The Consultative Committee for Space Data Systems

Draft Recommendation for
Space Data System Standards

CONJUNCTION DATA MESSAGE

DRAFT RECOMMENDED STANDARD

CCSDS 508.0-P-1.1

PINK BOOK
March 2024

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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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PREFACE

This document is a draft CCSDS Recommended Standard. Its 'Pink Book' status indicates that the CCSDS believes the document to be technically mature and has released it for formal review by appropriate technical organizations. As such, its technical contents are not stable, and several iterations of it may occur in response to comments received during the review process.

Implementers are cautioned **not** to fabricate any final equipment in accordance with this document's technical content.

Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

DOCUMENT CONTROL

Document	Title	Date	Status
CCSDS 508.0-B-1	Conjunction Data Message, Recommended Standard, Issue 1	June 2013	Current issue
CCSDS 508.0-P-1.1	Conjunction Data Message, Draft Recommended Standard, Issue 1.1	March 2024	Current draft revision: – A summary of changes is provided in annex J.

NOTE – Changes from the current issue are too numerous to permit meaningful markup.

CONTENTS

CONTENTS (continued)

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 H).

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 values for selected keywords.

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

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 CDM examples in both KVN and XML formats.

Annex H provides informative references.

Annex I provides items for an Interface Control Document (ICD)

Annex J describes changes versus previous versions of the CDM.

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;

– deg: degrees;

– n/a: (units are not applicable).

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)*. 9th ed. Sèvres, France: BIPM, 2019.

[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 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 505.0-B-3. Washington, D.C.: CCSDS, May 2023.

[7] "Online Index of Objects Launched into Outer Space." United Nations Office for Outer Space Affairs (UNOOSA). http://www.unoosa.org/oosa/osoindex.

[8] *IEEE Standard for Floating-Point Arithmetic*. 3rd ed. IEEE Std 754-2019. New York: IEEE, 2019.

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 small set of widely used reference frames (ITRF, GCRF—see reference [H11], EME2000);

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

– the relative position/velocity at TCA 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/data for Object1;

d) metadata/data for Object2; and

e) 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.

3.1.3 The method of exchanging CDMs should 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). Conditional indicates that the item is mandatory if specified conditions are met (e.g., providing all covariance matrix elements if any are provided).

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.	2.0	M
COMMENT	(See 6.3.4 for formatting rules.)	COMMENT This is a comment	O
CLASSIFICATION	User-defined free-text message classification or caveats of this CDM. It is recommended that selected values be pre-coordinated between exchanging entities by mutual agreement.	UNCLASSIFIED "Operator-proprietary data; secondary distribution not permitted"	O
CREATION_DATE	Message creation date/time in Coordinated Universal Time (UTC). (See 6.3.2.10 for formatting rules.)	2010-03-12T22:31:12.000 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 6.2.2.2 for formatting rules.)	See SANA	M
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 6.2.2.2 for formatting rules.)	201113719185 ABC-12_34	M

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). Conditional indicates that the item is mandatory if specified conditions are met (e.g., providing all covariance matrix elements if any are provided).

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

Keyword	Description	Units	MOC
COMMENT	(See 6.3.4 for formatting rules.)	n/a	O
CONJUNCTION_ID	Originator’s ID that uniquely identifies the conjunction to which the message refers, e.g. 20200610T10hz_SKYNET5B_GORIZONT9 (See 6.2.2.2 for formatting rules).	n/a	O
TCA	The date and time in UTC of the closest approach. 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. (See 6.3.2.10 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 radial component of Object2’s position relative to the Object1 centered Radial, Transverse, and Normal (RTN) coordinate frame. (See annex F for definition.) Data type = double.	m	O
RELATIVE_POSITION_T	The transverse component of Object2’s position relative to the Object1 centered RTN coordinate frame. (See annex F for definition.) Data type = double.	m	O
RELATIVE_POSITION_N	The normal component of Object2’s position relative to the Object1 centered RTN coordinate frame. (See annex F for definition.) Data type = double.	m	O

Keyword	Description	Units	MOC
RELATIVE_VELOCITY_R	The radial component of Object2's velocity relative to the Object1 centered RTN coordinate frame. (See annex F for definition.) Data type = double.	m/s	O
RELATIVE_VELOCITY_T	The transverse component of Object2's velocity relative to the Object1 centered RTN coordinate frame. (See annex F for definition.) Data type = double.	m/s	O
RELATIVE_VELOCITY_N	The normal component of Object2's velocity relative to the Object1 centered RTN coordinate frame. (See annex F for definition.) Data type = double.	m/s	O
APPROACH_ANGLE	The angle between the inertial velocity vector of Object1 and the relative velocity vector of Object2 with respect to Object1 in the inertial frame. 0 degrees reflects “overtaking” and 180 degrees reflects “head-on” condition.	deg	O
START_SCREEN_PERIOD	The start time in UTC of the screening period for the conjunction assessment. (See 6.3.2.10 for formatting rules.)	n/a	O
STOP_SCREEN_PERIOD	The stop time in UTC of the screening period for the conjunction assessment. (See 6.3.2.10 for formatting rules.)	n/a	O
SCREEN_TYPE	The type of screening to be used. The value(s) can be any combination of the following: {SHAPE, PC, PC_MAX} as comma delimited values. For collision probability (PC) or maximum collision probability (PC_MAX) screening, estimated collision probability values are compared against the specified SCREEN_PC_THRESHOLD.	n/a	O
SCREEN_VOLUME_SHAPE	The type of screening metric or algorithm used, to include SPHERE, ELLIPSOID, or BOX. (Condition: Mandatory if SCREEN_TYPE = SHAPE)	n/a	C
SCREEN_VOLUME_RADIUS	The radius of the screening volume. Data type = double. (Condition: Mandatory if SCREEN_VOLUME_SHAPE = SPHERE)	m	C
SCREEN_VOLUME_FRAME	Name of the Object1 centered reference frame in which the screening volume data are given. Available options are RTN and TVN (Transverse, Velocity, and Normal). (Condition: Mandatory if SCREEN_VOLUME_SHAPE = ELLIPSOID or BOX)	n/a	C

Keyword	Description	Units	MOC
SCREEN_VOLUME_X	The R or T (depending on if RTN or TVN is selected) component size of the screening volume in the SCREEN_VOLUME_FRAME. Data type = double. (Condition: Mandatory if SCREEN_VOLUME_SHAPE = ELLIPSOID or BOX)	m	C
SCREEN_VOLUME_Y	The T or V (depending on if RTN or TVN is selected) component size of the screening volume in the SCREEN_VOLUME_FRAME. Data type = double. (Condition: Mandatory if SCREEN_VOLUME_SHAPE = ELLIPSOID or BOX)	m	C
SCREEN_VOLUME_Z	The N component size of the screening volume in the SCREEN_VOLUME_FRAME. Data type = double. (Condition: Mandatory if SCREEN_VOLUME_SHAPE = ELLIPSOID or BOX)	m	C
SCREEN_ENTRY_TIME	The time in UTC when Object2 enters the screening volume (See 6.3.2.10 for formatting rules). (Condition: Mandatory if SCREEN_VOLUME_SHAPE being present)	n/a	C
SCREEN_EXIT_TIME	The time in UTC when Object2 exits the screening volume (See 6.3.2.10 for formatting rules). (Condition: Mandatory if SCREEN_VOLUME_SHAPE being present)	n/a	C
SCREEN_PC_THRESHOLD	The collision probability screening threshold used to identify this conjunction. Data type = double. (Condition: Mandatory for SCREEN_TYPE = PC or PC_MAX)	n/a	C
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. A COLLISION_PERCENTILE of 50% corresponds to the median (or typical) collision probability. A COLLISION_PERCENTILE of 20% indicates the collision probability that equals or exceeds 20% of all estimated collision probability values drawn from the full ensemble of possible Pc values. The entry consists of a single line of elements separated by white-spaces. Data type = integer array.	n/a	O

Keyword	Description	Units	MOC
COLLISION_PROBABILITY	If COLLISION_PERCENTILE is present, an array of 1 to n elements specifying the estimated collision probability at the specified COLLISION_PERCENTILE value (each element value in the range 0.0 to 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. For example, at a COLLISION_PERCENTILE of 50%, the median (or typical) collision probability value is estimated. The entry consists of a single line of elements separated by white-spaces. Data type = double array. If COLLISION_PERCENTILE is not present, the best estimate of probability at the instantaneous epoch of interest (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. Example options are 'FOSTER-1992' (see reference [H4]), 'CHAN-1997' (see reference [H5]), 'PATERA-2001' (see reference [H6]), 'ALFANO-2005' (see reference [H7]), and 'MCKINLEY-2006' (see reference [H9]). A list of currently registered options is available on the SANA Registry at https://sanaregistry.org/r/cdm_cpm/.	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_MAX_PROBABILITY. Example options are 'SCALE_COMBINED_COVAR' (see Eqn. 34 of [H16]) and 'SCALE_INDIV_COVAR' (see reference [H8])	n/a	O

Keyword	Description	Units	MOC
SEFI_COLLISION_PROBABILITY	If COLLISION_PERCENTILE is present, an array of 1 to n elements specifying the space environment fragmentation impact (SEFI) adjusted estimate of collision probability (each element value in the range 0.0 to 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 for each percentile specified in COLLISION_PERCENTILE. The entry consists of a single line of elements separated by white-spaces. Data type = double array. If COLLISION_PERCENTILE is 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. Data type = double. (See annex F for an example of space environment fragmentation impact adjustment.)	n/a	O
SEFI_COLLISION_PROBABILITY_METHOD	The method that was used to calculate the SEFI_COLLISION_PROBABILITY.	n/a	O
SEFI_FRAGMENTATION_MODEL	Free text field containing the name of the space environment fragmentation model used (formatting rules specified in 6.2.2.2).	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. (See 6.2.2.2 for formatting rules.)	n/a	O
PREVIOUS_MESSAGE_EPOCH	UTC epoch (CREATION_DATE) of the previous CDM issued for the event identified by CONJUNCTION_ID. (See 6.3.2.10 for formatting rules.)	n/a	O
NEXT_MESSAGE_EPOCH	Scheduled UTC epoch of the next CDM associated with the event identified by CONJUNCTION_ID. (See 6.3.2.10 for formatting rules.)	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 item is mandatory (M), optional (O) or conditional (C). Conditional indicates that the item is mandatory if specified conditions are met (e.g., providing all covariance matrix elements if any are provided).

NOTE – Table 3-4 and table 3-5 will define the metadata and data sections associated with each object involved in the conjunction. The OBJECT keyword, which is specified in table 3-4, will indicate whether metadata and data section relate to either Object 1 or Object 2.

Table 3-4: CDM KVN Metadata

Keyword	Description	Examples	MOC
COMMENT	(See 6.3.4 for formatting rules.)	COMMENT This is a comment	O
OBJECT	The object to which the metadata and data apply. Value must be either OBJECT1 or OBJECT2.	OBJECT1	M
OBJECT_DESIGNATOR	Free text field specification of the unique satellite identification designator for the object, as reflected in the catalogue whose name is “CATALOG_NAME”. If the ID is not known (uncorrelated object), “UNKNOWN” may be used. (see 6.2.2.2 for formatting rules.)	22444 18SPCS 18571 UNKNOWN	M
CATALOG_NAME	Free-text field containing the satellite catalog source (or source agency or operator, value to be drawn from the SANA registry list of Space Object Catalogs at https://sanaregistry.org/r/space_object_catalog, or alternatively, from the list of organizations listed in the ‘Abbreviation’ column of the SANA Organizations registry at https://sanaregistry.org/r/organizations) from which ‘OBJECT_DESIGNATOR’ was obtained. (See 6.2.2.2 for formatting rules.)	SATCAT	M
OBJECT_NAME	Free text field containing the name of the object (formatting rules specified in 6.2.2.2). 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 ENVISAT IRIDIUM NEXT-8 INTELSAT G-15 UNKNOWN	M

Keyword	Description	Examples	MOC
INTERNATIONAL_DESIGNATOR	Free text field containing an international designator for the object as assigned by the UN Committee on Space Research (COSPAR). Such designator values have the following COSPAR format: YYYY-NNNP{PP}, where: YYYY = Year of launch. NNN = Three-digit serial number of launch in year YYYY (with leading zeros). P{PP} = At least one capital letter for the identification of the part brought into space by the launch. In cases where the object has no international designator, the value UNKNOWN may be used. (See 6.2.2.2 for further formatting rules.)	2002-021A 2002-009A 1997-020AA 1998-037ABC 2001-049PE UNKNOWN	M
OBJECT_TYPE	Specification of the type of object. Value must be taken from the SANA registry for Object Types at https://sanaregistry.org/r/object_types/.	PAYLOAD	O
OPS_STATUS	Specification of the operational status of the space object. Value must be taken from the SANA registry for Operational Status at https://sanaregistry.org/r/operational_status/.	OPERATIONAL_MANEUVERABLE	O
OPERATOR_CONTACT_POSITION	Contact position of the owner/operator of the object.	ORBITAL SAFETY ANALYST (OSA) NETWORK CONTROLLER	O
OPERATOR_ORGANIZATION	Contact organization of the object.	EUMETSAT ESA INTELSAT IRIDIUM	O
OPERATOR_PHONE	Phone number of the contact position or organization for the object.	+49615130312	O
OPERATOR_EMAIL	Email address of the contact position or organization of the object.	JOHN.DOE@SOMEWHERE.NET	O

Keyword	Description	Examples	MOC
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. Users are encouraged to use the ODM_MSG_LINK keyword (below) for the specification of Orbit Data Message (ODM) formatted ephemeris data. If ODM_MSG_LINK is used, then EPHEMERIS_NAME shall be set to ODM.	EPH_SAT_A NONE ODM	M
ODM_MSG_LINK	Free text field containing a unique identifier of Orbit Data Message(s) that are linked (relevant) to this Conjunction Data Message. (Condition: Mandatory if EPHEMERIS_NAME=ODM)	ODM_MSG_35132.txt ODM_ID_0572	C
ADM_MSG_LINK	Free text field containing a unique identifier of Attitude Data Message(s) (ADM) that are linked (relevant) to this Conjunction Data Message.	ATT_MSG_35132.txt ATT_ID_0572	O
OBS_BEFORE_NEXT_MESSAGE	Flag indicating whether new tracking observations are anticipated prior to the issue of the next CDM associated with the event specified by CONJUNCTION_ID. Value must be taken from the following list: {YES, NO, UNKNOWN}	YES	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. Value must be taken from the following list: {CALCULATED, DEFAULT}	CALCULATED	M

Keyword	Description	Examples	MOC
COVARIANCE_SOURCE	A free text field which provides the source from which the covariance data used for the object originates. The purpose of this field addition is to highlight the method by which the covariance was derived.	O/O Covariance Quadratic-Error Growth HAC Covariance Vector Covariance Message (VCM)	O
MANEUVERABLE	The maneuver capacity of the object. Value must be taken from the following list: {YES, NO, UNKNOWN}	YES	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. Values should be taken from the SANA registry for Orbit Centers at https://sanaregistry.org/r/orbit_centers/. If not specified, the center is assumed to be Earth.	EARTH SUN MOON MARS	O
REF_FRAME	Name of the reference frame in which the state vector data are provided. The selected reference frame must be the same for both Object1 and Object2. Value must be taken from the following list: {GCRF, EME2000, ITRF} Reference frame definitions for these three frames may be found at the SANA registry for Celestial Body Reference Frames at https://sanaregistry.org/r/celestial_body_reference_frames/.	ITRF	M
ALT_COV_TYPE	Flag indicating the type of alternate covariance information provided. Value must be taken from the following list: {XYZ, CSIG3EIGVEC3}	XYZ	O

Keyword	Description	Examples	MOC
ALT_COV_REF_FRAME	Name of the reference frame in which the alternate covariance data are given. The selected reference frame must be the same for both Object 1 and Object 2 covariances. Value must be taken from the following list: {GCRF, EME2000, ITRF} Reference frame definitions for these three frames may be found at the SANA registry for Celestial Body Reference Frames at https://sanaregistry.org/r/celestial_body_reference_frames/. (Condition: Mandatory if ALT_COV_TYPE present)	ITRF	C
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. NOTE – Specifying a zero value for "order" (e.g., 2D 0O) denotes zonals (J2 … JD)	EGM-96: 36D 36O WGS-84: 8D 0O GGM-01: 36D 36O TEG-4: 36D 36O	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	JACCHIA_HASDM MSIS-86 JR71 NONE	O
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). Accepted values are enumerated in the SANA Registry of Orbit Centers, located at https://sanaregistry.org/r/orbit_centers/.	MOON SUN JUPITER NONE	O
SOLAR_RAD_PRESSURE	Indication of whether solar radiation pressure perturbations were used for the OD of the object. Value must be taken from the following list: {YES, NO}	YES	O

Keyword	Description	Examples	MOC
EARTH_TIDES	Indication of whether solid Earth and ocean tides were used for the OD of the object. Value must be taken from the following list: {YES, NO}	YES	O
INTRACK_THRUST	Indication of whether in-track thrust modelling was used for the OD of the object. Value must be taken from the following list: {YES, NO}	YES	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;

– Physical Parameters;

– State Vector; and

– Covariance Matrix.

3.5.2 Covariance shall be specified in the RTN reference frame. Alternate covariance may be specified in either XYZ or the eigenvector decomposition format, as indicated by the ALT_COV_TYPE keyword. If ALT_COV_TYPE is specified as XYZ, then the reference frame used for the covariance must be specified using the ALT_COV_REF_FRAME parameter.

3.5.2.1 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; (4) linearly-weighted blending of covariances across the bounding timespan of interest, and the resulting (5) recomposition of attained eigenvalues and eigenvectors into covariances at time(s) of interest (reference [H5]). 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.

3.5.2.2 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 (references [H14] and [H15]), 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). Conditional indicates that the item is mandatory if specified conditions are met (e.g., providing all covariance matrix elements if any are provided).

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 6.3.2.10 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 6.3.2.10 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. 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. Data type = double.	d	O
OBS_AVAILABLE	The number of observations, for the actual time span, available for the OD of the object. Data type = integer.	n/a	O
OBS_USED	The number of observations, for the actual time span, accepted for the OD of the object. Data type = integer.	n/a	O
TRACKS_AVAILABLE	The number of sensor tracks available for the OD of the object. This provides information about the independence of the observational data used in the OD. Data type = integer.	n/a	O
TRACKS_USED	The number of sensor tracks accepted for the OD of the object. This provides information about the independence of the observational data used in the OD. Data type = integer.	n/a	O

Keyword	Description	Units	MOC
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
OD_EPOCH	The epoch of the orbit determination used for this message (UTC).	n/a	O
MIN_MEDIAN_MAX_UPDATE_INTERVAL	For a collection of recent sets of positional knowledge for space objects, the minimum, median, and maximum time between epoch updates for the object in question across the successive sets. An example of such sets is 30 consecutive daily TLEs spanning the last 30 days. Data type = double(3).	d	O
Physical Parameters			
COMMENT	(See 6.3.4 for formatting rules.)	n/a	O
AREA_PC	The constant (i.e., non-attitude-dependent) portion of the cross-sectional area of the object used in the calculation of the probability of collision. If AREA_ALONG_OEB area values are also supplied, then the total cross-sectional area is calculated as discussed in Annex F. 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. Data type = double.	m**2	O
AREA_SRP	The effective area of the object exposed to solar radiation pressure. Data type = double.	m**2	O
OEB_PARENT_FRAME	Parent reference frame which maps to the Optimally Enclosing Box (OEB) frame via the quaternion-based transformation defined in annex F, section F3. Accepted values are enumerated in the SANA Registry of Orbit-Relative Reference Frames, located at https://sanaregistry.org/r/orbit_relative_reference_frames/. This keyword shall be provided if OEB_Q1,2,3,C are specified. Alternatively, a value of “UNKNOWN” can be used to indicate that attitude is tumbling, random, or otherwise unpredictable or unknown. In this case, OEB_Q1,2,3,C shall not be provided.	n/a	C
OEB_PARENT_FRAME_EPOCH	Epoch of the OEB reference frame if not intrinsic to the definition of the reference frame.	n/a	C

Keyword	Description	Units	MOC
OEB_Q1	q1 = e1 * sin(φ/2), where φ = 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 F3). Data type = double. If OEB_PARENT_FRAME is set to UNKNOWN, then OEB_Q1 shall not be provided.	n/a	O
OEB_Q2	q2 = e2 * sin(φ/2), where φ = 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 F3). Data type = double. If OEB_PARENT_FRAME is set to UNKNOWN, then OEB_Q2 shall not be provided.	n/a	O
OEB_Q3	q3 = e3 * sin(φ/2), where φ = 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 F3). Data type = double. If OEB_PARENT_FRAME is set to UNKNOWN, then OEB_Q3 shall not be provided.	n/a	O
OEB_QC	qc = cos(φ/2), where φ = Euler 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 F3). qc shall be made non-negative by convention, the signs of q1, q2, q3 will all be changed as appropriate to maintain the transformation direction. Data type = double. If OEB_PARENT_FRAME is set to UNKNOWN, then OEB_QC shall not be provided.	n/a	O
OEB_MAX	Maximum physical dimension of the OEB. Data type = double.	m	O
OEB_INT	Intermediate 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 F3. Data type = double.	m**2	O
AREA_ALONG_OEB_INT	Cross-sectional area of the object when viewed along intermediate OEB direction as defined in annex F, section F3. Data type = double.	m**2	O

Keyword	Description	Units	MOC
AREA_ALONG_OEB_MIN	Cross-sectional area of the object when viewed along minimum OEB direction as defined in annex F, section F3. 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 (Typically 5^{th} percentile). Data type = double.	m**2	O
RCS_MAX	Maximum Radar Cross Section observed for this object (Typically 95^{th} percentile). Data type = double.	m**2	O
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 F3, to a 1 Astronomical Unit (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 (Typically 5^{th} percentile). Data type = double. NOTE – The 'MIN' value represents the dimmest observation, which associates with a higher Vmag.	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 (Typically 95^{th} percentile). Data type = double.	n/a	O
REFLECTANCE	Typical (50th percentile) coefficient of REFLECTANCE of the space object over all possible viewing angles, ranging from 0 (none) to 1 (perfect reflectance). 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, for information only. 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. Data type = double.	m/s**2	O

Keyword	Description	Units	MOC
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
MIN_DV	An array composing of three elements corresponding to the minimum achievable RTN delta-v of the object. Data type = double(3).	m/s	O
MAX_DV	An array composing of three elements corresponding to the maximum achievable RTN delta-v of the object. Data type = double(3).	m/s	O
LEAD_TIME_REQD_BEFORE_TCA	Time required to plan and schedule a maneuver ahead of the predicted TCA.	h	O
APOAPSIS_ALTITUDE	The distance of the furthest point in the object's orbit above the equatorial radius of the central body about which the object is orbiting. Data type = double.	km	O
PERIAPSIS_ALTITUDE	The distance of the closest point in the object's orbit above the equatorial radius of the central body about which the object is orbiting. Data type = double.	km	O
INCLINATION	The angle between the object's 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: Mandatory if COV_CONFIDENCE present)	n/a	C
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 RTN frame definition) (Covariance Matrix 9×9 Lower Triangular Form. All parameters of the 6×6 position/velocity submatrix must be given. All data type=double.)			
COMMENT	(See 6.3.4 for formatting rules.)	n/a	O
CR_R	Object covariance matrix [1,1].	m**2	M
CT_R	Object covariance matrix [2,1].	m**2	M
CT_T	Object covariance matrix [2,2].	m**2	M
CN_R	Object covariance matrix [3,1].	m**2	M
CN_T	Object covariance matrix [3,2].	m**2	M

Keyword	Description	Units	MOC
CN_N	Object covariance matrix [3,3].	m**2	M
CRDOT_R	Object covariance matrix [4,1].	m**2/s	M
CRDOT_T	Object covariance matrix [4,2].	m**2/s	M
CRDOT_N	Object covariance matrix [4,3].	m**2/s	M
CRDOT_RDOT	Object covariance matrix [4,4].	m**2/s**2	M
CTDOT_R	Object covariance matrix [5,1].	m**2/s	M
CTDOT_T	Object covariance matrix [5,2].	m**2/s	M
CTDOT_N	Object covariance matrix [5,3].	m**2/s	M
CTDOT_RDOT	Object covariance matrix [5,4].	m**2/s**2	M
CTDOT_TDOT	Object covariance matrix [5,5].	m**2/s**2	M
CNDOT_R	Object covariance matrix [6,1].	m**2/s	M
CNDOT_T	Object covariance matrix [6,2].	m**2/s	M
CNDOT_N	Object covariance matrix [6,3].	m**2/s	M
CNDOT_RDOT	Object covariance matrix [6,4].	m**2/s**2	M
CNDOT_TDOT	Object covariance matrix [6,5].	m**2/s**2	M
CNDOT_NDOT	Object covariance matrix [6,6].	m**2/s**2	M
CDRG_R	Object covariance matrix [7,1].	m**3/kg	O
CDRG_T	Object covariance matrix [7,2].	m**3/kg	O
CDRG_N	Object covariance matrix [7,3].	m**3/kg	O
CDRG_RDOT	Object covariance matrix [7,4].	m**3/(kg*s)	O
CDRG_TDOT	Object covariance matrix [7,5].	m**3/(kg*s)	O
CDRG_NDOT	Object covariance matrix [7,6].	m**3/(kg*s)	O
CDRG_DRG	Object covariance matrix [7,7].	m**4/kg**2	O
CSRP_R	Object covariance matrix [8,1].	m**3/kg	O
CSRP_T	Object covariance matrix [8,2].	m**3/kg	O
CSRP_N	Object covariance matrix [8,3].	m**3/kg	O
CSRP_RDOT	Object covariance matrix [8,4].	m**3/(kg*s)	O
CSRP_TDOT	Object covariance matrix [8,5].	m**3/(kg*s)	O
CSRP_NDOT	Object covariance matrix [8,6].	m**3/(kg*s)	O
CSRP_DRG	Object covariance matrix [8,7].	m**4/kg**2	O
CSRP_SRP	Object covariance matrix [8,8].	m**4/kg**2	O
CTHR_R	Object covariance matrix [9,1].	m**2/s**2	O
CTHR_T	Object covariance matrix [9,2].	m**2/s**2	O
CTHR_N	Object covariance matrix [9,3].	m**2/s**2	O
CTHR_RDOT	Object covariance matrix [9,4].	m**2/s**3	O
CTHR_TDOT	Object covariance matrix [9,5].	m**2/s**3	O
CTHR_NDOT	Object covariance matrix [9,6].	m**2/s**3	O
CTHR_DRG	Object covariance matrix [9,7].	m**3/(kg*s**2)	O
CTHR_SRP	Object covariance matrix [9,8].	m**3/(kg*s**2)	O
CTHR_THR	Object covariance matrix [9,9].	m**2/s**4	O

Keyword	Description	Units	MOC
Covariance Matrix in the XYZ Coordinate Frame (defined by value of ALT_COV_REF_FRAME) (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 ALT_COV_TYPE = XYZ**			
COMMENT	(See 6.3.4 for formatting rules.)	n/a	O
CX_X	Object covariance matrix [1,1]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2	C
CY_X	Object covariance matrix [2,1]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2	C
CY_Y	Object covariance matrix [2,2].(Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2	C
CZ_X	Object covariance matrix [3,1]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2	C
CZ_Y	Object covariance matrix [3,2]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2	C
CZ_Z	Object covariance matrix [3,3]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2	C
CXDOT_X	Object covariance matrix [4,1]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2/s	C
CXDOT_Y	Object covariance matrix [4,2]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2/s	C
CXDOT_Z	Object covariance matrix [4,3]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2/s	C
CXDOT_XDOT	Object covariance matrix [4,4]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2/s**2	C
CYDOT_X	Object covariance matrix [5,1]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2/s	C
CYDOT_Y	Object covariance matrix [5,2]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2/s	C
CYDOT_Z	Object covariance matrix [5,3]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2/s	C
CYDOT_XDOT	Object covariance matrix [5,4]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2/s**2	C
CYDOT_YDOT	Object covariance matrix [5,5]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2/s**2	C
CZDOT_X	Object covariance matrix [6,1]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2/s	C
CZDOT_Y	Object covariance matrix [6,2]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2/s	C
CZDOT_Z	Object covariance matrix [6,3]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2/s	C
CZDOT_XDOT	Object covariance matrix [6,4]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2/s**2	C
CZDOT_YDOT	Object covariance matrix [6,5]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2/s**2	C
CZDOT_ZDOT	Object covariance matrix [6,6]. (Condition: Mandatory if ALT_COV_TYPE = XYZ)	m**2/s**2	C
CDRG_X	Object covariance matrix [7,1]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**3/kg	C
CDRG_Y	Object covariance matrix [7,2]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**3/kg	C

Keyword	Description	Units	MOC
CDRG_Z	Object covariance matrix [7,3]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**3/kg	C
CDRG_XDOT	Object covariance matrix [7,4]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**3/(kg*s)	C
CDRG_YDOT	Object covariance matrix [7,5]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**3/(kg*s)	C
CDRG_ZDOT	Object covariance matrix [7,6]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**3/(kg*s)	C
CDRG_DRG	Object covariance matrix [7,7]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**4/kg**2	C
CSRP_X	Object covariance matrix [8,1]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**3/kg	C
CSRP_Y	Object covariance matrix [8,2]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**3/kg	C
CSRP_Z	Object covariance matrix [8,3]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**3/kg	C
CSRP_XDOT	Object covariance matrix [8,4]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**3/(kg*s)	C
CSRP_YDOT	Object covariance matrix [8,5]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**3/(kg*s)	C
CSRP_ZDOT	Object covariance matrix [8,6]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**3/(kg*s)	C
CSRP_DRG	Object covariance matrix [8,7]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**4/kg**2	C
CSRP_SRP	Object covariance matrix [8,8]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**4/kg**2	C
CTHR_X	Object covariance matrix [9,1]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**2/s**2	C
CTHR_Y	Object covariance matrix [9,2]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**2/s**2	C
CTHR_Z	Object covariance matrix [9,3]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**2/s**2	C
CTHR_XDOT	Object covariance matrix [9,4]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**2/s**3	C
CTHR_YDOT	Object covariance matrix [9,5]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**2/s**3	C
CTHR_ZDOT	Object covariance matrix [9,6]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**2/s**3	C
CTHR_DRG	Object covariance matrix [9,7]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**3/(kg*s**2)	C
CTHR_SRP	Object covariance matrix [9,8]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**3/(kg*s**2)	C
CTHR_THR	Object covariance matrix [9,9]. (Condition: Optional if ALT_COV_TYPE = XYZ)	m**2/s**4	C
Covariance Matrix in Sigmas/Eigenvector format (Covariance sigmas and eigenvectors for major, intermediate, and minor eigenvalues and associated eigenvectors. All data type=double.) **Conditional on ALT_COV_TYPE = CSIG3EIGVEC3**			
COMMENT	(See 6.3.4 for formatting rules.)	n/a	C

Keyword	Description	Units	MOC
CSIG3EIGVEC3	The 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). (Condition: Mandatory if ALT_COV_TYPE = CSIG3EIGVEC3)	n/a	C
Additional covariance metadata (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
CSCALE_FACTOR_MIN	The minimum suggested covariance scale factor, used to improve covariance realism by scaling the eigenvalues corresponding to the covariance for this object. A scale factor of one denotes a “realistic” covariance that fairly represents the actual error distribution. Data type = double. NOTE 1 – The supplied one-sigma deviations get multiplied by CSCALE_FACTOR_MIN, while the covariance matrix must be multiplied by $\text{CSCALE\_FACTOR\_MIN}^2$ to scale the covariance appropriately as shown in annex F. 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

Keyword	Description	Units	MOC
CSCALE_FACTOR	The suggested (median) covariance scale factor, used to improve covariance realism by scaling the eigenvalues corresponding to the covariance for this object. A scale factor of one denotes a “realistic” covariance that fairly represents the actual error distribution. Data type = double. NOTE 1 – The supplied one-sigma deviations get multiplied by CSCALE_FACTOR, while the covariance matrix must be multiplied by CSCALE_FACTOR^2 to scale the covariance appropriately as shown in annex F. 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 by scaling the eigenvalues corresponding to the covariance for this object. A scale factor of one denotes a “realistic” covariance that fairly represents the actual error distribution. Data type = double. NOTE 1 – The supplied one-sigma deviations get multiplied by, CSCALE_FACTOR_MAX while the covariance matrix must be multiplied by CSCALE_FACTOR_MAX^2 to scale the covariance appropriately as shown in annex F. 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 the screening.	n/a	O
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). (See annex F4 and reference [H19] for more information.)	m	O

Keyword	Description	Units	MOC
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). (See annex F4 and reference [H19] for more information.)	m/s	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 user-defined parameters shall consist of the KVN elements defined in table 3-6, which specifies for each KVN metadata item:

a) the keyword to be used;

b) a short description of the item;

c) the units to be used if applicable;

d) examples of allowed values;

Table 3-6: CDM KVN User-Defined Parameters

Keyword	Description	Units	Examples
COMMENT	(See 6.3.4 for formatting rules.)	n/a	COMMENT This is a comment
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_MAX_MNVR_PER_HOUR=2

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:

https://nav.sanaregistry.org/r/ndmxml_unqualified/ndmxml-5.0.0-cdm-2.0.xsd for messages with elements not qualified with respect to a namespace.

https://nav.sanaregistry.org/r/ndmxml_qualified/ndmxml-5.0.0-cdm-2.0.xsd for messages with elements qualified with respect to a namespace. (For more information regarding messages with elements qualified with respect to a namespace, see reference [6], subsection 4.3.)

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:

https://nav.sanaregistry.org/r/ndmxml_unqualified/ndmxml-5.0.0-cdm-2.0.xsl for messages with elements not qualified with respect to a namespace.

https://nav.sanaregistry.org/r/ndmxml_qualified/ndmxml-5.0.0-cdm-2.0.xsl for messages with elements qualified with respect to a namespace.

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>
</header>
<body>
  <relativeMetadataData>
  </relativeMetadataData>
  <segment>
    <metadata>
    </metadata>
    <data>
    </data>
  </segment>
  <segment>
    <metadata>
    </metadata>
    <data>
    </data>
  </segment>
</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 3.6 (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 Sections 3.1 through 3.6.

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"

For messages with elements qualified with respect to a namespace, the NDM/XML namespace must next be coded, exactly as shown:

`xmlns:ndm="urn:ccsds:schema:ndmxml"`

The value that follows the ‘`xmlns:`’ in the NDM/XML name space (‘`ndm`’ in this case) is a prefix that must be used on every XML tag in the instantiation.

This `xmlns:ndm` setting is only necessary for messages with elements qualified with respect to a namespace, but it does not hurt anything for it to appear on any NDM/XML instantiation.

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="https://nav.sanaregistry.org/r/ndmxml_unqualified/ndmxml-5.0.0-master-4.0.xsd" for messages with elements not qualified with respect to a namespace.

xsi:noNamespaceSchemaLocation="https://nav.sanaregistry.org/r/ndmxml_qualified/ndmxml-5.0.0-master-4.0.xsd" for messages with elements qualified with respect to a namespace.

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 Uniform Resource Locator (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="2.0"’.

NOTE – The following example root element tag for a CDM instantiation combines all the directions in the preceding several subsections for messages with elements **not** qualified with respect to a namespace:

```
<?xml version="1.0" encoding="UTF-8"?>
<cdm xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation=
"https://nav.sanaregistry.org/r/ndmxml_unqualified/ndmxml-5.0.0-master-4.0.xsd"
id="CCSDS_CDM_VERS" version="2.0">
```

NOTE – The following example root element tag for a CDM instantiation combines all the directions in the preceding several subsections for messages with elements qualified with respect to a namespace:

```
<?xml version="1.0" encoding="UTF-8"?>
<cdm xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:ndm="urn:ccsds:schema:ndmxml"
xsi:noNamespaceSchemaLocation=
"https://nav.sanaregistry.org/r/ndmxml_qualified/ndmxml-5.0.0-master-4.0.xsd"
id="CCSDS_CDM_VERS" version="2.0"
```

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) optional <CLASSIFICATION>;

b) <CREATION_DATE>;

c) <ORIGINATOR>;

d) optional <MESSAGE_FOR>;

e) <MESSAGE_ID>.

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

```
<header>
  <COMMENT>Some comment string.</COMMENT>
  <CLASSIFICATION>UNCLASSIFIED</CLASSIFICATION>
  <CREATION_DATE>2010-03-12T22:31:12.000</CREATION_DATE>
  <ORIGINATOR> CSPOC </ORIGINATOR>
  <MESSAGE_FOR>SATELLITE A</MESSAGE_FOR>
  <MESSAGE_ID>201113719185</MESSAGE_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>
Physical Parameters	<physicalParameters>
State Vector	<stateVector>
Covariance Matrix in RTN	<covarianceMatrixRTN>
Covariance Matric in XYZ	<covarianceMatrixXYZ>
Covariance Matrix SIG3EIGVEC3	<covarianceMatrixSig3Eigvec3>
Additional Covariance Data	<additionalCovariance>
User Defined Parameters	<userDefinedParameters>

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 G, section G2.

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 seven 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 this specification, covariance information shall be provided. The object covariance may be specified as either a lower triangular matrix or in Eigenvalue/Eigenvector format:

– 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 6.3.2.5.

  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).

– 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.

5.2.8 For covariance matrix type, a lower triangular RTN formatted covariance shall be mandatory. If ALT_COV_TYPE is specified and has a value of XYZ, ALT_COV_REF_FRAME shall be mandatory specifying the reference frame of the mandatory lower triangular XYZ formatted covariance.

5.2.9 For vector types, all components shall be supplied.

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 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 Comments and free-text value fields may be in any case (or mix of upper and lower case) desired by the user.

6.3.2.2 Apart from comments and free-text fields, normative text value fields shall be constructed using only exclusively all uppercase or exclusively all lowercase.

6.3.2.3 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:

$$-2,147,483,648 \le x \le +2,147,483,647 \text{ (i.e., } -2^{31} \le x \le 2^{31}-1\text{, a 4-byte integer)}$$

$$\text{or } -9,223,372,036,854,775,808 <= x <= +9,223,372,036,854,775,807 \text{ (i.e., } -2^{63} \le x \le 2^{63}-1\text{, an 8 byte integer).}$$

NOTE – The commas in the range of values above are thousands separators and are used only for readability. They are not included in the integer representation in the actual message.

6.3.2.4 Non-integer numeric values may be expressed in either fixed-point or floating-point notation. Both representations may be used within a CDM.

6.3.2.5 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.

6.3.2.6 Non-integer numeric values expressed in floating-point notation shall conform to the IEEE binary64 floating point number format (see reference [8]). Such numbers consist of an optional sign, a mantissa, an alphabetic character separating the mantissa from the 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'.

d) The exponent must be an integer and may have either a '+' or '-' sign (if the sign is omitted, then '+' shall be assumed). Exponent values can range from -324 to +308.

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 4.941E-324, with 16 significant decimal digits precision.

6.3.2.7 For all numeric values, exchange participants may agree to further constrain or even extend beyond the default limit of 16 digits of precision.

6.3.2.8 Blanks shall not be used within numeric values.

6.3.2.9 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.

6.3.2.10 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 6.3.2.10.

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 (ICS) 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.

<u>Item Column</u>

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.

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; System Name(s)	

A2.1.4 Document Version

CCSDS 508.0-B-2	
Have any exceptions been required? 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	Classification	CLASSIFICATION	Table 3-2	O	
5	Message creation date/time	CREATION_DATE	Table 3-2	M	
6	Message originator	ORIGINATOR	Table 3-2	M	
7	Spacecraft name(s)	MESSAGE_FOR	Table 3-2	O	
8	Unique message identifier	MESSAGE_ID	Table 3-2	M	
9	CDM Relative Metadata and Relative Data	N/A	Table 3-3	M	
10	Comment	COMMENT	Table 3-3	O	
11	Unique conjunction identifier	CONJUNCTION_ID	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 Object2 with respect to Object1	RELATIVE_POSITION_R, RELATIVE_POSITION_T, RELATIVE_POSITION_N	Table 3-3	O	
17	Relative velocity of Object2 with respect to Object1	RELATIVE_VELOCITY_R, RELATIVE_VELOCITY_T, RELATIVE_VELOCITY_N	Table 3-3	O	
18	The approach angle between Object1 and Object2	APPROACH_ANGLE	Table 3-3	O	
19	Conjunction assessment screening period start/stop times	START_SCREEN_PERIOD, STOP_SCREEN_PERIOD	Table 3-3	O	
20	Object1 centered screening type	SCREEN_TYPE	Table 3-3	O	
21	Object1 centered screening volume reference frame, shape, and dimensions	SCREEN_VOLUME_SHAPE SCREEN_VOLUME_RADIUS SCREEN_VOLUME_FRAME, SCREEN_VOLUME_X, SCREEN_VOLUME_Y, SCREEN_VOLUME_Z	Table 3-3	C	
22	Screening volume entry/exit times for Object2	SCREEN_ENTRY_TIME, SCREEN_EXIT_TIME	Table 3-3	C	
23	Collision probability screening threshold	SCREEN_PC_THRESHOLD	Table 3-3	C	
24	Probability Cumulative Distribution Function (CDF) that Object1 and Object2 will collide	COLLISION_PERCENTILE COLLISION_PROBABILITY	Table 3-3	O	
25	Method that was used to calculate collision probability	COLLISION_PROBABILITY_METH OD	Table 3-3	O	

Item	Feature	Keyword	Reference	Status	Support
26	Collision maximum probability parameters	COLLISION_MAX_PROBABILITY COLLISION_MAX_PC_METHOD	Table 3-3	O	
27	Space environment fragmentation impact adjusted collision probability	SEFI_COLLISION_PROBABILITY	Table 3-3	O	
28	Method that was used to calculate the SEFI collision probability	SEFI_COLLISION_PROBABILITY_ METHOD	Table 3-3	O	
29	Space environment fragmentation model.	SEFI_FRAGMENTATION_MODEL	Table 3-3	O	
30	Message Information	N/A	Table 3-3	O	
31	Previous message ID	PREVIOUS_MESSAGE_ID	Table 3-3	O	
32	Previous message epoch	PREVIOUS_MESSAGE_EPOCH	Table 3-3	O	
33	Next message epoch	NEXT_MESSAGE_EPOCH	Table 3-3	O	
34	CDM Metadata	N/A	Table 3-4	M	
35	Comment	COMMENT	Table 3-4	O	
36	Specifies object (1 or 2) to which metadata/data apply	OBJECT	Table 3-4	M	
37	Satellite catalog designator for the object	OBJECT_DESIGNATOR	Table 3-4	M	
38	Satellite catalog used for the object	CATALOG_NAME	Table 3-4	M	
39	Spacecraft name for the object	OBJECT_NAME	Table 3-4	M	
40	Full international designator for the object	INTERNATIONAL_DESIGNATOR	Table 3-4	M	
41	Type of space object	OBJECT_TYPE	Table 3-4	O	
42	Operational status of object	OPS_STATUS	Table 3-4	O	
43	Contact information for the object's owner/operator	OPERATOR_CONTACT_POSITION , OPERATOR_ORGANIZATION, OPERATOR_PHONE, OPERATOR_EMAIL	Table 3-4	O	
44	Name of the external ephemeris file used	EPHEMERIS_NAME	Table 3-4	M	
45	Link to external ODM	ODM_MSG_LINK	Table 3-4	C	
46	Link to external ADM	ADM_MSG_LINK	Table 3-4	O	
47	Observations scheduled before next message	OBS_BEFORE_NEXT_MESSAGE	Table 3-4	O	
48	Describes how covariance matrix was derived	COVARIANCE_METHOD	Table 3-4	M	
49	Covariance source	COVARIANCE_SOURCE	Table 3-4	O	
50	Object's maneuver capacity	MANEUVERABLE	Table 3-4	M	
51	Defines the central body about which Object1/2 orbit	ORBIT_CENTER	Table 3-4	O	
52	Name of reference frame in	REF_FRAME	Table 3-4	M	

Item	Feature	Keyword	Reference	Status	Support
	which state vector is given				
53	Type of alternate covariance information provided	ALT_COV_TYPE	Table 3-4	O	
54	Alternate covariance reference frame if covariance provided in XYZ format (Conditional on ALT_COV_TYPE)	ALT_COV_REF_FRAME	Table 3-4	C	
55	Gravity model used for OD	GRAVITY_MODEL	Table 3-4	O	
56	Atmospheric density model used for OD	ATMOSPHERIC_MODEL	Table 3-4	O	
57	N-body gravitational perturbations used for OD	N_BODY_PERTURBATIONS	Table 3-4	O	
58	Indicates if solar radiation pressure perturbations were used in OD (Y/N)	SOLAR_RAD_PRESSURE	Table 3-4	O	
59	Indicates if solid Earth and ocean tides were used in OD (Y/N)	EARTH_TIDES	Table 3-4	O	
60	Indicates if in-track thrust modeling was used in OD (Y/N)	INTRACK_THRUST	Table 3-4	O	
61	CDM Data	N/A	Table 3-5	M	
62	Comment	COMMENT	Table 3-5	O	
63	Orbit Determination Parameters	N/A	Table 3-5	O	
64	Comment	COMMENT	Table 3-5	O	
65	Interval containing last accepted observation	TIME_LASTOB_START, TIME_LASTOB_END	Table 3-5	O	
66	Recommended/actual OD time span for object	RECOMMENDED_OD_SPAN, ACTUAL_OD_SPAN	Table 3-5	O	
67	Number of observations available/accepted in OD	OBS_AVAILABLE, OBS_USED	Table 3-5	O	
68	Number of sensor tracks available/accepted in OD	TRACKS_AVAILABLE, TRACKS_USED	Table 3-5	O	
69	Percentage of residuals accepted in OD	RESIDUALS_ACCEPTED	Table 3-5	O	
70	Weighted RMS of the residuals from OD	WEIGHTED_RMS	Table 3-5	O	
71	Epoch of the orbit determination	OD_EPOCH	Table 3-5	O	
72	Minimum, median, and maximum update interval for orbital information	MIN_MEDIAN_MAX_UPDATE_INTERVAL	Table 3-5	O	
73	PhysicalParameters	N/A	Table 3-5	O	
74	Comment	COMMENT	Table 3-5	O	
75	Actual area of the object	AREA_PC	Table 3-5	O	
76	Minimum area of the object	AREA_PC_MIN	Table 3-5	O	

Item	Feature	Keyword	Reference	Status	Support
77	Maximum area of the object	AREA_PC_MAX	Table 3-5	O	
78	Effective area of object exposed to atmospheric drag	AREA_DRG	Table 3-5	O	
79	Effective area of object exposed to solar radiation pressure	AREA_SRP	Table 3-5	O	
80	Reference frame for OEB	OEB_PARENT_FRAME	Table 3-5	O	
81	Epoch of OEB reference frame	OEB_PARENT_FRAME_EPOCH	Table 3-5	O	
82	Euler rotation for OEB	OEB_Q1	Table 3-5	O	
83	Euler rotation for OEB	OEB_Q2	Table 3-5	O	
84	Euler rotation for OEB	OEB_Q3	Table 3-5	O	
85	Euler rotation for OEB	OEB_QC	Table 3-5	O	
86	Maximum dimension of OEB	OEB_MAX	Table 3-5	O	
87	Intermediate dimension of OEB	OEB_INT	Table 3-5	O	
88	Minimum dimension of OEB	OEB_MIN	Table 3-5	O	
89	Area along maximum OEB	AREA_ALONG_OEB_MAX	Table 3-5	O	
90	Area along Intermediate OEB	AREA_ALONG_OEB_INT	Table 3-5	O	
91	Area along minimum OEB	AREA_ALONG_OEB_MIN	Table 3-5	O	
92	Typical radar cross-sectional area	RCS	Table 3-5	O	
93	Min radar cross-sectional area	RCS_MIN	Table 3-5	O	
94	Max radar cross-sectional area	RCS_MAX	Table 3-5	O	
95	Typical absolute visual magnitude	VM_ABSOLUTE	Table 3-5	O	
96	Min apparent visual magnitude	VM_APPARENT_MIN	Table 3-5	O	
97	Apparent visual magnitude	VM_APPARENT	Table 3-5	O	
98	Max apparent visual magnitude	VM_APPARENT_MAX	Table 3-5	O	
99	Typical surface reflectance	REFLECTANCE	Table 3-5	O	
100	Mass of the object	MASS	Table 3-5	O	
101	Hard-body radius	HBR	Table 3-5	O	
102	Object’s C_D•A/m and C_R•A/m used to propagate state vector and covariance to TCA	CD_AREA_OVER_MASS, CR_AREA_OVER_MASS	Table 3-5	O	
103	Object’s acceleration due to in-track thrust used to propagate state vector/covariance to TCA	THRUST_ACCELERATION	Table 3-5	O	
104	Specific Energy Dissipation Rate (SEDR)	SEDR	Table 3-5	O	
105	RTN array of minimum	MIN_DV	Table 3-5	O	

Item	Feature	Keyword	Reference	Status	Support
	achievable delta-v				
106	RTN array of maximum achievable delta-v	MAX_DV	Table 3-5	O	
107	Time required to plan and schedule a maneuver ahead of the predicted TCA	LEAD_TIME_REQD_BEFORE_TCA	Table 3-5	O	
108	Object's apoapsis height above the central body which it is orbiting	APOAPSIS_ALTITUDE	Table 3-5	O	
109	Object's periapsis height above the central body which it is orbiting	PERIAPSIS_ALTITUDE	Table 3-5	O	
110	Angle between objects orbit plane and body equatorial plane	INCLINATION	Table 3-5	O	
111	Covariance confidence	COV_CONFIDENCE	Table 3-5	O	
112	Method used to calculate COV_CONFIDENCE (COV_CONFIDENCE present)	COV_CONFIDENCE_METHOD	Table 3-5	C	
113	State Vector	N/A	Table 3-5	M	
114	Comment	COMMENT	Table 3-5	O	
115	Object Position Vector	X, Y, Z	Table 3-5	M	
116	Object Velocity Vector	X_DOT, Y_DOT, Z_DOT	Table 3-5	M	
117	Covariance Matrix in the RTN Coordinate Frame	N/A	Table 3-5	M	
118	Comment	COMMENT	Table 3-5	O	
119	Position/velocity 6×6 covariance matrix	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, CTDOT_RDOT, CTDOT_TDOT, CNDOT_R, CNDOT_T, CNDOT_N, CNDOT_RDOT, CNDOT_TDOT, CNDOT_NDOT	Table 3-5	M	
120	Covariance matrix row 7 (Drag related)	CDRG_R, CDRG_T, CDRG_N, CDRG_RDOT, CDRG_TDOT, CDRG_NDOT, CDRG_DRG	Table 3-5	O	
121	Covariance matrix row 8 (Solar Radiation Pressure related)	CSRP_R, CSRP_T, CSRP_N, CSRP_RDOT, CSRP_TDOT, CSRP_NDOT, CSRP_DRG, CSRP_SRP	Table 3-5	O	
122	Covariance matrix row 9 (In-track Thrust related)	CTHR_R, CTHR_T, CTHR_N, CTHR_RDOT, CTHR_TDOT, CTHR_NDOT, CTHR_DRG, CTHR_SRP, CTHR_THR	Table 3-5	O	
123	Covariance Matrix (ALT_COV_TYPE = XYZ)	N/A	Table 3-5	C	
124	Comment (ALT_COV_TYPE = XYZ)	COMMENT	Table 3-5	C	
125	Position/velocity 6×6 covariance matrix	CX_X, CY_X, CY_Y, CZ_X, CZ_Y, CZ_Z, CXDOT_X, CXDOT_Y,	Table 3-5	C	

Item	Feature	Keyword	Reference	Status	Support
	(ALT_COV_TYPE = XYZ)	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			
126	Covariance matrix row 7 (Drag related) (ALT_COV_TYPE = XYZ)	CDRG_X, CDRG_Y, CDRG_Z, CDRG_XDOT, CDRG_YDOT, CDRG_ZDOT, CDRG_DRG	Table 3-5	C	
127	Covariance matrix row 8 (Solar Radiation Pressure related) (ALT_COV_TYPE = XYZ)	CSRP_X, CSRP_Y, CSRP_Z, CSRP_XDOT, CSRP_YDOT, CSRP_ZDOT, CSRP_DRG, CSRP_SRP	Table 3-5	C	
128	Covariance matrix row 9 (In-track Thrust related) (ALT_COV_TYPE = XYZ)	CTHR_X, CTHR_Y, CTHR_Z, CTHR_XDOT, CTHR_YDOT, CTHR_ZDOT, CTHR_DRG, CTHR_SRP, CTHR_THR	Table 3-5	C	
129	Covariance Matrix (ALT_COV_TYPE = CSIG3EIGVEC3)	N/A	Table 3-5	C	
130	Comment (ALT_COV_TYPE = CSIG3EIGVEC3))	COMMENT	Table 3-5	C	
131	Covariance eigenvalues and eigenvectors (ALT_COV_TYPE = CSIG3EIGVEC3)	CSIG3EIGVEC3 (12 double values separated by spaces)	Table 3-5	C	
132	Additional covariance meta-data	N/A	Table 3-5	O	
133	Comment	COMMENT	Table 3-5	O	
134	Atmospheric density forecast error	DENSITY_FORECAST_UNCERTAINTY	Table 3-5	O	
135	Minimum covariance scale factor	CSCALE_FACTOR_MIN	Table 3-5	O	
136	Covariance scale factor	CSCALE_FACTOR	Table 3-5	O	
137	Maximum covariance scale factor	CSCALE_FACTOR_MAX	Table 3-5	O	
138	Screening data source	SCREENING_DATA_SOURCE	Table 3-5	O	
139	Drag position consider parameter	DCP_SENSITIVITY_VECTOR_POSITION	Table 3-5	O	
140	Drag velocity consider parameter	DCP_SENSITIVITY_VECTOR_VELOCITY	Table 3-5	O	
141	CDM User-Defined Parameters	N/A	Table 3-6	O	
142	Comment	COMMENT	Table 3-6	O	
143	User-defined parameter	USER_DEFINED_x	Table 3-6	O	

ANNEX B

VALUES FOR SELECTED KEYWORDS

(NORMATIVE)

The values in this annex represent the recommended values for selected keywords present in the CDM message. For details and descriptions of the keyword interpretations, the reader is directed to annex F. The message creator should seek to confirm with the recipient(s) that their software can support the selected keyword value, particularly for more complex content such as reference frames, orbital elements, and covariance definitions.

These recommended values are stored on the SANA Registry, globally accessible on the CCSDS SANA registry website located at:

https://sanaregistry.org/r/navigation_standard_registries/

The message creator or recipient may wish to automate processing of SANA registry normative content, which can be done by ingesting and processing of such content in electronic format. These formats can be accessed via the "Actions" link on each registry, e.g. for the Orbital Elements registry, a comma separated value (CSV) format can be exported at: https://sanaregistry.org/r/orbital_elements?_export=csv and a JavaScript Object Notation (JSON) format at: https://sanaregistry.org/r/orbital_elements?_export=json. Both the registry and these electronic data formats specify the number of vector elements corresponding to each keyword value.

Exchange partners may submit additional (new) keyword values for consideration of future inclusion into the SANA registry by submitting a detailed email request (mailto:info@sanaregistry.org) per annex C, section C2. The CCSDS Area or Working Group responsible for the maintenance of the CDM at the time of the request is the approval authority. Until a suggested value is included in the SANA registry, exchange partners may define and use values that are not listed in the SANA registry if mutually agreed between message exchange partners.

B1 MESSAGE ORIGINATORS

The set of recommended values for the ORIGINATOR keyword is enumerated in the SANA Registry of Organizations, located at:

https://sanaregistry.org/r/organizations

B2 SPACE OBJECT CATALOG NAMES

The set of recommended values for the CATALOG_NAME keyword is enumerated in the SANA Registry of Space Object Catalogue Names, located at:

https://sanaregistry.org/r/space_object_catalog

B3 REFERENCE FRAME CENTERS AND THIRD-BODY PERTURBATIONS

A set of allowed values for the reference frame center keywords (ORBIT_CENTER, and N_BODY_PERTURBATIONS) is enumerated in the SANA Registry of Orbit Centers, located at: https://sanaregistry.org/r/orbit_centers. It should be noted that these values may also be useful to specify another platform (satellite, airframe, ground vehicle, etc.) as the reference frame origin to permit the specification of relative positional state time history data. In this case, message authors shall clearly communicate to recipients that the orbit center is not a gravitational center, that propagation of ephemeris vectors or extrapolation of ephemeris start/stop states is not advisable, and that interpolation of state time histories should not be accomplished using classical orbit propagation forces (e.g., gravitational constants, drag).

B4 CELESTIAL BODY REFERENCE FRAMES

A set of allowed celestial body reference frame values for the **OEB_PARENT_FRAME** keyword is enumerated in the *SANA Registry of Celestial Body Reference Frames*, located at:

https://sanaregistry.org/r/celestial_body_reference_frames

B5 ORBIT-RELATIVE REFERENCE FRAMES

In addition to the above reference frames, maneuver and covariance data may be selected from the list of allowed orbit-relative reference frames using the **OEB_PARENT_FRAME** keyword values enumerated in the *SANA Registry of Orbit-Relative Reference Frames*, located at:

https://sanaregistry.org/r/orbit_relative_reference_frames

Two types of orbit-relative local reference frames exist: inertial and rotating. When transforming velocity terms between inertial and rotating frames, remember to properly incorporate the $(\overline{\boldsymbol{\omega}} \times \overline{\boldsymbol{r}})$ contribution.

B6 ATMOSPHERE MODELS

A set of allowed values for the ATMOSPHERIC_MODEL keyword is enumerated in the SANA Registry of Atmosphere Models, located at:

https://sanaregistry.org/r/atmosphere_models

B7 GRAVITY MODELS

A set of allowed values for the GRAVITY_MODEL keyword is enumerated in the SANA Registry of Gravity Models, located at:

https://sanaregistry.org/r/gravity_models

B8 COLLISION PROBABILITY METHOD

A set of allowed values for the COLLISION_PROBABILITY_METHOD keyword is enumerated in the SANA Registry of Collision Probability Methods, located at:

https://sanaregistry.org/r/cdm_cpm/

B9 OPERATIONAL STATUS

A set of allowed values for the **OPS_STATUS** keyword is enumerated in the *SANA Registry of Operational Status of Space Object*, located at:

https://sanaregistry.org/r/operational_status

B10 OBJECT TYPES

A set of allowed values for the **OBJECT_TYPE** keyword is enumerated in the *SANA Registry of Operational Status of Space Object*, located at:

https://sanaregistry.org/r/object_types

ANNEX C

SECURITY, SANA, AND PATENT CONSIDERATIONS

(INFORMATIVE)

C1 SECURITY CONSIDERATIONS

C1.1 ANALYSIS OF SECURITY CONSIDERATIONS

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

C1.2 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.

C1.3 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.

C1.4 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.

C1.5 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.

C1.6 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.

C1.7 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.

C1.8 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.

C1.9 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.

C1.10 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.

C1.11 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.

C2 SANA CONSIDERATIONS

The following CDM-related items are registered with the SANA Operator:

– The CDM XML schema;

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

The following normative CDM elements should be selected from the SANA registry (See annex B):

– Values for the keywords ORIGINATOR, CATALOG_NAME, ORBIT_CENTER, GRAVITY_MODEL, ATMOSPHERIC_MODEL, and N_BODY_PERTURBATIONS,

– A list of options for the COLLISION_PROBABILITY_METHOD keyword; and

– Definitions of celestial body and orbit-relative reference frames for use with the keyword REF_FRAME.

The general policy for changes to the CDM is Expert Review by the Working Group or Area responsible for the CDM standard. The registration rule for new entries in the registry is the approval of new requests by the CCSDS Area or Working Group responsible for the maintenance of the CDM at the time of the request.

C3 PATENT CONSIDERATIONS

The recommendations of this document have no patent issues.

ANNEX D

ABBREVIATIONS AND ACRONYMS

(INFORMATIVE)

ADM	Attitude Data Message
ASCII	American Standard Code for Information Interchange
ASW	Astrodynamics Support Workstation
AU	Astronomical Unit
CA	Conjunction Assessment
CATS	Critical Angle to the Sun
CCSDS	Consultative Committee for Space Data Systems
CDF	Cumulative Distribution Function
CDM	Conjunction Data Message
CSV	Comma Separated Value
DCP	Drag Consider Parameter
DRG	Atmospheric Drag
EME2000	Earth Mean Equator and Equinox of J2000 (Epoch J2000)
GCRF	Geocentric Celestial Reference Frame
GEO	Geosynchronous Orbit
HBR	Hard-Body Radius
ICD	Interface Control Document
ICS	Implementation Conformance Statement
ITRF	International Terrestrial Reference Frame
JSON	JavaScript Object Notation
KVN	Keyword = Value Notation
LEO	Low Earth Orbit
NDM	Navigation Data Message
O/O	Owner/Operator
OD	Orbit Determination
OBS	Observations
ODM	Orbit Data Message
OEB	Optimally Enclosing Box
RCS	Radar Cross Section
RL	Requirements List

RMS	Root Mean Square
RSO	Resident Space Object
RTN	Radial, Transverse, and Normal
SANA	Space Assigned Numbers Authority
SEDR	Specific Energy Dissipation Rate
SEFI	Space Environment Fragmentation Impact
SI	International System of Units
SRP	Solar Radiation Pressure
TCA	Time of Closest Approach
THR	Thrust
TVN	Transverse, Velocity, and Normal
URL	Uniform Resource Locator
UTC	Coordinated Universal Time
VCM	Vector Covariance Message
V_{MAG}	Visual Magnitude
XML	Extensible Markup Language
XSLT	Extensible Stylesheet Language Transformations
XYZ	Cartesian coordinate system

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 [H2]).	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 [H2]).	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.	6.3.2.10, 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 required in ISO 16158 (reference [H2]).	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 [H2]).	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 [H2]).	Table 3-4, Table 3-5
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 3-3, Table 3-5, 4.3.10, 6.3.3, 6.4.3
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 [H2]).	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 [H2]).	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 [H2]).	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
CDM-P17	The CDM shall provide the threshold of close approach used by the originator in the screening.	This datum is required in order to assess the risk of collision and assess potential preventive measures. Cited as desirable by ISO 16158 (reference [H2]).	Table 3-3
CDM-P18	The CDM shall provide the relative velocity of the two objects 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 desirable by ISO 16158 (reference [H2]).	Table 3-3

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
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 [H2]).	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 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

ANNEX F

TECHNICAL MATERIAL AND CONVENTIONS

(INFORMATIVE)

F1 RELATIVE DATA

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 [H18] and is performed as follows:

a) Compute collision probability;

b) Determine the orbital regime;

c) If Low Earth Orbit (LEO), then determine (using the simple NASA Standard Breakup Model) if this collision is anticipated to generate more than 200 fragments of greater than 10 cm;

d) If this collision is assessed as an event which will *not* produce more than 200 fragments of greater then 10 cm, then downgrade the collision probability value by one order of magnitude (otherwise, use the collision probability value "as is").

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 $\bar{r}_{1_{Inertial}}$, $\bar{r}_{2_{Inertial}}$, 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 $\bar{\rho}_{Inertial}$ is:

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

The relative position vector $\bar{\rho}_{EigenFrame}$ 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_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 as defined and referred to by the RSW_INERTIAL keyword value on the SANA registry's orbit relative reference frames section (https://sanaregistry.org/r/orbit_relative_reference_frames/). 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).

SCREEN_PC_THRESHOLD: The user-selected collision probability threshold used to identify whether a conjunction warrants notification and/or avoidance action.

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).

Comparison of 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.

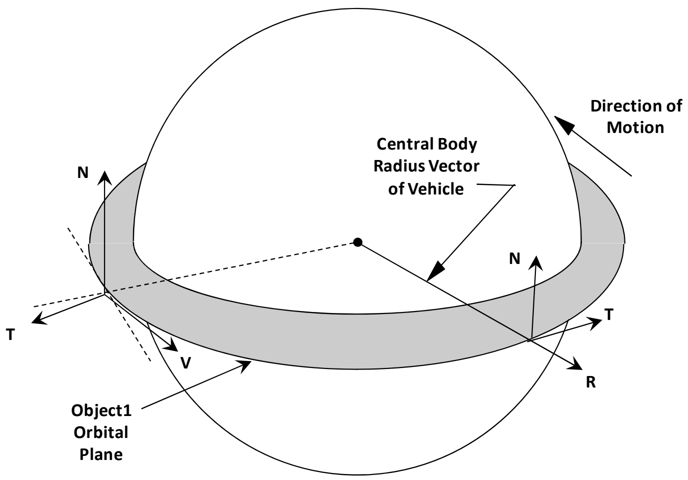

Figure F-1: Definition of the RTN and TVN Coordinate Frames

SCREEN_TYPE: Type of screening criteria (probability or shape), where shape can be either a sphere, ellipsoid or box of the screening volume used to screen the satellite catalog for possible conjunctors with Object1. If shape selected then the size will be specified by SCREEN_VOLUME_RADIUS or SCREEN_VOLUME_X/Y/Z as required.

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).

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.

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 ith observation;

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

σ_i is the standard deviation of the ith measurement;

$w_i = \frac{1}{\sigma_i^2}$ is the weight associated with the ith measurement; 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.

CSCALE_FACTOR_MIN and CSCALE_FACTOR_MAX:

These covariance scale factors are designed to scale the POSITIONAL standard deviations (square root of the covariance diagonal matrix elements) to account for a priori knowledge that a covariance matrix does not fully represent the errors that an orbit estimation process and covariance propagation may have or incur. The scale factors are applied to the entire covariance matrix AFTER its propagation (i.e., one must not scale up the covariance matrix and then propagate it). The MIN and MAX values are intended to capture the anticipated range of scale factors that would be required to make the covariance reflect the anticipated errors at the time(s) of interest.

The scale factor is applied as follows:

$$\begin{bmatrix} \sigma_x^2 & \sigma_x\sigma_y & \sigma_x\sigma_z \\ \sigma_x\sigma_y & \sigma_y^2 & \sigma_y\sigma_z \\ \sigma_x\sigma_z & \sigma_y\sigma_z & \sigma_z^2 \end{bmatrix}_{SCALED} = \begin{bmatrix} CSCALE\_FACTOR^2\sigma_x^2 & \sigma_x\sigma_y & \sigma_x\sigma_z \\ \sigma_x\sigma_y & CSCALE\_FACTOR^2\sigma_y^2 & \sigma_y\sigma_z \\ \sigma_x\sigma_z & \sigma_y\sigma_z & CSCALE\_FACTOR^2\sigma_z^2 \end{bmatrix}_{ORIGINAL}$$

F3 OBJECT PHYSICAL PARAMETERS

AREA_PC: The area (or cross-section) of the object 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.

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 $C_D \bullet A/m$, 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 $C_R \bullet A/m$, 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.

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

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

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.

Optimally Encompassing Box (OEB): For a box-shaped satellite without appendages, the satellite's volume in three-dimensional space and a corresponding OEB would have a one-to-one mapping.

6.4.4.1 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.

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

6.4.4.3 The OEB x-axis is along the **longest** dimension of the box ($\hat{\mathrm{X}}_{\mathrm{OEB\_MAX}}$). This is sometimes referred to as the "span" of the space object.

6.4.4.4 The OEB y-axis is along the **intermediate** orthonormal dimension ($\hat{\mathrm{y}}_{\mathrm{OEB\_INT}}$)

6.4.4.5 The OEB z-axis is along the **shortest** orthonormal dimension ($\hat{\mathrm{z}}_{\mathrm{OEB\_MIN}}$).

6.4.4.6 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, $\hat{x}_{\mathrm{OEB\_MAX}}$ is defined as the direction along one of those longest dimensions and the next as $\hat{y}_{\mathrm{OEB\_INT}}$.

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

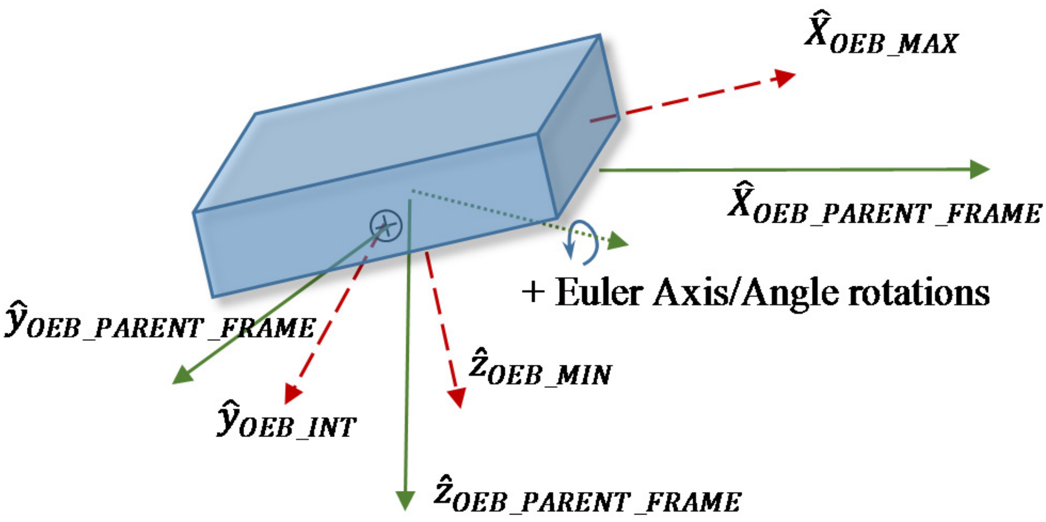

Figure F-2: Depiction of Optimally Enclosing Box and Definitions of MAX, INT, and MIN Orientation Vectors Relative to OEB Parent Fame

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 a quaternion (defined in SANA at https://sanaregistry.org/r/attitude_and_spacecraft_conventions).

6.4.4.8 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

$$[M] = \begin{bmatrix} {Q_1}^2 - {Q_2}^2 - {Q_3}^2 + {Q_c}^2 & 2(Q_1 Q_2 + Q_3 Q_c) & 2(Q_1 Q_3 - Q_2 Q_c) \\ 2(Q_1 Q_2 - Q_3 Q_c) & -{Q_1}^2 + {Q_2}^2 - {Q_3}^2 + {Q_c}^2 & 2(Q_2 Q_3 + Q_1 Q_c) \\ 2(Q_1 Q_3 + Q_2 Q_c) & 2(Q_2 Q_3 - Q_1 Q_c) & -{Q_1}^2 - {Q_2}^2 + {Q_3}^2 + {Q_c}^2 \end{bmatrix}$$

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

6.4.4.10 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:

6.4.4.11 $\text{TOTAL\_AREA} = \{\text{AREA\_PC or AREA\_DRG or AREA\_SRP}\} + \begin{bmatrix}\text{AREA\_ALONG\_OEB\_MAX}\\ \text{AREA\_ALONG\_OEB\_INT}\\ \text{AREA\_ALONG\_OEB\_MIN}\end{bmatrix} \cdot [M]\widehat{\begin{bmatrix}x\\ y\\ z\end{bmatrix}}_{\text{OEB\_PARENT\_FRAME}}$

NOTE – The last expression in the TOTAL_AREA formula above is a dot product.

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 H, reference [H13], 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]
$E_{EntranceAperture}$	Then point source irradiance reaching the sensor aperture [W/m^2]
$d_{SunToTarget}$	Distance from the sun to the target [m] (e.g. 1 AU = $1.4959787066 \times 10^{11}$ 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 [2.77894×10^{-8} W/m^2]
F	General shadowing term accounting for the penumbra region's influence [unitless, $0 < F \leq 1$, 0 = umbra, and 1 = full Sun illumination]
I_{Sun}	Solar Intensity ≈ $3.088374161 \times 10^{25}$ [W/sr]
I_{Target}	Intensity of reflected energy from target treated as a point source [W]
$Phase(\varphi)$	Geometric reflectance phase function [unitless, $0 < Phase(\varphi) \leq 1$]
$VM_{apparent}$	Apparent visual magnitude

φ	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)]
$\tau_{Atmosphere}$	Effective transmission of the atmosphere [unitless, $0 < \tau \leq 1$]

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

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

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

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

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

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

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

$$A_{Target} = \frac{\pi I_{Target}}{\rho F E_{Sun} Phase(\varphi)}\ [m^2]$$

NOTES

1. A_{Target} is undefined in umbra (F=0=darkness), or no reflection ($\rho = 0$).

2. 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:

$$\mathrm{VM}_{\mathrm{absolute}} = -2.5 \log_{10} \left\{ \frac{\mathrm{E}_{\mathrm{target}}}{\mathrm{E}_0} \right\}, \text{ from which:}$$

$$\mathrm{VM}_{\mathrm{absolute}} = -2.5 \ \log_{10} \left\{ \frac{\left[E_{Sun_{1\,AU}} = 1380\ {}^{W}\!/_{m^2}\right] [Phase(0\ rad) = 1.0\ ] [\ \rho\ A_{Target}\ from\ above,\ \ in\ m^2]}{\pi\ \left[E_0 = 2.77894 \times 10^{-8}\ {}^{W}\!/_{m^2}\right] [(40{,}000{,}000^2)\ m^2]} \right\}$$

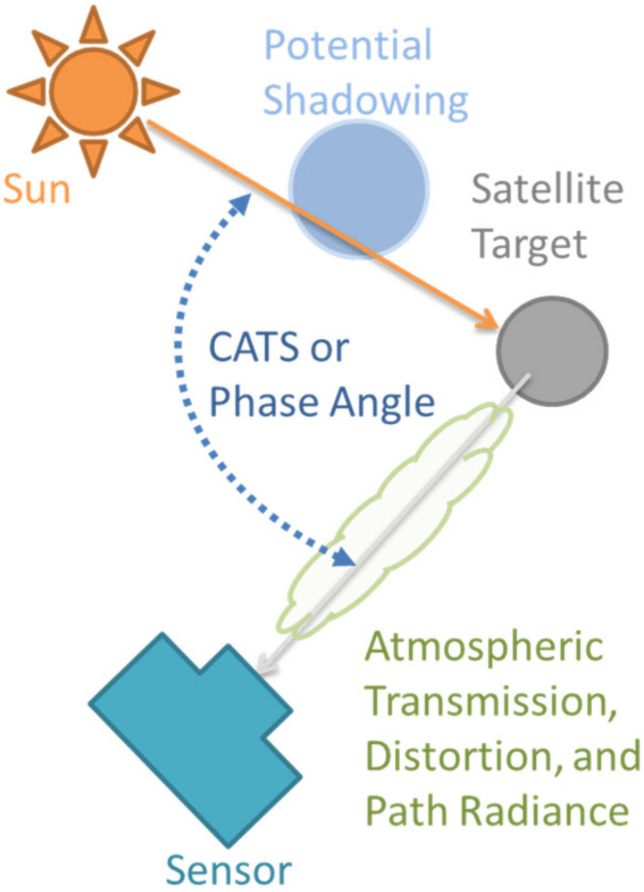

Figure F-3: Depiction of Optical Viewing Critical Angle to the Sun (CATS) Phase Angle Geometry

F4 DYNAMIC CONSIDER PARAMETERS– BACKGROUND AND APPLICATION

CDM Mean Position/Velocity State Vectors: CDMs can specify the mean position/velocity state vectors of the primary and secondary satellites at TCA in a couple of reference frames. For Pc computation, these states must be converted (if necessary) into an inertial reference frame. This analysis denotes the resulting mean inertial position and velocity vectors at TCA for the primary and secondary objects as $(\bar{\mathbf{r}}_p, \bar{\mathbf{v}}_p)$ and $(\bar{\mathbf{r}}_s, \bar{\mathbf{v}}_s)$, respectively.

CDM Position/Velocity State Covariance Matrices: CDMs specify position/velocity state covariances for the primary and secondary satellites using the radial-transverse-normal (RTN) coordinate frame. A CDM file specifies this symmetric 6×6 covariance for each object using keyword values for its 21 non-redundant matrix elements as follows

$$\boldsymbol{\mathcal{C}} = \begin{bmatrix} \mathcal{C}_{R,R} & \mathcal{C}_{T,R} & \mathcal{C}_{N,R} & \mathcal{C}_{\dot{R},R} & \mathcal{C}_{\dot{T},R} & \mathcal{C}_{\dot{N},R} \\ \mathcal{C}_{T,R} & \mathcal{C}_{T,T} & \mathcal{C}_{N,T} & \mathcal{C}_{\dot{R},T} & \mathcal{C}_{\dot{T},T} & \mathcal{C}_{\dot{N},T} \\ \mathcal{C}_{N,R} & \mathcal{C}_{N,T} & \mathcal{C}_{N,N} & \mathcal{C}_{\dot{R},N} & \mathcal{C}_{\dot{T},N} & \mathcal{C}_{\dot{N},N} \\ \mathcal{C}_{\dot{R},R} & \mathcal{C}_{\dot{R},T} & \mathcal{C}_{\dot{R},N} & \mathcal{C}_{\dot{R},\dot{R}} & \mathcal{C}_{\dot{T},\dot{R}} & \mathcal{C}_{\dot{N},\dot{R}} \\ \mathcal{C}_{\dot{T},R} & \mathcal{C}_{\dot{T},T} & \mathcal{C}_{\dot{T},N} & \mathcal{C}_{\dot{T},\dot{R}} & \mathcal{C}_{\dot{T},\dot{T}} & \mathcal{C}_{\dot{N},\dot{T}} \\ \mathcal{C}_{\dot{N},R} & \mathcal{C}_{\dot{N},T} & \mathcal{C}_{\dot{N},N} & \mathcal{C}_{\dot{N},\dot{R}} & \mathcal{C}_{\dot{N},\dot{T}} & \mathcal{C}_{\dot{N},\dot{N}} \end{bmatrix} \tag{1}$$

The RTN-frame covariance $\boldsymbol{\mathcal{C}}$ can be transformed into an inertial frame covariance $\mathbf{P}$ by applying the following equation (see refersnces [H22], [H23], and [H24]:

$$\mathbf{P} = \boldsymbol{\mathcal{M}}\,\boldsymbol{\mathcal{C}}\,\boldsymbol{\mathcal{M}}^T \tag{2}$$

with the 6×6 transformation matrix $\boldsymbol{\mathcal{M}}$ having the form

$$\boldsymbol{\mathcal{M}} = \begin{bmatrix} \mathbf{M} & \mathbf{0}_{3x3} \\ \mathbf{0}_{3x3} & \mathbf{M} \end{bmatrix} \tag{3}$$

with $\mathbf{0}_{3x3}$ representing a 3x3 matrix of zeros. The 3x3 orthonormal matrix $\mathbf{M}$ rotates vectors from the pseudo-inertial (non-rotating, instantaneously frozen) RTN frame into the inertial frame

$$\mathbf{M} = [\hat{\mathbf{R}}\ \ \hat{\mathbf{T}}\ \ \hat{\mathbf{N}}] \tag{4}$$

with column vectors given by the three RTN unit vectors, calculable from the object's inertial mean position and velocity vectors as follows

$$\hat{\mathbf{R}} = \bar{\mathbf{r}}/|\bar{\mathbf{r}}| \quad \text{and} \quad \hat{\mathbf{N}} = (\bar{\mathbf{r}} \times \bar{\mathbf{v}})/|\bar{\mathbf{r}} \times \bar{\mathbf{v}}| \quad \text{and} \quad \hat{\mathbf{T}} = \hat{\mathbf{N}} \times \hat{\mathbf{R}} \tag{5}$$

The 6×6 inertial frame covariance given in equation (2) can each be decomposed into three 3×3 sub-matrices

$$\mathbf{P} = \begin{bmatrix} \mathbf{A} & \mathbf{B}^T \\ \mathbf{B} & \mathbf{C} \end{bmatrix} \tag{6}$$

with $\mathbf{A}$ representing the marginalized covariance of the position vector, $\mathbf{C}$ the marginalized covariance of the velocity vector, and $\mathbf{B}$ position-velocity cross correlations.

When processing a CDM, equations (1)–(6) can be used to calculate inertial frame position/velocity state covariance matrices at TCA for the primary and secondary objects involved in a conjunction, $\mathbf{P}_p$ and $\mathbf{P}_s$, respectively, as well as the marginalized position covariance matrices, $\mathbf{A}_p$ and $\mathbf{A}_s$.

NOTE – Because RTN is an object-specific frame of reference, these calculations must employ different rotation matrices, $\mathbf{M}_p$ and $\mathbf{M}_s$, respectively.

Uncorrelated and Correlated Relative Position Covariance Matrices: Collision probability estimation using the 2D-Pc method requires the conjunction's inertial relative position miss-vector, $\bar{\mathbf{r}}_m = \bar{\mathbf{r}}_s - \bar{\mathbf{r}}_p$, along with the associated miss-vector covariance matrix, $\mathbf{A}_m$ (see references [H19], [H20], H4, and [H21]). If the primary and secondary position vectors are statistically independent (i.e., uncorrelated), then the relative position miss-vector covariance is given by their sum (see reference [H20]):

$$\mathbf{A}_m = \mathbf{A}_p + \mathbf{A}_s \tag{7}$$

This approach provides a viable approximation for 2D-Pc estimation for conjunctions in which $\mathbf{A}_p$ and $\mathbf{A}_s$ have sufficiently weak correlation. However, recent analysis has demonstrated that some conjunctions have stronger covariance correlations, due to shared atmospheric density forecast components arising from the Astrodynamics Support Workstation (ASW) global density portion of the Dynamic Consider Parameter (see reference [H19]). In these cases, the miss-vector covariance can be corrected by removing the cross-correlated components as follows

$$\mathbf{A}_m = \mathbf{A}_p + \mathbf{A}_s - \sigma_{p/g}\sigma_{s/g}\left[\mathbf{G}_p\mathbf{G}_s^T + \mathbf{G}_s\mathbf{G}_p^T\right] \tag{8}$$

with $\sigma_{p/g}$ and $\sigma_{s/g}$ denoting the atmospheric density 1-sigma relative uncertainties for the primary and secondary, respectively. The vectors $\mathbf{G}_s$ and $\mathbf{G}_p$ represent the sensitivity of the miss-vector covariance on global density relative uncertainties. (See equation (11) of reference [H19] and the related discussion for a derivation of equation (8) given above, and a more detailed explanation of its components. Also, instead of using the symbol "**A**" for 3×3 position covariances, reference [H19] uses the symbol "**P**" which has already been used for another purpose in this analysis.)

CDM files provide the sigma values and sensitivity vectors required to calculate corrected relative position covariance matrices using equation (8). These data are provided by the DENSITY_FORECAST_UNCERTAINTY, DCP_SENSITIVITY_VECTOR_POSITION, and DCP_SENSITIVITY_VECTOR_VELOCITY keywords

The first occurrence of the DCPsappear in the primary object section of the CDM, and provides $\sigma_{p/g}$ (the DCP density forecast 1-sigma uncertainty), $\mathbf{G}_p^{RTN}$ (the 3x1 DCP position sensitivity vector, expressed in the primary's RTN frame), and $\mathbf{H}_p^{RTN}$ (the 3x1 DCP velocity RTN-frame sensitivity vector). The second occurrence provides the corresponding DCPs for the secondary, i.e., $\sigma_{s/g}$, $\mathbf{G}_s^{RTN}$ and $\mathbf{H}_s^{RTN}$ The RTN frame sensitivity vectors provided in the CDM can be converted to inertial frame vectors using the transformation matrix defined in equation (4) separately for each object

$$\mathbf{G}_p = \mathbf{M}_p\mathbf{G}_p^{RTN} \text{ and } \mathbf{G}_s = \mathbf{M}_s\mathbf{G}_s^{RTN} \text{ and } \mathbf{H}_p = \mathbf{M}_p\mathbf{H}_p^{RTN} \text{ and } \mathbf{H}_s = \mathbf{M}_s\mathbf{H}_s^{RTN} \tag{9}$$

Uncorrelated and Correlated Relative Position/Velocity Covariance Matrices: For statistically independent primary and secondary states, the relative position/velocity miss-state covariance is given by the sum of the covariances for the two objects (see reference [H20]):

$$\mathbf{P}_m = \mathbf{P}_p + \mathbf{P}_s \tag{10}$$

This approach provides a viable approximation for conjunctions in which the primary and secondary position/velocity states have sufficiently weak correlation. In other cases, the miss-vector covariance can be corrected by removing the cross-correlated components as follows

$$\mathbf{P}_m = \mathbf{P}_p + \mathbf{P}_s - \sigma_{p/g}\sigma_{s/g}\left[\boldsymbol{\Gamma}_p\boldsymbol{\Gamma}_s^T + \boldsymbol{\Gamma}_s\boldsymbol{\Gamma}_p^T\right] \tag{11}$$

with $\sigma_{p/g}$ and $\sigma_{s/g}$ again denoting the atmospheric density 1-sigma relative uncertainties for the primary and secondary objects, respectively. The 6x1 vector $\boldsymbol{\Gamma}_p = [\mathbf{G}_p^T\ \mathbf{H}_p^T]^T$ represents the sensitivity of the primary object's miss-state covariance on global density relative uncertainties. The secondary object's 6x1 sensitivity vector is defined similarly. (Again, see reference [H19] for more detail on these dynamic consider parameter uncertainties and sensitivity vectors.) The RTN frame sensitivity vectors provided in the CDM can be converted to inertial frame vectors using the transformation matrix defined in equation (3) for each object

$$\boldsymbol{\Gamma}_p = \boldsymbol{\mathcal{M}}_p\boldsymbol{\Gamma}_p^{RTN} \qquad \text{and} \qquad \boldsymbol{\Gamma}_s = \boldsymbol{\mathcal{M}}_s\boldsymbol{\Gamma}_s^{RTN} \tag{12}$$

Pc Estimates with and without Covariance Correlation Correction: Conjunction 2D-Pc values calculated using the miss-vector covariance in equation (8) represent collision probabilities corrected for global atmospheric cross-correlation effects. These can differ from the uncorrected 2D-Pc values calculated using the covariance in equation (7). Analysis of archived conjunctions indicates that this correction usually does not change Pc values appreciably, except in a minority of conjunctions that have both elevated drag energy dissipation rates and an appropriate combination of orbital geometries (see reference [H19]). Among this minority, however, the corrections can potentially elevate Pc values by a factor of two or more, meaning that accurate and conservative risk assessments for these cases rely on applying the covariance cross-correlation corrections made possible by the ASW system's recent CDM modifications.

For low-velocity or multi-conjunction interactions, the statistically expected number of collisions (i.e., the "3D-Nc" value) can be calculated using the miss-state covariance matrix given in equation (11), which then can be used to estimate the Pc value for the interaction, as explained in detail in reference [H25].

ANNEX G

EXAMPLES

(INFORMATIVE)

G1 DISCUSSION—CDM/KVN EXAMPLES

G1.1 OVERVIEW

Subsections G1.2 through G1.4 show examples of a CDM message in KVN. Subsection G1.2 includes only mandatory keywords and subsections G1.3 through G1.4 include optional keywords as well as mandatory.

NOTE – Example G1.2 is compatible with CDM V1 specification.

G1.2 AN EXAMPLE OF A CDM IN KVN WITH ONLY MANDATORY KEYWORDS

```
CCSDS_CDM_VERS                 = 2.0
CREATION_DATE                  = 2010-03-12T22:31:12.000
ORIGINATOR                     = CSpOC
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]

G1.3 AN EXAMPLE OF A CDM IN KVN WHICH INCLUDES OPTIONAL KEYWORDS

```
CCSDS_CDM_VERS                  = 2.0
CLASSIFICATION                  = UNCLASSIFIED
CREATION_DATE                   = 2010-03-12T22:31:12.000
ORIGINATOR                      = CSpOC
MESSAGE_FOR                     = SATELLITE A
MESSAGE_ID                      = 201113719185
COMMENT Relative Metadata/Data
CONJUNCTION_ID                  = 20100313T10HZ_SAT_A_FEN_1C_DEB
TCA                             = 2010-03-13T22:37:52.618
MISS_DISTANCE                   = 715                          [m]
MAHALANOBIS_DISTANCE            = 2.3
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]
APPROACH_ANGLE                  = 35.2                         [deg]
START_SCREEN_PERIOD             = 2010-03-12T18:29:32:212
STOP_SCREEN_PERIOD              = 2010-03-15T18:29:32:212
SCREEN_TYPE                     = SHAPE
SCREEN_VOLUME_SHAPE             = ELLIPSOID
SCREEN_VOLUME_FRAME             = RTN
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                  = ODM
ODM_MSG_LINK                    = EPHEMERIS_SATELLITE_A.oem
COVARIANCE_METHOD               = CALCULATED
MANEUVERABLE                    = YES
REF_FRAME                       = EME2000
GRAVITY_MODEL                   = EGM-96: 36D 36O
ATMOSPHERIC_MODEL               = MSISE-90
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 Physical Parameters
AREA_PC                     = 5.2                   [m**2]
AREA_PC_MIN                 = 1.2                   [m**2]
AREA_PC_MAX                 = 5.04                  [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]
APOAPSIS_ALTITUDE           = 779                   [km]
PERIAPSIS_ALTITUDE          = 765                   [km]
INCLINATION                 = 86.4                  [deg]
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-2             [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	= MSISE-90	
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	
INCLINATION	= 98.9	[deg]
COMMENT Object2 Physical Parameters		
AREA_PC	= 0.9	[m**2]
RCS	= 2.27	[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]
APOAPSIS_ALTITUDE	= 786	[km]
PERIAPSIS_ALTITUDE	= 414	[km]
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]

G1.4 ANOTHER EXAMPLE OF A CDM IN KVN WHICH INCLUDES OPTIONAL KEYWORDS

```
CCSDS_CDM_VERS                     = 2.0
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_TYPE                        = SHAPE
SCREEN_VOLUME_SHAPE                = ELLIPSOID
SCREEN_VOLUME_FRAME                = RTN
SCREEN_VOLUME_X                    = 500                           [m]
SCREEN_VOLUME_Y                    = 1000                          [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_PERCENTILE               = 20.0 50.0 80.0
COLLISION_PROBABILITY              = 3.2e-7 5.7e-7 2.8e-6
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
ALT_COV_TYPE                       = XYZ
ALT_COV_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-02              [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  Object1 Covariance in the XYZ Coordinate Frame
CX_X                           = 932.916411              [m**2]
CY_X                           = 942.228217              [m**2]
CY_Y                           = 1106.220534             [m**2]
CZ_X                           = -686.647753             [m**2]
CZ_Y                           = -788.748013             [m**2]
CZ_Z                           = 606.263054              [m**2]
CXDOT_X                        = -0.004239               [m**2/s]
CXDOT_Y                        = -0.017835               [m**2/s]
CXDOT_Z                        = 0.001456                [m**2/s]
CXDOT_XDOT                     = 0.000768                [m**2/s**2]
CYDOT_X                        = -0.017445               [m**2/s]
CYDOT_Y                        = -0.007160               [m**2/s]
CYDOT_Z                        = 0.003966                [m**2/s]
CYDOT_XDOT                     = 0.000616                [m**2/s**2]
CYDOT_YDOT                     = 0.000587                [m**2/s**2]
CZDOT_X                        = -0.028730               [m**2/s]
CZDOT_Y                        = -0.029064               [m**2/s]
CZDOT_Z                        = 0.030090                [m**2/s]
CZDOT_XDOT                     = 0.001804                [m**2/s**2]
CZDOT_YDOT                     = 0.001573                [m**2/s**2]
CZDOT_ZDOT                     = 0.004455                [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	
ALT_COV_TYPE	= CSIG3EIGVEC3	
ALT_COV_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]
COMMENT Object1 Covariance in CSIG3EIGVEC3 format		
CSIG3EIGVEC3	= 140.697 25.552 14.989 -0.999982 0.005459 -0.002499 0.00598839 0.877100 -0.4802698 -0.00043000 -0.4802761 -0.8771172	
DENSITY_FORECAST_UNCERTAINTY	= 2.45030416E-01	
DCP_SENSITIVITY_VECTOR_POSITION	-1.67441647E+01 3.68889831E+02 1.63797508E-01	[m]
DCP_SENSITIVITY_VECTOR_VELOCITY	-3.98670591E-01 1.09452965E-02 4.83454839E-04	[m/s]

G2 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="https://nav.sanaregistry.org/r/ndmxml_unqualified/ndmxml-
5.0.0-master-4.0.xsd"
     id="CCSDS_CDM_VERS" version="2.0">

  <header>
    <COMMENT>Sample CDM - XML version</COMMENT>
    <CREATION_DATE>2010-03-12T22:31:12.000</CREATION_DATE>
    <ORIGINATOR> CSPOC </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_TYPE>SHAPE</SCREEN_TYPE>
      <SCREEN_VOLUME_SHAPE>ELLIPSOID</SCREEN_VOLUME_SHAPE>
      <SCREEN_VOLUME_FRAME>RTN</SCREEN_VOLUME_FRAME>
      <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>MSISE-90</ATMOSPHERIC_MODEL>
        <N_BODY_PERTURBATIONS>MOON,SUN</N_BODY_PERTURBATIONS>
        <SOLAR_RAD_PRESSURE>NO</SOLAR_RAD_PRESSURE>
```

```
        <EARTH_TIDES>NO</EARTH_TIDES>
        <INTRACK_THRUST>NO</INTRACK_THRUST>
      </metadata>
      <data>
        <COMMENT>Object1 Data</COMMENT>
        <odParameters>
          <COMMENT>Object1 OD Parameters</COMMENT>
          <TIME_LASTOB_START>2010-03-12T02:14:12.746</TIME_LASTOB_START>
          <TIME_LASTOB_END>2010-03-12T02:14:12.746</TIME_LASTOB_END>
          <RECOMMENDED_OD_SPAN units="d">7.88</RECOMMENDED_OD_SPAN>
          <ACTUAL_OD_SPAN units="d">5.50</ACTUAL_OD_SPAN>
          <OBS_AVAILABLE>592</OBS_AVAILABLE>
          <OBS_USED>579</OBS_USED>
          <TRACKS_AVAILABLE>123</TRACKS_AVAILABLE>
          <TRACKS_USED>119</TRACKS_USED>
          <RESIDUALS_ACCEPTED units="%">97.8</RESIDUALS_ACCEPTED>
          <WEIGHTED_RMS>0.864</WEIGHTED_RMS>
        </odParameters>
        <physicalParameters>
          <COMMENT>Object 1 Physical Parameters</COMMENT>
          <AREA_PC units="m**2">5.2</AREA_PC>
          <MASS units="kg">2516</MASS>
          <CD_AREA_OVER_MASS units="m**2/kg">0.045663</CD_AREA_OVER_MASS>
          <CR_AREA_OVER_MASS units="m**2/kg">0.000000</CR_AREA_OVER_MASS>
          <THRUST_ACCELERATION units="m/s**2">0.0</THRUST_ACCELERATION>
          <SEDR units="W/kg">4.54570E-05</SEDR>
          <APOAPSIS_ALTITUDE units="km">796</APOAPSIS_ALTITUDE>
          <PERIAPSIS_ALTITUDE units="km">765</PERIAPSIS_ALTITUDE>
          <INCLINATION units="deg">55</INCLINATION>
        </physicalParameters>
        <stateVector>
          <COMMENT>Object1 State Vector</COMMENT>
          <X units="km">2570.097065</X>
          <Y units="km">2244.654904</Y>
          <Z units="km">6281.497978</Z>
          <X_DOT units="km/s">4.418769571</X_DOT>
          <Y_DOT units="km/s">4.833547743</Y_DOT>
          <Z_DOT units="km/s">-3.526774282</Z_DOT>
        </stateVector>
        <covarianceMatrix>
          <COMMENT>Object1 Covariance in the RTN Coordinate Frame </COMMENT>
          <CR_R units="m**2">4.142E+01</CR_R>
          <CT_R units="m**2">-8.579E+00</CT_R>
          <CT_T units="m**2">2.533E+03</CT_T>
          <CN_R units="m**2">-2.313E+01</CN_R>
          <CN_T units="m**2">1.336E+01</CN_T>
          <CN_N units="m**2">7.098E+01</CN_N>
          <CRDOT_R units="m**2/s">2.520E-03</CRDOT_R>
          <CRDOT_T units="m**2/s">-5.476E+00</CRDOT_T>
          <CRDOT_N units="m**2/s">8.626E-04</CRDOT_N>
          <CRDOT_RDOT units="m**2/s**2">5.744E-03</CRDOT_RDOT>
          <CTDOT_R units="m**2/s">-1.006E-02</CTDOT_R>
          <CTDOT_T units="m**2/s">4.041E-03</CTDOT_T>
          <CTDOT_N units="m**2/s">-1.359E-03</CTDOT_N>
          <CTDOT_RDOT units="m**2/s**2">-1.502E-05</CTDOT_RDOT>
          <CTDOT_TDOT units="m**2/s**2">1.049E-05</CTDOT_TDOT>
          <CNDOT_R units="m**2/s">1.053E-03</CNDOT_R>
          <CNDOT_T units="m**2/s">-3.412E-03</CNDOT_T>
          <CNDOT_N units="m**2/s">1.213E-02</CNDOT_N>
          <CNDOT_RDOT units="m**2/s**2">-3.004E-06</CNDOT_RDOT>
          <CNDOT_TDOT units="m**2/s**2">-1.091E-06</CNDOT_TDOT>
          <CNDOT_NDOT units="m**2/s**2">5.529E-05</CNDOT_NDOT>
        </covarianceMatrix>
      </data>
    &lt;/segment&gt;
    &lt;segment&gt;
      <metadata>
```

```
      <COMMENT>Object2 Metadata</COMMENT>
      <OBJECT>OBJECT2</OBJECT>
      <OBJECT_DESIGNATOR>30337</OBJECT_DESIGNATOR>
      <CATALOG_NAME>SATCAT</CATALOG_NAME>
      <OBJECT_NAME>FENGYUN 1C DEB</OBJECT_NAME>
      <INTERNATIONAL_DESIGNATOR>1999-025AA</INTERNATIONAL_DESIGNATOR>
      <OBJECT_TYPE>DEBRIS</OBJECT_TYPE>
      <EPHEMERIS_NAME>NONE</EPHEMERIS_NAME>
      <COVARIANCE_METHOD>CALCULATED</COVARIANCE_METHOD>
      <MANEUVERABLE>NO</MANEUVERABLE>
      <REF_FRAME>EME2000</REF_FRAME>
      <GRAVITY_MODEL>EGM-96: 36D 36O</GRAVITY_MODEL>
      <ATMOSPHERIC_MODEL> MSISE-90</ATMOSPHERIC_MODEL>
      <N_BODY_PERTURBATIONS>MOON,SUN</N_BODY_PERTURBATIONS>
      <SOLAR_RAD_PRESSURE>YES</SOLAR_RAD_PRESSURE>
      <EARTH_TIDES>NO</EARTH_TIDES>
      <INTRACK_THRUST>NO</INTRACK_THRUST>
    </metadata>
    <data>
      <COMMENT>Object2 Data</COMMENT>
      <odParameters>
        <COMMENT>Object2 OD Parameters</COMMENT>
        <TIME_LASTOB_START>2010-03-12T01:14:12.746</TIME_LASTOB_START>
        <TIME_LASTOB_END>2010-03-12T03:14:12.746</TIME_LASTOB_END>
        <RECOMMENDED_OD_SPAN units="d">2.63</RECOMMENDED_OD_SPAN>
        <ACTUAL_OD_SPAN units="d">2.63</ACTUAL_OD_SPAN>
        <OBS_AVAILABLE>592</OBS_AVAILABLE>
        <OBS_USED>579</OBS_USED>
        <TRACKS_AVAILABLE>15</TRACKS_AVAILABLE>
        <TRACKS_USED>15</TRACKS_USED>
        <RESIDUALS_ACCEPTED units="%">97.8</RESIDUALS_ACCEPTED>
        <WEIGHTED_RMS>0.864</WEIGHTED_RMS>
      </odParameters>
      <physicalParameters>
        <COMMENT>Object2 Physical Parameters</COMMENT>
        <AREA_PC units="m**2">0.9</AREA_PC>
        <CD_AREA_OVER_MASS units="m**2/kg">0.118668</CD_AREA_OVER_MASS>
        <CR_AREA_OVER_MASS units="m**2/kg">0.075204</CR_AREA_OVER_MASS>
        <THRUST_ACCELERATION units="m/s**2">0.0</THRUST_ACCELERATION>
        <SEDR units="W/kg">5.40900E-03</SEDR>
        <APOAPSIS_ALTITUDE units="km">768</APOAPSIS_ALTITUDE>
        <PERIAPSIS_ALTITUDE units="km">414</PERIAPSIS_ALTITUDE>
        <INCLINATION units="deg">98.6</INCLINATION>
      </physicalParameters>

      <stateVector>
        <COMMENT>Object2 State Vector</COMMENT>
        <X units="km">2569.540800</X>
        <Y units="km">2245.093614</Y>
        <Z units="km">6281.599946</Z>
        <X_DOT units="km/s">-2.888612500</X_DOT>
        <Y_DOT units="km/s">-6.007247516</Y_DOT>
        <Z_DOT units="km/s">3.328770172</Z_DOT>
      </stateVector>
      <covarianceMatrix>
        <COMMENT>Object2 Covariance in the RTN Coordinate Frame</COMMENT>
        <CR_R units="m**2">1.337E+03</CR_R>
        <CT_R units="m**2">-4.806E+04</CT_R>
        <CT_T units="m**2">2.492E+06</CT_T>
        <CN_R units="m**2">-3.298E+01</CN_R>
        <CN_T units="m**2">-7.5888E+02</CN_T>
        <CN_N units="m**2">7.105E+01</CN_N>
        <CRDOT_R units="m**2/s">2.591E-03</CRDOT_R>
        <CRDOT_T units="m**2/s">-4.152E-02</CRDOT_T>
        <CRDOT_N units="m**2/s">-1.784E-06</CRDOT_N>
        <CRDOT_RDOT units="m**2/s**2">6.886E-05</CRDOT_RDOT>
        <CTDOT_R units="m**2/s">-1.016E-02</CTDOT_R>
```

```
          <CTDOT_T units="m**2/s">-1.506E-04</CTDOT_T>
          <CTDOT_N units="m**2/s">1.637E-03</CTDOT_N>
          <CTDOT_RDOT units="m**2/s**2">-2.987E-06</CTDOT_RDOT>
          <CTDOT_TDOT units="m**2/s**2">1.059E-05</CTDOT_TDOT>
          <CNDOT_R units="m**2/s">4.400E-03</CNDOT_R>
          <CNDOT_T units="m**2/s">8.482E-03</CNDOT_T>
          <CNDOT_N units="m**2/s">8.633E-05</CNDOT_N>
          <CNDOT_RDOT units="m**2/s**2">-1.903E-06</CNDOT_RDOT>
          <CNDOT_TDOT units="m**2/s**2">-4.594E-06</CNDOT_TDOT>
          <CNDOT_NDOT units="m**2/s**2">5.178E-05</CNDOT_NDOT>
        </covarianceMatrix>
      </data>
    &lt;/segment&gt;
  </body>
</cdm>
```

ANNEX H

INFORMATIVE REFERENCES

(INFORMATIVE)

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ANNEX I

ITEMS FOR AN INTERFACE CONTROL DOCUMENT (ICD)

(INFORMATIVE)

I1 STANDARD ICD ITEMS

In several places of this document, there are references to items that are recommended to be specified in an Interface Control Document (ICD) between participants that supplements an exchange of conjunction data. In general, an ICD is jointly produced by both participants in a cross-support involving the transfer of conjunction data. This annex compiles those recommendations into a single section. Although the Conjunction Data Messages described in this document may at times be used in situations in which participants have not negotiated ICDs, it is recommended that they be developed and negotiated whenever specified in this Recommended Standard.

Item	Section
1) Detailed description of any user defined parameters	3.6
2) Specification of whether KVN or XML formatted messages will be used.	2.2
3) Methods of exchanging CDMs.	3.1.3
4) Specific information security interoperability provisions that may apply between agencies.	C1.11

ANNEX J

CHANGES VERSUS PREVIOUS VERSION

(INFORMATIVE)

This annex lists the differences between CDM 1.0 and CDM 2.0. The differences are divided into those which affect the content of conjunction data messages, and those which only affect the document.

J1 CHANGES TO MESSAGE

The following enhancements have been made to the Conjunction Data Message. Whilst the following changes have been made, backwards compatibility to CDM V1.0 has been ensured by the use of optional parameters:

1) Parameter clarifications

2) Improved message tagging (Classification, Conjunction ID, last and next message tagging)

3) Improved object definitions (Screening, Observations/OD, Covariance, Area PC)

4) Hard-Body Radius (HBR)

5) Optimally Enclosing Box (OEB)

6) Visual Magnitude (Vmag)

7) Radar Cross Section (RCS)

8) Mahalanobis Distance

9) Support for different covariance frames and types (RTN, XYZ, and Sigma/Eigenvector)

10) Covariance Realism

11) Cumulative Distribution Function of Probability of Collision (CDF of PC)

12) Dynamic Consider Parameters

13) Space Environment Fragmentation Impact (SEFI)

14) Specification of conjunction approach angle

15) Maneuver scheduling information

16) Facility for the specification of user defined parameters

J2 CHANGES IN THE DOCUMENT

1) A new CCSDS repository for normative keyword values for navigation messages has been created at the SANA Registry, accessible on the Internet at: https://nav.sanaregistry.org/r/navigation_standard_registries/. (See annex B for details on the affected keywords and links to the content.)

2) Several annexes were added. Some are required by CCSDS rule changes, and some are for the provision of supplementary material.

3) CDM examples for KVN CDM and XML CDM that formerly appeared in sections 3.6 and 4.4 respectively, have been moved to an informative annex.