The Consultative Committee for Space Data Systems

Draft Recommendation for Space Data System Standards

RE-ENTRY DATA MESSAGE

PROPOSED STANDARD

CCSDS 000.0-W-41

WHITE BOOK

JuneApril 2017

AUTHORITY

Issue:	White Book, Issue 4~~3~~
Date:	April 2017
Location:	Not Applicable

(WHEN THIS RECOMMENDED STANDARD IS FINALIZED, IT WILL CONTAIN THE FOLLOWING STATEMENT OF AUTHORITY:)

This document has been approved for publication by the Management Council of the Consultative Committee for Space Data Systems (CCSDS) and represents the consensus technical agreement of the participating CCSDS Member Agencies. The procedure for review and authorization of CCSDS documents is detailed in *Organization and Processes for the Consultative Committee for Space Data Systems* (CCSDS A02.1-Y-4), and the record of Agency participation in the authorization of this document can be obtained from the CCSDS Secretariat at the address below.

This document is published and maintained by:

CCSDS Secretariat
Space Communications and Navigation Office, 7L70
Space Operations Mission Directorate
NASA Headquarters
Washington, DC 20546-0001, USA

FOREWORD

This document is a Draft Standard for Re-entry Data Messages (RDM) and has been prepared by the CCSDS. The RDM described in this Draft Standard is intended for re-entry (prediction) information exchange between interested parties.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CCSDS shall not be held responsible for identifying any or all such patent rights.

Through the process of normal evolution, it is expected that expansion, deletion, or modification of this document may occur. This Recommended Standard is therefore subject to CCSDS document management and change control procedures, which are defined in *Organization and Processes for the Consultative Committee for Space Data Systems* (CCSDS A02.1-Y-4). Current versions of CCSDS documents are maintained at the CCSDS Web site:

http://www.ccsds.org/

Questions relating to the contents or status of this document should be addressed to the CCSDS Secretariat at the address indicated on page i.

At time of publication, the active Member and Observer Agencies of the CCSDS were:

Member Agencies

- Agenzia Spaziale Italiana (ASI)/Italy.
- Canadian Space Agency (CSA)/Canada.
- Centre National d'Etudes Spatiales (CNES)/France.
- China National Space Administration (CNSA)/People's Republic of China.
- Deutsches Zentrum für Luft- und Raumfahrt (DLR)/Germany.
- European Space Agency (ESA)/Europe.
- Federal Space Agency (FSA)/Russian Federation.
- Instituto Nacional de Pesquisas Espaciais (INPE)/Brazil.
- Japan Aerospace Exploration Agency (JAXA)/Japan.
- National Aeronautics and Space Administration (NASA)/USA.
- UK Space Agency/United Kingdom.

Observer Agencies

- Austrian Space Agency (ASA)/Austria.
- Belgian Federal Science Policy Office (BFSPO)/Belgium.
- Central Research Institute of Machine Building (TsNIIMash)/Russian Federation.
- China Satellite Launch and Tracking Control General, Beijing Institute of Tracking and Telecommunications Technology (CLTC/BITTT)/China.
- Chinese Academy of Sciences (CAS)/China.
- Chinese Academy of Space Technology (CAST)/China.
- Commonwealth Scientific and Industrial Research Organization (CSIRO)/Australia.
- Danish National Space Center (DNSC)/Denmark.
- Departamento de Ciência e Tecnologia Aeroespacial (DCTA)/Brazil.
- European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)/Europe.
- European Telecommunications Satellite Organization (EUTELSAT)/Europe.
- Geo-Informatics and Space Technology Development Agency (GISTDA)/Thailand.
- Hellenic National Space Committee (HNSC)/Greece.
- Indian Space Research Organization (ISRO)/India.
- Institute of Space Research (IKI)/Russian Federation.
- KFKI Research Institute for Particle & Nuclear Physics (KFKI)/Hungary.
- Korea Aerospace Research Institute (KARI)/Korea.
- Ministry of Communications (MOC)/Israel.
- National Institute of Information and Communications Technology (NICT)/Japan.
- National Oceanic and Atmospheric Administration (NOAA)/USA.
- National Space Agency of the Republic of Kazakhstan (NSARK)/Kazakhstan.
- National Space Organization (NSPO)/Chinese Taipei.
- Naval Center for Space Technology (NCST)/USA.
- Scientific and Technological Research Council of Turkey (TUBITAK)/Turkey.
- South African National Space Agency (SANSA)/Republic of South Africa.
- Space and Upper Atmosphere Research Commission (SUPARCO)/Pakistan.
- Swedish Space Corporation (SSC)/Sweden.
- Swiss Space Office (SSO)/Switzerland.
- United States Geological Survey (USGS)/USA.

PREFACE

This document is a draft CCSDS Recommended Standard. Its 'White Book' status indicates that its contents are not stable, and several iterations resulting in substantial technical changes are likely to occur before it is considered to be sufficiently mature to be released for review by the CCSDS Agencies.

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 and Issue	Date	Status
CCSDS 000.0-W-0	Re-entry Data Message, Proposed Draft Recommended Standard, Issue 1	July 2016	Version sent before Rome meetings
CCSDS 000.0-W-0	Re-entry Data Message, Proposed Draft Recommended Standard, Issue 2	October 2016	Internal version
CCSDS 000.0-W-0	Re-entry Data Message, Proposed Draft Recommended Standard, Issue 3	April 2017	Draft version for 2017 San Antonio meetingsCurrent draft version
CCSDS 000.0-W-4	Re-entry Data Message, Proposed Draft Recommended Standard, Issue 4	June 2017	Current draft version

CONTENTS

Section Page

Figure

Table

1 INTRODUCTION

1.1 PURPOSE AND SCOPE

The Re-entry Data Message (RDM) Draft Standard specifies a standard message format to be used in the exchange of spacecraft (re-)entry information between Space Situational Awareness (SSA) or Space Surveillance and Tracking (SST)[1] data providers, satellite owners/operators, and other parties. These messages can be used to inform spacecraft owners/operators of predicted re-entries or warn civil protection agencies about potential ground impacts.

This standard will:

a) facilitate interoperability and enable consistent warning between data providers who supply re-entry prediction data and the entities who use it;

b) facilitate the automation of re-entry prediction processes; and

c) provide critical information to enable timely re-entry decisions (e.g. a change in the controlled re-entry strategy).

The document also includes informative descriptions of the information needed for re-entry prediction.

1.2 APPLICABILITY

This standard is applicable to Space Surveillance and Tracking activities, spacecraft operations, and other “ground” based activities (e.g. civil protection, civil and military aviation) where re-entering space objects are concerns. It contains the specifications for an RDM designed for re-entry prediction (though it can be used post-facto as well) information exchange between originators of re-entry data and recipients. Re-entry data includes remaining orbital lifetime, start and end of the re-entry and impact windows, impact location, and object physical properties. Further information about the types of data exchanged can be found in section 3.

The RDM is suitable for both manual and automated interaction, and ~~is suitable~~ for machine-to-machine interfaces due to the large amount of data present. The RDM is self-contained, but it can be paired with other Navigation Data Messages to enhance its functionality. For example an RDM could be paired with several OPMs to exchange state vectors at critical epochs (last orbit determination, current, re-entry, etc.) or with one OEM to give the trajectory for most of the re-entry. The presence of users defined keywords allows other information to be exchanged after being specified in an Interface Control Document (ICD);

[1] The SSA term is more commonly used in the US, while SST is preferred in Europe. This document shall use SST from now on.

ICDs are expected (especially if ODMs are to be exchanged for object position), but not necessary for most RDM exchanges.

It is desirable that RDM originators maintain consistency with respect to the optional keywords provided in their implementations; i.e., it is desirable that the composition of the RDMs provided not change on a frequent basis.[AM1]

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 re-entries and calculate the associated data (e.g. probability of ground impact and impact location) are also outside the scope of this standard.

1.3 DOCUMENT STRUCTURE

Section 2 provides a short overview of the CCSDS-draft RDM.

Section 3 describes the structure and content of the 'keyword = value' (KVN) version of the RDM.

~~[The XML version of the RDM].~~

Section 4 discusses the data and syntax of RDM messages, both the KVN and XML versions.

ANNEX A lists agreed values for some of the keywords in this standard [to be replaced by SANA registries in the future].

ANNEX B shows the Implementation Conformance Statement (ICS), listing all the requirements an RDM implementation should meet.

ANNEX C presents RDM examples.

ANNEX D discusses security, SANA and patent issues.

ANNEX E presents the abbreviations and acronyms used in this document.

ANNEX F shows the requirements this Draft Standard was designed to meet.

ANNEX G presents a summary sheet that shows which optional metadata entries should be present for the data blocks in the message.

ANNEX H describes the types of information exchanged in an RDM.

ANNEX I provides a list of informative references.

~~[Description of any other annexes to be added later.]~~

1.4 CONVENTIONS AND DEFINITIONS

1.4.1 UNIT NOTATION

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]~~[1]~~[1]~~). The units used within this document are as follows:

– km: kilometres;

– m: meters;

– d: days (86400 s);

– s: seconds of time;

– kg: kilograms

– W: watts;

– %: per cent.

For compound units the following conventions are used:

– multiplication is denoted with a single asterisk, ‘*’(e.g. ‘kg*s’);

– division is denoted with a single forward slash, ‘/’ (e.g. ‘km/s’);

– exponents are denoted with a double asterisk, ‘**’ (e.g. ‘km**2’).

The usual mathematical conventions for operation order (e.g. exponents before multiplication) apply.

1.4.2 NOMENCLATURE

The following conventions apply to the normative specifications in this Draft 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’ denote statements of fact.

NOTE – These conventions do not apply to any text that is informative in nature (e.g. overview sections).

The following conventions applies when referring to Earth re-entry prediction simulations:

a) *short-term re-entry prediction* refers to all simulations where the object's altitude is below 200 km, typically covering the last few days (up to a few weeks) before re-entry;

b) *long and medium term prediction* refers to simulations spanning from a few weeks to years before re-entry.

1.4.3 OTHER CONVENTIONS

The term 'ASCII' is generally used in this document to refer to the text character set defined in [2]

[2]

[2]. The term 'n/a' is used to mean 'not applicable' or 'not available'.

1.5 REFERENCES

The following publications contain provisions which, through reference in this text, constitute provisions of this document. 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][1] *The International System of Units (SI)*. 8th ed. Sèvres, France: BIPM, 2006, updated 2014.

[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.

[2]

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

[3]

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

[4]

[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.

[5]

[6] *United Nations Register of Objects Launched into Outer Space.* Available at

[6] http://www.unoosa.org/oosa/en/spaceobjectregister/index.html

[7] *Space Assigned Number Authority (SANA) Registry for Conjunction Data Message ORIGINATOR.* Available at https://sanaregistry.org/r/cdm_originator

[7]

[8] *Space Assigned Number Authority (SANA) Registry for Conjunction Data Message CATALOG_NAME.* Available at https://sanaregistry.org/r/cdm_catalog

[87] http://sanaregistry.org/r/cdm_catalog/cdm_catalog.html

[9] *Space Assigned Number Authority (SANA) Registry for Organizations.* Available at https://sanaregistry.org/r/organizations

[9]

2 OVERVIEW

2.1 GENERAL

This section provides a high-level overview of the CCSDS RDM, a message format designed to help the exchange of re-entry data between originators of re-entry data, spacecraft operators, and other interested entities. The originators of re-entry data can be SST entities or even the spacecraft operators themselves (e.g. in the case of a controlled re-entry).

2.2 RDM CONTENT

The RDM is an ASCII format, encoded either as plain text (usually referred to as KVN) or XML (see [2][2], [3][3][1] and, [4][4][3] and [4]). This Draft Standard describes both.

The RDM contains information about a single re-entry event:

- information about the message itself (creation date, originator, etc.);
- identification of the re-entering object (name, id);
- basic re-entry information (mandatory): remaining orbital lifetime, whether the re-entry is controlled or not, and which celestial body the object is orbiting;
- more complex re-entry information (optional): re-entry and impact windows, impact location and probabilities, state vector, object properties, the OD process, and observations used to predict the re-entry.

The information is used by satellite operators, civil protection, or aviation authorities to assess the re-entry risk and plan any needed mitigation measures.

The RDM is not limited to man-made objects re-entering the Earth's atmosphere. It could be used for any entry/impact event by specified the appropriate CENTER_NAME, REF_FRAME and OBJECT_TYPE values (e.g. a space probe landing on Venus).

3 RE-ENTRY DATA MESSAGE STRUCTURE AND CONTENT

This section contains a description of the structure, content and keywords allowed in a Re-entry Data Message.

3.1 GENERAL

3.1.1 The RDM shall be plain text consisting of re-entry (prediction) data for a single re-entry event. It shall be easily readable by both humans and computers.

3.1.2 The RDM in KVN shall consist of digital data represented as ASCII text lines. The RDM shall contain the following:

a) a header;

b) a metadata section;

c) a data section.

NOTES

1 KVN messages contain one keyword per line (see 4.3.1.4).

2 The standard order of keywords in the KVN representation is fixed by this Draft Standard (see 4.3.1.10).

3.1.3 The RDM file naming scheme should be agreed to on a case-by-case basis between the participating agencies, typically specified in an ICD. In general, the file name syntax and length must not violate computer constraints for those computing environments in use by Member Agencies for processing re-entry data.

3.1.4 The exchange method for RDMs shall be determined on a case-by-case basis and should be documented in an ICD.

3.2 RDM HEADER

The RDM header shall only consist of the KVN elements defined in Table 3-1~~Table 3-1Table 3-1~~, which specifies for each header item:

a) the keyword to be used;

b) a short description of the item;

c) examples of allowed values;

d) whether the item is mandatory (M) or optional (O).

Table 3-1 RDM KVN Header

Keyword	Description of values	Examples of values	M/O
CCSDS_RDM_VERS	Format version in the form of 'x.y', where 'y' is incremented for corrections and minor changes, and 'x' is incremented for major changes.	1.0	M
COMMENT	Comments (allowed in the RDM Header only immediately after the RDM version number).	COMMENT This is a comment	O
CREATION_DATE	File creation date and time in UTC. For format specification, see 4.3.2.5.	2001-11-06T11:17:33 2002-204T15:56:23	M
ORIGINATOR	Creating agency or operator (value should be taken from the [TBD] CDM originators[AM2] SANA registry [7][7][7]). The country of origin should also be provided where the originator is not a national space agency.	DLR ESOC	M
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.	201113719185	M

3.3 RDM METADATA

3.3.1 The RDM metadata shall only consist of the KVN elements defined in Table 3-2Table 3-2Table 3-2, which specifies for each metadata item:

a) the keyword;

b) a short description of the item;

c) normative values or examples of values;

d) whether the values are normative (N – all values allowed are in the list in the third column) or examples of values allowed (E);

e) whether the item is mandatory (M) or optional (O).

3.3.2 Mandatory items shall appear in every RDM Metadata Section. Items that are not mandatory may or may not appear, at the discretion of the data producer, based on the requirements of the data and its intended application (see ANNEX G for an RDM Summary Sheet that illustrates the relationships between data types and metadata).

Table 3-2 RDM KVN metadata

Keyword	Description	Examples of values	N/E	M/O

Keyword	Description	Examples of values	N/E	M/O
`COMMENT`	Comments (allowed only at the beginning of RDM metadata)	`COMMENT This is a comment`	E	O
General information identifying the object, which celestial body it is orbiting and the time system of all the epoch information.				

`OBJECT_NAME`	Spacecraft name for which the orbit state is provided. There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the UN OOSA registry [6] [6] [6], which includes Object name and international designator of the participant (see 4.2.3.3 for formatting rules).	`SENTINEL-1A`
		`GOCE`
		`ENVISAT`
		`BRIZ R/B`
		`DEBRIS`
		`UNKNOWN`
			E	M

`INTERNATIONAL_DESIGNATOR`	The full international designator (COSPAR ID) for the object. Values shall have the format YYYY-NNNP{PP}, where:
	YYYY = year of launch;
	NNN = three-digit serial number of launch (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 should be (see 4.2.3.3 for formatting rules).
		`2010-012C`
		`2016-001A`
		`1985-067CD`
		`UNKNOWN`
			E	M

`CATALOG_NAME`	The satellite catalog used for the object (see 4.2.3.3 for formatting rules). The name should be taken from the appropriate SANA registry (see [8] [8][7]).	`SATCAT` `ESA SST`	E	O
`OBJECT_DESIGNATOR`	The CATALOG_NAME satellite catalog designator for the object (see 4.2.3.3 for formatting rules).	`37451` `125387U`	E	O

`OBJECT_TYPE`	The object type.	`PAYLOAD`
		`ROCKET BODY`
		`DEBRIS`
		`UNKNOWN`
		`OTHER`
			N	O

`OBJECT_OWNER`	Owner or operator of the spacecraft (e.g. company, agency or country owning the satellite)[AM3]. The value should be taken from the SANA registry for organizations [9][9].	`DLR`
		`INTELSAT`
		`ESA`
		`UNKNOWN`
			E	O

`OBJECT_OPERATOR`	Operator of the spacecraft (e.g. company, agency or country owning the satellite)[AM4]. The value should be taken from the SANA registry for organizations [9][9].	`ESA` `EUMETSAT`	E	O

Keyword	Description	Examples of values	N/E	M/O
CONTROLLED_REENTRY	Specify if the re-entry is controlled or not	YES NO UNKNOWN	N	M
CENTER_NAME[AM5]	Celestial body orbited by the object and origin of reference frame, which may be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this case the value for 'CENTER_NAME' is subject to the same rules as for 'OBJECT_NAME').	EARTH ~~EARTH BARYCENTRE~~ MOON JUPITER	E	M
TIME_SYSTEM	Time system for all data/metadata. Use of values other than those in A1 must be documented in an ICD. If keyword is not present, UTC shall be assumed.	UTC TAI	E	M
EPOCH_TZERO	Epoch from which the ORBIT_LIFETIME is calculated (see 4.3.2.5 for formatting rules).	2001-11-06T11:17:33 2002-204T15:56:23	E	M
The reference of frame of the orbit data or the identifier of external ODM files.				
REF_FRAME	Reference frame in which the (optional) orbit information will be provided. Use of values other than those in A2 must be documented in an ICD. The reference frame must be the same for all data elements, with the exception of the covariance matrix, for which a different reference frame may be specified. This keyword becomes mandatory if state vectors are provided in the data section.	ITRF-97 EME2000 ICRF	E	O
REF_FRAME_EPOCH	Epoch of reference frame, if not intrinsic to the definition of the reference frame (see 4.3.2.5 for formatting rules).	2001-11-06T11:17:33 2002-204T15:56:23Z	E	O
EPHEMERIS_NAME	Unique identifier of an external ephemeris file used or none.	NONE EPHEMERIS INTELSAT2	E	O
The modeling used to determine the re-entry data				
GRAVITY_MODEL	The gravity model used in the simulation. The degree (D) and order (O) of the spherical harmonic coefficients applied should be given along with the name of the model.	EGM-96: 36D 36O JGM-2: 41D 41)	E	O
ATMOSPHERIC_MODEL[AM6]	The atmosphere model(s) used in the simulation[AM7].	MSIS JACCHIA 70	E	O

Keyword	Description	Examples of values	N/E	M/O
		MSISE-90 NRLMSISE-00		
SOLAR_FLUX_PREDICTION	The method used to predict the solar flux and geomagnetic indices.[AM8]	MONTE CARLO PREDICTED: [AM9]MLLRT	E	O
N_BODY_PERTURBATIONS	List of other bodies used in the simulation	MOON, SUN JUPITER NONE	E	O
SOLAR_RAD_PRESSURE	Indicator on whether solar radiation pressure was used in the simulation. Specify model name, or NO if it was not used.	GSPM04 NO	E	O
EARTH_TIDES	Indicator on whether solid Earth and ocean tides were included. Specify model name, or NO if they were not used.	ESR NO	E	O
INTRACK_THRUST	Indication of whether in-track thrust modeling was used in the simulation.	YES NO	N	O
RE_ENTRY_DISINTEGRATION	Indication on what aspects of disintegration during re-entry were considered during simulations: none (the object was treated as a point mass), mass loss, break-ups or both. This is a coarse indication on whether the impact area in the date covers potential fragments as well.	NONE MASS-LOSS BREAK-UP MASS-LOSS & BREAK-UP	N	O
IMPACT_LOCATION_UNCERTAINTY[AM10]	Indication on how the confidence interval for the impact location was determined.	ANALYTICAL MONTE CARLO EMPIRICAL	N	O
Information about the previous and next messages to be issued				
PREVIOUS_MESSAGE_ID	ID of the previous RDM issued for this spacecraft.	ESOC/2015-563892348	E	O
PREVIOUS_MESSAGE_EPOCH	UTC Epoch of the previous RDM issued for this spacecraft (see 4.3.2.5 for formatting rules).	2001-11-06T11:17:33	E	O[AM11]
NEXT_MESSAGE_EPOCH	Scheduled UTC epoch of the next RDM for the same object (see 4.3.2.5 for formatting rules). Use N/A if no other message is	2001-11-06T11:17:33 N/A	E	O

Keyword	Description	Examples of values	N/E	M/O
	scheduled.			

3.4 RDM DATA

3.4.1 The RDM data section shall be formatted as logical blocks:

– Atmospheric re-entry and ground impact data;

– State vector (including epoch);

– Position/velocity covariance matrix (associated with the state vector and at the same epoch);

– Spacecraft parameters;

– Orbit determination parameters;

– User defined parameters.[AM12]

3.4.2 The logical blocks of the RDM data section shall consist of KVN lines defined in Table 3-3~~Table 3-3Table 3-3~~, which specifies:

a) the keyword to be used;

b) a description of the content;

c) the units to be used

d) whether the item is mandatory (M) or optional (O).

Table 3-3 RDM KVN data

Keyword	Description of values	Units	M/O
Atmospheric re-entry ~~and ground impact~~ data[AM13]			
`COMMENT`	`COMMENT This is a comment`	`n/a`	O
`ORBIT_LIFETIME`	Time until re-entry: from the `EPOCH_TZERO` epoch in the metadata (days –double precision values allowed; integer values assumed to be .0) to permanently crossing the altitude specified in REENTRY_ALTITUDE. If the NOMINAL_REENTRY_EPOCH keyword is present, its value is to be used for computations rather than the ORBIT_LIFETIME.	`d`	M

Keyword	Description of values	Units	M/O
LIFETIME_DISPERSION	Dispersion (1 sigma) of remaining orbit lifetime. This is a coarse value for long-term predictions, REENTRY_WINDOW_START and _END should be used for accurate results.	%	O
REENTRY_ALTITUDE	Defined re-entry altitude over a spherical Earth (radius of 6371 km) – once a spacecraft's altitude permanently drops below this value, it is considered to be captured by the central body's atmosphere.	km	M
NOMINAL_REENTRY_EPOCH[AM14]	Predicted epoch at which the object's altitude permanently drops below NOMINAL_REENTRY_ALTITUDE (see 4.3.2.5 for formatting rules).	n/a	O
REENTRY_WINDOW_START	Start epoch of the predicted atmospheric re-entry window (see 4.3.2.5 for formatting rules).	n/a	O
REENTRY_WINDOW_END[AM15]	End epoch of the predicted atmospheric re-entry window[AM16] (see 4.3.2.5 for formatting rules).	n/a	O
Ground impact and burn-up data			
COMMENT	COMMENT This is a comment	n/a	O
PROBABILITY_OF_IMPACT[AM17]	Probability of any fragment impacting the Earth (either land or sea).	n/a	O
PROBABILITY_OF_BURN-UP	Probability of the entire spacecraft and any fragments burning up during atmospheric re-entry (0 to 1).	n/a	O
PROBABILITY_OF_BREAK-UP	Probability of the spacecraft breaking up during re-entry (0 to 1).	n/a	O
PROBABILITY_OF_LAND_IMPACT	Probability of any fragment impacting solid ground (0 to 1).	n/a	O
PROBABILITY_OF_CASUALTY	Probability of the re-entry event causing any casualties (severe injuries or deaths – 0 to 1).	n/a	O
NOMINAL_IMPACT_EPOCH	Epoch of the predicted impact (see 4.3.2.5 for formatting rules).	n/a	O
IMPACT_WINDOW_START	Start epoch of the predicted impact window (see 4.3.2.5 for formatting rules).	n/a	O
IMPACT_WINDOW_END	End epoch of the predicted impact window (see 4.3.2.5 for formatting rules).	n/a	O
IMPACT_REF_FRAME[AM18]	Reference frame of the impact location data[AM19]	n/a	O
NOMINAL_IMPACT_LON	Longitude of the predicted impact location.	deg	O

Keyword	Description of values	Units	M/O
NOMINAL_IMPACT_LAT	Latitude of the predicted impact location.	deg	O
NOMINAL_IMPACT_ALT	Altitude of the impact location.	m	O
IMPACT_1_CONFIDENCE[AM20]	First (lowest) confidence interval for the impact location.	%	O
IMPACT_1~~S~~_START_LON[AM21]	Longitude of the start of the ~~1-sigma~~first confidence interval along the ground track.	deg	O
IMPACT_1~~S~~_START_LAT	Latitude of the start of the ~~1-sigma~~first confidence interval along the ground track.	deg	O
IMPACT_1~~S~~_STOP_LON	Longitude of the end of the ~~1-sigma~~first confidence interval along the ground track.	deg	O
IMPACT_1~~S~~_STOP_LAT	Latitude of the end of the ~~1-sigma~~first confidence interval along the ground track.	deg	O
IMPACT_1~~S~~_CROSS_TRACK	Size of the cross-track ~~1-sigma~~first confidence interval.	km	O
IMPACT_2_CONFIDENCE	Second confidence interval for the impact location.	%	O
IMPACT_2~~S~~_START_LON	Longitude of the start of the ~~2-sigma~~second confidence interval along the ground track.	deg	O
IMPACT_2~~S~~_START_LAT	Latitude of the start of the second~~2-sigma~~ confidence interval along the ground track.	deg	O
IMPACT_2~~S~~_STOP_LON	Longitude of the end of the second~~2-sigma~~ confidence interval along the ground track.	deg	O
IMPACT_2~~S~~_STOP_LAT	Latitude of the end of the second~~2-sigma~~ confidence interval along the ground track.	deg	O
IMPACT_2~~S~~_CROSS_TRACK	Size of the cross-track second~~2-sigma~~ confidence interval.	km	O
IMPACT_3_CONFIDENCE	Third (highest) confidence interval for the impact location.	%	O
IMPACT_3~~S~~_START_LON	Longitude of the start of the ~~3-sigma~~third confidence interval along the ground track.	deg	O
IMPACT_3~~S~~_START_LAT	Latitude of the start of the third~~3-sigma~~ confidence interval along the ground track.	deg	O
IMPACT_3~~S~~_STOP_LON	Longitude of the end of the third~~3-sigma~~ confidence interval along the ground track.	deg	O
IMPACT_3~~S~~_STOP_LAT	Latitude of the end of the third~~3-sigma~~ confidence interval along the ground track.	deg	O
IMPACT_3~~S~~_CROSS_TRACK	Size of the cross-track third~~3-sigma~~ confidence interval.	km	O

Keyword	Description of values	Units	M/O
State vector components in the coordinate system specified in the metadata			
COMMENT	COMMENT This is a comment	n/a	O
EPOCH	Epoch at which the state vector is given (see 4.3.2.5 for formatting rules).	n/a	O
X	x-component of the satellite state vector	km	O
Y	y-component of the satellite state vector	km	O
Z	z-component of the satellite state vector	km	O
X_DOT	x-component of the satellite state vector	km/s	O
Y_DOT	y-component of the satellite state vector	km/s	O
Z_DOT	z-component of the satellite state vector	km/s	O
Position/velocity covariance matrix (6x6 lower triangular form. None or all of the components of the matrix must be given. COV_REF_FRAME can be omitted if it is the same as the orbit reference frame)			
COMMENT	COMMENT This is a comment	n/a	
COV_REF_FRAME	Reference frame for the covariance information. Omitted if it is the same as REF_FRAME. Use of values other than those in A3 must be documented in an ICD.	n/a	O
CX_X	covariance matrix [1,1]	km**2	O
CY_X	covariance matrix [2,1]	km**2	O
CY_Y	covariance matrix [2,2]	km**2	O
CZ_X	covariance matrix [3,1]	km**2	O
CZ_Y	covariance matrix [3,2]	km**2	O
CZ_Z	covariance matrix [3,3]	km**2	O
CX_DOT_X	covariance matrix [4,1]	km**2/s	O
CX_DOT_Y	covariance matrix [4,2]	km**2/s	O
CX_DOT_Z	covariance matrix [4,3]	km**2/s	O
CX_DOT_X_DOT	covariance matrix [4,4]	km**2/s**2	O
CY_DOT_X	covariance matrix [5,1]	km**2/s	O
CY_DOT_Y	covariance matrix [5,2]	km**2/s	O
CY_DOT_Z	covariance matrix [5,3]	km**2/s	O
CY_DOT_X_DOT	covariance matrix [5,4]	km**2/s**2	O

Keyword	Description of values	Units	M/O
CY_DOT_Y_DOT	covariance matrix [5,5]	km**2/s**2	O
CZ_DOT_X	covariance matrix [6,1]	km**2/s	O
CZ_DOT_Y	covariance matrix [6,2]	km**2/s	O
CZ_DOT_Z	covariance matrix [6,3]	km**2/s	O
CZ_DOT_X_DOT	covariance matrix [6,4]	km**2/s**2	O
CZ_DOT_Y_DOT	covariance matrix [6,5]	km**2/s**2	O
CZ_DOT_Z_DOT	covariance matrix [6,6]	km**2/s**2	O
Spacecraft parameters[AM22]			
COMMENT	COMMENT This is a comment	n/a	O
MASS	Object mass	kg	O
SOLAR_RAD_AREA	Object area exposed to SRP	m**2	O
SOLAR_RAD_COEFF	Object radiation coefficient	n/a	O
DRAG_AREA	Object cross-sectional area	m**2	O
DRAG_COEFF	Object drag coefficient	n/a	O
RCS	Object radar cross section	m**2	O
BALLISTIC_COEFF	Object ballistic coefficient	kg/m**2	O
THRUST_ACCELERATION [AM23]	The object's acceleration due to in-track thrust used to propagate the state vector and covariance to RENTRY_EPOCH (if a controlled re-entry).	m/s**2	O
Orbit determination parameters[AM24]			
COMMENT	COMMENT This is a comment	n/a	O
TIME_LASTOB_START	The start of a time interval (in the time system specified in the metadata) that contains the time of the last accepted observation. For an exact time, the time interval is of zero duration (i.e., same value as that of TIME_LASTOB_END). See 4.3.2.5 for formatting rules.	n/a	O
TIME_LASTOB_END	The end of a time interval (in the time system specified in the metadata) that contains the time of the last accepted observation. For an exact time, the time interval is of zero duration (i.e., same value as that of TIME_LASTOB_START). See 4.3.2.5 for formatting rules.	n/a	O
RECOMMENDED_OD_SPAN	The recommended OD time span calculated for the object (double precision).	d	O

Keyword	Description of values	Units	M/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 (double precision).	d	O
OBS_AVAILABLE	Number of observations available for orbit determination of the object.	n/a	O
OBS_USED	Number of observations accepted by the OD system.	n/a	O
TRACKS_AVAILABLE	Number of sensor tracks available for OD of the object.	n/a	O
TRACKS_USED	Number of sensor tracks accepted by the OD system.	n/a	O
RESIDUALS_ACCEPTED	The percentage of residuals accepted in the OD of the object.	%	O
WEIGHTED_RMS	The weighted root mean square of the residuals from batch OD.	n/a	O
User defined parameters (all such parameters must be described in an ICD)[AM25]			
COMMENT	COMMENT This is a comment	n/a	O
USER_DEFINED_x	User defined parameter, where x is replaced by a variable length user specified character string. Any number of user defined parameters may be included, if necessary to provide essential information that cannot be conveyed in COMMENT statements.	n/a	O

3.4.3 Table 3-3Table 3-3Table 3-3 contains sevenix logical blocks, each of which has a descriptive heading. These descriptive headings shall not be included in an RDM, unless they appear in a properly formatted COMMENT statement.

3.4.4 COMMENT lines may be used at the beginning of each logical block of the data section.

3.4.5 If a ground impact location is given, the IMPACT_REF_FRAME keyword shall be mandatory and at least NOMINAL_IMPACT_LAT and, NOMINAL_IMPACT_LON shall be present. NOMINAL_IMPACT_ALT may be given as well.

3.4.6 If one confidence intervals isare present then all the values associated with one that n-sigma valueinterval shall be present: IMPACT_n_CONFIDENCE, (e.g. IMPACT_n1S_START_LON, IMPACT_n1S_START_LAT, IMPACT_n1S_STOP_LON, IMPACT_n1S_STOP_LAT, and IMPACT_n1S_CROSS_TRACK).

3.4.7 If only one confidence interval is present then the IMPACT_1_* keywords shall be used.

3.4.8 If two confidence intervals are present then the IMPACT_1_* and IMPACT_2_* keywords shall be used.

~~3.4.6~~3.4.9 If more than one confidence interval is present, then IMPACT_1_CONFIDENCE shall be smaller than IMPACT_2_CONFIDENCE, which in turn shall be smaller than IMPACT_3_CONFIDENCE, if it is present.

3.4.10 If the RE_ENTRY_DISINTEGRATION keyword in the metadata indicates that break-up was simulated, then the ground impact location keywords refer to all potential fragments related to the event, i.e. the NOMINAL_IMPACT_LAT and _LON will correspond to the highest probability of any fragment impacting there, the ~~1-sigma~~confidence intervals will apply to all fragments, etc.

~~3.4.7~~3.4.11 The probability of ground impact at the following four points: the start and end of the confidence interval in the along-track direction, and the nominal impact location ± the cross-track confidence interval should be within 5 % [TBC] for each confidence interval given.

~~3.4.8~~3.4.12 The state vector and covariance data are at the epoch specified by the EPOCH keyword in the data section. There are no restrictions on which epoch this is supposed to be (orbit determination epoch, message creation epoch, re-entry epoch, etc.). If the covariance block is present then the state vector shall be present as well.

~~3.4.9~~3.4.13 If the state vector block is present then all elements in the block have to be present, with the exception of the comment line. No partial state vectors are allowed in an RDM. State vector values shall be expressed in standard double precision as related in 4.2.3.2.

~~3.4.10~~3.4.14 Values in the covariance matrix shall be expressed in the applicable reference frame (COV_REF_FRAME keyword if used, or REF_FRAME keyword if not), and shall be presented sequentially from upper left [1,1] to lower right [6,6], lower triangular form, row by row left to right. If the covariance block is present in the message, all covariance matrix elements need to be present. Variance and covariance values shall be expressed in standard double precision as related in 4.2.3.2.

~~3.4.11~~3.4.15 Since re-entry prediction services are still in their infancy and some might need to provide information that is not foreseen, a section of User Defined Parameters is allowed at the end of the data section. In principle, this provides flexibility, but also introduces complexity, non-standardization, potential ambiguity, and potential processing errors. Accordingly, if used, the keywords and their meanings must be described in an ICD. User Defined Parameters, if included in an RDM, should be used as sparingly as possible; their use is not encouraged.

4 RE-ENTRY DATA MESSAGE DATA AND SYNTAX

4.1 OVERVIEW

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

4.2 COMMON RDM SYNTAX

4.2.1 OVERVIEW

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

4.2.2 RDM LINES

4.2.2.1 Each RDM line must not exceed 254 ASCII characters and spaces (excluding line termination character[s]).

4.2.2.2 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.

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

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

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

4.2.3 RDM VALUES

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

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

4.2.3.3 Text value fields must be constructed using only all uppercase ("_", "-", blank spaces, and digits are permitted as well). An exception is made for comment values (see 4.2.5 for formatting rules).

4.2.3.4 Blanks shall not be permitted within numeric values and time strings.

4.2.4 RDM UNITS

4.2.4.1 If units are applicable, as specified in Table 3-3~~Table 3-3Table 3-3~~, they must be displayed and they must exactly match the units specified in each table (including case). (See 1.4.1 for units conventions and operations).

4.2.4.2 The notation '[n/a]' shall not appear in an RDM as a units designator.

NOTE – Some of the items in Table 3-3~~Table 3-3Table 3-3~~ are dimensionless (e.g. DRAG_COEFF). 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.

4.2.5 RDM COMMENTS

4.2.5.1 Comment lines shall be optional in the RDM.

4.2.5.2 Comments shall be placed as specified in tables in section 3 describing the keywords. In the places where comments are allowed any number of comments may appear.

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

4.3 THE RDM IN KVN

4.3.1 RDM LINES IN KVN

4.3.1.1 Each RDM file shall consist of a set of RDM lines. Each RDM line shall be one of the following:

– Header line;

– Metadata line;

– Data line; or

– Blank line.

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

4.3.1.3 All header, metadata, and data lines shall use 'keyword = value' notation. For this purpose, only those keywords shown in Table 3-1~~Table 3-1Table 3-1~~, Table 3-2~~Table 3-2Table 3-2~~, and Table 3-3~~Table 3-3Table 3-3~~, shall be used in an RDM.

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

4.3.1.5 Keywords must be uppercase and must not contain blanks.

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

4.3.1.7 Any white space immediately preceding or following the 'equals' sign shall not be significant.

4.3.1.8 Any white space immediately preceding or following the units shall not be significant.

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

4.3.1.10 The order in which obligatory and optional KVN assignments appear shall be fixed as shown in the tables in section 3 that describe the RDM keywords.

4.3.2 RDM VALUES IN KVN

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

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

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

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

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

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

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

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

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

e) The maximum positive floating point value is approximately $1.798 \cdot 10^{308}$, with 16 significant decimal digits precision. The minimum positive floating point value is approximately $4.94 \cdot 10^{-324}$, with 16 significant decimal digits precision.

4.3.2.4 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. This does not apply to leading or trailing blanks, as per 4.3.1.7, 4.3.1.8, and 4.3.1.9.

4.3.2.5 In value fields representing a time tag or epoch, the following two formats shall be used:

*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. All fields require leading zeros. (See reference [5]

~~[5]~~

~~[5]~~, ASCII Time Code A or B.)

4.3.3 RDM UNITS IN KVN

When units are displayed:

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

b) units shall be in the correct case (e.g. lowercase for km, uppercase for K or W), as indicated in Table 3-3~~Table 3-3Table 3-3~~;

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

4.3.4 RDM 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.

4.4 THE RDM IN XML

[To be added in a future draft]

ANNEX A

VALUES FOR TIME_SYSTEM AND FRAME RELARED KEYWORDS

[AM26]

(NORMATIVE)

The values in this annex represent the set of acceptable values for the TIME_SYSTEM, REF_FRAME, and COV_REF_FRAME, and IMPACT_REF_FRAME keywords in the RDM. For details on these keywords, please see [I1][I1][I1].

A1 TIME_SYSTEM METADATA KEYWORD

TIME_SYSTEM value	meaning
GMST	Greenwich Mean Sidereal Time
GPS	Global Positioning System (time)
TAI	International Atomic Time
TCB	Barycentric Coordinate Time
TDB	Barycentric Dynamical Time
TCG	Geocentric Coordinate Time
TT	Terrestrial Time
UT1	Universal Time
UTC	Coordinated Universal Time

A2 REF_FRAME METADATA KEYWORD

REF_FRAME value	meaning
EME2000	Earth Mean Equator and Equinox of J2000
GCRF	Geocentric Celestial Reference Frame
GRC	Greenwich Rotating Coordinates
ICRF	International Celestial Reference Frame
ITRF2000	International Terrestrial Reference Frame 2000
ITRF-93	International Terrestrial Reference Frame 1993
ITRF-97	International Terrestrial Reference Frame 1997
MCI	Mars Centered Inertial
TDR	True of Date, Rotating

TOD	True of Date

A3 COV_REF_FRAME DATA KEYWORD

TIME_SYSTEM value	meaning
RSW	Another name for 'Radial, Transverse, Normal'
RTN	Radial, Transverse, Normal
TNW	A local orbital coordinate frame that has the T-axis along the velocity vector, W along the orbital angular momentum vector, and N completes the right handed system.

A4 IMPACT_REF_FRAME DATA KEYWORD

IMPACT_REF_FRAME value	meaning
WGS84	World Geodetic System 84

ANNEX B

IMPLEMENTATION CONFORMANCE STATEMENT (ICS) PROFORMA

(NORMATIVE)

B1 INTRODUCTION

B1.1 OVERVIEW

This annex provides the Implementation Conformance Statement (ICS) Requirements List (RL) for an implementation of a Re-entry Data Message. The ICS for an implementation is generated by completing the RL in accordance with the instructions below. An implementation claiming conformance must satisfy the mandatory requirements referenced in the RL.

B1.2 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.

<u>Feature Column</u>

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

<u>Status Column</u>

The status column uses the following notations:

- M mandatory;
- O optional;
- C conditional;
- X prohibited;
- I out of scope;
- N/A not applicable.

<u>Support Column Symbols</u>

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.

The support column should also be used, when appropriate, to enter values supported for a given capability.

B1.3 INSTRUCTIONS FOR COMPLETING THE RL

An implementer shows the extent of compliance to the RDM Draft 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 B1.2. 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.

B2 ICS PROFORMA FOR RDM

B2.1 GENERAL INFORMATION

B2.1.1 Identification of ICS

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

B2.1.2 Identification of Implementation Under Test

Implementation Name	
Implementation Version	
Special Configuration	
Other Information	

B2.1.3 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)	

B2.1.4 Identification of Specification

[CCSDS Document Number]	
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 [ ]

B2.2 REQUIREMENTS LIST[AM27]

1	**Feature**	**Keyword**	**Reference**	**Status**	**Support**
2	RDM Header	`N/A`	Table 3-1~~Table 3-1Table 3-1~~	M	
3	RDM version	`CCSDS_RDM_VERS`	Table 3-1~~Table 3-1Table 3-1~~	M	
4	Comment	`COMMENT`	Table 3-1~~Table 3-1Table 3-1~~	O	
5	Message creation date/time	`CREATION_DATE`	Table 3-1~~Table 3-1Table 3-1~~	M	

6	Message originator	ORIGINATOR	Table 3-1Table 3-1Table 3-1	M	
7	Spacecraft name	MESSAGE_FOR	Table 3-1	M	
87	Unique message identifier	MESSAGE_ID	Table 3-1Table 3-1Table 3-1	M	
98	RDM Metadata	N/A	Table 3-2Table 3-2Table 3-2	M	
109	Comment	COMMENT	Table 3-2Table 3-2Table 3-2	O	
1110	General information about the re-entering object	N/A	Table 3-2Table 3-2Table 3-2	M	
1211	Spacecraft name	OBJECT_NAME	Table 3-2Table 3-2Table 3-2	M	
1312	Spacecraft international designator	INTERNATIONAL_DESIGNATOR	Table 3-2Table 3-2Table 3-2	M	
13	Object catalogue used	CATALOG_NAME	Table 3-2	O	
14	Spacecraft ID in the catalogue	OBJECT_DESIGNATOR	Table 3-2	O	
1415	Spacecraft type	OBJECT_TYPE	Table 3-2Table 3-2Table 3-2	M	
1516	Spacecraft owner	OBJECT_OWNER	Table 3-2Table 3-2Table 3-2	O	
17	Spacecraft operator	OBJECT_OPERATOR	Table 3-2	O	
1618	Controlled re-entry	CONTROLLED_REENTRY	Table 3-2Table 3-2Table 3-2	M	
1719	Celestial body orbited by	ORBIT_CENTERCENTER_NAME	Table	M	

	the object		3-2Table 3-2Table 3-2		
1820	Time system user for the data in the metadata and data sections	TIME_SYSTEM	Table 3-2Table 3-2Table 3-2	O	
21	Reference epoch to which orbit lifetime is computed	EPOCH_TZERO	Table 3-2	M	
1922	Information about any provided orbit data for the object/spacecraft	N/A	Table 3-2Table 3-2Table 3-2	O	
2023	Reference frame	REF_FRAME	Table 3-2Table 3-2Table 3-2	O	
2124	Reference frame epoch	REF_FRAME_EPOCH	Table 3-2Table 3-2Table 3-2	O	
2225	External ephemeris file identifier	EPHEMERIS_NAME	Table 3-2Table 3-2Table 3-2	O	
2326	Information about the orbit propagator used for re-entry prediction and orbit determination	N/A	Table 3-2Table 3-2Table 3-2	O	
2427	gGravity model used	GRAVITY_MODEL	Table 3-2Table 3-2Table 3-2	O	
2528	aAtmospheric model used	ATMOSPHERIC_MODEL	Table 3-2Table 3-2Table 3-2	O	
29	method used to estimate the solar flux indices for the atmospheric model	SOLAR_FLUX_PREDICTION	Table 3-2	O	
2630	n-body perturbations considered	N_BODY_PERTURBATIONS	Table 3-2Table 3-2Table 3-2	O	
2731	solar rad pressure	SOLAR_RAD_PRESSURE	Table 3-2Table 3-2Table 3-2	O	

2832	earth tides	EARTH_TIDES	Table 3-2Table 3-2Table 3-2	O	
2933	any thrust from the spacecraft	INTRACK_THRUST	Table 3-2Table 3-2Table 3-2	O	
34	any accounting for break-up and demise	RE_ENTRY_DISINTEGRATION	Table 3-2	O	
35	method used to determine the uncertainty in the ground impact location	IMPACT_LOCATION_UNCERTAINTY	Table 3-2	O	
3036	Previous and next related RDM	N/A	Table 3-2Table 3-2Table 3-2	O	
3137	Identifier of the previous RDM	PREVIOUS_MESSAGE_ID	Table 3-2Table 3-2Table 3-2	O	
3238	Epoch of the previous RDM (predicted)	PREVIOUS_MESSAGE_EPOCH	Table 3-2Table 3-2Table 3-2	O	
3339	Time at which the next RDM will be issued (predicted)	NEXT_MESSAGE_EPOCH	Table 3-2Table 3-2Table 3-2	O	
3440	RDM Data	N/A	Table 3-3Table 3-3Table 3-3	M	
3541	Atmospheric Rre-entry/impact information	N/A	Table 3-3Table 3-3Table 3-3	M	
3642	Comment	COMMENT	Table 3-3Table 3-3Table 3-3	O	
3743	Remaining orbit lifetime	ORBIT_LIFETIME	Table 3-3Table 3-3Table 3-3	M	
3844	Dispersion of remaining orbit lifetime	LIFETIME_DISPERSION	Table 3-3Table 3-3Table	O	

			3-3		
45	Defined re-entry altitude	REENTRY_ALTITUDE	Table 3-3	M	
3946	Predicted re-entry epoch	NOMINAL_REENTRY_EPOCH	Table 3-3Table 3-3Table 3-3	O	
4047	Re-entry window	REENTRY_WINDOW_START	Table 3-3Table 3-3Table 3-3	O	
4148		REENTRY_WINDOW_END	Table 3-3Table 3-3Table 3-3	O	
49	Ground impact information	N/A	Table 3-3	O	
50	Comment	COMMENT	Table 3-3	O	
51	Probability any re-entry fragments reach the Earth surface	PROBABILITY_OF_IMPACT	Table 3-3	O	
52	Probability all re-entry fragments suffer total demise	PROBABILITY_OF_BURN-UP	Table 3-3	O	
53	Probability fragments are generated during re-entry	PROBABILITY_OF_BREAK-UP	Table 3-3	O	
4254	Land impact probability	PROBABILITY_OF_LAND_IMPACT [AM28]	Table 3-3Table 3-3Table 3-3	O	
55	Probabilities of casualties occurring due to the re-entry	PROBABILITY_OF_CASUALTY	Table 3-3	O	
4356	Predicted (ground) impact epoch	NOMINAL_IMPACT_EPOCH	Table 3-3Table 3-3Table 3-3	O	
4457	Predicted (ground) impact window	IMPACT_WINDOW_START	Table 3-3Table 3-3Table 3-3	O	
4558		IMPACT_WINDOW_END	Table 3-3Table 3-3Table 3-3	O	
4659	Reference frame of (ground) impact location	IMPACT_REF_FRAME[AM29]	Table 3-3Table	O	

			3-3Table 3-3		
4760	Impact location	IMPACT_LON	Table 3-3Table 3-3Table 3-3	O	
4861		IMPACT_LAT	Table 3-3Table 3-3Table 3-3	O	
4962		IMPACT_ALT	Table 3-3Table 3-3Table 3-3	O	
5063	Impact dispersion	IMPACT_1_CONFIDENCECNORTH_NORTH	Table 3-3Table 3-3Table 3-3	O	
5164		IMPACT_1_START_LONCNORTH_EAST	Table 3-3Table 3-3Table 3-3	O	
5265		IMPACT_1_START_LATCEAST_EAST	Table 3-3Table 3-3Table 3-3	O	
66		IMPACT_1_STOP_LON	Table 3-3	O	
67		IMPACT_1_STOP_LAT	Table 3-3	O	
68		IMPACT_1_CROSS_TRACK	Table 3-3	O	
69		IMPACT_2_CONFIDENCE	Table 3-3	O	
70		IMPACT_2_START_LON	Table 3-3	O	
71		IMPACT_2_START_LAT	Table 3-3	O	
72		IMPACT_2_STOP_LON	Table 3-3	O	
73		IMPACT_2_STOP_LAT	Table 3-3	O	
74		IMPACT_2_CROSS_TRACK	Table 3-3	O	
75		IMPACT_3_CONFIDENCE	Table 3-3	O	
76		IMPACT_3_START_LON	Table 3-3	O	
77		IMPACT_3_START_LAT	Table 3-3	O	
78		IMPACT_3_STOP_LON	Table 3-3	O	

79		IMPACT_3_STOP_LAT	Table 3-3	O	
80		IMPACT_3_CROSS_TRACK	Table 3-3	O	
5381	Spacecraft state vector section	N/A	Table 3-3Table 3-3Table 3-3	O	
5482	Comment	COMMENT	Table 3-3Table 3-3Table 3-3	O	
5583	State vector epoch	EPOCH	Table 3-3Table 3-3Table 3-3	O	
5684	Position and velocity vectors	X	Table 3-3Table 3-3Table 3-3	O	
5785		Y	Table 3-3Table 3-3Table 3-3	O	
5886		Z	Table 3-3Table 3-3Table 3-3	O	
5987		X_DOT	Table 3-3Table 3-3Table 3-3	O	
6088		Y_DOT	Table 3-3Table 3-3Table 3-3	O	
6189		Z_DOT	Table 3-3Table 3-3Table 3-3	O	
6290	Spacecraft state vector covariance information	N/A	Table 3-3Table 3-3Table 3-3	O	
6391	Comment	COMMENT	Table 3-3Table 3-3Table 3-3	O	
6492	Covariance reference	COV_REF_FRAME	Table	O	

	frame		3-3Table 3-3Table 3-3		
6593	6x6 position/velocity covariance matrix elements	CX_X	Table 3-3Table 3-3Table 3-3	O	
6694		CY_X	Table 3-3Table 3-3Table 3-3	O	
6795		CY_Y	Table 3-3Table 3-3Table 3-3	O	
6896		CZ_X	Table 3-3Table 3-3Table 3-3	O	
6997		CZ_Y	Table 3-3Table 3-3Table 3-3	O	
7098		CZ_Z	Table 3-3Table 3-3Table 3-3	O	
7199		CX_DOT_X	Table 3-3Table 3-3Table 3-3	O	
72100		CX_DOT_Y	Table 3-3Table 3-3Table 3-3	O	
73101		CX_DOT_Z	Table 3-3Table 3-3Table 3-3	O	
74102		CX_DOT_X_DOT	Table 3-3Table 3-3Table 3-3	O	
75103		CY_DOT_X	Table 3-3Table 3-3Table 3-3	O	
76104		CY_DOT_Y	Table	O	

			3-3Table 3-3Table 3-3		
77105		CY_DOT_Z	Table 3-3Table 3-3Table 3-3	O	
78106		CY_DOT_X_DOT	Table 3-3Table 3-3Table 3-3	O	
79107		CY_DOT_Y_DOT	Table 3-3Table 3-3Table 3-3	O	
80108		CZ_DOT_X	Table 3-3Table 3-3Table 3-3	O	
81109		CZ_DOT_Y	Table 3-3Table 3-3Table 3-3	O	
82110		CZ_DOT_Z	Table 3-3Table 3-3Table 3-3	O	
83111		CZ_DOT_X_DOT	Table 3-3Table 3-3Table 3-3	O	
84112		CZ_DOT_Y_DOT	Table 3-3Table 3-3Table 3-3	O	
85113		CZ_DOT_Z_DOT	Table 3-3Table 3-3Table 3-3	O	
86114	Spacecraft properties	N/A	Table 3-3Table 3-3Table 3-3	O	
87115	Comments	COMMENT	Table 3-3Table 3-3Table 3-3	O	
88116	Mass	MASS	Table	O	

			3-3Table 3-3Table 3-3		
89117	Solar radiation area	SOLAR_RAD_AREA	Table 3-3Table 3-3Table 3-3	O	
90118	Solar radiation coefficient	SOLAR_RAD_COEFF	Table 3-3Table 3-3Table 3-3	O	
91119	Drag area	DRAG_AREA	Table 3-3Table 3-3Table 3-3	O	
92120	Coefficient of drag	DRAG_COEFF	Table 3-3Table 3-3Table 3-3	O	
93121	Radar Cross-Section	RCS[AM30]	Table 3-3Table 3-3Table 3-3	O	
94122	Ballistic coefficient	BALLISTIC_COEFF	Table 3-3Table 3-3Table 3-3	O	
95	Specific Energy Dissipation Rate	SEDR	Table 3-3	O	
96123	Object's acceleration used in OD and propagation	THRUST_ACCELERATION[AM31]	Table 3-3Table 3-3Table 3-3	O	
97124	Orbit determination information	N/A	Table 3-3Table 3-3Table 3-3	O	
98125	Comment	COMMENT	Table 3-3Table 3-3Table 3-3	O	
99126	Interval during which the last accepted observation occurred	TIME_LASTOB_START	Table 3-3Table 3-3Table 3-3	O	
100127		TIME_LASTOB_END	Table 3-3Table 3-3Table	O	

			3-3		
101128	Recommend timespan for OD and actual timespan used	RECOMMENDED_OD_SPAN	Table 3-3Table 3-3Table 3-3	O	
102129		ACTUAL_OD_SPAN	Table 3-3Table 3-3Table 3-3	O	
103130	Total number of observations available and used	OBS_AVAILABLE	Table 3-3Table 3-3Table 3-3	O	
10413		OBS_USED	Table 3-3Table 3-3Table 3-3	O	
10513	Total number of sensor tracks available and used	TRACKS_AVAILABLE	Table 3-3Table 3-3Table 3-3	O	
10613		TRACKS_USED	Table 3-3Table 3-3Table 3-3	O	
10713	Percentage of residuals accepted in OD	RESIDUALS_ACCEPTED	Table 3-3Table 3-3Table 3-3	O	
10813	Weighted RMS of the OD residuals	WEIGHTED_RMS	Table 3-3Table 3-3Table 3-3	O	

ANNEX C

RE-ENTRY DATA MESSAGE EXAMPLES

(INFORMATIVE)

Figure C-1Figure C-1Figure C-1 -and Figure C-2Figure C-2Figure C-2 show examples of RDM messages in KVN. The former only includes mandatory keywords, while the latter uses optional keywords. Figure C-1Figure C-1Figure C-1 presents a very basic RDM, the kind a Member Agency (or any other group) would make available to the interested public (e.g. amateur astronomers wishing to observe a re-entry) for long-term re-entry prediction and containing only the remaining orbital lifetime. Figure C-2Figure C-2Figure C-2 shows a more complex message, containing the state vector, position/velocity covariance matrix, the kind of information two Member Agencies might exchange with each other for short-term re-entry predictions.

```
CCSDS_RDM_VERS                = 1.00.1
CREATION_DATE                 = 20185-04-22T09:31:34.00
ORIGINATOR                    = ESA
MESSAGE_FOR                   = SPACEOBJECT
MESSAGE_ID                    = ESA/201850422-001

OBJECT_NAME                   = SPACEOBJECT
INTERNATIONAL_DESIGNATOR      = 2018-099B
OBJECT_TYPE                   = ROCKET BODY
CONTROLLED_REENTRY            = NO
CENTER_NAME                   = EARTH
TIME_SYSTEM                   = UTC
EPOCH_TZERO                   = 20185-04-22T00:00:00.00

ORBIT_LIFETIME                = 23.0                               [d]
REENTRY_ALTITUDE              = 150.0                              [km]
```

Figure C-1 Sample RDM in KVN using only mandatory keywords

```
CCSDS_RDM_VERS                = 1.00.1
CREATION_DATE                 = 20185-04-22T09:31:34.00
ORIGINATOR                    = ESA
MESSAGE_FOR                   = SPACEOBJECT
MESSAGE_ID                    = ESA/201850422-001

OBJECT_NAME                   = SPACEOBJECT
INTERNATIONAL_DESIGNATOR      = 2018-099B
CATALOG_NAME                  = SATCAT
OBJECT_DESIGNATOR             = 81594
OBJECT_TYPE                   = ROCKET BODY
OBJECT_OWNER                  = ESA
CONTROLLED_REENTRY            = NO
CENTER_NAME                   = EARTH
TIME_SYSTEM                   = UTC
EPOCH_TZERO                   = 2015-04-22T09:00:00.00
REF_FRAME                     = EME2000
GRAVITY_MODEL                 = EGM-96: 36D 36O
ATMOSPHERIC_MODEL             = MSISE-90NRLMSISE-00
```

```
N_BODY_PERTURBATIONS          = MOON
SOLAR_RAD_PRESSURE            = NO
EARTH_TIDES                   = ESR
INTRACK_THRUST                = NO
RE_ENTRY_DISINTEGRATION       = MASS-LOSS & BREAK-UP
PREVIOUS_MESSAGE_ID           = ESTEC/20150421-007
NEXT_MESSAGE_EPOCH            = 2015-04-23T09:00:00

COMMENT Short term re-entry prediction results
ORBIT_LIFETIME                = 5                              [d]
REENTRY_ALTITUDE              = 80.0                           [km]
REENTRY_WINDOW_START          = 20185-04-27T11:45:33
REENTRY_WINDOW_END            = 20185-04-27T22:12:56

PROBABILITY_OF_IMPACT         = 0.0
PROBABILITY_OF_BURN-up        = 1.0

COMMENT State vector at the last OD epoch
EPOCH                         = 20185-04-22T09:30:12
X                             = 4000.000000                    [km]
Y                             = 4000.000000                    [km]
Z                             = 4000.000000                    [km]
X_DOT                         = 7.000000                       [km/s]
Y_DOT                         = 7.000000                       [km/s]
Z_DOT                         = 7.000000                       [km/s]

COMMENT Position/velocity covariance matrix at last OD epoch
COV_REF_FRAME                 = RTN
CX_X                          = 0.10000                        [km**2]
CY_X                          = 0.10000                        [km**2]
CY_Y                          = 0.10000                        [km**2]
CZ_X                          = 0.10000                        [km**2]
CZ_Y                          = 0.10000                        [km**2]
CZ_Z                          = 0.10000                        [km**2]
CX_DOT_X                      = 0.02000                        [km**2/s]
CX_DOT_Y                      = 0.02000                        [km**2/s]
CX_DOT_Z                      = 0.02000                        [km**2/s]
CX_DOT_X_DOT                  = 0.00500                        [km**2/s**2]
CY_DOT_X                      = 0.02000                        [km**2/s]
CY_DOT_Y                      = 0.02000                        [km**2/s]
CY_DOT_Z                      = 0.02000                        [km**2/s]
CY_DOT_X_DOT                  = 0.00600                        [km**2/s**2]
CY_DOT_Y_DOT                  = 0.00600                        [km**2/s**2]
CZ_DOT_X                      = 0.02000                        [km**2/s]
CZ_DOT_Y                      = 0.02000                        [km**2/s]
CZ_DOT_Z                      = 0.02000                        [km**2/s]
CZ_DOT_X_DOT                  = 0.00400                        [km**2/s**2]
CZ_DOT_Y_DOT                  = 0.00400                        [km**2/s**2]
CZ_DOT_Z_DOT                  = 0.00400                        [km**2/s**2]

COMMENT Spacecraft parameters used in OD and re-entry prediction
MASS                          = 3582                           [kg]
DRAG_AREA                     = 23.3565                        [m**2]
DRAG_COEFF                    = 2.2634

COMMENT OD parameters from batch orbit determination
ACTUAL_OD_SPAN                = 3.4554                         [d]
OBS_AVAILABLE                 = 137
OBS_USED                      = 129
TRACKS_AVAILABLE              = 18
TRACKS_USED                   = 17
```

Figure C-2 Sample RDM in KVN using optional keywords

ANNEX D

SECURITY, SANA, AND PATENT CONSIDERATIONS

(INFORMATIVE)

D1 SECURITY CONSIDERATIONS

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

D1.1 SECURITY CONCERNS WITH RESPECT TO THE CCSDS DOCUMENT

D1.1.1 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.

D1.1.2 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.

D1.1.3 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.

D1.1.4 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.

D1.1.5 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.

D1.2 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, (b) unauthorized access to the messages during transmission between exchange partners, and (c) modification of the messages between partners. Protection from unauthorized access during transmission is especially important if the RDM provider and users utilize open ground networks, such as the Internet, to exchange 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.

D1.3 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. The orbit data included in the RDM could allow an unintended recipient to track a re-entering spacecraft, and the ground impact data could allow them to collect any debris.

D2 SANA CONSIDERATIONS

[See CCSDS 313.0-Y-1, *Space Assigned Numbers Authority (SANA)—Role, Responsibilities, Policies, and Procedures* (Yellow Book, Issue 1, July 2011).]

The following RDM related items will be registered with the SANA Operator:

– The RDM XML templates

The following RDM elements should be taken from the appropriate SANA registry:

– The RDM originator should be taken from the SANA Organizations registry.

– The catalog name should be taken from the SANA CDM catalog name registry.

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 PRM at the time of the request. New requests for this registry should be sent to SANA (mailto:info@sanaregistry.org).

D3 PATENT CONSIDERATIONS

The recommendations of this Draft Standard have no patent issues.

ANNEX E

ABBREVIATIONS AND ACRONYMS

(INFORMATIVE)

ASCII	American Standard Code for Information Interchange
CCSDS	Consultative Committee for Space Data Systems
COSPAR	Committee on Space Research
CDM	Conjunction Data Message
ICD	Interface Control Document
ICS	Implementation Conformance Statement
KVN	Keyword Value Notation
NDM	Navigation Data Message
OD	Orbit Determination
OEM	Orbit Ephemeris Message
OPM	Orbit Parameter Message
RDM	Re-entry Data Message
RL	Requirements List
SANA	Space Assigned Numbers Authority
SI	International System of Units
SRP	Solar Radiation Pressure
SSA	Space Situational Awareness
SST	Space Surveillance and Tracking
UN OOSA	United Nations Office for Outer Space Affairs
UTC	Coordinated Universal Time
XML	eXtensible Markup Language

ANNEX F

RATIONALE AND REQUIREMENTS FOR RE-ENTRY DATA MESSAGES

(INFORMATIVE)

This annex presents the rationale and requirements behind the design of the Re-entry Data Message. Table F-1~~Table F-1Table F-1~~ shows the RDM requirements':

– requirement identifier;

– requirement text;

– rationale behind the requirement

– traceability to sections of this Draft Standard

– whether the requirement is mandatory (M) (shall) or optional (O), but desirable (should).

Table F-1 Re-entry Data Message requirements and rationale

#	Requirement	Rationale	Trace	M/O
RDM-0010	The RDM shall be provided in digital form.	To facilitate automatic interaction	section 2.2	M
RDM-0020	The RDM shall be provided in platform-independent data structures.	The CCSDS objective of promoting interoperability is best met by avoiding proprietary data formats.	section 3	M
RDM-0030	The RDM shall provide a means of uniquely identifying each message.	The file name is not sufficient for these purposes and a unique ID facilitates exchange.	Table 3-1~~Table 3-1Table 3-1~~	M
RDM-0040	The RDM shall clearly identify the object predicted to (re)enter.	Any ambiguity in the object reduces the usefulness of the message.	Table 3-2~~Table 3-2Table 3-2~~	M
RDM-0050	The RDM shall provide the remaining orbit lifetime of the object.	This information is needed to determine the timeliness of any needed mitigation measures.	Table 3-3~~Table 3-3Table 3-3~~	M
RDM-0055	The RDM shall specify whether the re-entry is controlled or not.	To determine if/what mitigation measures are needed. Unknown is a valid value as well.	Table 3-2~~Table 3-2Table 3-2~~	M
RDM-0060	The RDM shall provide time measurements in the accepted CCSDS timecode formats.	To fulfill the CCSDS' objective of promoting interoperability and to make them easier to read and understand by humans	Table 3-2~~Table 3-2Table 3-2~~	M
RDM-0070	The RDM shall provide the units used for all the	To promote interoperability and reduce confusion.	Table 3-3~~Table~~	M

	measurements.		3-3Table 3-3	
RDM-0080	The RDM shall allow the exchange of (re-)entry information for objects orbiting and arbitrary body.	Allows the use of the standard for Moon/Mars/Jupiter atmospheric entry besides Earth, further promoting the use of this standard.	Table 3-2Table 3-2Table 3-2	M
RDM-0090	The information in the RDM shall be usable without the need to model any (re-)entry spacecraft dynamics by the receiving entity.	There are several situations in which this is useful, such as remaining orbit lifetime is too short for modeling or the receiving entity is a civil protection agency without those capabilities.	Table 3-3Table 3-3Table 3-3	M
RDM-0100	The RDM should be extensible, without disrupting existing uses	Some users might need other parameters and they should be able to use them with user defined lines specified in an ICD.	Table 3-3Table 3-3Table 3-3	O
RDM-0110	The RDM should be consistent with the other CCSDS messages.	To facilitate use and improve readability.	Table 3-2Table 3-2Table 3-2	O
RDM-0120	The RDM shall allow for the object owner/operator to be specified.	Can help with mitigation measures.	Table 3-2Table 3-2Table 3-2	O
RDM-0130	The RDM shall allow the exchange of one spacecraft position/velocity state vector and associated information.	Allows the message to be self-contained and not rely on ODMs (which might require an ICD).	Table 3-3Table 3-3Table 3-3	O
RDM-0140	The RDM shall allow the exchange of covariance information for the position/velocity state vector.	To allow the uncertainty in the state vector to be exchanged as well.	Table 3-3Table 3-3Table 3-3	O
RDM-0150	The RDM should allow the modeling used to determine the data to be specified.	Necessary if the data is to be verified by the received agency.	Table 3-2Table 3-2Table 3-2	O
RDM-0160	The RDM shall contain information about the previous and next messages for the same spacecraft.	Due to modeling uncertainties it is expected that RDMs for the same spacecraft would be published regularly.	Table 3-2Table 3-2Table 3-2	O
RDM-0170	The RDM shall specify the predicted ground impact location and epoch for the object.	Important information if ground impact is predicted.	Table 3-3Table 3-3Table 3-3	O
RDM-0180	The RDM shall contain the spacecraft parameters used in OD and re-entry prediction.	Allows verification and independent orbit propagation.	Table 3-3Table 3-3Table 3-3	O
RDM-0190	The RDM shall contain information about the observations used in OD.	Allows the receiving agency to ascertain how reliable the data is.	Table 3-3Table 3-3Table 3-3	O

ANNEX G

RDM SUMMARY SHEET

(INFORMATIVE)

This annex is intended to provide a helpful guide (see Table G-2~~Table G-2Table G-2~~) in determining which optional metadata keywords (from Table 3-2~~Table 3-2Table 3-2~~) and data blocks (from Table 3-3~~Table 3-3Table 3-3~~) should be present for each block in the data section (from Table 3-3~~Table 3-3Table 3-3~~).

Table G-2 Relationship between RDM data blocks and optional metadata keywords

Data block	Required metadata optional keywords	Required data blocks
long-term atmospheric re-entry	required: none	required: none (only mandatory keywords)
	recommended: GRAVITY_MODEL ATMPSPHERIC_MODEL SOLAR_FLUX_PREDICTION	recommended: spacecraft parameters
short-term atmospheric re-entry~~ and ground impact data~~	~~none~~ required: none ~~recommended:~~ ~~GRAVITY_MODEL~~ ~~ATMPSPHERIC_MODEL~~ ~~N_BODY_PERTURBATIONS~~	required: none
	recommended: GRAVITY_MODEL ATMPSPHERIC_MODEL SOLAR_FLUX_PREDICTION N_BODY_PERTURBATIONS	recommended: NOMINAL_REENTRY_EPOCH REENTRY_WINDOW_START REENTRY_WINDOW_END
ground impact data	required: RE_ENTRY_DISINTEGRATION	required: ground impact and burn-up data
	recommended: same as short-term atmospheric re-entry, and: IMPACT_LOCATION_UNCERTAINTY	recommended: same as short-term atmospheric re-entry
object state vector	REF_FRAME	none
position/velocity covariance matrix	none	object state vector
spacecraft parameters	none	none
orbit determination parameters	GRAVITY_MODEL ATMOSPHERIC_MODEL SOLAR_FLUX_PREDICTION N_BODY_PERTURBATIONS SOLAR_RAD_PRESSURE[AM32] EARTH_TIDES	spacecraft parameters

	INTRACK_THRUST	

ANNEX H

RE-ENTRY INFORMATION DESCRIPTION

(INFORMATIVE)

H1 RE-ENTRY PREDICTION

As of April 2017, slightly more than 24000, or 56 % of all catalogued objects, have decayed and re-entered the atmosphere and several more re-enter every month. Re-entries can pose risk to ground based infrastructure and population, either due to the large mass of the spacecraft (e.g. Mir, Skylab or the Salyut space stations), or due to hazardous materials (e.g. Cosmos 954).

Predicting and simulating re-entries covers:

– long and medium term re-entry predictions (several years to a few weeks before re-entry);

– short term re-entry predictions (last days/weeks before re-entry; altitude below 200 km);

– break-up and survival (out of scope of the RDM standard);

– ground impact and on-ground risk (~~mostly~~ partially out of scope of the RDM standard, due to limitations in break-up and survival estimations).

The following subsections describe re-entry simulations and modeling for the Earth, but similar considerations apply to other celestial bodies. For more details, please see chapter 9 of [I2], which describes re-entry simulations and how they applied to the Mir re-entry. Details on ESA's contributions to IADC (Inter-Agency Debris Coordination committee) re-entry campaigns can be found in [I3] and [I4].

The estimation of the orbit lifetime is covered by an ISO standard, 27852 [I5]. The standard focuses on long- and medium-term predictions and contains useful information to determine which mathematical models (e.g. gravity and atmospheric models) are appropriate in most situations. ISO is also working on a standard on atmospheric modelling, but as of the writing of this document, it has not been completed.

H1.1 LONG AND MEDIUM TERM RE-ENTRY PREDICTIONS

In the context of re-entry predictions, long and medium term means several years to a few weeks of orbital lifetime remaining. The current typical approach for these simulations is to use singly averaged perturbation equations integrated over a time step between 0.1 and 5 orbits. The perturbations accounted for by existing modeling software are: non-spherical Earth gravitation potential, dynamic oblate Earth atmosphere, luni-solar gravity perturbations, and solar radiation pressure combined with an~~d~~ oblate cylindrical Earth shadow. The end goal of these simulations is to estimate the remaining orbital lifetime.

Long and medium term re-entry predictions require simulating the decrease in the orbit's semi-major axis. For nearly circular orbits the rate of change of the semi-major axis w.r.t. time can be approximated by:

$$\frac{da}{dt} \approx -C_D \frac{A}{m} \rho a v_a$$

where v_a is the velocity with respect to the atmosphere. While v_a and the atmospheric density can be estimated using Earth atmosphere models and orbit dynamics, the ballistic coefficient cannot. Uncontrolled objects tumble, so their angle of attack, and hence aerodynamic cross-section and drag coefficient are not constant. One approach to this issue is to retro-fit the simulated semi-major axis time history over observed values over a period of time by adjusting the ballistic parameter.

Besides the ballistic parameter, other sources of uncertainty in the results are atmospheric density modeling (both the models themselves and unexpected space weather events) and the orbit state. A standard deviation of ±20 % for the remaining orbital lifetime is a good estimate for all the above in nominal conditions. More complex uncertainty modeling is also possible, e.g. accounting for orbit covariance and ballistic coefficient fit residuals.

H1.2 SHORT-TERM RE-ENTRY PREDICTIONS AND IMPACT

When the orbit altitude drops below ~200 km, the assumptions used in long term predictions (perturbation effects are small, no cross-coupling effects) no longer hold and more accurate modeling is needed. A numerical solution to the perturbed Newton equations is used, typically accounting for: Earth gravity, luni-solar attraction, solar radiation pressure with umbra and penumbra transits, and atmospheric drag.

Below ~120 km atmospheric drag becomes the dominating force, and properly accounting for the change in drag coefficient between free-molecular flow, transitional, and continuum conditions is critical. For example, the drag coefficient of the Mir space station decreased from 2.21 in the free-molecular flow regime to 1.18 in the continuum sub-sonic regime. Atmospheric drag steepens the flight path, making the orbit more eccentric. At some point the re-entering object will achieve equilibrium free fall, leading to an impact velocity:

$$v_{impact} \approx \sqrt{\frac{2mg_0}{c_D A \rho_0}}$$

Dispersion in the impact location of a re-entry survivor object is driven by uncertainties in the area-to-mass ratio, aerodynamic coefficients (drag, lift, and side-force), air density, and initial orbit and attitude state and it is given in the along- and cross-track directions. Monte Carlo simulations are needed to determine a geographic probability distribution. The probability density function in a given area can be computed as the fraction of impact in said area over total number of simulations. The PDF in the along-track direction is distorted 2D Gaussian, further complicating matters.

Simpler approaches are sometimes used. Analytical formulae allow the computation of dispersion due to aerodynamic forces, based on lift, drag, and side-force coefficients and the ratio of lift and side-force, but they can be difficult to use and do not account for the main sources of uncertainty. An alternative is to assume a standard Gaussian distribution, compute the along-track dispersion by varying the aerodynamic drag term (ρ·B) and use an empirical value for the cross-track dispersion (e.g. a 1-σ value of 20 km).

H1.3 SURVIVAL AND BREAK-UP DURING RE-ENTRY

During re-entry aerodynamic braking and aerothermal heating can lead to:

- disintegration – the object breaks up into multiple fragments or losses external parts (e.g. solar panels, thermal shielding);
- mass loss – heating leads to melting and ablative mass loss;
- total demise – the object burns up completely and there is no impact.

The heat flux due to aerothermal heating depends on the flow conditions (free molecular, transitional, continuum super-, and subsonic), hence on object velocity and atmospheric density. How to estimate this flux is beyond the scope of this informative annex. The heat flux into the object leads to an increase in internal temperature, melting (once temperature is high enough), and radiating heat away from the object. Assuming a uniform composition leads to the following equations:

$$\dot{Q} = \rho c_p V \dot{T} + \epsilon \sigma A T^4, \qquad T < T_m$$

$$\dot{Q} = -\rho h_m \dot{V} + \epsilon \sigma A T^4, \qquad T = T_m$$

Until the object's surface reaches the melting temperature, the heat flux in is equal to the heat absorbed by increasing internal temperature and the heat radiated away. Once the surface reaches the melting temperature, the heat flux is equal to the heat lost by mass ablation and the heat radiated away. This leads to two ways in which an object can survive re-entry: absorb the re-entry heat without reaching the melting temperature or radiate the heat away efficiently. If the analysis is restricted to solid metallic spheres, very small objects (smaller than ~1 cm), can do the latter, while very large objects (larger than ~ 10 cm) can do the former. Object in between (e.g. most nuts and bolts used in spacecraft assembly) will suffer total demise.

Simulating disintegration and mass loss for complex object is multi-disciplinary process, since spacecraft have complex shapes and contain a multitude of materials. The SCARAB tool, for example, can simulate it by dividing the spacecraft into basic elements, each with consistent material properties and each element into multiple voxels (volume elements). The simulation accounts for the forces acting on each element/voxel (as in H1.2) and computes heat fluxes, temperatures, and normal and shear stresses for a thermal and structural analysis. This determines break-ups (when stresses exceed the ultimate tensile or shear stress in the structure) and ablative mass loss.

Exchanging the information needed to accurately replicate these types of simulations is beyond the scope of the RDM. Furthermore, the tools needed to replicate the results are not widely available, which restricts usefulness. Break-ups during re-entry tend to happen at around 80 km altitude, when the combined aerodynamic and thermal loads are highest, but without knowing the structure of the object nothing more can be said.

H2 ATMOSPHERIC RE-ENTRY AND GROUND IMPACT DATA KEYWORDS

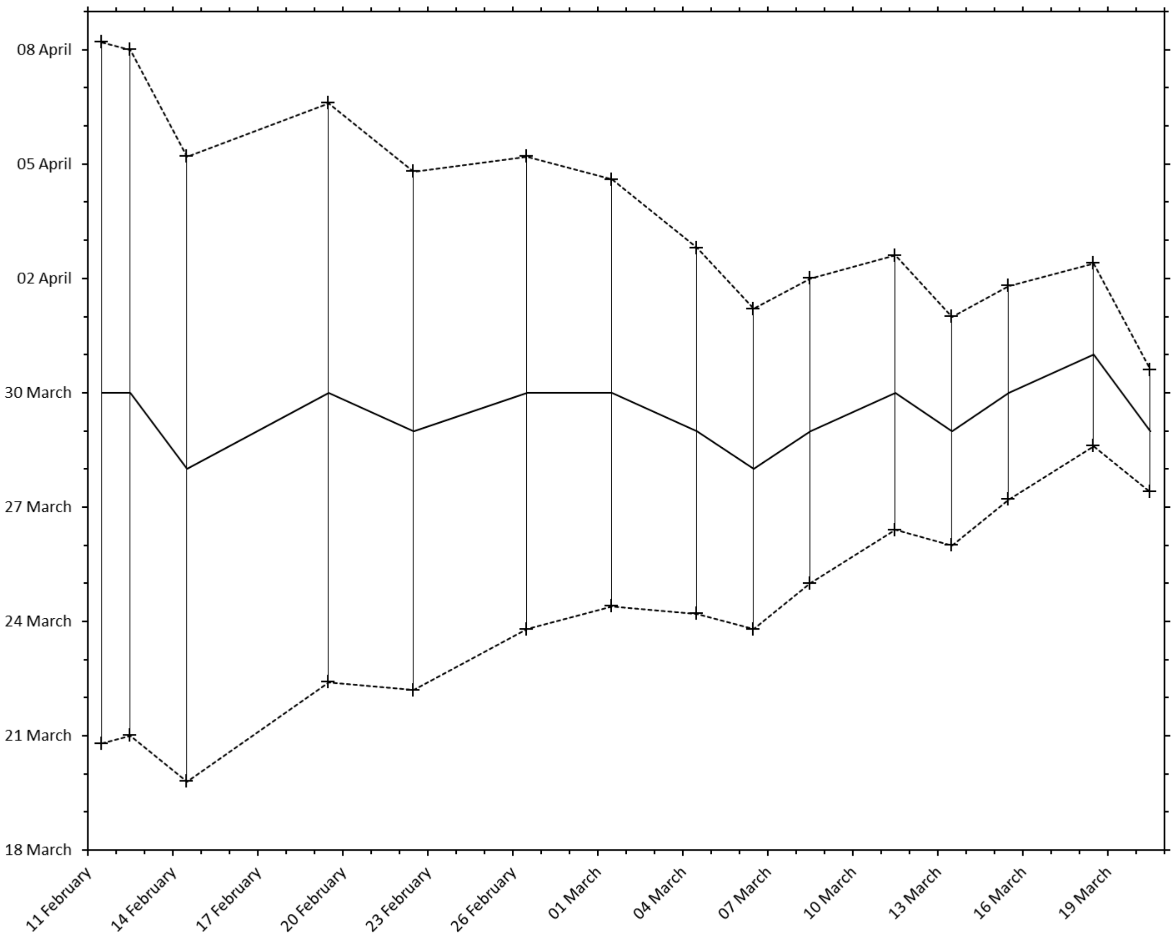
ORBIT_LIFETIME: The remaining time in orbit of the object, in days, from the EPOCH_TZERO keyword in the metadata. This is intended to be a coarse estimation, useful for long and medium term (more than a few days) re-entry prediction. The orbit lifetime is considered to end when the altitude permanently drops below the REENTRY_ALTITUDE. This keyword has two roles:

– Specify whether long/medium or short term re-entry simulations were used for the object (e.g. a high value means a long term simulation was performed).

– Give an estimate of the remaining orbit lifetime, especially for long term predictions, with appropriate accuracy.

LIFETIME_DISPERSION: The uncertainty time window associated with the ORBIT_LIFETIME keyword and meant for long term re-entry predictions. A value of 20 % provides an acceptable estimate for nominal conditions, accounting for uncertainties in the ballistic coefficient, atmospheric density, and orbit parameters.

Figure G-3~~Figure G-3~~ shows the type of information that can be generated from medium-term re-entry prediction RDMs. It assumes a new RDM containing an updated orbital lifetime prediction and uncertainty (fixed at 20 %) is issues every couple of days. The predicted re-entry date (orbit lifetime + epoch t_zero) is plotted against the date at which the simulation was run (creation date), with the 20 % dispersion plotted as well.



~~Figure G-3 shows the type of information that can be generated from medium-term re-entry prediction RDMs. It assumes a new RDM containing an updated orbital lifetime prediction and uncertainty (fixed at 20 %) is issues every couple of days. The predicted re-entry date (orbit lifetime + epoch t_zero) is plotted against the date at which the simulation was run (creation date), with the 20 % dispersion plotted as well.~~

REENTRY_ALTITUDE: The altitude at which the orbit lifetime ends and at which re-entry is defined. Depending on the particular re-entry event, different values can be specified, e.g. 150 km for “object captured by the Earth’s atmosphere”, 70 km for “object likely to break-up at this altitude”, or simply the altitude limit at which the re-entry simulation stops.

NOMINAL_REENTRY_EPOCH: Predicted re-entry epoch, providing much greater precision for short term (last couple of days before re-entry, when altitude is below 200 km) re-entry predictions.

REENTRY_WINDOW_START and **REENTRY_WINDOW_END**: Allow the RDM originator to specify a re-entry time window, which does not have to be symmetric around the nominal re-entry epoch. They can account for uncertainties in the modeling (atmospheric density, drag coefficient, attitude influence) or for under/over performance of thrusting maneuvers in a controlled re-entry.

PROBABILITY_OF_IMPACT: Probability of the object or **any** resulting fragments impacting the Earth (land **or** sea). This is the first step in assessing any casualty probability, in conjunction with population density mapping.

PROBABILITY_OF_BURN-UP: Total demise probability for the object and/or any resulting fragments.

PROBABILITY_OF_BREAK-UP: Probability of fragments being generated during re-entry, both "shedding" of parts (e.g. solar panels, heat shields) and fragmentation of the main structure.

PROBABILITY_OF_LAND_IMPACT: Probability of the object or **any** resulting fragments impacting solid land. This is the first step in assessing any casualty probability, in conjunction with population density mapping.

NOMINAL_IMPACT_EPOCH: The nominal (predicted) epoch at which the object hits the surface of the Earth (either solid land or ocean).

IMPACT_WINDOW_START and **IMPACT_WINDOW_END**: The same as REENTRY_WINDOW_START and _END, but for the impact epoch.

IMPACT_REF_FRAME, **NOMINAL_IMPACT_LON**, **_LAT**, **_ALT**: Allow the specification of the nominal (predicted) impact location in geodetic coordinates.

IMPACT_n_CONFIDENCE, IMPACT_nS_START_LON, _STOP, _LAT, IMPACT_n_START_LAT, IMPACT_n_STOP_LON, IMPACT_n_STOP_LAT, IMPACT_nS_CROSS_TRCK: Uncertainties in the ground impact location are expressed in the along-track and cross-track directions, which means the (predicted) ground track needs to be known. Since the probability distribution is skewed, the method is chosen to deal with these two issues is:

– Give the coordinates corresponding to the maximum probability, with the NOMINAL_IMPACT_LON and _LAT keywords.

– Define up to three confidence intervals.

– Give the coordinates of the two points on the ground track corresponding to the start and end of the 1/2/3-sigma(up to) three confidence intervals.

– Depending on how many pairs of points are given, a polynomial interpolation can be performed, so a good estimate of the ground track is providedAs long as at least three points are provided the ground track can be estimated as one or more segments of a great circle..

– The cross-track confidence intervals (in km) can be used to determine the swaths of impact probability, which can then be used together with population density mapping to determine the casualty probability.

The ground impact location and uncertainties are supposed to cover all eventual re-entry fragments (fragments generated during re-entry, not before). For example, iIf the re-entry data is obtained through Monte Carlo simulations, NOMINAL_IMPACT_LON, _LAT would correspond to the bin with the most impacts,, the firstthe swath would cover IMPACT_1_CONFIDENCE1-sigma swath would cover roughly 47 % (for a rectangle, less for an ellipse) of the impacts, and so on. If analytical formulae are used for the 1-sigma confidence interval, IMPACT_1_CONFIDENCE should be 47 % (for rectangular, rather than elliptical areas), the IMPACT_1_START/STOP_LAT/LON values can be determined from the formulae and the ground track, and IMPACT_1_CROSS_TRACK from the formula used.

H3 ORBIT DETERMINATION KEYWORDS

To promote consistency and ease implementation, the orbit determination keywords are the same as in the Conjunction Data Message. These keywords are present to give the consumer of the message an idea of the quality of the data provided and when was the re-entering object last observed.

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

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

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

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

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

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

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

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

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

WIGHTED_RMS:

$$Weighted\ RMS = \sqrt{\frac{\sum_{i=1}^{N} w_i \left(y_i - y_{i,estimated}\right)}{N}}$$

Where:

y_i is the ith observation;

$y_{i,estimated}$ is the estimated value (from the resulting orbit) of y_i;

w_i is the weighting of the observation; and

N is the total number of observations.

This is a value that can generally identify the quality of the most recent orbit update, and is used by the analyst in evaluating the OD process.

ANNEX I

INFORMATIVE REFERENCES

(INFORMATIVE)

[I1] *Navigation data – Definitions and Conventions*. Issue 3. Informational report for Space Data Systems Standards (Green Book), CCSDS 500.0-G-3. Washington, D.C.: CCSDS, May 2010

[I2] Klinkrad, H. *Space debris*. John Wiley & Sons, Ltd, 2010.

[I3] Virgili, B.B., Flohrer, T., Lemmens, S. and Krag, H., 2014. *GOCE Re-entry Campaign*. In Proceedings of the fifth international GOCE user workshop.

[I4] Virgili, B.B., Lemmens, S., Siminski, J. and Funke, Q., 2017. Practicalities of re-entry Predictions – the Vega-01 AVUM case. In Proceedings of the 7th European Conference on Space Debris.

[I5] ISO 27852:2016, *Space Systems – Determining Orbit Lifetime*. International Organization for Standardization, Geneva, Switzerland (2016).