature is supported by entering Y, N, or N/A, indicating:

Y Yes, supported by the implementation.

N No, not supported by the implementation.

N/A Not applicable.

## A1.3 INSTRUCTIONS FOR COMPLETING THE RL

An implementer shows the extent of compliance to the Recommended Standard by completing the RL; that is, the state of compliance with all mandatory requirements and the options supported are shown. The resulting completed RL is called an ICS. The implementer shall complete the RL by entering appropriate responses in the support or values supported column, using the notation described in A1.2. If a conditional requirement is inapplicable, N/A should be used. If a mandatory requirement is not satisfied, exception information must be supplied by entering a reference X*i*, where *i* is a unique identifier, to an accompanying rationale for the noncompliance.

# A2 ICS PROFORMA FOR CONJUNCTION DATA MESSAGE

## A2.1 GENERAL INFORMATION

### A2.1.1 Identification of ICS

| | |
|---|---|
| Date of Statement (DD/MM/YYYY) | |
| ICS serial number | |
| System Conformance statement cross-reference | |

### A2.1.2 Identification of Implementation Under Test (IUT)

| | |
|---|---|
| Implementation name | |
| Implementation version | |
| Special Configuration | |
| Other Information | |

### A2.1.3 Identification of Supplier

| | |
|---|---|
| Supplier | |
| Contact Point for Queries | |
| Implementation Name(s) and Versions | |
| Other information necessary for full identification, e.g., name(s) and version(s) for machines and/or operating systems;<br><br>System Name(s) | |

### A2.1.4 Document Version

| | |
|---|---|
| CCSDS 508.0 Document Version | |

| | |
|---|---|
| Have any exceptions been required?<br><br>(Note: A YES answer means that the implementation does not conform to the Recommended Standard. Non-supported mandatory capabilities are to be identified in the ICS, with an explanation of why the implementation is non-conforming. | Yes _____ No_____ |

### A2.1.5 Requirements List

| Item | Feature | Keyword | Reference | Status | Support |
|---|---|---|---|---|---|
| 1 | CDM Header | N/A | Table 3-2 | M | |
| 2 | CDM version | CCSDS_CDM_VERS | Table 3-2 | M | |
| 3 | Comment | COMMENT | Table 3-2 | O | |
| 4 | Message creation date/time | CREATION_DATE | Table 3-2 | M | |
| 5 | Message originator | ORIGINATOR | Table 3-2 | M | |
| 6 | Classification | CLASSIFICATION | Table 3-2 | O | |
| 7 | Spacecraft name(s) | MESSAGE_FOR | Table 3-2 | O | |
| 8 | Unique message identifier | MESSAGE_ID | Table 3-2 | M | |
| 9 | Unique conjunction identifier | CONJUCNTION_ID | Table 3-2 | O | |
| 10 | CDM Relative Metadata and Relative Data | N/A | Table 3-3 | M | |
| 11 | Comment | COMMENT | Table 3-3 | O | |
| 12 | Time of closest approach | TCA | Table 3-3 | M | |
| 13 | Miss distance at TCA | MISS_DISTANCE | Table 3-3 | M | |
| 14 | Mahalanobis distance at TCA | MAHALANOBIS_DISTANCE | Table 3-3 | O | |
| 15 | Relative speed at TCA | RELATIVE_SPEED | Table 3-3 | O | |
| 16 | Relative position of Object 2 with respect to Object 1 | RELATIVE_POSITION_R,<br>RELATIVE_POSITION_T,<br>RELATIVE_POSITION_N | Table 3-3 | O | |
| 17 | Relative velocity of Object 2 with respect to Object 1 | RELATIVE_VELOCITY_R,<br>RELATIVE_VELOCITY_T,<br>RELATIVE_VELOCITY_N | Table 3-3 | O | |
| 18 | Conjunction assessment screening period start/stop times | START_SCREEN_PERIOD,<br>STOP_SCREEN_PERIOD | Table 3-3 | O | |
| 19 | Object1 centered screening volume reference frame, shape, and dimensions | SCREEN_VOLUME_SHAPE<br>SCREEN_VOLUME_RADIUS<br>SCREEN_PC_THRESHOLD<br>SCREEN_VOLUME_FRAME,<br>SCREEN_VOLUME_X,<br>SCREEN_VOLUME_Y,<br>SCREEN_VOLUME_Z | Table 3-3 | O | |
| 20 | Screening volume entry/exit times for Object2 | SCREEN_ENTRY_TIME,<br>SCREEN_EXIT_TIME | Table 3-3 | O | |
| 21 | Probability CDF that Object1 and Object2 will collide | COLLISION_PERCENTILE<br>COLLISION_PROBABILITY | Table 3-3 | O | |
| 22 | Method that was used to calculate collision probability | COLLISION_PROBABILITY_METH OD | Table 3-3 | O | |
| 23 | Collision maximum probability parameters | COLLISION_MAX_PROBABILITY<br>COLLISION_MAX_PC_METHOD | Table 3-3 | O | |

| Item | Feature | Keyword | Reference | Status | Support |
|---|---|---|---|---|---|
| 24 | Space environment fragmentation impact adjusted collision probability. | SEFI_COLLISION_PROBABILITY | Table 3-3 | O | |
| 25 | Previous message ID | PREVIOUS_MESSAGE_ID | Table 3-3 | O | |
| 26 | Previous message epoch | PREVIOUS_MESSAGE_EPOCH | Table 3-3 | O | |
| 27 | Next message epoch | NEXT_MESSAGE_EPOCH | Table 3-3 | O | |
| 28 | CDM Metadata | N/A | Table 3-4 | M | |
| 29 | Comment | COMMENT | Table 3-4 | O | |
| 30 | Specifies object (1 or 2) to which metadata/data apply | OBJECT | Table 3-4 | M | |
| 31 | Satellite catalog designator for the object | OBJECT_DESIGNATOR | Table 3-4 | M | |
| 32 | Satellite catalog used for the object | CATALOG_NAME | Table 3-4 | M | |
| 33 | Spacecraft name for the object | OBJECT_NAME | Table 3-4 | M | |
| 34 | Full international designator for the object | INTERNATIONAL_DESIGNATOR | Table 3-4 | M | |
| 35 | Type of space object | OBJECT_TYPE | Table 3-4 | O | |
| 36 | Contact information for the object's owner/operator | OPERATOR_CONTACT_POSITION<br>,<br>OPERATOR_ORGANIZATION,<br>OPERATOR_PHONE,<br>OPERATOR_EMAIL | Table 3-4 | O | |
| 37 | Link to external ODM | ODM_MESSAGE_LINK | Table 3-4 | O | |
| 38 | Link to external ADM | ADM_MESSAGE_LINK | Table 3-4 | O | |
| 39 | Link to external TDM | TDM_MESSAGE_LINK | Table 3-4 | O | |
| 40 | Observations scheduled before next message | OBS_BEFORE_NEXT_MESSAGE | Table 3-4 | O | |
| 41 | Name of the external ephemeris file used, if any. | EPHEMERIS_NAME | Table 3-4 | M | |
| 42 | Describes how covariance matrix was derived | COVARIANCE_METHOD | Table 3-4 | M | |
| 43 | Object's maneuver capacity | MANEUVERABLE | Table 3-4 | M | |
| 44 | Defines the central body about which Object1/2 orbit | ORBIT_CENTERCENTER_NAME | Table 3-4 | O | |
| 45 | Name of reference frame in which state vector is given | REF_FRAME | Table 3-4 | M | |
| 46 | Type of covariance information provided | COV_TYPE | Table 3-4 | O | |
| 47 | Covariance reference frame if covariance provided in XYZ format (Conditional on COV_TYPE) | COV_REF_FRAME | Table 3-4 | MC | |
| 48 | Gravity model used for OD | GRAVITY_MODEL | Table 3-4 | O | |
| 49 | Atmospheric density model used for OD of the object | ATMOSPHERIC_MODEL | Table 3-4 | O | |
| 50 | N-body gravitational perturbations used for OD | N_BODY_PERTURBATIONS | Table 3-4 | O | |

| Item | Feature | Keyword | Reference | Status | Support |
|---|---|---|---|---|---|
| 51 | Indicates if solar radiation pressure perturbations were used in OD (Y/N) | SOLAR_RAD_PRESSURE | Table 3-4 | O | |
| 52 | Indicates if solid Earth and ocean tides were used in OD (Y/N) | EARTH_TIDES | Table 3-4 | O | |
| 53 | Indicates if in-track thrust modeling was used in OD (Y/N) | INTRACK_THRUST | Table 3-4 | O | |
| 54 | CDM Data | N/A | Table 3-5 | M | |
| 55 | Comment | COMMENT | Table 3-5 | O | |
| 56 | Orbit Determination Parameters | N/A | Table 3-5 | O | |
| 57 | Comment | COMMENT | Table 3-5 | O | |
| 58 | Interval containing last accepted observation | TIME_LASTOB_START, TIME_LASTOB_END | Table 3-5 | O | |
| 59 | Recommended/actual OD time span for object | RECOMMENDED_OD_SPAN, ACTUAL_OD_SPAN | Table 3-5 | O | |
| 60 | Number of observations available/accepted in OD | OBS_AVAILABLE, OBS_USED | Table 3-5 | O | |
| 61 | Number of sensor tracks available/accepted in OD | TRACKS_AVAILABLE, TRACKS_USED | Table 3-5 | O | |
| 62 | Percentage of residuals accepted in OD | RESIDUALS_ACCEPTED | Table 3-5 | O | |
| 63 | Weighted RMS of the residuals from OD | WEIGHTED_RMS | Table 3-5 | O | |
| 64 | Additional Modeling Parameters | N/A | Table 3-5 | O | |
| 65 | Comment | COMMENT | Table 3-5 | O | |
| 66 | Actual area of the object | AREA_PC | Table 3-5 | O | |
| 67 | Minimum area of the object | AREA_PC_MIN | Table 3-5 | O | |
| 68 | Maximum area of the object | AREA_PC_MAX | Table 3-5 | O | |
| 69 | Effective area of object exposed to atmospheric drag | AREA_DRG | Table 3-5 | O | |
| 70 | Effective area of object exposed to solar radiation pressure | AREA_SRP | Table 3-5 | O | |
| 71 | Reference frame for OEB | OEB_PARENT_FRAME | Table 3-5 | O | |
| 72 | Epoch of OEB reference frame | OEB_PARENT_FRAME_EPOCH | Table 3-5 | O | |
| 73 | Euler rotation for OEB | OEB_Q1 | Table 3-5 | O | |
| 74 | Euler rotation for OEB | OEB_Q2 | Table 3-5 | O | |
| 75 | Euler rotation for OEB | OEB_Q3 | Table 3-5 | O | |
| 76 | Euler rotation for OEB | OEB_QC | Table 3-5 | O | |
| 77 | Max dimension of OEB | OEM_MAX | Table 3-5 | O | |
| 78 | Medium dimension of OEB | OEB_MED | Table 3-5 | O | |
| 79 | Mini dimension of OEB | OEB_MIN | Table 3-5 | O | |
| 80 | Area along max OEB | AREA_ALONG_OEB_MAX | Table 3-5 | O | |
| 81 | Area along med OEB | AREA_ALONG_OEB_MED | Table 3-5 | O | |
| 82 | Area along min OEB | AREA_ALONG_OEB_MIN | Table 3-5 | O | |

| Item | Feature | Keyword | Reference | Status | Support |
|---|---|---|---|---|---|
| 83 | Typical radar cross-sectional area | RCS | Table 3-5 | O | |
| 84 | Min radar cross-sectional area | RCS_MIN | Table 3-5 | O | |
| 85 | Max radar cross-sectional area | RCS_MAX | Table 3-5 | O | |
| 86 | Typical visual magnitude | VM_ABSOLUTE | Table 3-5 | O | |
| 87 | Min apparent visual magnitude | VM_APPARENT_MIN | Table 3-5 | O | |
| 88 | Apparent visual magnitude | VM_APPARENT | Table 3-5 | O | |
| 89 | Max apparent visual magnitude | VM_APPARENT_MAX | Table 3-5 | O | |
| 90 | Typical coefficient of reflectivity | REFLECTIVITY | Table 3-5 | O | |
| 91 | Mass of the object | MASS | Table 3-5 | O | |
| 92 | Hard-body radius | HBR | Table 3-5 | O | |
| 93 | Object's $C_D$•A/m and $C_R$•A/m used to propagate state vector covariance to TCA | CD_AREA_OVER_MASS, CR_AREA_OVER_MASS | Table 3-5 | O | |
| 94 | Object's acceleration due to in-track thrust used to propagate state vector/covariance to TCA | THRUST_ACCELERATION | Table 3-5 | O | |
| 95 | Specific Energy Dissipation Rate (SEDR) | SEDR | Table 3-5 | O | |
| 96 | Objects apsis height above the central body which it is orbiting | APOAPSIS_HEIGHT | Table 3-5 | O | |
| 97 | Objects periapsis height above the central body which it is orbiting | PERIAPSIS_HEIGHT | Table 3-5 | O | |
| 98 | Angle between objects orbit plane and body equatorial plane | INCLINATION | Table 3-5 | O | |
| 99 | Covariance confidence | COV_CONFIDENCE | Table 3-5 | O | |
| 100 | Method used to calculate COV_CONFIDENCE (COV_CONFIDENCE present) | COV_CONFIDENCE_METHOD | Table 3-5 | MC | |
| 101 | State Vector | N/A | Table 3-5 | M | |
| 102 | Comment | COMMENT | Table 3-5 | O | |
| 103 | Object Position Vector | X, Y, Z | Table 3-5 | M | |
| 104 | Object Velocity Vector | X_DOT, Y_DOT, Z_DOT | Table 3-5 | M | |
| 105 | Covariance Matrix (COV_TYPE not present or = RTN) | NA | Table 3-5 | M | |
| 106 | Comment (COV_TYPE not present or = RTN) | COMMENT | Table 3-5 | OC | |
| 107 | Position/velocity 6×6 covariance matrix (COV_TYPE not present or = RTN) | CR_R, CT_R, CT_T, CN_R, CN_T, CN_N, CRDOT_R, CRDOT_T, CRDOT_N, CRDOT_RDOT, CTDOT_R, CTDOT_T, CTDOT_N, | Table 3-5 | MC | |

| Item | Feature | Keyword | Reference | Status | Support |
|---|---|---|---|---|---|
| | | CTDOT_RDOT, CTDOT_TDOT, CNDOT_R, CNDOT_T, CNDOT_N, CNDOT_RDOT, CNDOT_TDOT, CNDOT_NDOT | | | |
| 108 | Covariance matrix row 7 (Drag related) (COV_TYPE not present or = RTN) | CDRG_R, CDRG_T, CDRG_N, CDRG_RDOT, CDRG_TDOT, CDRG_NDOT, CDRG_DRG | Table 3-5 | OC | |
| 109 | Covariance matrix row 8 (Solar Radiation Pressure related) (COV_TYPE not present or = RTN) | CSRP_R, CSRP_T, CSRP_N, CSRP_RDOT, CSRP_TDOT, CSRP_NDOT, CSRP_DRG, CSRP_SRP | Table 3-5 | OC | |
| 110 | Covariance matrix row 9 (In-track Thrust related) (COV_TYPE not present or = RTN) | CTHR_R, CTHR_T, CTHR_N, CTHR_RDOT, CTHR_TDOT, CTHR_NDOT, CTHR_DRG, CTHR_SRP, CTHR_THR | Table 3-5 | OC | |
| 111 | Covariance Matrix (COV_TYPE = XYZ) | NA | Table 3-5 | M | |
| 112 | Comment (COV_TYPE = XYZ) | COMMENT | Table 3-5 | OC | |
| 113 | Position/velocity 6×6 covariance matrix (COV_TYPE = XYZ) | CX_X, CY_X, CY_Y, CZ_X, CZ_Y, CZ_Z, CXDOT_X, CXDOT_Y, CXDOT_Z, CXDOT_XDOT, CYDOT_X, CYDOT_Y, CYDOT_Z, CYDOT_XDOT, CYDOT_YDOT, CZDOT_X, CZDOT_Y, CZDOT_Z, CZDOT_XDOT, CZDOT_YDOT, CZDOT_ZDOT | Table 3-5 | MC | |
| 114 | Covariance matrix row 7 (Drag related) (COV_TYPE = XYZ) | CDRG_X, CDRG_Y, CDRG_Z, CDRG_XDOT, CDRG_YDOT, CDRG_ZDOT, CDRG_DRG | Table 3-5 | OC | |
| 115 | Covariance matrix row 8 (Solar Radiation Pressure related) (COV_TYPE = XYZ) | CSRP_X, CSRP_Y, CSRP_Z, CSRP_XDOT, CSRP_YDOT, CSRP_ZDOT, CSRP_DRG, CSRP_SRP | Table 3-5 | OC | |
| 116 | Covariance matrix row 9 (In-track Thrust related) (COV_TYPE = XYZ) | CTHR_X, CTHR_Y, CTHR_Z, CTHR_XDOT, CTHR_YDOT, CTHR_ZDOT, CTHR_DRG, CTHR_SRP, CTHR_THR | Table 3-5 | OC | |
| 117 | Covariance Matrix (COV_TYPE = EIG) | NA | Table 3-5 | M | |
| 118 | Comment (COV_TYPE = EIG)) | COMMENT | Table 3-5 | OC | |
| 119 | Covariance eigenvalues and eigenvectors (COV_TYPE = EIG) | CSIG3EIGVEC3 (12 double values separated by spaces) | Table 3-5 | MC | |
| 120 | Comment | COMMENT | Table 3-5 | O | |
| 121 | Atmospheric density forecast error | DENSITY_FORECAST_UNCERTAINTY | Table 3-5 | O | |
| 122 | Covariance scale factor parameters | CSCALE_FACTOR_MIN CSCALE_FACTOR CSCALE_FACTOR_MAX | Table 3-5 | O | |
| 123 | Screening data source | SCREENING_DATA_SOURCE | Table 3-5 | O | |

| Item | Feature | Keyword | Reference | Status | Support |
|---|---|---|---|---|---|
| 124 | Drag consider parameters | DCP_SENSITIVITY_VECTOR_POSITION<br>DCP_SENSITIVITY_VECTOR_VELOCITY | Table 3-5 | O | |
| 125 | CDM User-Defined Parameters | | Table 3-6 | O | |
| 126 | Comment | COMMENT | Table 3-6 | O | |
| 127 | User-defined parameter | USER_DEFINED_x | Table 3-6 | O | |

# ANNEX B

# SECURITY, SANA, AND PATENT CONSIDERATIONS

# (INFORMATIVE)

## B1 SECURITY CONSIDERATIONS

### B1.1 ANALYSIS OF SECURITY CONSIDERATIONS

This subsection presents the results of an analysis of security considerations applied to the technologies specified in this Recommended Standard.

### B1.2 CONSEQUENCES OF NOT APPLYING SECURITY TO THE TECHNOLOGY

The consequences of not applying security to the systems and networks on which this Recommended Standard is implemented could include potential loss, corruption, and theft of data. Because these messages are used in collision avoidance analyses and potential maneuvers, the consequences of not applying security to the systems and networks on which this Recommended Standard is implemented could include compromise or loss of the mission if malicious tampering of a particularly severe nature occurs.

### B1.3 POTENTIAL THREATS AND ATTACK SCENARIOS

Potential threats or attack scenarios include, but are not limited to, (a) unauthorized access to the programs/processes that generate and interpret the messages, and (b) unauthorized access to the messages during transmission between exchange partners. Protection from unauthorized access during transmission is especially important if the mission utilizes open ground networks, such as the Internet, to provide ground-station connectivity for the exchange of data formatted in compliance with this Recommended Standard. It is strongly recommended that potential threats or attack scenarios applicable to the systems and networks on which this Recommended Standard is implemented be addressed by the management of those systems and networks.

### B1.4 DATA PRIVACY

Privacy of data formatted in compliance with the specifications of this Recommended Standard should be assured by the systems and networks on which this Recommended Standard is implemented.

## B1.5 DATA INTEGRITY

Integrity of data formatted in compliance with the specifications of this Recommended Standard should be assured by the systems and networks on which this Recommended Standard is implemented.

## B1.6 AUTHENTICATION OF COMMUNICATING ENTITIES

Authentication of communicating entities involved in the transport of data which complies with the specifications of this Recommended Standard should be provided by the systems and networks on which this Recommended Standard is implemented.

## B1.7 DATA TRANSFER BETWEEN COMMUNICATING ENTITIES

The transfer of data formatted in compliance with this Recommended Standard between communicating entities should be accomplished via secure mechanisms approved by the Information Technology Security functionaries of exchange participants.

## B1.8 CONTROL OF ACCESS TO RESOURCES

Control of access to resources should be managed by the systems upon which originator formatting and recipient processing are performed.

## B1.9 AUDITING OF RESOURCE USAGE

Auditing of resource usage should be handled by the management of systems and networks on which this Recommended Standard is implemented.

## B1.10 UNAUTHORIZED ACCESS

Unauthorized access to the programs/processes that generate and interpret the messages should be prohibited in order to minimize potential threats and attack scenarios.

## B1.11 DATA SECURITY IMPLEMENTATION SPECIFICS

Specific information-security interoperability provisions that may apply between agencies and other independent users involved in an exchange of data formatted in compliance with this Recommended Standard could be specified in an ICD.

## B2 SANA CONSIDERATIONS

The following CDM-related items will be registered with the SANA Operator. The registration rule for new entries in the registry is the approval of new requests by the CCSDS Navigation Working Group chair. New requests for this registry should be sent to SANA (mailto:info@sanaregistry.org).

– The CDM XML schema;

– A transform from the CDM XML to the CDM KVN version;

– Values for the keywords ORIGINATOR and CATALOG_NAME; and

– A list of options for the COLLISION_PROBABILITY_METHOD keyword.

## B3 PATENT CONSIDERATIONS

The recommendations of this document have no patent issues.

# ANNEX C

# CONJUNCTION DATA MESSAGE EXAMPLES

# (INFORMATIVE)

## C1 DISCUSSION—CDM/KVN EXAMPLES

### C1.1 OVERVIEW

Subsections C1.2 through C1.4 show examples of a CDM message in KVN. Subsection C1.2 includes only mandatory keywords and subsections C1.3 through C1.4 include optional keywords as well as mandatory.

### C1.2 AN EXAMPLE OF A CDM IN KVN WITH ONLY MANDATORY KEYWORDS

```
CCSDS_CDM_VERS              = 1.0
CREATION_DATE               = 2010-03-12T22:31:12.000
ORIGINATOR                  = JSPOC
MESSAGE_ID                  = 201113719185
TCA                         = 2010-03-13T22:37:52.618
MISS_DISTANCE               = 715                       [m]
OBJECT                      = OBJECT1
OBJECT_DESIGNATOR           = 12345
CATALOG_NAME                = SATCAT
OBJECT_NAME                 = SATELLITE A
INTERNATIONAL_DESIGNATOR    = 1997−030E
EPHEMERIS_NAME              = EPHEMERIS SATELLITE A
COVARIANCE_METHOD           = CALCULATED
MANEUVERABLE                = YES
REF_FRAME                   = EME2000
X                           = 2570.097065               [km]
Y                           = 2244.654904               [km]
Z                           = 6281.497978               [km]
X_DOT                       = 4.418769571               [km/s]
Y_DOT                       = 4.833547743               [km/s]
Z_DOT                       = −3.526774282              [km/s]
CR_R                        = 4.142E+01                 [m**2]
CT_R                        = −8.579E+00                [m**2]
CT_T                        = 2.533E+03                 [m**2]
CN_R                        = −2.313E+01                [m**2]
CN_T                        = 1.336E+01                 [m**2]
CN_N                        = 7.098E+01                 [m**2]
CRDOT_R                     = 2.520E−03                 [m**2/s]
CRDOT_T                     = −5.476E+00                [m**2/s]
CRDOT_N                     = 8.626E−04                 [m**2/s]
CRDOT_RDOT                  = 5.744E−03                 [m**2/s**2]
```

| | | |
|---|---|---|
| CTDOT_R | = −1.006E−02 | [m**2/s] |
| CTDOT_T | = 4.041E−03 | [m**2/s] |
| CTDOT_N | = −1.359E−03 | [m**2/s] |
| CTDOT_RDOT | = −1.502E−05 | [m**2/s**2] |
| CTDOT_TDOT | = 1.049E−05 | [m**2/s**2] |
| CNDOT_R | = 1.053E−03 | [m**2/s] |
| CNDOT_T | = −3.412E−03 | [m**2/s] |
| CNDOT_N | = 1.213E-02 | [m**2/s] |
| CNDOT_RDOT | = -3.004E-06 | [m**2/s**2] |
| CNDOT_TDOT | = -1.091E-06 | [m**2/s**2] |
| CNDOT_NDOT | = 5.529E-05 | [m**2/s**2] |
| OBJECT | = OBJECT2 | |
| OBJECT_DESIGNATOR | = 30337 | |
| CATALOG_NAME | = SATCAT | |
| OBJECT_NAME | = FENGYUN 1C DEB | |
| INTERNATIONAL_DESIGNATOR | = 1999-025AA | |
| EPHEMERIS_NAME | = NONE | |
| COVARIANCE_METHOD | = CALCULATED | |
| MANEUVERABLE | = NO | |
| REF_FRAME | = EME2000 | |
| X | = 2569.540800 | [km] |
| Y | = 2245.093614 | [km] |
| Z | = 6281.599946 | [km] |
| X_DOT | = -2.888612500 | [km/s] |
| Y_DOT | = -6.007247516 | [km/s] |
| Z_DOT | = 3.328770172 | [km/s] |
| CR_R | = 1.337E+03 | [m**2] |
| CT_R | = -4.806E+04 | [m**2] |
| CT_T | = 2.492E+06 | [m**2] |
| CN_R | = -3.298E+01 | [m**2] |
| CN_T | = -7.5888E+02 | [m**2] |
| CN_N | = 7.105E+01 | [m**2] |
| CRDOT_R | = 2.591E-03 | [m**2/s] |
| CRDOT_T | = -4.152E-02 | [m**2/s] |
| CRDOT_N | = -1.784E-06 | [m**2/s] |
| CRDOT_RDOT | = 6.886E-05 | [m**2/s**2] |
| CTDOT_R | = -1.016E-02 | [m**2/s] |
| CTDOT_T | = -1.506E-04 | [m**2/s] |
| CTDOT_N | = 1.637E-03 | [m**2/s] |
| CTDOT_RDOT | = -2.987E-06 | [m**2/s**2] |
| CTDOT_TDOT | = 1.059E-05 | [m**2/s**2] |
| CNDOT_R | = 4.400E-03 | [m**2/s] |
| CNDOT_T | = 8.482E-03 | [m**2/s] |
| CNDOT_N | = 8.633E-05 | [m**2/s] |
| CNDOT_RDOT | = -1.903E-06 | [m**2/s**2] |
| CNDOT_TDOT | = -4.594E-06 | [m**2/s**2] |
| CNDOT_NDOT | = 5.178E-05 | [m**2/s**2] |

## C1.3 AN EXAMPLE OF A CDM IN KVN WHICH INCLUDES OPTIONAL KEYWORDS

| | |
|---|---|
| CCSDS_CDM_VERS | = 1.0 |
| CREATION_DATE | = 2010-03-12T22:31:12.000 |

| | | |
|---|---|---|
| ORIGINATOR | = JSPOC | |
| MESSAGE_FOR | = SATELLITE A | |
| MESSAGE_ID | = 201113719185 | |
| COMMENT Relative Metadata/Data | | |
| TCA | = 2010-03-13T22:37:52.618 | |
| MISS_DISTANCE | = 715 | [m] |
| RELATIVE_SPEED | = 14762 | [m/s] |
| RELATIVE_POSITION_R | = 27.4 | [m] |
| RELATIVE_POSITION_T | = -70.2 | [m] |
| RELATIVE_POSITION_N | = 711.8 | [m] |
| RELATIVE_VELOCITY_R | = -7.2 | [m/s] |
| RELATIVE_VELOCITY_T | = -14692.0 | [m/s] |
| RELATIVE_VELOCITY_N | = -1437.2 | [m/s] |
| START_SCREEN_PERIOD | = 2010-03-12T18:29:32:212 | |
| STOP_SCREEN_PERIOD | = 2010-03-15T18:29:32:212 | |
| SCREEN_VOLUME_FRAME | = RTN | |
| SCREEN_VOLUME_SHAPE | = ELLIPSOID | |
| SCREEN_VOLUME_X | = 200 | [m] |
| SCREEN_VOLUME_Y | = 1000 | [m] |
| SCREEN_VOLUME_Z | = 1000 | [m] |
| SCREEN_ENTRY_TIME | = 2010-03-13T22:37:52.222 | |
| SCREEN_EXIT_TIME | = 2010-03-13T22:37:52.824 | |
| COLLISION_PROBABILITY | = 4.835E-05 | |
| COLLISION_PROBABILITY_METHOD | = FOSTER-1992 | |
| COMMENT Object1 Metadata | | |
| OBJECT | = OBJECT1 | |
| OBJECT_DESIGNATOR | = 12345 | |
| CATALOG_NAME | = SATCAT | |
| OBJECT_NAME | = SATELLITE A | |
| INTERNATIONAL_DESIGNATOR | = 1997-030E | |
| OBJECT_TYPE | = PAYLOAD | |
| OPERATOR_CONTACT_POSITION | = OSA | |
| OPERATOR_ORGANIZATION | = EUMETSAT | |
| OPERATOR_PHONE | = +49615130312 | |
| OPERATOR_EMAIL | = JOHN.DOE@SOMEWHERE.NET | |
| | | |
| EPHEMERIS_NAME | = EPHEMERIS SATELLITE A | |
| COVARIANCE_METHOD | = CALCULATED | |
| MANEUVERABLE | = YES | |
| REF_FRAME | = EME2000 | |
| GRAVITY_MODEL | = EGM-96: 36D 36O | |
| ATMOSPHERIC_MODEL | = JACCHIA 70 DCA | |
| N_BODY_PERTURBATIONS | = MOON, SUN | |
| SOLAR_RAD_PRESSURE | = NO | |
| EARTH_TIDES | = NO | |
| INTRACK_THRUST | = NO | |
| COMMENT Object1 Data | | |
| COMMENT Object1 OD Parameters | | |
| TIME_LASTOB_START | = 2010-03-12T02:14:12.746 | |
| TIME_LASTOB_END | = 2010-03-12T02:14:12.746 | |
| RECOMMENDED_OD_SPAN | = 7.88 | [d] |
| ACTUAL_OD_SPAN | = 5.50 | [d] |
| OBS_AVAILABLE | = 592 | |

| | | |
|---|---|---|
| OBS_USED | = 579 | |
| TRACKS_AVAILABLE | = 123 | |
| TRACKS USED | = 119 | |
| RESIDUALS_ACCEPTED | = 97.8 | [%] |
| WEIGHTED_RMS | = 0.864 | |
| COMMENT Object1 Additional Parameters | | |
| COMMENT Apogee Altitude=779 km | | |
| COMMENT Perigee Altitude=765 km | | |
| COMMENT Inclination=86.4 deg | | |
| AREA_PC | = 5.2 | [m**2] |
| MASS | = 251.6 | [kg] |
| CD_AREA_OVER_MASS | = 0.045663 | [m**2/kg] |
| CR_AREA_OVER_MASS | = 0.000000 | [m**2/kg] |
| THRUST_ACCELERATION | = 0.0 | [m/s**2] |
| SEDR | = 4.54570E-05 | [W/kg] |
| COMMENT Object1 State Vector | | |
| X | = 2570.097065 | [km] |
| Y | = 2244.654904 | [km] |
| Z | = 6281.497978 | [km] |
| X_DOT | = 4.418769571 | [km/s] |
| Y_DOT | = 4.833547743 | [km/s] |
| Z_DOT | = -3.526774282 | [km/s] |
| COMMENT Object1 Covariance in the RTN Coordinate Frame | | |
| CR_R | = 4.142E+01 | [m**2] |
| CT_R | = -8.579E+00 | [m**2] |
| CT_T | = 2.533E+03 | [m**2] |
| CN_R | = -2.313E+01 | [m**2] |
| CN_T | = 1.336E+01 | [m**2] |
| CN_N | = 7.098E+01 | [m**2] |
| CRDOT_R | = 2.520E-03 | [m**2/s] |
| CRDOT_T | = -5.476E+00 | [m**2/s] |
| CRDOT_N | = 8.626E-04 | [m**2/s] |
| CRDOT_RDOT | = 5.744E-03 | [m**2/s**2] |
| CTDOT_R | = -1.006E-02 | [m**2/s] |
| CTDOT_T | = 4.041E-03 | [m**2/s] |
| CTDOT_N | = -1.359E-03 | [m**2/s] |
| CTDOT_RDOT | = -1.502E-05 | [m**2/s**2] |
| CTDOT_TDOT | = 1.049E-05 | [m**2/s**2] |
| CNDOT_R | = 1.053E-03 | [m**2/s] |
| CNDOT_T | = -3.412E-03 | [m**2/s] |
| CNDOT_N | = 1.213E-02 | [m**2/s] |
| CNDOT_RDOT | = -3.004E-06 | [m**2/s**2] |
| CNDOT_TDOT | = -1.091E-06 | [m**2/s**2] |
| CNDOT_NDOT | = 5.529E-05 | [m**2/s**2] |
| CDRG_R | = -1.862E+00 | [m**3/kg] |
| CDRG_T | = 3.530E+00 | [m**3/kg] |
| CDRG_N | = -3.100E-01 | [m**3/kg] |
| CDRG_RDOT | = -1.214E-04 | [m**3/(kg*s)] |
| CDRG_TDOT | = 2.580E-04 | [m**3/(kg*s)] |
| CDRG_NDOT | = -6.467E-05 | [m**3/(kg*s)] |
| CDRG_DRG | = 3.483E-06 | [m**4/kg**2] |
| CSRP_R | = -1.492E+02 | [m**3/kg] |
| CSRP_T | = 2.044E+02 | [m**3/kg] |

| | | |
|---|---|---|
| CSRP_N | = -2.331E+01 | [m**3/kg] |
| CSRP_RDOT | = -1.254E-03 | [m**3/(kg*s)] |
| CSRP_TDOT | = 2.013E-02 | [m**3/(kg*s)] |
| CSRP_NDOT | = -4.700E-03 | [m**3/(kg*s)] |
| CSRP_DRG | = 2.210E-04 | [m**4/kg**2] |
| CSRP_SRP | = 1.593E-02 | [m**4/kg**2] |
| COMMENT Object2 Metadata | | |
| OBJECT | = OBJECT2 | |
| OBJECT_DESIGNATOR | = 30337 | |
| CATALOG_NAME | = SATCAT | |
| OBJECT_NAME | = FENGYUN 1C DEB | |
| INTERNATIONAL_DESIGNATOR | = 1999-025AA | |
| OBJECT_TYPE | = DEBRIS | |
| EPHEMERIS_NAME | = NONE | |
| COVARIANCE_METHOD | = CALCULATED | |
| MANEUVERABLE | = NO | |
| REF_FRAME | = EME2000 | |
| GRAVITY_MODEL | = EGM-96: 36D 36O | |
| ATMOSPHERIC_MODEL | = JACCHIA 70 DCA | |
| N_BODY_PERTURBATIONS | = MOON, SUN | |
| SOLAR_RAD_PRESSURE | = YES | |
| EARTH_TIDES | = NO | |
| INTRACK_THRUST | = NO | |
| COMMENT Object2 Data | | |
| COMMENT Object2 OD Parameters | | |
| TIME_LASTOB_START | = 2010-03-12T01:14:12.746 | |
| TIME_LASTOB_END | = 2010-03-12T03:14:12.746 | |
| RECOMMENDED_OD_SPAN | = 2.63 | [d] |
| ACTUAL_OD_SPAN | = 2.63 | [d] |
| OBS_AVAILABLE | = 592 | |
| OBS_USED | = 579 | |
| TRACKS_AVAILABLE | = 15 | |
| TRACKS_USED | = 15 | |
| RESIDUALS_ACCEPTED | = 97.8 | [%] |
| WEIGHTED_RMS | = 0.864 | |
| COMMENT Object2 Additional Parameters | | |
| COMMENT Apogee Altitude=786 km | | |
| COMMENT Perigee Altitude=414 km | | |
| COMMENT Inclination=98.9 deg | | |
| AREA_PC | = 0.9 | [m**2] |
| CD_AREA_OVER_MASS | = 0.118668 | [m**2/kg] |
| CR_AREA_OVER_MASS | = 0.075204 | [m**2/kg] |
| THRUST_ACCELERATION | = 0.0 | [m/s**2] |
| SEDR | = 5.40900E-03 | [W/kg] |
| COMMENT Object2 State Vector | | |
| X | = 2569.540800 | [km] |
| Y | = 2245.093614 | [km] |
| Z | = 6281.599946 | [km] |
| X_DOT | = -2.888612500 | [km/s] |
| Y_DOT | = -6.007247516 | [km/s] |
| Z_DOT | = 3.328770172 | [km/s] |
| COMMENT Object2 Covariance in the RTN Coordinate Frame | | |
| CR_R | = 1.337E+03 | [m**2] |

| | | |
|---|---|---|
| CT_R | = -4.806E+04 | [m**2] |
| CT_T | = 2.492E+06 | [m**2] |
| CN_R | = -3.298E+01 | [m**2] |
| CN_T | = -7.5888E+02 | [m**2] |
| CN_N | = 7.105E+01 | [m**2] |
| CRDOT_R | = 2.591E-03 | [m**2/s] |
| CRDOT_T | = -4.152E-02 | [m**2/s] |
| CRDOT_N | = -1.784E-06 | [m**2/s] |
| CRDOT_RDOT | = 6.886E-05 | [m**2/s**2] |
| CTDOT_R | = -1.016E-02 | [m**2/s] |
| CTDOT_T | = -1.506E-04 | [m**2/s] |
| CTDOT_N | = 1.637E-03 | [m**2/s] |
| CTDOT_RDOT | = -2.987E-06 | [m**2/s**2] |
| CTDOT_TDOT | = 1.059E-05 | [m**2/s**2] |
| CNDOT_R | = 4.400E-03 | [m**2/s] |
| CNDOT_T | = 8.482E-03 | [m**2/s] |
| CNDOT_N | = 8.633E-05 | [m**2/s] |
| CNDOT_RDOT | = -1.903E-06 | [m**2/s**2] |
| CNDOT_TDOT | = -4.594E-06 | [m**2/s**2] |
| CNDOT_NDOT | = 5.178E-05 | [m**2/s**2] |
| CDRG_R | = -5.117E-01 | [m**3/kg] |
| CDRG_T | = 1.319E+00 | [m**3/kg] |
| CDRG_N | = -9.034E-02 | [m**3/kg] |
| CDRG_RDOT | = -7.708E-05 | [m**3/(kg*s)] |
| CDRG_TDOT | = 7.402E-05 | [m**3/(kg*s)] |
| CDRG_NDOT | = -1.903E-05 | [m**3/(kg*s)] |
| CDRG_DRG | = 1.053E-06 | [m**4/kg**2] |
| CSRP_R | = -3.297E+01 | [m**3/kg] |
| CSRP_T | = 8.164E+01 | [m**3/kg] |
| CSRP_N | = -5.651E+00 | [m**3/kg] |
| CSRP_RDOT | = -4.636E-03 | [m**3/(kg*s)] |
| CSRP_TDOT | = 4.738E-03 | [m**3/(kg*s)] |
| CSRP_NDOT | = -1.198E-03 | [m**3/(kg*s)] |
| CSRP_DRG | = 6.407E-05 | [m**4/kg**2] |
| CSRP_SRP | = 4.108E-03 | [m**4/kg**2] |

## C1.4 ANOTHER EXAMPLE OF A CDM IN KVN WHICH INCLUDES OPTIONAL KEYWORDS

| | | |
|---|---|---|
| CCSDS_CDM_VERS | = 1.0 | |
| CREATION_DATE | = 2012-09-12T22:31:12.000 | |
| ORIGINATOR | = SDC | |
| MESSAGE_FOR | = GALAXY 15 | |
| MESSAGE_ID | = 20120912223112 | |
| COMMENT Relative Metadata/Data | | |
| TCA | = 2012-09-13T22:37:52.618 | |
| MISS_DISTANCE | = 104.92 | [m] |
| RELATIVE_SPEED | = 12093.52 | [m/s] |
| RELATIVE_POSITION_R | = 30.6 | [m] |
| RELATIVE_POSITION_T | = 100.2 | [m] |
| RELATIVE_POSITION_N | = 5.7 | [m] |
| RELATIVE_VELOCITY_R | = -20.3 | [m/s] |
| RELATIVE_VELOCITY_T | = -12000.0 | [m/s] |

| | | |
|---|---|---|
| RELATIVE_VELOCITY_N | = -1500.9 | [m/s] |
| START_SCREEN_PERIOD | = 2012-09-12T18:29:32:212 | |
| STOP_SCREEN_PERIOD | = 2012-09-15T18:29:32:212 | |
| SCREEN_VOLUME_FRAME | = RTN | |
| SCREEN_VOLUME_SHAPE | = ELLIPSOID | |
| SCREEN_VOLUME_X | = 500 | [m] |
| SCREEN_VOLUME_Y | = 500 | [m] |
| SCREEN_VOLUME_Z | = 500 | [m] |
| SCREEN_ENTRY_TIME | = 2012-09-13T20:25:43.222 | |
| SCREEN_EXIT_TIME | = 2012-09-13T23:44:29.324 | |
| COLLISION_PROBABILITY | = 2.355e-03 | |
| COLLISION_PROBABILITY_METHOD | = ALFANO-2005 | |
| COMMENT Object1 Metadata | | |
| OBJECT | = OBJECT1 | |
| OBJECT_DESIGNATOR | = 28884 | |
| CATALOG_NAME | = SATCAT | |
| OBJECT_NAME | = GALAXY 15 | |
| INTERNATIONAL_DESIGNATOR | = 2005-041A | |
| OBJECT_TYPE | = PAYLOAD | |
| OPERATOR_ORGANIZATION | = INTELSAT | |
| EPHEMERIS_NAME | = GALAXY-15A-2012JAN-WMANEUVER23A | |
| COVARIANCE_METHOD | = CALCULATED | |
| MANEUVERABLE | = YES | |
| REF_FRAME | = EME2000 | |
| COMMENT Object1 Data | | |
| COMMENT Object1 OD Parameters | | |
| TIME_LASTOB_START | = 2012-09-06T20:25:43.222 | |
| TIME_LASTOB_END | = 2012-09-06T20:25:43.222 | |
| X | = -41600.46272465 | [km] |
| Y | = 3626.912120064 | [km] |
| Z | = 6039.06350924 | [km] |
| X_DOT | = -0.306132852503 | [km/s] |
| Y_DOT | = -3.044998353334 | [km/s] |
| Z_DOT | = -0.287674310725 | [km/s] |
| COMMENT Object1 Covariance in the RTN Coordinate Frame | | |
| CR_R | = 4.142E+01 | [m**2] |
| CT_R | = -8.579E+00 | [m**2] |
| CT_T | = 2.533E+03 | [m**2] |
| CN_R | = -2.313E+01 | [m**2] |
| CN_T | = 1.336E+01 | [m**2] |
| CN_N | = 7.098E+01 | [m**2] |
| CRDOT_R | = 2.520E-03 | [m**2/s] |
| CRDOT_T | = -5.476E+00 | [m**2/s] |
| CRDOT_N | = 8.626E-04 | [m**2/s] |
| CRDOT_RDOT | = 5.744E-03 | [m**2/s**2] |
| CTDOT_R | = -1.006E-02 | [m**2/s] |
| CTDOT_T | = 4.041E-03 | [m**2/s] |
| CTDOT_N | = -1.359E-03 | [m**2/s] |
| CTDOT_RDOT | = -1.502E-05 | [m**2/s**2] |
| CTDOT_TDOT | = 1.049E-05 | [m**2/s**2] |
| CNDOT_R | = 1.053E-03 | [m**2/s] |
| CNDOT_T | = -3.412E-03 | [m**2/s] |
| CNDOT_N | = 1.213E-02 | [m**2/s] |

```
CNDOT_RDOT                        = -3.004E-06                     [m**2/s**2]
CNDOT_TDOT                        = -1.091E-06                     [m**2/s**2]
CNDOT_NDOT                        = 5.529E-05                      [m**2/s**2]
COMMENT Object2 Metadata
OBJECT                            = OBJECT2
OBJECT_DESIGNATOR                 = 21139
CATALOG_NAME                      = SATCAT
OBJECT_NAME                       = ASTRA 1B
INTERNATIONAL_DESIGNATOR          = 1991-051A
OBJECT_TYPE                       = PAYLOAD
EPHEMERIS_NAME                    = NONE
COVARIANCE_METHOD                 = CALCULATED
MANEUVERABLE                      = YES
REF_FRAME                         = EME2000
COMMENT Object2 Data
COMMENT Object2 OD Parameters
TIME_LASTOB_START                 = 2012-08-03T10:22:14.548
TIME_LASTOB_END                   = 2012-08-03T10:22:14.548
X                                 = -2956.02034826                 [km]
Y                                 = 42584.37595741                 [km]
Z                                 = 123.77550476                   [km]
X_DOT                             = -3.047096589536                [km/s]
Y_DOT                             = -0.211583631026                [km/s]
Z_DOT                             = 0.062261259643                 [km/s]
COMMENT  Object2 Covariance in the RTN Coordinate Frame
CR_R                              = 1.337E+03                      [m**2]
CT_R                              = -4.806E+04                     [m**2]
CT_T                              = 2.492E+06                      [m**2]
CN_R                              = -3.298E+01                     [m**2]
CN_T                              = -7.5888E+02                    [m**2]
CN_N                              = 7.105E+01                      [m**2]
CRDOT_R                           = 2.591E-03                      [m**2/s]
CRDOT_T                           = -4.152E-02                     [m**2/s]
CRDOT_N                           = -1.784E-06                     [m**2/s]
CRDOT_RDOT                        = 6.886E-05                      [m**2/s**2]
CTDOT_R                           = -1.016E-02                     [m**2/s]
CTDOT_T                           = -1.506E-04                     [m**2/s]
CTDOT_N                           = 1.637E-03                      [m**2/s]
CTDOT_RDOT                        = -2.987E-06                     [m**2/s**2]
CTDOT_TDOT                        = 1.059E-05                      [m**2/s**2]
CNDOT_R                           = 4.400E-03                      [m**2/s]
CNDOT_T                           = 8.482E-03                      [m**2/s]
CNDOT_N                           = 8.633E-05                      [m**2/s]
CNDOT_RDOT                        = -1.903E-06                     [m**2/s**2]
CNDOT_TDOT                        = -4.594E-06                     [m**2/s**2]
CNDOT_NDOT                        = 5.178E-05                      [m**2/s**2]
```

## C2 DISCUSSION—CDM/XML EXAMPLE

The following is a sample of a CDM in XML format:


```
<?xml version="1.0" encoding="UTF-8"?>
<cdm  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:noNamespaceSchemaLocation="http://sanaregistry.org/r/ndmxml/ndmxml-1.0-master.xsd"
    id="CCSDS_CDM_VERS" version="1.0">

  <header>
   <COMMENT>Sample CDM - XML version</COMMENT>
   <CREATION_DATE>2010-03-12T22:31:12.000</CREATION_DATE>
   <ORIGINATOR>JSPOC</ORIGINATOR>
   <MESSAGE_FOR>SATELLITE A</MESSAGE_FOR>
   <MESSAGE_ID>20111371985</MESSAGE_ID>
  </header>
  <body>
   <relativeMetadataData>
    <COMMENT>Relative Metadata/Data</COMMENT>
    <TCA>2010-03-13T22:37:52.618</TCA>
    <MISS_DISTANCE units="m">715</MISS_DISTANCE>
    <RELATIVE_SPEED units="m/s">14762</RELATIVE_SPEED>
    <relativeStateVector>
     <RELATIVE_POSITION_R units="m">27.4</RELATIVE_POSITION_R>
     <RELATIVE_POSITION_T units="m">-70.2</RELATIVE_POSITION_T>
     <RELATIVE_POSITION_N units="m">711.8</RELATIVE_POSITION_N>
     <RELATIVE_VELOCITY_R units="m/s">-7.2</RELATIVE_VELOCITY_R>
     <RELATIVE_VELOCITY_T units="m/s">-14692.0</RELATIVE_VELOCITY_T>
     <RELATIVE_VELOCITY_N units="m/s">-1437.2</RELATIVE_VELOCITY_N>
    </relativeStateVector>
    <START_SCREEN_PERIOD>2010-03-12T18:29:32.212</START_SCREEN_PERIOD>
    <STOP_SCREEN_PERIOD>2010-03-15T18:29:32.212</STOP_SCREEN_PERIOD>
    <SCREEN_VOLUME_FRAME>RTN</SCREEN_VOLUME_FRAME>
    <SCREEN_VOLUME_SHAPE>ELLIPSOID</SCREEN_VOLUME_SHAPE>
    <SCREEN_VOLUME_X units="m">200</SCREEN_VOLUME_X>
    <SCREEN_VOLUME_Y units="m">1000</SCREEN_VOLUME_Y>
    <SCREEN_VOLUME_Z units="m">1000</SCREEN_VOLUME_Z>
    <SCREEN_ENTRY_TIME>2010-03-13T20:25:43.222</SCREEN_ENTRY_TIME>
    <SCREEN_EXIT_TIME>2010-03-13T23:44:29.324</SCREEN_EXIT_TIME>
    <COLLISION_PROBABILITY>4.835E-05</COLLISION_PROBABILITY>
    <COLLISION_PROBABILITY_METHOD>FOSTER-1992</COLLISION_PROBABILITY_METHOD>
   </relativeMetadataData>
   &lt;segment&gt;
    <metadata>
     <COMMENT>Object1 Metadata</COMMENT>
     <OBJECT>OBJECT1</OBJECT>
     <OBJECT_DESIGNATOR>12345</OBJECT_DESIGNATOR>
     <CATALOG_NAME>SATCAT</CATALOG_NAME>
     <OBJECT_NAME>SATELLITE A</OBJECT_NAME>
     <INTERNATIONAL_DESIGNATOR>1997-030E</INTERNATIONAL_DESIGNATOR>
     <OBJECT_TYPE>PAYLOAD</OBJECT_TYPE>
     <OPERATOR_CONTACT_POSITION>OSA</OPERATOR_CONTACT_POSITION>
     <OPERATOR_ORGANIZATION>EUMETSAT</OPERATOR_ORGANIZATION>
     <OPERATOR_PHONE>+49615130312</OPERATOR_PHONE>
     <OPERATOR_EMAIL>JOHN.DOE@SOMEWHERE>NET</OPERATOR_EMAIL>
```

```
    <EPHEMERIS_NAME>EPHEMERIS SATELLITE A</EPHEMERIS_NAME>
    <COVARIANCE_METHOD>CALCULATED</COVARIANCE_METHOD>
    <MANEUVERABLE>YES</MANEUVERABLE>
    <REF_FRAME>EME2000</REF_FRAME>
    <GRAVITY_MODEL>EGM-96: 36D 36O</GRAVITY_MODEL>
    <ATMOSPHERIC_MODEL>JACCHIA 70 DCA</ATMOSPHERIC_MODEL>
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    <EARTH_TIDES>NO</EARTH_TIDES>
    <INTRACK_THRUST>NO</INTRACK_THRUST>
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      <Z units="km">6281.497978</Z>
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      <CRDOT_R units="m**2/s">2.520E-03</CRDOT_R>
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```

```
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    <OBJECT_NAME>FENGYUN 1C DEB</OBJECT_NAME>
    <INTERNATIONAL_DESIGNATOR>1999-025AA</INTERNATIONAL_DESIGNATOR>
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    <EPHEMERIS_NAME>NONE</EPHEMERIS_NAME>
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    <MANEUVERABLE>NO</MANEUVERABLE>
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    <ATMOSPHERIC_MODEL>JACCHIA 70 DCA</ATMOSPHERIC_MODEL>
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    <INTRACK_THRUST>NO</INTRACK_THRUST>
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      <COMMENT>Inclination=98.8 deg</COMMENT>
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</cdm>
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# ANNEX D

# ABBREVIATIONS AND ACRONYMS

# (INFORMATIVE)

| | |
|---|---|
| ASCII | American Standard Code for Information Interchange |
| CA | Conjunction Assessment |
| CCSDS | Consultative Committee for Space Data Systems |
| CDM | Conjunction Data Message |
| DRG | Atmospheric Drag |
| EME2000 | Earth Mean Equator and Equinox of J2000 (Epoch J2000) |
| GCRF | Geocentric Celestial Reference Frame |
| ICD | Interface Control Document |
| ITRF | International Terrestrial Reference Frame |
| KVN | Keyword = Value Notation |
| NDM | Navigation Data Message |
| O/O | Owner/Operator |
| OD | Orbit Determination |
| OBS | Observations |
| OEB | Optimally Enclosing Box |
| RCS | Radar Cross Section |
| RMS | Root Mean Square |
| RTN | Radial, Transverse and Normal |
| SANA | Space Assigned Numbers Authority |
| SEDR | Specific Energy Dissipation Rate |
| SI | International System of Units |
| SRP | Solar Radiation Pressure |
| TCA | Time of Closest Approach |
| THR | Thrust |
| TVN | Transverse, Velocity and Normal |
| UTC | Coordinated Universal Time |
| XML | Extensible Markup Language |
| XSLT | Extensible Stylesheet Language Transformations |

# ANNEX E

# RATIONALE AND REQUIREMENTS FOR CONJUNCTION DATA MESSAGES

# (INFORMATIVE)

## E1 OVERVIEW

This annex presents the rationale behind the design of the Conjunction Data Message.

A specification of requirements agreed to by all parties is essential to focus design and to ensure the product meets the needs of the satellite owner/operators and other authorized parties. There are many ways of organizing requirements, but the categorization of requirements is not as important as the agreement on a sufficiently comprehensive set. In this annex, the requirements are organized into two categories:

a) Primary Requirements, which are the most elementary and necessary requirements. They would exist no matter the context in which the CCSDS is operating, i.e., regardless of pre-existing conditions within the CCSDS, satellite owner/operators, or other independent users.

b) Desirable Characteristics, which are not requirements, but are felt to be important or useful features of the Recommended Standard.

## E2 PRIMARY REQUIREMENTS ACCEPTED BY THE CDM

**Table E-1: Primary Requirements**

| Reqt # | Requirement | Rationale | Trace |
|---|---|---|---|
| CDM-P01 | The CDM data shall be provided in digital form (computer file). | Facilitates computerized processing of CDMs. | 3.1.1, 3.1.2 |
| CDM-P02 | The CDM shall be provided in data structures (e.g., files) that are readily ported between, and useable within, 'all' computing environments in use by satellite owner/operators and other authorized parties. | The CCSDS objective of promoting interoperability is not met if messages are produced using esoteric or proprietary data structures. | 3.1.2 |
| CDM-P03 | The CDM shall provide a mechanism by which messages may be uniquely identified and clearly annotated. The file name alone is considered insufficient for this purpose. | Facilitates discussion between a message recipient and the originator should it become necessary. | Table 3-2 |

| Reqt # | Requirement | Rationale | Trace |
|---|---|---|---|
| CDM-P04 | The CDM shall clearly and unambiguously identify the two objects involved in a conjunction. | This information is fundamental to the owner/operators of the objects in the conjunction. Cited as required in ISO 16158 (reference [G2]). | Table 3-4 |
| CDM-P05 | The CDM shall provide the time of closest approach of the two objects involved in the conjunction. | This datum is required in order to determine remaining reaction time, to assess the risk of collision, and to assess potential preventive measures. Cited as required in ISO 16158 (reference [G2]). | Table 3-3 |
| CDM-P06 | The CDM shall provide time measurements (time stamps, or epochs) in commonly used, clearly specified systems. | The CCSDS objective of promoting interoperability is not met if time measurements are produced in esoteric or proprietary time systems. | 6.3.2.6, 6.4.2.4, |
| CDM-P07 | The CDM shall provide the states of the two objects involved in the conjunction at the time of closest approach. | The states at time of closest approach are required for calculation of collision probability in most methods. This information is useful to owner/operators who wish to perform an independent assessment of the conjunction and/or the probability of collision. Cited as desirable in ISO 16158 (reference [G2]). | Table 3-5 |
| CDM-P08 | The CDM shall provide the miss distance of the two objects involved in the conjunction at the time of closest approach. | This datum is required in order to assess the risk of collision and assess potential preventive measures. Cited as required in ISO 16158 (reference [G2]). | Table 3-3 |
| CDM-P09 | The CDM shall provide state vector information for both objects involved in the conjunction in a reference frame that is clearly identified and unambiguous. | Clearly understanding the frame of reference in which measurements are provided is fundamental to the analysis of most, if not all, physical processes. Cited as required in ISO 16158 (reference [G2]). | Table 3-4 |
| CDM-P10 | The CDM shall provide for clear specification of units of measure. | Without clear specification of units of measure, mistakes can be made that involve the unit system in effect (e.g., Metric or Imperial) and/or orders of magnitude (e.g., meters or kilometers). | Table 3-5, 4.3.10, 6.3.3, 6.4.3, Table 3-23-3 |
| CDM-P11 | The CDM shall provide a covariance matrix that includes at least 6×6 position/velocity uncertainty information. | The determination of a satellite state is subject to measurement and process uncertainties at all phases of its development. Consideration of this uncertainty is a necessary part of conjunction analysis and risk assessment. The covariance matrix captures the requisite uncertainty. Cited as required in ISO 16158 (reference [G2]). | Table 3-5 |

| Reqt # | Requirement | Rationale | Trace |
|---|---|---|---|
| CDM-P12 | The CDM shall provide the most recently known operational status of the two objects. | This datum is required in order to assess the risk of collision and assess potential preventive measures. Cited as required in ISO 16158 (reference [G2]). | Table 3-4 |
| CDM-P13 | The CDM shall allow the possibility to exchange information regarding conjunctions of objects orbiting an arbitrary body or point in space. | While Earth is the most likely central body about which orbiting objects may collide, there are other orbit centers with more than one orbiting object (e.g., the Moon, Mars, Earth/Sun L1, Earth/Sun L2). | Table 3-4 |
| CDM-P14 | The CDM shall provide data and/or metadata that will allow the recipient to calculate the probability of collision if it is not provided by the CDM originator. | Some CDM originators will not want to explicitly provide a probability of collision, but their customers may be interested in performing a calculation of their own based on data in the CDM. The probability of collision is cited as desirable in ISO 16158 (reference [G2]). | Table 3-3, Table 3-4, Table 3-5 |
| CDM-P15 | The CDM must not require of the receiving exchange partner the separate application of, or modeling of, spacecraft dynamics or gravitational force models, or integration or propagation. | The situation in which a CDM is provided may not allow time for checking/confirming a predicted conjunction by a recipient. Some owner/operators may not be able to perform the required computations. | Table 3-3, Table 3-4, Table 3-5 |
| CDM-P16 | The CDM shall provide an indicator as to the ephemerides that were used in identifying the conjunction. | Informs the recipient as to whether the ephemeris used was owner/operator supplied or was created by the CDM originator. | Table 3-4 |

## Table E-2: Desirable Characteristics

| ID | Requirement | Rationale | Trace |
|---|---|---|---|
| CDM-D01 | The CDM should be extensible with no disruption to existing users/uses. | Space agencies and owner/operators upgrade systems and processes on schedules that make sense for their organizations. In practice, some organizations will be early adopters but others will opt to wait until performance of a new version of the CDM has been proven in other operations facilities. | Table 3-2 |
| CDM-D02 | The CDM should be as consistent as reasonable with any related CCSDS Recommended Standards used for Earth-to-spacecraft or spacecraft-to-spacecraft applications. | Ideally, the set of Recommended Standards developed by a given CCSDS Working Group will be consistent. | 2.2 |

| ID | Requirement | Rationale | Trace |
|---|---|---|---|
| CDM-D03 | CDM originators should maintain consistency with respect to the optional keywords provided in their implementations; i.e., the composition of the CDMs provided should not change on a frequent basis. | Implementations that change on a frequent basis do not promote stable operations or interoperability. | 1.2 |
| CDM-D04 | The CDM should allow the option for originators to provide a probability of collision of the two objects involved in the conjunction. | Some CDM originators will be interested in providing this datum. Cited as desirable by ISO 16158 (reference [G2]). | Table 3-3 |
| CDM-D05 | The CDM should provide information with which each object's spherical radius may be calculated. | The object radius is required for calculation of collision probability in most methods, which usually model objects as spheres given the lack of attitude information. | Table 3-5 |
| CDM-D06 | The CDM should provide the threshold of close approach used by the originator in the screening. | This datum is desirable in order to assess the risk of collision and assess potential preventive measures. Cited as desirable by ISO 16158 (reference [G2]). | Table 3-3 |
| CDM-D07 | The CDM should provide the components of the relative position at the time of closest approach. | These data allow an owner/operator to quickly do a first-order qualitative assessment of the probability of collision immediately upon receipt of a CDM. | Table 3-3 |
| CDM-D08 | The CDM should provide the relative velocity of the two objects in the conjunction at the time of closest approach. | This datum is desirable in order to assess the risk of collision and assess potential preventive measures. Cited as desirable by ISO 16158 (reference [G2]). | Table 3-3 |
| CDM-D09 | The CDM shall be provided using file name syntax and length that do not violate computer constraints for those computing environments in use by satellite owner/operators and other authorized parties. | The CCSDS objective of promoting interoperability is not met if messages are provided using nonstandard file-name syntax or length. | 3.1.2 |

# ANNEX F

# CONJUNCTION INFORMATION DESCRIPTION

# (INFORMATIVE)

## F1 RELATIVE DATA

**TCA (Time of Closest Approach)**: The date and time of the predicted conjunction. This time tag is also the epoch of the relative state vector, Object1 and Object2 state vectors, as well as the effective time of the covariance matrices for both Object1 and Object2.

COLLISION_PERCENTILE: An array of 1 to n elements specifying the percentile estimate of collision probability specified in COLLISION_PROBABILITY. The entry consists of a single line of elements separated by single white-spaces.

**COLLISION_PROBABILITY**: The probability that Object1 and Object2 will collide. If COLLISION_PERCENTILE is present then COLLSION_PROBABILILY contains an array of probabilities corresponding to the percentile estimates specified in COLLISION_PERCENTILE separated by single white-spaces. If COLLISION_PERCENTILE does not exist then COLLISION_PROBAILITY consists of a single value representing the median value of the collision probability.

**COLLISION_PROBABILITY_METHOD**: The method used to compute the value associated with the COLLISION_PROBABILITY keyword. Example options are 'FOSTER-1992' (see reference [G4]), 'CHAN-1997' (see reference [G8]), 'PATERA-2001' (see reference [G6]), 'ALFANO-2005' (see reference [G7]), and 'MCKINLEY-2006' (see reference [G9]). A list of currently registered options is available on the SANA Registry at http://sanaregistry.org. (To register a new option for this keyword, see annex B, subsection B2.)

**COLLISION_MAX_PC_METHOD**: The method used to compute the value associated with the COLLISION_MAX_PROBABILITY keyword. Example options are 'SCALE_COMBINED_COVAR' (see Eqn. 34 of [G16]) and 'SCALE_INDIV_COVAR' (see reference [G17][G8]).

**SEFI_COLLISION_PROBABILITY:** The space environment fragmentation impact adjusted collision probability. The adjustment consists of reducing the collision probability by an order of magnitude if the collision is assessed as not having a major impact on the local space environment. This assessment is detailed in reference [G18] and is performed as follows:

1) Compute collision probability;
2) Determine the orbital regime;
3) If LEO, then determine (using the simple NASA Std Breakup Model) if this collision is anticipated to generate more than 200 fragments;

4) If this collision is assessed as an event which will *not* produce more than 200 fragments, then downgrade the collision probability value by one order of magnitude (otherwise, use the collision probability value "as is").

**MISS_DISTANCE**: The miss distance is the norm of the relative position vector. It indicates how close the two objects are at the time of the predicted encounter.

**MAHALANOBIS_DISTANCE**: The miss distance normalized to the 1-sigma error dispersion of the combined error covariance in the direction of the relative position vector. It indicates how close the two objects are at the time of the predicted encounter, scaled to the uncertainty in positional knowledge along that direction.

Mahalanobis miss distance may be computed from $\bar{r}_{1_{\text{Inertial}}}$, $\bar{r}_{2_{\text{Inertial}}}$, and the 1σ dispersions ($\sigma_x$, $\sigma_y$, $\sigma_z$, which are the square root of the respective eigenvalues) and associated eigenvectors (of unit length) which define the eigenframe as follows:

Relative position vector $\bar{\rho}_{\text{Inertial}}$ is:

$$\begin{bmatrix}\rho_x\\ \rho_y\\ \rho_z\end{bmatrix}_{\text{Inertial}} = \begin{bmatrix}x_2\\ y_2\\ z_2\end{bmatrix}_{\text{Inertial}} - \begin{bmatrix}x_1\\ y_1\\ z_1\end{bmatrix}_{\text{Inertial}}$$

The relative position vector $\bar{\rho}_{\text{EigenFrame}}$ is:

$$\begin{bmatrix}\rho_x\\ \rho_y\\ \rho_z\end{bmatrix}_{EigenFrame} = \begin{bmatrix}[\widehat{EigVecMaj}_{Inertial}]\\ [\widehat{EigVecInt}_{Inertial}]\\ [\widehat{EigVecMin}_{Inertial}]\end{bmatrix} \begin{bmatrix}\rho_x\\ \rho_y\\ \rho_z\end{bmatrix}_{Inertial}$$

From which:

$$\text{Mahalanobismissdistance} = \sqrt{\frac{{\rho_x}_{\text{EigenFrame}}^2}{\sigma_x^2} + \frac{{\rho_y}_{\text{EigenFrame}}^2}{\sigma_y^2} + \frac{{\rho_z}_{\text{EigenFrame}}^2}{\sigma_z^2}}$$

**RELATIVE_SPEED**: The relative speed is the norm of the relative velocity vector. It indicates how fast the two objects are moving relative to each other at the time of the predicted encounter.

**RELATIVE_POSITION/RELATIVE_VELOCITY**: Object2's position/velocity relative to Object1's position/velocity, calculated by taking the difference of the position and velocity vectors relative to the frame in which they are defined, with components expressed in the Object1-centered RTN coordinate frame at the time of closest approach.

**RTN Coordinate Frame**: Object-centered quasi-inertial coordinate system. The Object1-centered RTN coordinate frame: R (Radial) is the unit vector in the radial direction pointed outward from the center of the central body, T (Transverse) is the unit vector perpendicular to the R vector in the direction of the spacecraft velocity, and N (Normal) is the unit vector normal to the satellite's inertial orbit plane (in the direction of the satellite's angular momentum) that completes the right-hand coordinate frame (see figure F-1).

**TVN Coordinate Frame**: Object-centered coordinate system. The Object1-centered TVN coordinate frame is defined as: V (Velocity) is the unit vector in the inertial velocity direction, N (Normal) is the unit vector normal to the satellite's inertial orbit plane (in the direction of the satellite's angular momentum), and T (Transverse) is the unit vector that completes the right-hand coordinate frame (see figure F-1).

Commonality Between RTN and TVN

The primary difference between the RTN and the TVN frames is that the RTN frame is anchored on the unit radial vector R, and the TVN frame is anchored on the unit inertial velocity vector V. The unit normal vector N is the same vector for both the RTN and TVN frames. The unit transverse vector T completes the right-hand coordinate frame for both the RTN and TVN frames, but is not in the same direction for both frames. The TVN frame can be particularly useful for analyzing non-circular orbits where the user would like one coordinate axis to align with the velocity direction of motion. The RTN and TVN frames are the same when Object1 is at apoapsis, periapsis, or when its orbit is perfectly circular.

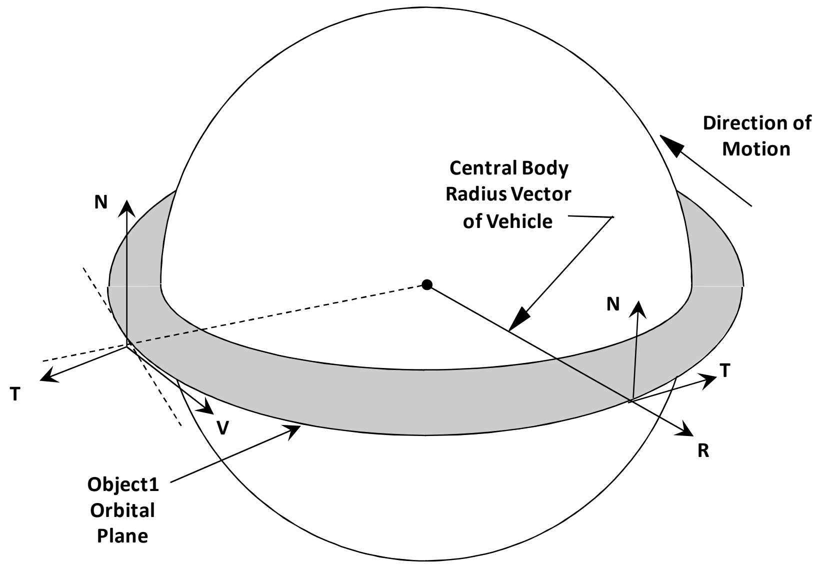


**Figure F-1: Definition of the RTN and TVN Coordinate Frames**

**SCREEN_VOLUME_SHAPE/SCREEN_VOLUME**: Shape (ellipsoid or box) of the screening volume used to screen the satellite catalog for possible conjunctors with Object1. The screening volume is the component size of the screening volume shape (in the Object1 centered RTN or TVN reference frame).

## F2 ORBIT DETERMINATION PARAMETERS

**Observation**: Unique measurement of a satellite's location from a single sensor at a single time (e.g., azimuth from a single sensor at a single time).

**TIME_LASTOB_START and TIME_LASTOB_END**: The start and end of a time interval (UTC) that contains the time of the last accepted observation (see 6.3.2.6 for formatting rules). For an exact time, the time interval is of zero duration (i.e., TIME_LASTOB_START = TIME_LASTOB_END).

**RECOMMENDED_OD_SPAN**: How many days of observations were recommended for the OD of the object.

**ACTUAL_OD_SPAN**: The actual time span used for the OD of the object based on the observations available and the RECOMMENDED_OD_SPAN.

**OBS_AVAILABLE**: The number of observations, for the recommended time span, that were available for the OD.

**OBS_USED**: The number of observations, for the recommended time span, that were accepted for the OD.

**Sensor Track**: A set of at least three observations for the same object, observed by the same sensor, where each observation is within a specified number of minutes (which is dependent on the orbit regime of the object) of the other observations in the track.

**TRACKS_AVAILABLE**: The number of sensor tracks, for the recommended time span, that were available for the OD. This provides information about the independence of the observational data used in the OD.

**TRACKS_USED**: The number of sensor tracks, for the recommended time span, that were accepted for the OD. This provides information about the independence of the observational data used in the OD.

**WEIGHTED_RMS**:

$$Weighted\ RMS = \sqrt{\frac{\sum_{i=1}^{N} w_i \left(y_i - \hat{y}_i\right)^2}{N}}$$

Where

$y_i$ is the observation measurement at the $i$th time;

$\hat{y}_i$ is the estimate of $y_i$;

$w_i = \frac{1}{\sigma_i^2}$ is the weight associated with the measurement at the *i*th 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.

## F3 MODEL PARAMETERS

**GRAVITY_MODEL**: The geopotential model used in the state vector update. The degree (D) and order (O) of the spherical harmonic coefficients applied should be given along with the name of the model.

**ATMOSPHERIC_MODEL**: The atmospheric density model used in the state vector update.

**N_BODY_PERTURBATIONS**: Which (if any) N-body gravitational perturbations were included in the state vector update. The value is a comma-separated list of the body names.

**SOLAR_RAD_PRESSURE**: Whether perturbations due to solar radiation pressure were included in the state vector update.

**EARTH_TIDES**: Whether perturbations due to solid Earth and ocean tides were included in the state vector update.

## F4 ADDITIONAL PARAMETERS

**AREA_PC**: The typical area (or cross-section) of the object to be used in the calculation of the probability of collision (m**2). The area could be known by the owner/operator of the satellite or defined by using a Radar Cross Section (RCS) as in the case of debris. If the value of the area is unknown or not available, ‘0.0’ may be displayed. AREA_PC_MIN and AREA_PC_MAX provide minimum and maximum bounding values for this area.

**AREA_DRG**: The effective area of the object (m**2) exposed to atmospheric drag.

**AREA_SRP**: The effective area of the object (m**2) exposed to solar radiation pressure.

**RCS:** Typical (50th percentile) effective Radar Cross Section (m**2) of the space object sampled over all possible viewing angles. RCS_MIN and RCS_MAX provide minimum and maximum bounding values for the object RCS.

**HBR:** The object Hard-Body Radius (m), the radius of a sphere which encapsulates the physical object. This quantity is often used in the calculation of Probability of Collision.

**CD_AREA_OVER_MASS**: The coefficient of the perturbation of the object due to atmospheric drag (m**2/kg) used to propagate the state vector and covariance to TCA, defined as $C_D$•*A/m*, where $C_D$ is the drag coefficient, *A* is the effective area of the object exposed to atmospheric drag, and *m* is the mass of the object.

**CR_AREA_OVER_MASS**: The coefficient of the perturbation of the object due to solar radiation pressure (m**2/kg) used to propagate the state vector and covariance to TCA, defined as $C_R$•*A/m*, calculated using solar flux at 1 AU, where $C_R$ is the solar radiation pressure coefficient, *A* is the effective area of the object exposed to solar radiation pressure and *m* is the mass of the object.

**THRUST_ACCELERATION**: The object's acceleration due to in-track thrust (m/s**2) used to propagate the state vector and covariance of the object to TCA.

**SEDR (Specific Energy Dissipation Rate)**: 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, in order 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.

**APOAPSIS_HEIGHT and PERIAPSIS HEIGHT:** Apoapsis and periapsis denote the positions in an objects orbit about a central body where they are at the greatest and least distance from that central body respectively. Height denotes the distance from the equatorial radius of the central body.

**INCLINATION:** The orbital inclination (deg) of the object which is measures as the angle between the orbit plane of the object and the equatorial plane of the orbit center.

**COV_SCALE_MIN and COV_SCALE_MAX:** The minimum and maximum scale factor to be applied to the covariance matric in order to achieve realism.

**COV_CONFIDENCE:** A measure of the confidence in the covariance errors matching reality, as characterized via a Wald test, a Chi-squared test, the log of likelihood, or a numerical representation per mutual agreement.

**Optimally-Encompassing Box (OEB):** For a box-shaped satellite (e.g., a CubeSat) without appendages, the satellite and a corresponding OEB would be a one-to-one mapping.

For a satellite having solar arrays that extend from the spacecraft body structure, the OEB would extend from the main satellite body to encompass the deployed solar arrays as well.

The OEB shape is shown in figure F-2 below. As illustrated, the OEB reference frame axes (depicted in RED) are defined by convention as follows:

- The OEB x-axis is along the **longest** dimension of the box ($\widehat{\mathrm{X}}_{\mathrm{OEB\_MAX}}$). This is sometimes referred to the “span” of the space object.
- The OEB y-axis is along the **intermediate** orthonormal dimension ($\hat{y}_{\mathrm{OEB\_INT}}$)
- The OEB z-axis is along the **shortest** orthonormal dimension ($\hat{z}_{\mathrm{OEB\_MIN}}$).

The BOX shape can easily represent a cube by setting all orthonormal dimensions equal. In the event that the longest two or three orthonormal dimensions are equivalent, $\widehat{\mathrm{X}}_{\mathrm{OEB\_MAX}}$ is defined as the direction along one of those longest dimensions and the next as $\hat{y}_{\mathrm{OEB\_INT}}$.

In the event that the longest two or three principal axis dimensions of the box are equivalent, $\widehat{\mathrm{X}}_{\mathrm{OEB\_MAX}}$ is defined as the direction along one of those longest principal dimensions and the next as $\hat{y}_{\mathrm{OEB\_MED}}$.

The OEB z-axis is always defined as: $\hat{z}_{\mathrm{OEB\_MIN}} = \widehat{\mathrm{X}}_{\mathrm{OEB\_MAX}} \times \hat{y}_{\mathrm{OEB\_INT}}$.

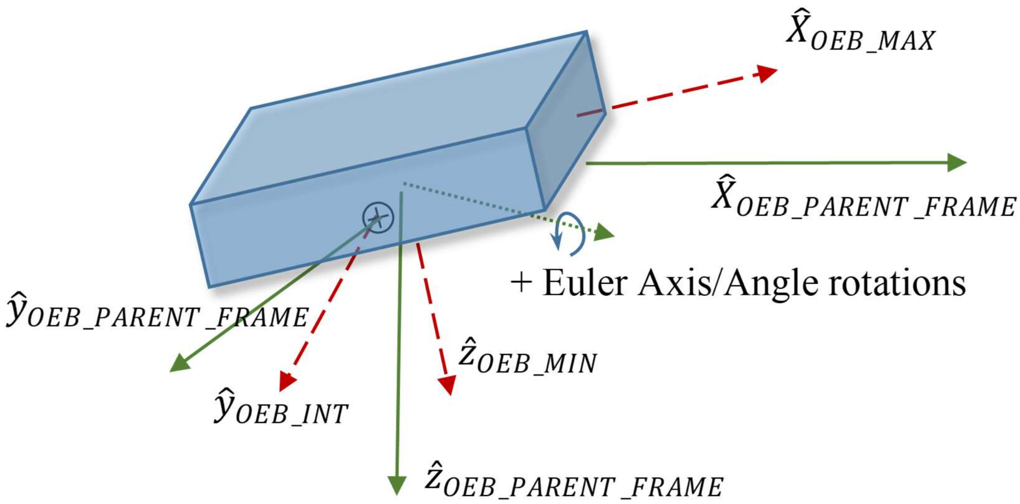


**Figure F-2: Depiction of Optimally-Enclosing Box and Definitions of MAX, INT and MIN Orientation Vectors Relative to OEB Parent Fame**

NOTE: parent and body axis are shown in proximity to each other for display purposes only, but could generally be in any orientation as specified by the quaternion.

A fixed orientation of the Optimally-Encompassing Box with respect to the user-specified "OEB_PARENT_FRAME" is defined using a **quaternion** that maps from the user-specified OEB_PARENT_FRAME to the Optimally-Encompassing Box vector directions. The above figure shows the proper definitions and adopted sign conventions. The resulting transformation sequence is:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\mathrm{OEB}} = [M] \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{OEB\_PARENT\_FRAME}$$

Where the frame transformation matrix [M] is a function of the quaternion components

$$[M] = \begin{bmatrix} {Q_1}^2 - {Q_2}^2 - {Q_3}^2 + {Q_c}^2 & 2(Q_1Q_2 + Q_3Q_c) & 2(Q_1Q_3 - Q_2Q_c) \\ 2(Q_1Q_2 - Q_3Q_c) & -{Q_1}^2 + {Q_2}^2 - {Q_3}^2 + {Q_c}^2 & 2(Q_2Q_3 + Q_1Q_c) \\ 2(Q_1Q_3 + Q_2Q_c) & 2(Q_2Q_3 - Q_1Q_c) & -{Q_1}^2 - {Q_2}^2 + {Q_3}^2 + {Q_c}^2 \end{bmatrix}$$

The physical dimensions of the OEB (long, intermediate, and short dimensions) are specified via OEB_MAX, OEB_INT, and OEB_MIN respectively.

The cross-sectional area as viewed along the OEB x, y and z axes (long, intermediate and short dimension directions) are specified via AREA_ALONG_OEB_MAX, AREA_ALONG_OEB_INT, and AREA_ALONG_OEB_MIN, respectively. These projected areas can represent the actual cross-sectional area presented normal to each axis direction, which can be useful for drag, lift and SRP force estimates. For example, the total cross-sectional area observed when viewed from an arbitrary unit-vector direction [x y z] for estimation of drag forces could be:

$$\mathrm{DRAG\_AREA} = \mathrm{DRAG\_ADDL\_AREA} + \begin{bmatrix} \mathrm{AREA\_ALONG\_OEB\_MAX} \\ \mathrm{AREA\_ALONG\_OEB\_INT} \\ \mathrm{AREA\_ALONG\_OEB\_MIN} \end{bmatrix} \cdot [\mathrm{M}] \widehat{\begin{bmatrix} x \\ y \\ z \end{bmatrix}}_{\mathrm{OEB\_PARENT\_FRAME}}$$

**Apparent-to-Absolute Visual Magnitude Relationship:** These parameters present the relationships to be used to map apparent to absolute visual magnitude for inclusion in a CDM. These equations, based on ANNEX G, Reference [G13], examine signal magnitude for reflected illumination by a Resident Space Object (RSO) that is exoatmospheric, meaning that its illumination by the Sun is not reduced or impeded by atmospheric transmission losses. The equations do not account for spatial distribution across multiple detectors, which involves characterizing the Point Spread Function of the system.

Definitions:

| | |
|---|---|
| $A_{Target}$ | Effective area of the target $[m^2]$ |
| $E_{EntranceAperture}$ | Target's specific entrance aperture radiance [W/m$^2$] |
| $d_{SunToTarget}$ | Distance from the sun to the target [m] (e.g. 1 AU = $1.4959787066\times10^{11}$ m) |
| $d_{TargetToSensor}$ | Distance from target to sensor [m] |
| $dia_{Target}$ | Effective diameter of the target, [m] |
| $E_{Sun}$ | Exoatmospheric solar irradiance, nominally 1380 $[{}^{W}/_{m^2}]$ at 1 AU |
| $E_{Target}$ | Target Irradiance at Sensor without atmospheric loss [W/m$^2$] |
| $E_0$ | Ref. Visual Magnitude (Vega) Irradiance $[2.77894\times 10^{-8}\ {}^{W}/_{m^2}]$ |
| F | General shadowing term accounting for the penumbra region's influence [unitless, $0 < F \le 1$, 0 = umbra, and 1 = full Sun illumination] |
| $I_{Sun}$ | Solar Intensity ≈ $3.088374161\times10^{25}$ [W] |
| $I_{Target}$ | Intensity of reflected energy from target treated as a point source [W] |
| Phase(φ) | Geometric reflectance function [unitless, $0 < \mathrm{Phase}(\varphi) \le 1$] |
| φ | Phase or Critical Angle to the Sun (CATS) from sun to the sensor, as shown in figure F-3 and measured at the observed target [rad] |
| π | Pi constant |
| ρ | Reflectance of the target [between 0 (none) and 1 (perfect reflectance)] |
| $\tau_{Atmosphere}$ | Atmospheric transmission [unitless, $0 < \tau \le 1$] |

Given an optical sensor's measured target entrance aperture radiance:

$$E_{target} = \frac{E_{EntranceAperture}}{\tau_{Atmosphere}(\theta)} [\mathrm{W/m^2}]$$

$$VM_{apparent} = -2.5 \log_{10} \frac{E_{target}}{E_0}$$, measured on the visual magnitude scale

or if $VM_{apparent}$ known: $E_{target} = E_0\, 10^{\left[-\frac{VM_{apparent}}{2.5}\right]}$

$$I_{target} = E_{target} d^2_{TargetToSensor} \ [W]$$

$$E_{Sun} = \frac{I_{Sun}}{d^2_{SunToTarget}} \ [W/m^2]$$

$$Phase(\varphi) = \frac{\sin\varphi + (\pi - \varphi)\cos\varphi}{\pi}$$

$A_{Target} = \frac{\pi I_{Target}}{\rho F E_{Sun} Phase(\varphi)}$ [$m^2$] {NOTE1: undefined in umbra (F=0=darkness), or no reflection ($\rho = 0$). NOTE2: If reflectance is unknown, one can assume a standard reference reflectance of fifteen percent]}

From which an effective diameter of the physical object can be roughly approximated as:

$$dia_{Target} \approx \sqrt{\frac{4\ A_{Target}}{\pi}}$$

From the above equations, $VM_{absolute}$ “normalized” to a 1 AU Sun-to-target distance, a phase angle of 0° and an example reference 40,000 km target-to-sensor distance (equivalent to a GEO satellite tracked at 15.6° elevation above the optical site’s local horizon), is obtained as:

$VM_{absolute}$ = -2.5 $\log_{10}\left\{\frac{E_{target}}{E_0}\right\}$, from which:

$$VM_{absolute} = -\mathbf{2.5}\ \mathbf{log_{10}} \left\{ \frac{\left[E_{Sun1\,AU} = 1380\ W/_{m^2}\right] [Phase(0\ rad) = 1.0\ ][\ \rho\ A_{Target}\ from\ above,\ \ in\ m^2]}{\pi\ \left[E_0 = 2.77894 \times 10^{-8}\ W/_{m^2}\right][(1.6 \times 10^{15})\ m^2]} \right\}$$

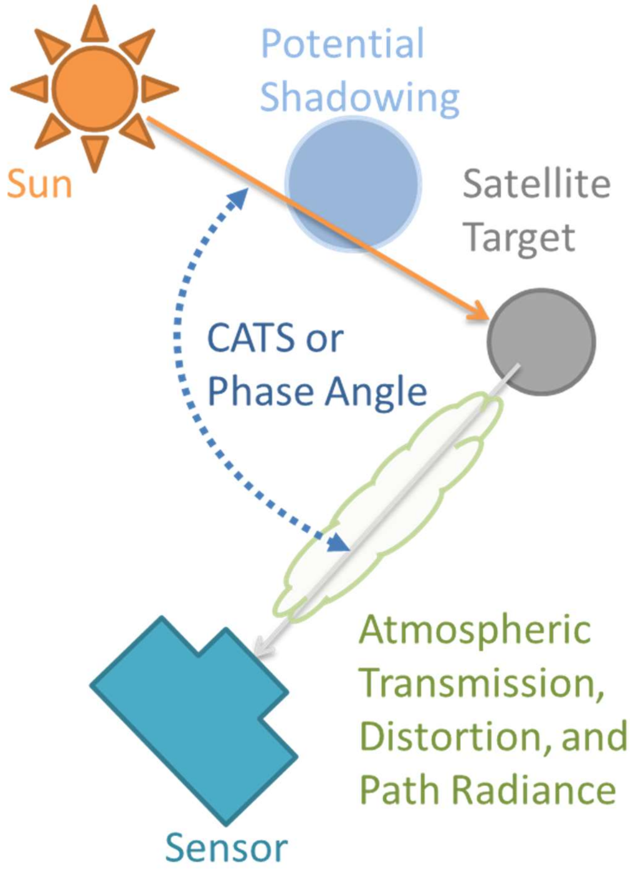


**Figure F-3: Depiction of Optical Viewing Critical Angle to the Sun (CATS) Phase Angle Geometry**

## F5 COVARIANCE MATRIX

The object covariance may be specified in one of two formats, this being either lower triangular format or sigmas/eigenvectors format:

- Lower Triangular Format: The covariance matrix is mandatory for the position and velocity terms, given in the lower triangular form of a 6×6 matrix. If any of the diagonal terms are zero, the entire row and column of the matrix related to that term should be discounted. Optional terms for CD_AREA_OVER_MASS (denoted 'DRG'), CR_AREA_OVER_MASS (denoted 'SRP'), and THRUST_ACCELERATION (denoted 'THR') can be added to the 6×6 matrix, in the lower triangular form, to complete a 9×9 matrix. If any element in any of these rows (7, 8, or 9) is provided, then all of the elements for that row and all preceding rows need to be provided (i.e., a subset of the terms for any of these rows is not allowed). The purpose for providing the 7, 8, and 9 terms is so that users, who have the originator's propagator model available (along with the appropriate CD_AREA_OVER_MASS and/or CR_AREA_OVER_MASS and/or THRUST_ACCELERATION terms), can correctly propagate the 6×6 position and velocity covariance to another time point.

The lower triangular format may be specified in either RTN or XYZ frame as specified by the COV_TYPE keyword, if XYZ frame is used the reference frame is specified by the COV_REF) FRAME keyword.

- Sigma/Eigenvector Format: This format is selected using the COV_TYPE keyword. The covariance is specified by the CSIG3EIGVEC3keyword and comprises the major, intermediate and minor one-sigma dispersions followed by their accompanying major, intermediate and minor eigenvectors specified as a single line of twelve parameters separated by spaces.

If the COV_TYPE flag is omitted then a lower triangular RTN covariance is expected in line with previous versions of this standard to provide backwards compatibility.

# ANNEX G

# INFORMATIVE REFERENCES

# (INFORMATIVE)


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