The Consultative Committee for Space Data Systems

RE-ENTRY DATA MESSAGE TEST PLAN/REPORT

DRAFT CCSDS RECORD

CCSDS 508.2-Y-1.4

DRAFT YELLOW BOOK

February 2019

FOREWORD

[Foreword text specific to this document goes here. The text below is boilerplate.]

Through the process of normal evolution, it is expected that expansion, deletion, or modification of this document may occur. This document is therefore subject to CCSDS document management and change control procedures, which are defined in the *Procedures Manual for the Consultative Committee for Space Data Systems*. 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.

DOCUMENT CONTROL

Document	Title and Issue	Date	Status
CCSDS 508.2-Y-1	Re-entry Data Message prototyping test plan/report, Draft CCSDS Record, Issue 1	April 2018	Initial draft
CCSDS 508.2-Y-1.1	Re-entry Data Message prototyping test plan/report, Draft CCSDS Record, Issue 1.1	November 2018	pre-prototyping draft
CCSDS 508.2-Y-1.3	Re-entry Data Message prototyping test plan/report, Draft CCSDS Record, Issue 1.3	December 2018	post-prototyping draft
CCSDS 508.2-Y-1.4	Re-entry Data Message prototyping test plan/report, Draft CCSDS Record, Issue 1.4	February 2019	final draft

CONTENTS

1 INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this document is to describe the prototyping conducted for the CCSDS Re-entry Data Message (RDM), specified in reference [1]. Both the prototyping plan and the report are contained in this document.

The scope of this document is test plans and test reports for version 1 of the CCSDS Re-entry Data Message.

1.2 APPLICABILITY

The document applies to the entirety of the Re-entry Data Message, version 1, as specified in reference [1].

1.3 DOCUMENT STRUCTURE

Section 2 contains the promotion criteria from a Red Book to a Blue Book.

Section 3 presents the conclusions and recommendations of this prototyping campaign.

Section 4 presents the test plan followed by the RDM prototyping campaign.

Section 5 contains the results of the RDM prototyping campaign.

Annex A lists the distribution of RDM keywords between the prototyping tests.

Annex B contains the test plan report template.

Annex C lists the acronyms used in this document.

Annex D contains the OPMs used an input f he re-entry simulations in the prototyping campaign.

Annex E contains the RDMs generated during the prototyping campaign.

1.4 REFERENCES

The following publications are referenced in this document. At the time of publication, the editions indicated were valid. All publications are subject to revision, and users of this document 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] *Re-entry Data Message*. Recommendation for Space Data System Standards (Red

Book), CCSDS 508.1-R-1.3. Washington, D.C.: CCSDS, October 2018.

[2] *Organization and Processes for the Consultative Committee for Space Data Systems*. Issue 4. Report Concerning Space Data Systems Standards (Yellow Book). CCSDS A02.1-Y-4. Washington, D.C.: CCSDS, April 2014.

2 BLUE BOOK PROMOTION CRITERIA

The CCSDS Procedures Manual [2] states that for a Recommendation to become a Blue Book, the standard must be tested in an operational manner. Reference [2] contains the following requirements for an implementation exercise:

"At least two independent and interoperable prototypes or implementations must have been developed and demonstrated in an operationally relevant environment, either real or simulated, unless a waiver of the interoperability testing requirement has been approved:"

This document will outline the Navigation Working Group's approach to meeting this requirement for the RDM.

3 TENTATIVE CONCLUSIONS AND RECOMMENDATION

Three RDM Prototypes were developed at two CCSDS member agencies: ESA/ESOC (2 prototypes)and DLR/GSOC. A suite of five test cases covered the interagency exchange of re-entry prediction results (long-term, short-term, ground impact location, ground impact location uncertainty, and KVN to XML conversion). The re-entry data was generated by the re-entry prediction systems operated by ESA/ESOC and DLR/GSOC using their normal operational procedures and processes. An orbit based on the SATCAT was used for the long-term prediction test case, while orbits determined by ESA/ESOC from real tracking data were used for the short-term, ground impact, and ground impact uncertainty cases. Based on this operational diversity and the positive test results, the RDM prototyping effort successfully addresses the Blue Book promotion criteria. It is thus proposed to approve the Re-entry Data Message as a CCSDS Recommended Standard.

4 RDM TEST PLAN

4.1 RDM TEST PLAN OVERVIEW

The testing approach for the RDM will contain the following cases:

- Long term re-entry prediction
- Short term re-entry prediction
- Ground impact (no uncertainty)
- Ground impact (with impact location uncertainty)
- XML Re-entry Data Message

The following table lists the test number, spacecraft, agencies involved (including the direction of the data flow), which test case is being covered, and tentative schedule.

Test#	Spacecraft	Agencies, Direction	Test Case	Schedule
1	multiple spacecraft	ESA/ESOC internal	KVN-XML conversion	Late 2018
2	AVUM R/B (2012-006K)	ESA/ESOC internal (2 prototypes) DLR/GSOC=>ESA/ESOC	Long term prediction	Late 2018
3	AVUM R/B (2012-006K)	ESA/ESOC internal (2 prototypes) DLR/GSOC=>ESA/ESOC	Short term prediction	Late 2018 – Early 2019
4	AVUM R/B (2012-006K)	ESA/ESOC internal (2 prototypes) DLR/GSOC=>ESA/ESOC	Ground impact location (no uncertainty)	Late 2018 – Early 2019
5	AVUM R/B (2012-006K)	ESA/ESOC internal (2 prototypes) DLR/GSOC=>ESA/ESOC	Ground impact location (with impact location uncertainty)	Late 2018 – Early 2019

All tests described in this document will be conducted to meet the CCSDS prototyping requirements. The results of these tests are presented in section 5. The distribution of mandatory and optional keywords between the test cases can be found in annex A.

4.2 TEST PLAN DETAILS

4.2.1 TEST CASE #1: KVN-XML CONVERSION

This is an internal test case and will not involve message exchange between agencies. ESA/ESOC will generate a set of KVN RDM for multiple dummy re-entries. The RDMs will contain all the mandatory keywords, plus varying optional keywords by message, and user defined keywords. ESA will process the RDM with its RDM tool and convert it from KVN to

XML to KVN to XML to KVN. The XML RDMs will be checked for compliance against the RDM XML schema with Liquid XML. The two sets of KVN RDMs generated by the ESOC prototype tool will be compared to see if they are identical as well. The Test Data Sheet will be supplied by ESA/ESOC.

Expected results

The conversions from KVN to XML and from XML to KVN shall be completed without errors. The XML RDMs will comply with the schema. The KVN RDMs produced by the tool and the originals shall contain the same data (allowing for formatting differences). The KVN RDMs generated by the tool at different steps shall be identical. Assuming these criteria are met, the test will be considered successful. In the event of discrepancies, troubleshooting will be conducted by ESA/ESOC.

4.2.2 TEST CASE #2: LONG TERM PREDICTION

For this test case, a reference OPM for the 2012-00K AVUM rocket body will be generated, based on its TLE around 1 year before re-entry. This OPM will be ingested by both the ESA/ESOC and DLR/GSOC re-entry prediction systems and both will generate one RDM containing the remaining orbit lifetime, re-entry altitude, orbit lifetime window start and end, one state vector, and object properties(a full list of expected keywords in these RDMs can be found in column #2 in the table in annex A). The contents of the two RDMs (one generated by ESA/ESOC, one by DLR/GSOC) will be compared. ESA/ESOC will generate RDMs in XML and DLR/GSOC in KVN. The Test Data Sheet will be provided by ESA/ESOC.

As both the ESA/ESOC and DLR/GSOC re-entry prediction systems write the state vector used as input to the output RDM, re-running the tests with the other agency's RDM as input will not be performed. The KVN-XML converter will be used to read the files and check that they comply with the standard. The converter does not share any code with the ESA/ESOC re-entry prediction system or its RDM generating components.

Expected results

It is anticipated that the two RDMs produced will contain remaining orbital lifetimes within each other's confidence intervals and that both will be read/converted without issues. Assuming these criteria are met, the test will be considered successful. In the event of discrepancies, troubleshooting will be conducted by the participating agencies.

4.2.3 TEST CASE #3: SHORT TERM PREDICTION

For this test case, a reference OPM and/or OEM for the 2012-00K AVUM rocket body will be generated by ESA/ESOC, based on available tracking data in the last few weeks/days before re-entry. The OPM/OEM will be ingested by both the ESA/ESOC and DLR/GSOC re-entry prediction system and both will generate one RDM containing the predicted re-entry epoch, re-entry window start/end, one state vector, and object properties (a full list of expected keywords in these RDMs can be found in column #3 in the table in annex A). The contents of the two RDMs (one generated by ESA/ESOC, one by DLR/GSOC) will be

compared. ESA/ESOC will generate RDMs in XML and DLR/GSOC in KVN. The Test Data Sheet will be provided by ESA/ESOC.

As both the ESA/ESOC and DLR/GSOC re-entry prediction systems write the state vector used as input to the output RDM, re-running the tests with the other agency's RDM will not be performed. The KVN-XML converter will be used to read the files and check that they comply with the standard. The converter does not share any code with the ESA/ESOC re-entry prediction system or its RDM generating components.

Expected results

It is anticipated that the two RDMs produced will contain predicted re-entry epochs within each other's re-entry windows and that both will be read/converted without issues.. Assuming these criteria are met, the test will be considered successful. In the event of discrepancies, troubleshooting will be conducted by the participating agencies.

4.2.4 TEST CASE #4: GROUND IMPACT LOCATION

For this test case, a reference OPM for the 2012-00K AVUM rocket body will be generated by ESA/ESOC, based on available tracking data in the last few weeks/days before re-entry. The OPM will be ingested by both the ESA/ESOC and DLR/GSOC re-entry prediction system and both will generate one RDM containing the predicted ground impact location (a full list of expected keywords in these RDMs can be found in column #4 in the table in annex A). The contents of the two RDMs (one generated by ESA/ESOC, one by DLR/GSOC) will be compared and the location plotted. ESA/ESOC will generate RDMs in XML and DLR/GSOC in KVN. The KVN-XML converter will be used to read the files and check that they comply with the standard. The converter does not share any code with the ESA/ESOC re-entry prediction system or its RDM generating components. The Test Data Sheet will be provided by ESA/ESOC.

Expected results

It is anticipated that both RDM will be read/converted without issues and the ground impact location can be plotted. In the event of discrepancies, troubleshooting will be conducted by the participating agencies.

4.2.5 TEST CASE #5: GROUND IMPACT LOCATION UNCERTAINTY

For this test case, a reference OPM for the 2012-00K AVUM rocket body will be generated by ESA/ESOC, based on available tracking data in the last few weeks/days before re-entry. The OPM will be ingested by both the ESA/ESOC and DLR/GSOC re-entry prediction system and both will generate one RDM containing the predicted ground impact location and 3 confidence intervals (a full list of expected keywords in these RDMs can be found in column #5 in the table in annex A). The contents of the two RDMs (one generated by ESA/ESOC, one by DLR/GSOC) will be compared. ESA/ESOC will generate RDMs in XML and DLR/GSOC in KVN. The KVN-XML converter will be used to read the files and check that they comply with the standard. The converter does not share any code with the

ESA/ESOC re-entry prediction system or its RDM generating components. The Test Data Sheet will be provided by ESA/ESOC.

Expected results

It is anticipated that both RDM will be read/converted without issues and the ground impact location and uncertainties can be plotted. In the event of discrepancies, troubleshooting will be conducted by the participating agencies.

5 RDM TEST REPORT

5.1 TEST RESULTS OVERVIEW

Engineers at participating agencies will prepare test data sheets as noted in the Test Plan Details above, and send them to the Navigation Working Group via email.

The Test Report Details will be found in the following sections of this document. A summary of the test process and the recommendation of the Navigation Working Group may be found in Section 3 of the report. The report will be posted to the Navigation Working Group Common Working Environment (CWE) on the CCSDS web page at http://cwe.ccsds.org . The report will be submitted to the CCSDS Engineering Steering Group (CESG) and CCSDS Management Council (CMC), along with results of the Agency Reviews. At that time, a formal request will be submitted to the CMC for progression of the RDM to CCSDS Blue Book status.

Annex B contains a format for the test data sheets that will be used to report the results of individual tests.

Annex D contains the OPM files used as input for the simulations.

Annex E contains all the RDMs produced for test cases #2 to #5 (both KVN and XML).

5.2 TEST RESULTS

5.2.1 TEST CASE #1: KVN TO XML CONVERSION

1	Test Case Number:	1
2	Report Date:	1-Nov-2018
3	Program Under Test:	Re-entry Data Message V1 (RDM) Prototype
4	Agencies Participating in this Test Case:	ESA/ESOC: Space Debris Office
5	Agency Responsible for Prototype:	RDM Generation: ESA/ESOC RDM Processing: ESA/ESOC
6	Prototype Version # (if applicable):	RDM Generation: v0.3 RDM Processing: v0.3
7	Test Engineer:	RDM Generation: Alexandru Mancas RDM Processing: Alexandru Mancas
8	Spacecraft:	multiple dummy spacecraft
9	Re-entry keywords tested:	all keywords tested in 7 files: `reference_kvn_all_keywords.rdm`: all keywords, including 3 user defined keywords `reference_kvn_all_keywords_no_blanks.rdm`: all keywords, including 3 user defined keywords `reference_kvn_covariance.rdm`: mandatory keywords + covariance-related keywords `reference_kvn_ground_impact_small.rdm`: mandatory keywords + 2 ground impact keywords `reference_kvn_minimal.rdm`: only mandatory keywords `reference_kvn_spacecraft.rdm`: mandatory keywords + object physical properties keywords `reference_kvn_state_vector.rdm`: mandatory keywords + state vector keywords `reference_kvn_state_vector_covariance.rdm`: mandatory keywords + state vector keywords + covariance keywords
10	Values for the keywords of interest:	n/a
11	Variances from Expected Results:	none
12	Results (Pass, Partial Pass, Fail):	Pass
13	Comments:	ESA/ESOC developed a converter between XML and KVN RDM in FORTRAN. The tool reads multiple RDM files in either XML or KVN and writes one output RDM in KVN on XML respectively for each RDM read. No changes are made to the contents of the input messages, but the 'default' formatting is imposed on all output files. The tool successfully read KVN RDMs written by hand or by the tool and XML RDMs written by the tool. All the XML RDMs written were checked against the schema with Liquid XML and were compliant. This test case included all keywords, including user defined keywords.

5.2.2 TEST CASE #2: LONG TERM PREDICTION

1	Test Case Number:	2
2	Report Date:	18-Feb-2019
3	Program Under Test:	Re-entry Data Message V1 (RDM) Prototype
4	Agencies Participating in this Test Case:	ESA/ESOC DLR/GSOC
5	Agency Responsible for Prototype:	RDM Generation: ESA/ESOC, DLR/GSOC RDM Processing: ESA/ESOC
6	Prototype Version # (if applicable):	RDM Generation: n/a RDM Processing: n/a
7	Test Engineer:	RDM Generation: Alexandru Mancas, Michael Kirschner RDM Processing: Alexandru Mancas
8	Spacecraft:	AVUM R/B (2012-006 K)
9	Re-entry keywords tested:	ORBIT_LIFETIME, REENTRY_ALTITUDE, ORBIT_LIFETIME_WINDOW_START, ORBIT_LIFETIME_WINDOW_END, state vector block, covariance block, object properties block
10	Values for the keywords of interest:	see table later in section 5.2.2
11	Variances from Expected Results:	The ORBIT_LIFETIME_CONFIDENCE values did not appear to be correct. After discussions with the other engineers involved in the prototyping, it was determined the name of the keyword does not match the description that well, and that the description is not clear enough. The value is supposed to be a confidence level, but was interpreted during prototype implementation as a confidence interval.
12	Results (Pass, Partial Pass, Fail):	Pass
13	Comments:	The orbit lifetime of each message is within the lifetime window of the other message. Both re-entry prediction systems write the state vector that was used as input to the output RDM. Since the state vectors are (almost) the same (there is a 20 ms difference between them), there was no need to re-run the simulation using the other agency's RDM as input.

The RDM files produced by ESA/ESOC and DLR/GSOC contained the relevant keywords and values shown the table below.

keyword	**ESA/ESOC value**	**DLR/GSOC value**
header		
CCSDS_RDM_VERS	0.1	1.0
COMMENT	Test-case#2: long term prediction	—
CREATION_DATE	2015-11-02T11:24:20.000000	2018-11-30T15:30:54.272
ORIGINATOR	ESA-SDO	GSOC
MESSAGE_ID	2012-006K_20181108112420_ESA-	GSOC/2018-11-30T15:30:54UTC

	SDO_5343	
metadata		
COMMENT	—	—
OBJECT_NAME	AVUM (Vega)	AVUM R/B
INTERNATIONAL_DESIGNATOR	2012-006K	2012-006K
CATALOG_NAME	SATCAT	SATCAT
OBJECT_DESIGNATOR	38086	12345
OBJECT_TYPE	ROCKET BODY	UNKNOWN
CONTROLLED_REENTRY	NO	NO
CENTER_NAME	EARTH	EARTH
TIME_SYSTEM	UTC	UTC
EPOCH_TZERO	2015-11-01T20:05:40.020000	2015-11-01T20:05:40.000
REF_FRAME	EME2000	TOD
GRAVITY_MODEL	GEM-T1: 8D 8O	GGM01S: 08D 08O
ATMOSPHERIC_MODEL	DTM-13	JACCHIA-GILL
SOLAR_FLUX_PREDICTION	ESA SOLMAG	PREDICTED: MLLRT
N_BODY_PERTURBATIONS	MOON, SUN	SUN, MOON
SOLAR_RAD_PRESSURE	CYLINDRICAL	CANNONBALL
EARTH_TIDES	NO	MCCARTHY1996
INTRACK_THRUST	NO	NO
DRAG_PARAMETERS_SOURCE	CD FITTING WITH FOCUS2	OD
DRAG_PARAMETERS_ALTITUDE	244.72	491.8595
REENTRY_UNCERTAINTY_METHOD	EMPIRICAL	EMPIRICAL
REENTRY_DISINTEGRATION	NONE	NONE
data		
atmospheric re-entry		
COMMENT	Prediction 1 year before re-entry	—
ORBIT_LIFETIME	366.677083333333	385.4993
REENTRY_ALTITUDE	78.417	120.0000
ORBIT_LIFETIME_WINDOW_START	293.341666666667	308.3994
ORBIT_LIFETIME_WINDOW_END	440.0125	462.5992
ORBIT_LIFETIME_CONFIDENCE	20.0000	20.0
state vector		
COMMENT	epoch of latest TLE (same as epoch_tzero)	—
EPOCH	2015-11-01T20:05:40.020000	2015-11-01T20:05:40.000
X	-5915.23575248928	-5925.7575000000
Y	2990.05003661959	2969.1288510000
Z	-0.00415629948475475	-9.2273870000
X_DOT	-1.22748377325454	-1.2300694874
Y_DOT	-2.47530416266088	-2.4793156054
Z_DOT	7.38675878149886	7.3849831139
object properties		

COMMENT	Cr is fixed, Cd includes all effects	—
WET_MASS	960.0	960.0
DRY_MASS	410.0	—
SOLAR_RAD_AREA	1.0	1.0
SOLAR_RAD_COEFF	1.2	1.2
DRAG_AREA	3.9545	3.95
DRAG_COEFF	2.4108	2.4108
BALLISTIC_COEFF	0.009931	—

5.2.3 TEST CASE #3: SHORT TERM PREDICTION

1	Test Case Number:	3
2	Report Date:	18-Feb-2019
3	Program Under Test:	Re-entry Data Message V1 (RDM) Prototype
4	Agencies Participating in this Test Case:	ESA/ESOC DLR/GSOC
5	Agency Responsible for Prototype:	RDM Generation: ESA/ESOC, DLR/GSOC RDM Processing: ESA/ESOC
6	Prototype Version # (if applicable):	RDM Generation: n/a RDM Processing: n/a
7	Test Engineer:	RDM Generation: Alexandru Mancas, Michael Kirschner RDM Processing: Alexandru Mancas
8	Spacecraft:	AVUM R/B (2012-006 K)
9	Re-entry keywords tested:	ORBIT_LIFETIME, REENTRY_ALTITUDE, NOMINAL_REENTRY_EPOCH, REENTRY_WINDOW_START, REENTRY_WINDOW_END state vector block, covariance block, spacecraft properties block
10	Values for the keywords of interest:	See table later in section 5.2.3
11	Variances from Expected Results:	The two re-entry prediction systems use different atmospheric models, solar flux predictions, and slightly different re-entry altitudes (all are clearly described in the metadata of each message): 70 km for DLR/GSOC and 76.88 km for ESA/ESOC. As a consequence, there is a 3.5 hour difference between the values of the NOMINAL_REENTRY_EPOCH keywords between the messages, but both are inside the predicted re-entry window of the other message. The two predicted windows show the same shift of about 4 hours between the ESA/ESOC and DLR/GSOC start/stop epochs. The ORBIT_LIFETIME_CONFIDENCE values did not appear to be correct. After discussions with the other engineers involved in the prototyping, it was determined the name of the keyword does not match the description that well, and that the description is not clear enough. The value is supposed to be a confidence level, but was interpreted during prototype implementation as a confidence interval.
12	Results (Pass, Partial Pass, Fail):	Pass
13	Comments:	Both re-entry prediction systems write the state vector that was used as input to the output RDM. Since the state vectors are (almost) the same (there is a 3.84 ms difference between them), there was no need to re-run the simulation using the other agency's RDM as input.

The RDM files produced by ESA/ESOC and DLR/GSOC contained the relevant keywords and values shown the table below.

keyword	ESA/ESOC value	DLR/GSOC value
header		
CCSDS_RDM_VERS	0.3	1.0
COMMENT	Test-case#3: short term prediction	—
CREATION_DATE	2016-10-28T14:22:56.000000	2019-01-10T13:13:24.063
ORIGINATOR	ESA-SDO	GSOC
MESSAGE_ID	2012-006K_20181108142256_ESA-SDO_9F5B	GSOC/2019-01-10T13:13:24UTC
metadata		
OBJECT_NAME	AVUM (Vega)	AVUM R/B
INTERNATIONAL_DESIGNATOR	2012-006K	2012-006K
CATALOG_NAME	SATCAT	—
OBJECT_DESIGNATOR	38086	—
OBJECT_TYPE	ROCKET BODY	—
CONTROLLED_REENTRY	NO	NO
CENTER_NAME	EARTH	EARTH
TIME_SYSTEM	UTC	UTC
EPOCH_TZERO	2016-10-28T11:41:00.000384	2016-10-28T11:41:00.000
REF_FRAME	EME2000	TOD
GRAVITY_MODEL	GEM-T1: 8D 8O	GGM01S: 20D 20O
ATMOSPHERIC_MODEL	DTM-13	JACCHIA-GILL
SOLAR_FLUX_PREDICTION	ESA SOLMAG	PREDICTED: MLLRT
N_BODY_PERTURBATIONS	MOON, SUN	SUN, MOON
SOLAR_RAD_PRESSURE	CYLINDRICAL SHADOW	CANNONBALL
EARTH_TIDES	NO	MCCARTHY1996
INTRACK_THRUST	NO	NO
DRAG_PARAMETERS_SOURCE	CD FITTING WITH FOCUS2	—
DRAG_PARAMETERS_ALTITUDE	244.72	—
REENTRY_UNCERTAINTY_METHOD	EMPIRICAL	—
REENTRY_DISINTEGRATION	NONE	NONE
data		
atmospheric re-entry		
COMMENT	Prediction based on 2 TIRA passes as last orbit state, 5 days before re-entry	—
ORBIT_LIFETIME	5.04375	4.8915
REENTRY_ALTITUDE	76.88	70.0000
NOMINAL_REENTRY_EPOCH	2016-11-02T12:38:07.000000	2016-11-02T09:04:43.000
REENTRY_WINDOW_START	2016-11-01T12:31:31.000000	2016-11-01T09:35:58.400
REENTRY_WINDOW_END	2016-11-03T12:56:43.000000	2016-11-03T08:33:27.600
ORBIT_LIFETIME_CONFIDENCE	20.0000	20.0000

state vector		
COMMENT	epoch of OD from 2 TIRA tracks	—
EPOCH	2016-10-28T11:41:00.000384	2016-10-28T11:41:00.000
X	-2095.41001813074	-2092.8991170000
Y	-3040.70137293811	-3048.2867570000
Z	5458.83815375429	5455.5699160000
X_DOT	6.87141346593969	6.8607473416
Y_DOT	1.3852134950239	1.4109533544
Z_DOT	3.36023038345871	3.3712971129
object properties		
COMMENT	Cr is fixed, Cd includes all effects	—
WET_MASS	960.0	960.0000000000
DRY_MASS	410.0	—
SOLAR_RAD_AREA	1.0	1.0000000000
SOLAR_RAD_COEFF	1.2	1.2000000000
DRAG_AREA	3.9545	3.9500000000
DRAG_COEFF	2.3588	2.3588000000
BALLISTIC_COEFF	0.009717	—
OD parameters		
COMMENT	two TIRA tracks	—
TIME_LASTOB_START	2016-10-27T11:54:20.000000	—
TIME_LASTOB_END	2016-10-28T11:41:00.000000	—
RECOMMENDED_OD_SPAN	2.0	—
ACTUAL_OD_SPAN	1.0	—
OBS_AVAILABLE	655	—
OBS_USED	655	—
TRACKS_AVAILABLE	2	—
TRACKS_USED	2	—
RESIDUALS_ACCEPTED	100.0	—
WEIGHTED_RMS	0.0097	—

5.2.4 TEST CASE #4: GROUND IMPACT LOCATION

1	Test Case Number:	4
2	Report Date:	18-Feb-2019
3	Program Under Test:	Re-entry Data Message V1 (RDM) Prototype
4	Agencies Participating in this Test Case:	ESA/ESOC DLR/GSOC
5	Agency Responsible for Prototype:	RDM Generation: ESA/ESOC, DLR/GSOC RDM Processing: ESA/ESOC
6	Prototype Version # (if applicable):	RDM Generation: n/a RDM Processing: n/a
7	Test Engineer:	RDM Generation: Alexandru Mancas, Michael Kirschner RDM Processing: Alexandru Mancas
8	Spacecraft:	AVUM R/B (2012-006 K)
9	Re-entry keywords tested:	ORBIT_LIFETIME, REENTRY_ALTITUDE, NOMINAL_REENTRY_EPOCH, REENTRY_WINDOW_START, REENTRY_WINDOW_END, NOMINAL_IMPACT_EPOCH, IMPACT_WINDOW_START, IMPACT_WINDOW_END, IMPACT_REF_FRAME, NOMINAL_IMPACT_LON, NOMINAL_IMPACT_LAT, NOMINAL_IMAPCT_ALT. state vector block, covariance block, spacecraft properties block
10	Values for the keywords of interest:	See table later in section 5.2.4
11	Variances from Expected Results:	The nominal impact location coordinates are quite different, but the nominal impact epochs are within the other message's window. The former is to be expected, as the two re-entry prediction systems use different gravity, atmospheric, solar flux, solar radiation pressure, and Earth tides models. The ORBIT_LIFETIME_CONFIDENCE values did not appear to be correct. After discussions with the other engineers involved in the prototyping, it was determined the name of the keyword does not match the description that well, and that the description is not clear enough. The value is supposed to be a confidence level, but was interpreted during prototype implementation as a confidence interval.
12	Results (Pass, Partial Pass, Fail):	Pass
13	Comments:	—

The RDM files produced by ESA/ESOC and DLR/GSOC contained the relevant keywords and values shown the table below.

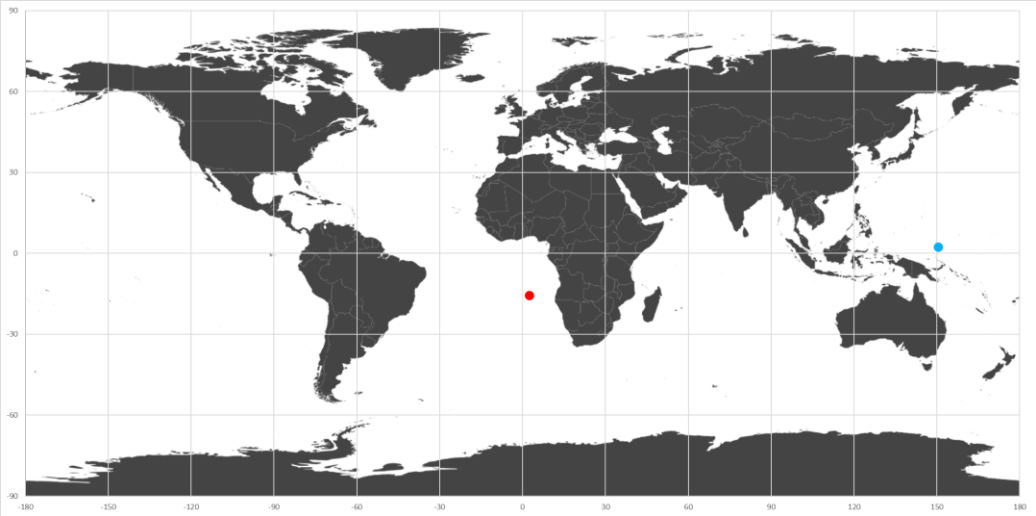
keyword	**ESA/ESOC value**	**DLR/GSOC value**

header		
CCSDS_RDM_VERS	0.1	1.0
COMMENT	Test-case#4: short term prediction with ground impact location	—
CREATION_DATE	2016-10-28T15:22:56.000000	2019-01-10T13:18:45.160
ORIGINATOR	ESA-SDO	GSOC
MESSAGE_ID	2012-006K_20181108152256_ESA-SDO_2345	GSOC/2019-01-10T13:18:45UTC
metadata		
OBJECT_NAME	AVUM (Vega)	AVUM R/B
INTERNATIONAL_DESIGNATOR	2012-006K	2012-006K
CATALOG_NAME	SATCAT	—
OBJECT_DESIGNATOR	38086	—
OBJECT_TYPE	ROCKET BODY	—
CONTROLLED_REENTRY	NO	NO
CENTER_NAME	EARTH	EARTH
TIME_SYSTEM	UTC	UTC
EPOCH_TZERO	2016-10-28T11:41:00.000384	2016-10-28T11:41:00.000
REF_FRAME	EME2000	—
GRAVITY_MODEL	GEM-T1: 8D 8O	—
ATMOSPHERIC_MODEL	DTM-13	—
SOLAR_FLUX_PREDICTION	ESA SOLMAG	—
N_BODY_PERTURBATIONS	MOON, SUN	—
SOLAR_RAD_PRESSURE	CYLINDRICAL SHADOW	—
EARTH_TIDES	NO	—
INTRACK_THRUST	NO	—
DRAG_PARAMETERS_SOURCE	CD FITTING WITH FOCUS2	—
DRAG_PARAMETERS_ALTITUDE	179.490	—
REENTRY_UNCERTAINTY_METHOD	EMPIRICAL	—
REENTRY_DISINTEGRATION	NONE	NONE
data		
atmospheric re-entry		
COMMENT	Prediction based on 2 TIRA passes as last orbit state, 5 days before re-entry	—
ORBIT_LIFETIME	5.04375	4.8913
REENTRY_ALTITUDE	76.88	70.0000
NOMINAL_REENTRY_EPOCH	2016-11-02T12:38:07.000000	—
REENTRY_WINDOW_START	2016-11-01T12:31:31.000000	—
REENTRY_WINDOW_END	2016-11-03T12:56:43.000000	—
ORBIT_LIFETIME_CONFIDENCE	20.0000	20.0000
ground impact		
COMMENT	As it is 5 days before re-entry,	—

	still all the world is under the ground-track	
PROBABILITY_OF_IMPACT	1.0	—
PROBABILITY_OF_BURN_UP	0.0	—
PROBABILITY_OF_BREAK_UP	0.5	—
PROBABILITY_OF_LAND_IMPACT	0.3	—
PROBABILITY_OF_CASUALTY	1e-05	—
NOMINAL_IMPACT_EPOCH	2016-11-02T12:44:07.000000	2016-11-02T09:04:30.000
IMPACT_WINDOW_START	2016-11-01T12:31:31.000000	2016-11-01T09:35:48.000
IMPACT_WINDOW_END	2016-11-03T12:56:43.000000	2016-11-03T08:33:12.000
IMPACT_REF_FRAME	WGS84	WGS84
NOMINAL_IMPACT_LON	150.47	2.3946
NOMINAL_IMPACT_LAT	-29.79	-15.6304
NOMINAL_IMPACT_ALT	8.2028	70.0000
state vector		
COMMENT	epoch of OD from 2 TIRA tracks	—
EPOCH	2016-10-28T11:41:00.000384	—
X	-2095.41001813074	—
Y	-3040.70137293811	—
Z	5458.83815375429	—
X_DOT	6.87141346593969	—
Y_DOT	1.3852134950239	—
Z_DOT	3.36023038345871	—
object properties		
COMMENT	Cr is fixed, Cd includes all effects	—
WET_MASS	960.0	—
DRY_MASS	410.0	—
SOLAR_RAD_AREA	1.0	—
SOLAR_RAD_COEFF	1.2	—
DRAG_AREA	3.9545	—
DRAG_COEFF	2.3588	—
BALLISTIC_COEFF	0.009717	—
OD parameters		
COMMENT	two TIRA tracks	—
TIME_LASTOB_START	2016-10-27T11:54:20.000000	—
TIME_LASTOB_END	2016-10-28T11:41:00.000000	—
RECOMMENDED_OD_SPAN	2.0	—
ACTUAL_OD_SPAN	1.0	—
OBS_AVAILABLE	655	—
OBS_USED	655	—
TRACKS_AVAILABLE	2	—
TRACKS_USED	2	—
RESIDUALS_ACCEPTED	100.0	—

WEIGHTED_RMS	0.0097	—

The compasion between the DLR/GSOC predicted impact location (red) and ESA/ESOC predicted location (blue) can be seen in the figure below.



5.2.5 TEST CASE #5: GROUND IMPACT LOCATION UNCERTAINTY

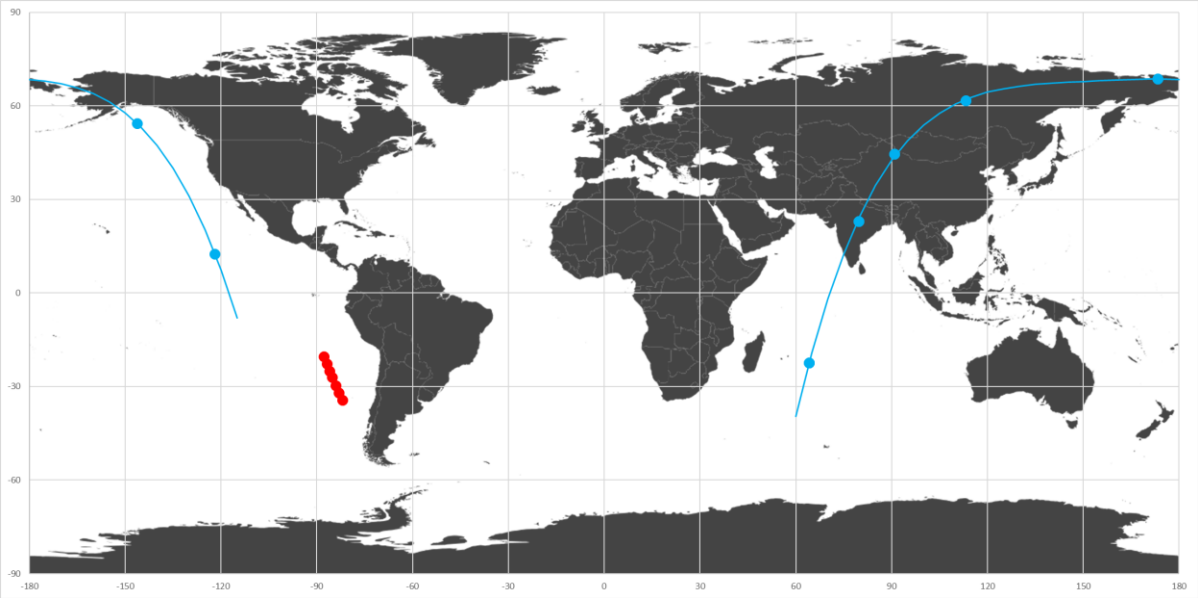
1	Test Case Number:	5
2	Report Date:	18-Feb-2019
3	Program Under Test:	Re-entry Data Message V1 (RDM) Prototype
4	Agencies Participating in this Test Case:	ESA/ESOC DLR/GSOC
5	Agency Responsible for Prototype:	RDM Generation: ESA/ESOC, DLR/GSOC RDM Processing: ESA/ESOC
6	Prototype Version # (if applicable):	RDM Generation: n/a RDM Processing: n/a
7	Test Engineer:	RDM Generation: Alexandru Mancas, Michael Kirschner RDM Processing: Alexandru Mancas
8	Spacecraft:	AVUM R/B (2012-006 K)
9	Re-entry keywords tested:	ORBIT_LIFETIME, REENTRY_ALTITUDE, NOMINAL_REENTRY_EPOCH, REENTRY_WINDOW_START, REENTRY_WINDOW_END, NOMINAL_IMPACT_EPOCH, IMPACT_WINDOW_START, IMPACT_WINDOW_END, IMPACT_REF_FRAME, NOMINAL_IMPACT_LON, NOMINAL_IMPACT_LAT, NOMINAL_IMAPCT_ALT, IMPACT_*_CONFIDENCE, IMPACT_*_START_LON, IMPACT_*_START_LAT, IMPACT_*_STOP_LON, IMPACT_*_STOP_LAT, IMPACT_*_CROSS_TRACK.
10	Values for the keywords of interest:	See table later in section 5.2.5
11	Variances from Expected Results:	The DLR/GSOC-predicted ground impact epoch is 50 minutes before the epoch predicted by ESA/ESOC, but inside ESA's impact window. The DLR impact window is short and the ESA nominal impact epoch is outside of it. The predicted impact locations and uncertainties do not match, but that is to be expected due to the different modelling and impact uncertainty methods used. The ORBIT_LIFETIME_CONFIDENCE values did not appear to be correct. After discussions with the other engineers involved in the prototyping, it was determined the name of the keyword does not match the description that well, and that the description is not clear enough. The value is supposed to be a confidence level, but was interpreted during prototype implementation as a confidence interval.
12	Results (Pass, Partial Pass, Fail):	Pass
13	Comments:	—

The RDM files produced by ESA/ESOC and DLR/GSOC contained the relevant keywords and values shown the table below.

keyword	ESA/ESOC value	DLR/GSOC value
header		
CCSDS_RDM_VERS	0.1	1.0
COMMENT	Test-case#5: very short term prediction with ground impact location and uncertainties	—
CREATION_DATE	2016-11-01T20:14:02.000000	2018-11-30T15:15:51.554
ORIGINATOR	ESA-SDO	GSOC
MESSAGE_ID	2012-006K_20181109141402_ESA-SDO_E231	GSOC/2018-11-30T15:15:51UTC
metadata		
OBJECT_NAME	AVUM (Vega)	AVUM R/B
INTERNATIONAL_DESIGNATOR	2012-006K	2012-006K
CATALOG_NAME	SATCAT	—
OBJECT_DESIGNATOR	38086	—
OBJECT_TYPE	ROCKET BODY	—
CONTROLLED_REENTRY	NO	NO
CENTER_NAME	EARTH	EARTH
TIME_SYSTEM	UTC	UTC
EPOCH_TZERO	2016-11-01T19:03:00.673920	2016-11-01T19:03:00.000
REF_FRAME	EME2000	—
GRAVITY_MODEL	GEM-T1: 8D 8O	—
ATMOSPHERIC_MODEL	DTM-13	—
SOLAR_FLUX_PREDICTION	ESA SOLMAG	—
N_BODY_PERTURBATIONS	MOON, SUN	—
SOLAR_RAD_PRESSURE	CYLINDRICAL	—
EARTH_TIDES	NO	—
INTRACK_THRUST	NO	—
DRAG_PARAMETERS_SOURCE	CD FITTING WITH FOCUS2	—
DRAG_PARAMETERS_ALTITUDE	141.04	—
REENTRY_UNCERTAINTY_METHOD	EMPIRICAL	—
REENTRY_DISINTEGRATION	NONE	BREAK-UP
IMPACT_UNCERTAINTY_METHOD	EMPIRICAL	MONTE CARLO
data		
atmospheric re-entry		
COMMENT	COMMENT Latest prediction	—
ORBIT_LIFETIME	0.416666666666667	0.3758
REENTRY_ALTITUDE	77.0460000000000	80.0000
NOMINAL_REENTRY_EPOCH	2016-11-02T04:57:42.000000	—
REENTRY_WINDOW_START	2016-11-02T02:57:42.000000	—
REENTRY_WINDOW_END	2016-11-02T06:57:42.000000	—
ground impact		

COMMENT	Still 3 complete ground tracks around the globe	—
NOMINAL_IMPACT_EPOCH	2016-11-02T05:03:42.000000	2016-11-02T04:13:13.000
IMPACT_WINDOW_START	2016-11-02T03:03:42.000000	2016-11-02T04:11:03.000
IMPACT_WINDOW_END	2016-11-02T07:03:42.000000	2016-11-02T04:14:42.000
IMPACT_REF_FRAME	WGS84	WGS84
NOMINAL_IMPACT_LON	113.21	-85.1700
NOMINAL_IMPACT_LAT	61.73	-27.1000
NOMINAL_IMPACT_ALT	8.22	0.0000
IMPACT_1_CONFIDENCE	10.0000000000000	66.6667
IMPACT_1_START_LON	90.8728300000000	-85.9810
IMPACT_1_START_LAT	44.5794400000000	-25.0910
IMPACT_1_STOP_LON	173.207370000000	-84.0710
IMPACT_1_STOP_LAT	68.6096400000000	-29.7080
IMPACT_1_CROSS_TRACK	2.00000000000000	0.7510
IMPACT_2_CONFIDENCE	20.0000000000000	95.0000
IMPACT_2_START_LON	79.6142500000000	-86.8830
IMPACT_2_START_LAT	23.0323900000000	-22.7720
IMPACT_2_STOP_LON	-146.303880000000	-83.0500
IMPACT_2_STOP_LAT	54.4247800000000	-32.0050
IMPACT_2_CROSS_TRACK	5.00000000000000	1.5020
IMPACT_3_CONFIDENCE	30.0000000000000	99.7300
IMPACT_3_START_LON	64.0955300000000	-87.7540
IMPACT_3_START_LAT	-22.4338300000000	-20.4470
IMPACT_3_STOP_LON	-121.898660000000	-81.9780
IMPACT_3_STOP_LAT	12.4541700000000	-34.2910
IMPACT_3_CROSS_TRACK	10.0000000000000	2.2520

The compasion between the DLR/GSOC predicted impact locationnad location uncertainty (red) and ESA/ESOC predicted location and location uncertainty (blue) can be seen in the figure below.


90
60
30
0
-30
-60
-90
-180
-150
-120
-90
-60
-30
0
30
60
90
120
150
180

ANNEX A

RDM KEYWORD DISTRIBUTION BETWEEN TEST CASES

The following table shows the distribution of mandatory and optional RDM keywords between the five test cases. An 'X' in the column of a test number means that keyword will be covered in the test. The color coding is as follows:

- Blue – mandatory keywords, will be covered in all test cases;
- Red – optional keywords, covered only in test #1 (KVN-XML conversion);
- Orange – TBD; and
- Green – optional keywords, covered in at least one of tests #2 to #5.

	Feature	Keyword	Status	#1	#2	#3	#4	#5
1	RDM Header	N/A	M					
2	RDM version	CCSDS_RDM_VERS	M	X	X	X	X	X
3	Comment	COMMENT	O	X				
4	Message creation date/time	CREATION_DATE	M	X	X	X	X	X
5	Message originator	ORIGINATOR	M	X	X	X	X	X
6	Unique message identifier	MESSAGE_ID	M	X	X	X	X	X
7	RDM Metadata	N/A	M					
8	Comment	COMMENT	O	X				
9	General information about the re-entering object	N/A	M					
10	Spacecraft name	OBJECT_NAME	M	X	X	X	X	X
11	Spacecraft international designator	INTERNATIONAL_DESIGNATOR	M	X	X	X	X	X
12	Object catalogue used	CATALOG_NAME	O	X	X	X	X	X
13	Spacecraft ID in the catalogue	OBJECT_DESIGNATOR	O	X	X	X	X	X
14	Spacecraft type	OBJECT_TYPE	O	X	X	X	X	X
15	Spacecraft owner	OBJECT_OWNER	O	X				

	Feature	Keyword	Status	#1	#2	#3	#4	#5
16	Spacecraft operator	OBJECT_OPERATOR	O	X				
17	Controlled re-entry	CONTROLLED_REENTRY	M	X	X	X	X	X
18	Celestial body orbited by the object	CENTER_NAME	M	X	X	X	X	X
19	Time system user for the data in the metadata and data sections	TIME_SYSTEM	M	X	X	X	X	X
20	Reference epoch to which orbit lifetime is computed	EPOCH_TZERO	M	X	X	X	X	X
21	Information about any provided orbit data for the object/spacecraft	N/A	O					
22	Reference frame	REF_FRAME	O	X	X	X		
23	Reference frame epoch	REF_FRAME_EPOCH	O	X				
24	External ephemeris file identifier	EPHEMERIS_NAME	O	X				
25	Information about the orbit propagator used for re-entry prediction and orbit determination	N/A	O					
26	gravity model used	GRAVITY_MODEL	O	X	X	X	X	X
27	atmospheric model used	ATMOSPHERIC_MODEL	O	X	X	X	X	X
28	method used to estimate the solar flux indices for the atmospheric model	SOLAR_FLUX_PREDICTION	O	X	X	X	X	X
29	n-body perturbations considered	N_BODY_PERTURBATIONS	O	X	X	X	X	X
30	solar rad pressure	SOLAR_RAD_PRESSURE	O	X	X	X	X	X
31	earth tides	EARTH_TIDES	O	X	X	X	X	X
32	any thrust from the spacecraft	INTRACK_THRUST	O	X				
33	the source of the object drag parameters	DRAG_PARAMETERS_SOURCE	O	X				
34	the altitude at which the drag parameters apply	DRAG_PARAMETERS_ALTITUDE	O	X				
35	the method used to	REENTRY_UNCERTAINTY_METHOD	O	X				

	Feature	Keyword	Status	#1	#2	#3	#4	#5
	estimate the uncertainty in the reentry date							
36	any accounting for break-up and demise	REENTRY_DISINTEGRATION	O	X	X	X	X	X
37	method used to determine the uncertainty in the ground impact location	IMPACT_UNCERTAINTY_METHOD	O	X			X	X
38	Previous and next related RDM	N/A	O					
39	Identifier of the previous RDM	PREVIOUS_MESSAGE_ID	O	X				
40	Epoch of the previous RDM (predicted)	PREVIOUS_MESSAGE_EPOCH	O	X				
41	Time at which the next RDM will be issued (predicted)	NEXT_MESSAGE_EPOCH	O	X				
42	RDM Data	N/A	M					
43	Atmospheric re-entry information	N/A	M					
44	Comment	COMMENT	O	X				
45	Remaining orbit lifetime	ORBIT_LIFETIME	M	X	X	X	X	X
46	Defined re-entry altitude	REENTRY_ALTITUDE	M	X	X	X	X	X
47	Orbit lifetime window	ORBIT_LIFETIME_WINDOW_START	O	X	X			
		ORBIT_LIFETIME_WINDOW_END	O	X	X			
48	Predicted re-entry epoch	NOMINAL_REENTRY_EPOCH	O	X		X	X	X
49	Re-entry window	REENTRY_WINDOW_START	O	X		X	X	X
50		REENTRY_WINDOW_END	O	X		X	X	X
51	Orbit lifetime confidence	ORBIT_LIFETIME_CONFIDENCE	O	X				
52	Ground impact information	N/A	O	X				
53	Comment	COMMENT	O	X				
54	Probability any re-entry fragments reach the Earth surface	PROBABILITY_OF_IMPACT	O	X				
55	Probability all re-entry	PROBABILITY_OF_BURN_UP	O	X				

	Feature	Keyword	Status	#1	#2	#3	#4	#5
	fragments suffer total demise							
56	Probability fragments are generated during re-entry	PROBABILITY_OF_BREAK_UP	O	X				
57	Land impact probability	PROBABILITY_OF_LAND_IMPACT	O	X				
58	Probabilities of casualties occurring due to the re-entry	PROBABILITY_OF_CASUALTY	O	X				
59	Predicted (ground) impact epoch	NOMINAL_IMPACT_EPOCH	O	X			X	X
60	Predicted (ground) impact window	IMPACT_WINDOW_START	O	X			X	X
61		IMPACT_WINDOW_END	O	X			X	X
62	Reference frame of (ground) impact location	IMPACT_REF_FRAME	O	X			X	X
63	Impact location	NOMINAL_IMPACT_LON	O	X			X	X
64		NOMINAL_IMPACT_LAT	O	X			X	X
65		NOMINAL_IMPACT_ALT	O	X			X	
66	Impact dispersion	IMPACT_1_CONFIDENCE	O	X				X
67		IMPACT_1_START_LON	O	X				X
68		IMPACT_1_START_LAT	O	X				X
69		IMPACT_1_STOP_LON	O	X				X
70		IMPACT_1_STOP_LAT	O	X				X
71		IMPACT_1_CROSS_TRACK	O	X				X
72		IMPACT_2_CONFIDENCE	O	X				X
73		IMPACT_2_START_LON	O	X				X
74		IMPACT_2_START_LAT	O	X				X
75		IMPACT_2_STOP_LON	O	X				X
76		IMPACT_2_STOP_LAT	O	X				X
77		IMPACT_2_CROSS_TRACK	O	X				X
78		IMPACT_3_CONFIDENCE	O	X				X
79		IMPACT_3_START_LON	O	X				X

	Feature	Keyword	Status	#1	#2	#3	#4	#5
80		IMPACT_3_START_LAT	O	X				X
81		IMPACT_3_STOP_LON	O	X				X
82		IMPACT_3_STOP_LAT	O	X				X
83		IMPACT_3_CROSS_TRACK	O	X				X
84	Spacecraft state vector section	N/A	O					
85	Comment	COMMENT	O	X				
86	State vector epoch	EPOCH	O	X	X	X	X	X
87	Position and velocity vectors	X	O	X	X	X	X	X
88		Y	O	X	X	X	X	X
89		Z	O	X	X	X	X	X
90		X_DOT	O	X	X	X	X	X
91		Y_DOT	O	X	X	X	X	X
92		Z_DOT	O	X	X	X	X	X
93	Spacecraft state vector covariance information	N/A	O					
94	Comment	COMMENT	O	X				
95	Covariance reference frame	COV_REF_FRAME	O	X	?	?		
96	6x6 position/velocity covariance matrix elements	CX_X	O	X		X	X	X
97		CY_X	O	X		X	X	X
98		CY_Y	O	X		X	X	X
99		CZ_X	O	X		X	X	X
100		CZ_Y	O	X		X	X	X
101		CZ_Z	O	X		X	X	X
102		CX_DOT_X	O	X		X	X	X
103		CX_DOT_Y	O	X		X	X	X
104		CX_DOT_Z	O	X		X	X	X
105		CX_DOT_X_DOT	O	X		X	X	X
106		CY_DOT_X	O	X		X	X	X

	Feature	Keyword	Status	#1	#2	#3	#4	#5
107		CY_DOT_Y	O	X		X	X	X
108		CY_DOT_Z	O	X		X	X	X
109		CY_DOT_X_DOT	O	X		X	X	X
110		CY_DOT_Y_DOT	O	X		X	X	X
111		CZ_DOT_X	O	X		X	X	X
112		CZ_DOT_Y	O	X		X	X	X
113		CZ_DOT_Z	O	X		X	X	X
114		CZ_DOT_X_DOT	O	X		X	X	X
115		CZ_DOT_Y_DOT	O	X		X	X	X
116		CZ_DOT_Z_DOT	O	X		X	X	X
117	Spacecraft properties	N/A	O					
118	Comments	COMMENT	O	X	X			
119	Total (wet) mass	WET_MASS	O	X	X	X	X	X
120	Dry mass	DRY_MASS	O	X				
121	List of hazardous substances on board	HAZARDOUS_SUBSTANCES	O	X	X	X	X	X
122	Solar radiation area	SOLAR_RAD_AREA	O	X				
123	Solar radiation coefficient	SOLAR_RAD_COEFF	O	X				
124	Drag area	DRAG_AREA	O	X	X	X	X	X
125	Coefficient of drag	DRAG_COEFF	O	X	X	X	X	X
126	Radar Cross-Section	RCS	O	X	X	X	X	X
127	Ballistic coefficient	BALLISTIC_COEFF	O	X	X	X	X	X
128	Object’s acceleration used in OD and propagation	THRUST_ACCELERATION	O	X				
129	Orbit determination information	N/A	O					
130	Comment	COMMENT	O	X				
131	Interval during which the last accepted observation occurred	TIME_LASTOB_START	O	X				
132		TIME_LASTOB_END	O	X				

	Feature	Keyword	Status	#1	#2	#3	#4	#5
133	Recommend timespan for OD and actual timespan used	RECOMMENDED_OD_SPAN	O	X				
134		ACTUAL_OD_SPAN	O	X				
135	Total number of observations available and used	OBS_AVAILABLE	O	X				
136		OBS_USED	O	X				
137	Total number of sensor tracks available and used	TRACKS_AVAILABLE	O	X				
138		TRACKS_USED	O	X				
139	Percentage of residuals accepted in OD	RESIDUALS_ACCEPTED	O	X				
140	Weighted RMS of the OD residuals	WEIGHTED_RMS	O	X				
141	User defined parameters	USER_DEFINED_x Any supported user defined parameters should be listed here.	O	X				

ANNEX B

SAMPLE RDM PROTOTYPE TEST DATA SHEET

1	Test Case Number:	
2	Report Date:	
3	Program Under Test:	Re-entry Data Message V1 (RDM) Prototype
4	Agencies Participating in this Test Case:	ESA/ESOC DLR/GSOC
5	Agency Responsible for Prototype:	RDM Generation: RDM Processing:
6	Prototype Version # (if applicable):	RDM Generation: RDM Processing:
7	Test Engineer:	RDM Generation: RDM Processing:
8	Spacecraft:	AVUM R/B (2012-006 K)
9	Re-entry keywords tested:	
10	Values for the keywords of interest:	
11	Variances from Expected Results:	
12	Results (Pass, Partial Pass, Fail):	
13	Comments:	

ANNEX C

ACRONYMS

Some text

CCSDS	Consultative Committee for Space Data Systems
CESG	CCSDS Engineering Steering Group
CMC	CCSDS Management Council
CWE	Common Working Environment
DLR	Deutsches Zentrum für Luft und Raumfahrt
ESA	European Space Agency
ESOC	European Space Operations Centre
GSOC	German Space Operations Centre
KVN	Keyword Value Notation
NASA	National Aeronautics and Space Administration
RID	Review Item Discrepancy
RDM	Re-entry Data Message
XML	eXtensible Markup Language

ANNEX D

OPMS USED AS RE-ENTRY SIMULATION INPUT

The following OPMs were prepared by ESA/ESOC as input for both ESA/ESOC and DLR/GSOC re-entry prediction simulations.

```
CCSDS_OPM_VERS = 2.0
COMMENT Input OPM for Test Case #2 - long term re-entry prediction
CREATION_DATE  = 2018-11-30T07:39:00
ORIGINATOR     = ESA/SDO

OBJECT_NAME = AVUM R/B
OBJECT_ID   = 2012-006K
CENTER_NAME = EARTH
REF_FRAME   = EME2000
TIME_SYSTEM = UTC

COMMENT obtained from the latest TLE
EPOCH = 2015-11-01T20:05:40
X     = -5915.235752489283
Y     =  2990.050036619588
Z     =    -0.004156299484754752
X_DOT =    -1.2274837732545412
Y_DOT =    -2.475304162660883
Z_DOT =     7.386758781498862

MASS            = 960.0
SOLAR_RAD_AREA  =   1.000
SOLAR_RAD_COEFF =   1.200
DRAG_AREA       =   3.9545
DRAG_COEFF      =   2.4108

COMMENT made-up covariance for the TLE
COV_REF_FRAME = RTN
CX_X          =  0.0109
CY_X          =  0.00262
CY_Y          =  0.309
CZ_X          =  0.0000236
CZ_Y          =  0.0047
CZ_Z          =  0.0192
CX_DOT_X      = -0.00000299
CX_DOT_Y      = -0.0000114
CX_DOT_Z      = -0.000000401
CX_DOT_X_DOT  =  0.000000312
CY_DOT_X      = -0.0003
```

```
CY_DOT_Y      = -0.00000158
CY_DOT_Z      = -0.000000337
CY_DOT_X_DOT  =  0.00000000185
CY_DOT_Y_DOT  =  0.0000000122
CZ_DOT_X      = -0.00000722
CZ_DOT_Y      = -0.000000151
CZ_DOT_Z      =  0.00000122
CZ_DOT_X_DOT  =  0.00000000022
CZ_DOT_Y_DOT  = -0.00000000169
CZ_DOT_Z_DOT  =  0.0000000218
```

Figure D-1 Input OPM for Test Case #2 - long term re-entry prediction

```
CCSDS_OPM_VERS = 2.0
COMMENT Input OPM for Test Case #3 - short term re-entry prediction
CREATION_DATE  = 2018-11-30T07:39:00
ORIGINATOR     = ESA/SDO

OBJECT_NAME = AVUM R/B
OBJECT_ID   = 2012-006K
CENTER_NAME = EARTH
REF_FRAME   = EME2000
TIME_SYSTEM = UTC

COMMENT OD from 2 TIRA passes; EPOCH is OD epoch
EPOCH = 2016-10-28T11:41:00
X     = -2095.410018130742
Y     = -3040.7013729381097
Z     =  5458.838153754293
X_DOT =     6.871413465939689
Y_DOT =     1.3852134950239
Z_DOT =     3.360230383458709

COMMENT CD fitting with FOCUS2
MASS            = 960.0
SOLAR_RAD_AREA  =   1.000
SOLAR_RAD_COEFF =   1.200
DRAG_AREA       =   3.9545
DRAG_COEFF      =   2.3588

COMMENT covariance from the OD
COV_REF_FRAME = RTN
CX_X          =  0.00834
CY_X          = -0.00271
CY_Y          =  0.00189
CZ_X          =  0.000735
CZ_Y          =  0.00153
```

```
CZ_Z          =  0.00327
CX_DOT_X      =  0.0000586
CX_DOT_Y      = -0.0000102
CX_DOT_Z      =  0.00000501
CX_DOT_X_DOT  =  0.000000442
CY_DOT_X      = -0.0000177
CY_DOT_Y      =  0.0000029
CY_DOT_Z      =  0.0000113
CY_DOT_X_DOT  = -0.0000000725
CY_DOT_Y_DOT  =  0.0000000126
CZ_DOT_X      =  0.00000664
CZ_DOT_Y      = -0.00000162
CZ_DOT_Z      =  0.0000235
CZ_DOT_X_DOT  =  0.0000000553
CZ_DOT_Y_DOT  = -0.0000000115
CZ_DOT_Z_DOT  =  0.000000172
```

Figure D-2 Input OPM for Test Case #3 - short term re-entry prediction

```
CCSDS_OPM_VERS = 2.0
COMMENT Input OPM for Test Case #4 - short term re-entry prediction with
COMMENT ground impact location
CREATION_DATE  = 2018-11-30T07:39:00
ORIGINATOR     = ESA/SDO

OBJECT_NAME = AVUM R/B
OBJECT_ID   = 2012-006K
CENTER_NAME = EARTH
REF_FRAME   = EME2000
TIME_SYSTEM = UTC

COMMENT OD from 2 TIRA passes; EPOCH is OD epoch
EPOCH = 2016-10-28T11:41:00
X     = -2095.410018130742
Y     = -3040.7013729381097
Z     =  5458.838153754293
X_DOT =     6.871413465939689
Y_DOT =     1.3852134950239
Z_DOT =     3.360230383458709

COMMENT CD fitting with FOCUS2
MASS            = 960.0
SOLAR_RAD_AREA  =   1.000
SOLAR_RAD_COEFF =   1.200
DRAG_AREA       =   3.9545
DRAG_COEFF      =   2.3588
```

```
COMMENT covariance from the OD
COV_REF_FRAME = RTN
CX_X          =  0.00834
CY_X          = -0.00271
CY_Y          =  0.00189
CZ_X          =  0.000735
CZ_Y          =  0.00153
CZ_Z          =  0.00327
CX_DOT_X      =  0.0000586
CX_DOT_Y      = -0.0000102
CX_DOT_Z      =  0.00000501
CX_DOT_X_DOT  =  0.000000442
CY_DOT_X      = -0.0000177
CY_DOT_Y      =  0.0000029
CY_DOT_Z      =  0.0000113
CY_DOT_X_DOT  = -0.0000000725
CY_DOT_Y_DOT  =  0.0000000126
CZ_DOT_X      =  0.00000664
CZ_DOT_Y      = -0.00000162
CZ_DOT_Z      =  0.0000235
CZ_DOT_X_DOT  =  0.0000000553
CZ_DOT_Y_DOT  = -0.0000000115
CZ_DOT_Z_DOT  =  0.000000172
```

Figure D-3 Input OPM for Test Case #4 - short term re-entry prediction with ground impact location

```
CCSDS_OPM_VERS = 2.0
COMMENT Input OPM for Test Case #5 - very short term re-entry prediction
with
COMMENT ground impact location and ground impact location uncertainty
CREATION_DATE  = 2018-11-30T07:39:00
ORIGINATOR     = ESA/SDO

OBJECT_NAME = AVUM R/B
OBJECT_ID   = 2012-006K
CENTER_NAME = EARTH
REF_FRAME   = EME2000
TIME_SYSTEM = UTC

COMMENT from latest TLE
EPOCH = 2016-11-01T19:03:00
X     =  4388.709204989278
Y     = -1149.1211887059094
Z     =  4686.185669397925
X_DOT =     5.692732085207659
Y_DOT =     2.594935544817214
Z_DOT =    -4.69455708111904
```

```
COMMENT CD fitting with FOCUS2
MASS            = 960.0
SOLAR_RAD_AREA  =   1.000
SOLAR_RAD_COEFF =   1.200
DRAG_AREA       =   3.9545
DRAG_COEFF      =   2.5388
```

Figure D-4 Input OPM for Test Case #5 - very short term re-entry prediction with ground impact location uncertainty

ANNEX E

RE-ENTRY DATA MESSAGES PRODUCED DURING PROTOTYPING

The following XML RDMs were produced by the ESA/ESOC prototype.


```
<?xml version="1.0" encoding="utf-8"?>
<ndm:rdm xmlns:ndm="urn:ccsds:recommendation:navigation:schema:ndmxml"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="../xmlSchema/ndmxml-1.0-rdm-1.0-oneFile.xsd"
id="CCSDS_RDM_VERS" version="0.3">
  <header>
    <COMMENT>Test-case#2: long term prediction</COMMENT>
    <CREATION_DATE>2015-11-02T11:24:20.000000</CREATION_DATE>
    <ORIGINATOR>ESA-SDO</ORIGINATOR>
    <MESSAGE_ID>2012-006K_20181108112420_ESA-SDO_5343</MESSAGE_ID>
  </header>
  <body>
    &lt;segment&gt;
      <metadata>
        <OBJECT_NAME>AVUM (Vega)</OBJECT_NAME>
        <INTERNATIONAL_DESIGNATOR>2012-006K</INTERNATIONAL_DESIGNATOR>
        <CATALOG_NAME>SATCAT</CATALOG_NAME>
        <OBJECT_DESIGNATOR>38086</OBJECT_DESIGNATOR>
        <OBJECT_TYPE>ROCKET BODY</OBJECT_TYPE>
        <CONTROLLED_REENTRY>NO</CONTROLLED_REENTRY>
        <CENTER_NAME>EARTH</CENTER_NAME>
        <TIME_SYSTEM>UTC</TIME_SYSTEM>
        <EPOCH_TZERO>2015-11-01T20:05:40.020000</EPOCH_TZERO>
        <REF_FRAME>EME2000</REF_FRAME>
        <GRAVITY_MODEL>GEM-T1: 8D 8O</GRAVITY_MODEL>
        <ATMOSPHERIC_MODEL>DTM-13</ATMOSPHERIC_MODEL>
        <SOLAR_FLUX_PREDICTION>ESA SOLMAG</SOLAR_FLUX_PREDICTION>
        <N_BODY_PERTURBATIONS>MOON, SUN</N_BODY_PERTURBATIONS>
        <SOLAR_RAD_PRESSURE>CYLINDRICAL SHADOW</SOLAR_RAD_PRESSURE>
        <EARTH_TIDES>NO</EARTH_TIDES>
        <INTRACK_THRUST>NO</INTRACK_THRUST>
        <DRAG_PARAMETERS_SOURCE>CD FITTING WITH FOCUS2</DRAG_PARAMETERS_SOURCE>
        <DRAG_PARAMETERS_ALTITUDE units="km">244.72</DRAG_PARAMETERS_ALTITUDE>
        <REENTRY_UNCERTAINTY_METHOD>EMPIRICAL</REENTRY_UNCERTAINTY_METHOD>
        <REENTRY_DISINTEGRATION>NONE</REENTRY_DISINTEGRATION>
        <IMPACT_UNCERTAINTY_METHOD>EMPIRICAL</IMPACT_UNCERTAINTY_METHOD>
      </metadata>
      <data>
        <atmosphericReentryParameters>
```

```
        <COMMENT>Prediction 1 year before re-entry</COMMENT>
        <ORBIT_LIFETIME units="d">366.677083333333</ORBIT_LIFETIME>
        <REENTRY_ALTITUDE units="km">78.417</REENTRY_ALTITUDE>
        <ORBIT_LIFETIME_WINDOW_START
units="d">293.341666666667</ORBIT_LIFETIME_WINDOW_START>
        <ORBIT_LIFETIME_WINDOW_END units="d">440.0125</ORBIT_LIFETIME_WINDOW_END>
        <NOMINAL_REENTRY_EPOCH>2016-11-02T12:15:36.000000</NOMINAL_REENTRY_EPOCH>
        <REENTRY_WINDOW_START>2016-08-21T04:19:01.000000</REENTRY_WINDOW_START>
        <REENTRY_WINDOW_END>2017-01-14T20:25:01.000000</REENTRY_WINDOW_END>
        <ORBIT_LIFETIME_CONFIDENCE units="%">20.0</ORBIT_LIFETIME_CONFIDENCE>
      </atmosphericReentryParameters>
      <stateVector>
        <COMMENT>epoch of latest TLE (same as epoch_tzero)</COMMENT>
        <EPOCH>2015-11-01T20:05:40.020000</EPOCH>
        <X units="km">-5915.23575248928</X>
        <Y units="km">2990.05003661959</Y>
        <Z units="km">-0.0041562994848475475</Z>
        <X_DOT units="km/s">-1.22748377325454</X_DOT>
        <Y_DOT units="km/s">-2.47530416266088</Y_DOT>
        <Z_DOT units="km/s">7.38675878149886</Z_DOT>
      </stateVector>
      <covarianceMatrix>
        <COMMENT>This is an invented covariance for a TLE</COMMENT>
        <COV_REF_FRAME>RTN</COV_REF_FRAME>
        <CX_X units="km**2">0.0109</CX_X>
        <CY_X units="km**2">0.00262</CY_X>
        <CY_Y units="km**2">0.309</CY_Y>
        <CZ_X units="km**2">2.36e-05</CZ_X>
        <CZ_Y units="km**2">0.0047</CZ_Y>
        <CZ_Z units="km**2">0.0192</CZ_Z>
        <CX_DOT_X units="km**2/s">-2.99e-06</CX_DOT_X>
        <CX_DOT_Y units="km**2/s">-1.14e-05</CX_DOT_Y>
        <CX_DOT_Z units="km**2/s">-4.01e-07</CX_DOT_Z>
        <CX_DOT_X_DOT units="km**2/s**2">3.12e-07</CX_DOT_X_DOT>
        <CY_DOT_X units="km**2/s">-0.0003</CY_DOT_X>
        <CY_DOT_Y units="km**2/s">-1.58e-06</CY_DOT_Y>
        <CY_DOT_Z units="km**2/s">-3.37e-07</CY_DOT_Z>
        <CY_DOT_X_DOT units="km**2/s**2">1.85e-09</CY_DOT_X_DOT>
        <CY_DOT_Y_DOT units="km**2/s**2">1.22e-08</CY_DOT_Y_DOT>
        <CZ_DOT_X units="km**2/s">-7.22e-06</CZ_DOT_X>
        <CZ_DOT_Y units="km**2/s">-1.51e-07</CZ_DOT_Y>
        <CZ_DOT_Z units="km**2/s">1.22e-06</CZ_DOT_Z>
        <CZ_DOT_X_DOT units="km**2/s**2">2.2e-10</CZ_DOT_X_DOT>
        <CZ_DOT_Y_DOT units="km**2/s**2">-1.69e-09</CZ_DOT_Y_DOT>
        <CZ_DOT_Z_DOT units="km**2/s**2">2.18e-08</CZ_DOT_Z_DOT>
      </covarianceMatrix>
```

```
      <spacecraftParameters>
        <COMMENT>Cr is fixed, Cd includes all effects</COMMENT>
        <WET_MASS units="kg">960.0</WET_MASS>
        <DRY_MASS units="kg">410.0</DRY_MASS>
        <SOLAR_RAD_AREA units="m**2">1.0</SOLAR_RAD_AREA>
        <SOLAR_RAD_COEFF>1.2</SOLAR_RAD_COEFF>
        <DRAG_AREA units="m**2">3.9545</DRAG_AREA>
        <DRAG_COEFF>2.4108</DRAG_COEFF>
        <BALLISTIC_COEFF units="kg/m**2">0.009931</BALLISTIC_COEFF>
      </spacecraftParameters>
    </data>
  &lt;/segment&gt;
 </body>
</ndm:rdm>
```

Figure E-1 ESA/ESOC XML RDM for Test Case #2

```
<?xml version="1.0" encoding="utf-8"?>
<ndm:rdm xmlns:ndm="urn:ccsds:recommendation:navigation:schema:ndmxml"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="../xmlSchema/ndmxml-1.0-rdm-1.0-oneFile.xsd"
id="CCSDS_RDM_VERS" version="0.3">
  <header>
    <COMMENT>Test-case#3: short term prediction</COMMENT>
    <CREATION_DATE>2016-10-28T14:22:56.000000</CREATION_DATE>
    <ORIGINATOR>ESA-SDO</ORIGINATOR>
    <MESSAGE_ID>2012-006K_20181108142256_ESA-SDO_9F5B</MESSAGE_ID>
  </header>
  <body>
    &lt;segment&gt;
      <metadata>
        <OBJECT_NAME>AVUM (Vega)</OBJECT_NAME>
        <INTERNATIONAL_DESIGNATOR>2012-006K</INTERNATIONAL_DESIGNATOR>
        <CATALOG_NAME>SATCAT</CATALOG_NAME>
        <OBJECT_DESIGNATOR>38086</OBJECT_DESIGNATOR>
        <OBJECT_TYPE>ROCKET BODY</OBJECT_TYPE>
        <CONTROLLED_REENTRY>NO</CONTROLLED_REENTRY>
        <CENTER_NAME>EARTH</CENTER_NAME>
        <TIME_SYSTEM>UTC</TIME_SYSTEM>
        <EPOCH_TZERO>2016-10-28T11:41:00.000384</EPOCH_TZERO>
        <REF_FRAME>EME2000</REF_FRAME>
        <GRAVITY_MODEL>GEM-T1: 8D 8O</GRAVITY_MODEL>
        <ATMOSPHERIC_MODEL>DTM-13</ATMOSPHERIC_MODEL>
        <SOLAR_FLUX_PREDICTION>ESA SOLMAG</SOLAR_FLUX_PREDICTION>
        <N_BODY_PERTURBATIONS>MOON, SUN</N_BODY_PERTURBATIONS>
        <SOLAR_RAD_PRESSURE>CYLINDRICAL SHADOW</SOLAR_RAD_PRESSURE>
        <EARTH_TIDES>NO</EARTH_TIDES>
```

```
      <INTRACK_THRUST>NO</INTRACK_THRUST>
      <DRAG_PARAMETERS_SOURCE>CD FITTING WITH FOCUS2</DRAG_PARAMETERS_SOURCE>
      <DRAG_PARAMETERS_ALTITUDE units="km">179.49</DRAG_PARAMETERS_ALTITUDE>
      <REENTRY_UNCERTAINTY_METHOD>EMPIRICAL</REENTRY_UNCERTAINTY_METHOD>
      <REENTRY_DISINTEGRATION>NONE</REENTRY_DISINTEGRATION>
      <IMPACT_UNCERTAINTY_METHOD>EMPIRICAL</IMPACT_UNCERTAINTY_METHOD>
      <PREVIOUS_MESSAGE_ID></PREVIOUS_MESSAGE_ID>
    </metadata>
    <data>
      <atmosphericReentryParameters>
        <COMMENT>Prediction based on 2 TIRA passes as last orbit state, 5 days
before re-entry</COMMENT>
        <ORBIT_LIFETIME units="d">5.04375</ORBIT_LIFETIME>
        <REENTRY_ALTITUDE units="km">76.88</REENTRY_ALTITUDE>
        <ORBIT_LIFETIME_WINDOW_START units="d">4.035</ORBIT_LIFETIME_WINDOW_START>
        <ORBIT_LIFETIME_WINDOW_END units="d">6.0525</ORBIT_LIFETIME_WINDOW_END>
        <NOMINAL_REENTRY_EPOCH>2016-11-02T12:38:07.000000</NOMINAL_REENTRY_EPOCH>
        <REENTRY_WINDOW_START>2016-11-01T12:31:31.000000</REENTRY_WINDOW_START>
        <REENTRY_WINDOW_END>2016-11-03T12:56:43.000000</REENTRY_WINDOW_END>
        <ORBIT_LIFETIME_CONFIDENCE units="%">20.0</ORBIT_LIFETIME_CONFIDENCE>
      </atmosphericReentryParameters>
      <stateVector>
        <COMMENT>epoch of OD from 2 TIRA tracks</COMMENT>
        <EPOCH>2016-10-28T11:41:00.000384</EPOCH>
        <X units="km">-2095.41001813074</X>
        <Y units="km">-3040.70137293811</Y>
        <Z units="km">5458.83815375429</Z>
        <X_DOT units="km/s">6.87141346593969</X_DOT>
        <Y_DOT units="km/s">1.3852134950239</Y_DOT>
        <Z_DOT units="km/s">3.36023038345871</Z_DOT>
      </stateVector>
      <covarianceMatrix>
        <COMMENT>This is the covariance from the OD</COMMENT>
        <COV_REF_FRAME>RTN</COV_REF_FRAME>
        <CX_X units="km**2">0.00834</CX_X>
        <CY_X units="km**2">-0.00271</CY_X>
        <CY_Y units="km**2">0.00189</CY_Y>
        <CZ_X units="km**2">0.000735</CZ_X>
        <CZ_Y units="km**2">0.00153</CZ_Y>
        <CZ_Z units="km**2">0.00327</CZ_Z>
        <CX_DOT_X units="km**2/s">5.86e-05</CX_DOT_X>
        <CX_DOT_Y units="km**2/s">-1.02e-05</CX_DOT_Y>
        <CX_DOT_Z units="km**2/s">5.01e-06</CX_DOT_Z>
        <CX_DOT_X_DOT units="km**2/s**2">4.42e-07</CX_DOT_X_DOT>
        <CY_DOT_X units="km**2/s">-1.77e-05</CY_DOT_X>
        <CY_DOT_Y units="km**2/s">2.9e-06</CY_DOT_Y>
```

```
        <CY_DOT_Z units="km**2/s">1.13e-05</CY_DOT_Z>
        <CY_DOT_X_DOT units="km**2/s**2">-7.25e-08</CY_DOT_X_DOT>
        <CY_DOT_Y_DOT units="km**2/s**2">1.26e-08</CY_DOT_Y_DOT>
        <CZ_DOT_X units="km**2/s">6.64e-06</CZ_DOT_X>
        <CZ_DOT_Y units="km**2/s">-1.62e-06</CZ_DOT_Y>
        <CZ_DOT_Z units="km**2/s">2.35e-05</CZ_DOT_Z>
        <CZ_DOT_X_DOT units="km**2/s**2">5.53e-08</CZ_DOT_X_DOT>
        <CZ_DOT_Y_DOT units="km**2/s**2">-1.15e-08</CZ_DOT_Y_DOT>
        <CZ_DOT_Z_DOT units="km**2/s**2">1.72e-07</CZ_DOT_Z_DOT>
      </covarianceMatrix>
      <spacecraftParameters>
        <COMMENT>Cr is fixed, Cd includes all effects</COMMENT>
        <WET_MASS units="kg">960.0</WET_MASS>
        <DRY_MASS units="kg">410.0</DRY_MASS>
        <SOLAR_RAD_AREA units="m**2">1.0</SOLAR_RAD_AREA>
        <SOLAR_RAD_COEFF>1.2</SOLAR_RAD_COEFF>
        <DRAG_AREA units="m**2">3.9545</DRAG_AREA>
        <DRAG_COEFF>2.3588</DRAG_COEFF>
        <BALLISTIC_COEFF units="kg/m**2">0.009717</BALLISTIC_COEFF>
      </spacecraftParameters>
      <odParameters>
        <COMMENT>two TIRA tracks</COMMENT>
        <TIME_LASTOB_START>2016-10-27T11:54:20.000000</TIME_LASTOB_START>
        <TIME_LASTOB_END>2016-10-28T11:41:00.000000</TIME_LASTOB_END>
        <RECOMMENDED_OD_SPAN units="d">2.0</RECOMMENDED_OD_SPAN>
        <ACTUAL_OD_SPAN units="d">1.0</ACTUAL_OD_SPAN>
        <OBS_AVAILABLE>655</OBS_AVAILABLE>
        <OBS_USED>655</OBS_USED>
        <TRACKS_AVAILABLE>2</TRACKS_AVAILABLE>
        <TRACKS_USED>2</TRACKS_USED>
        <RESIDUALS_ACCEPTED units="%">100.0</RESIDUALS_ACCEPTED>
        <WEIGHTED_RMS>0.0097</WEIGHTED_RMS>
      </odParameters>
    </data>
  &lt;/segment&gt;
 </body>
</ndm:rdm>
```

Figure E-2 ESA/ESOC XML RDM for Test Case #3

```
<?xml version="1.0" encoding="utf-8"?>
<ndm:rdm xmlns:ndm="urn:ccsds:recommendation:navigation:schema:ndmxml"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="../xmlSchema/ndmxml-1.0-rdm-1.0-oneFile.xsd"
id="CCSDS_RDM_VERS" version="0.3">
  <header>
    <COMMENT>Test-case#4: short term prediction with ground impact
```

```
location</COMMENT>
    <CREATION_DATE>2016-10-28T15:22:56.000000</CREATION_DATE>
    <ORIGINATOR>ESA-SDO</ORIGINATOR>
    <MESSAGE_ID>2012-006K_20181108152256_ESA-SDO_2345</MESSAGE_ID>
  </header>
  <body>
    &lt;segment&gt;
      <metadata>
        <OBJECT_NAME>AVUM (Vega)</OBJECT_NAME>
        <INTERNATIONAL_DESIGNATOR>2012-006K</INTERNATIONAL_DESIGNATOR>
        <CATALOG_NAME>SATCAT</CATALOG_NAME>
        <OBJECT_DESIGNATOR>38086</OBJECT_DESIGNATOR>
        <OBJECT_TYPE>ROCKET BODY</OBJECT_TYPE>
        <CONTROLLED_REENTRY>NO</CONTROLLED_REENTRY>
        <CENTER_NAME>EARTH</CENTER_NAME>
        <TIME_SYSTEM>UTC</TIME_SYSTEM>
        <EPOCH_TZERO>2016-10-28T11:41:00.000384</EPOCH_TZERO>
        <REF_FRAME>EME2000</REF_FRAME>
        <GRAVITY_MODEL>GEM-T1: 8D 8O</GRAVITY_MODEL>
        <ATMOSPHERIC_MODEL>DTM-13</ATMOSPHERIC_MODEL>
        <SOLAR_FLUX_PREDICTION>ESA SOLMAG</SOLAR_FLUX_PREDICTION>
        <N_BODY_PERTURBATIONS>MOON, SUN</N_BODY_PERTURBATIONS>
        <SOLAR_RAD_PRESSURE>CYLINDRICAL SHADOW</SOLAR_RAD_PRESSURE>
        <EARTH_TIDES>NO</EARTH_TIDES>
        <INTRACK_THRUST>NO</INTRACK_THRUST>
        <DRAG_PARAMETERS_SOURCE>CD FITTING WITH FOCUS2</DRAG_PARAMETERS_SOURCE>
        <DRAG_PARAMETERS_ALTITUDE units="km">179.49</DRAG_PARAMETERS_ALTITUDE>
        <REENTRY_UNCERTAINTY_METHOD>EMPIRICAL</REENTRY_UNCERTAINTY_METHOD>
        <REENTRY_DISINTEGRATION>NONE</REENTRY_DISINTEGRATION>
        <IMPACT_UNCERTAINTY_METHOD>EMPIRICAL</IMPACT_UNCERTAINTY_METHOD>
        <PREVIOUS_MESSAGE_ID></PREVIOUS_MESSAGE_ID>
      </metadata>
      <data>
        <atmosphericReentryParameters>
          <COMMENT>Prediction based on 2 TIRA passes as last orbit state, 5 days
before re-entry</COMMENT>
          <ORBIT_LIFETIME units="d">5.04375</ORBIT_LIFETIME>
          <REENTRY_ALTITUDE units="km">76.88</REENTRY_ALTITUDE>
          <ORBIT_LIFETIME_WINDOW_START units="d">4.035</ORBIT_LIFETIME_WINDOW_START>
          <ORBIT_LIFETIME_WINDOW_END units="d">6.0525</ORBIT_LIFETIME_WINDOW_END>
          <NOMINAL_REENTRY_EPOCH>2016-11-02T12:38:07.000000</NOMINAL_REENTRY_EPOCH>
          <REENTRY_WINDOW_START>2016-11-01T12:31:31.000000</REENTRY_WINDOW_START>
          <REENTRY_WINDOW_END>2016-11-03T12:56:43.000000</REENTRY_WINDOW_END>
          <ORBIT_LIFETIME_CONFIDENCE units="%">20.0</ORBIT_LIFETIME_CONFIDENCE>
        </atmosphericReentryParameters>
        <groundImpactParameters>
```

```
        <COMMENT>As it is 5 days before re-entry, still all the world is under the
ground-track</COMMENT>
        <PROBABILITY_OF_IMPACT>1.0</PROBABILITY_OF_IMPACT>
        <PROBABILITY_OF_BURN_UP>0.0</PROBABILITY_OF_BURN_UP>
        <PROBABILITY_OF_BREAK_UP>0.5</PROBABILITY_OF_BREAK_UP>
        <PROBABILITY_OF_LAND_IMPACT>0.3</PROBABILITY_OF_LAND_IMPACT>
        <PROBABILITY_OF_CASUALTY>1e-05</PROBABILITY_OF_CASUALTY>
        <NOMINAL_IMPACT_EPOCH>2016-11-02T12:44:07.000000</NOMINAL_IMPACT_EPOCH>
        <IMPACT_WINDOW_START>2016-11-01T12:31:31.000000</IMPACT_WINDOW_START>
        <IMPACT_WINDOW_END>2016-11-03T12:56:43.000000</IMPACT_WINDOW_END>
        <IMPACT_REF_FRAME>WGS84</IMPACT_REF_FRAME>
        <NOMINAL_IMPACT_LON units="deg">150.47</NOMINAL_IMPACT_LON>
        <NOMINAL_IMPACT_LAT units="deg">-29.79</NOMINAL_IMPACT_LAT>
        <NOMINAL_IMPACT_ALT units="m">8.2028</NOMINAL_IMPACT_ALT>
      </groundImpactParameters>
      <stateVector>
        <COMMENT>epoch of OD from 2 TIRA tracks</COMMENT>
        <EPOCH>2016-10-28T11:41:00.000384</EPOCH>
        <X units="km">-2095.41001813074</X>
        <Y units="km">-3040.70137293811</Y>
        <Z units="km">5458.83815375429</Z>
        <X_DOT units="km/s">6.87141346593969</X_DOT>
        <Y_DOT units="km/s">1.3852134950239</Y_DOT>
        <Z_DOT units="km/s">3.36023038345871</Z_DOT>
      </stateVector>
      <covarianceMatrix>
        <COMMENT>This is the covariance from the OD</COMMENT>
        <COV_REF_FRAME>RTN</COV_REF_FRAME>
        <CX_X units="km**2">0.00834</CX_X>
        <CY_X units="km**2">-0.00271</CY_X>
        <CY_Y units="km**2">0.00189</CY_Y>
        <CZ_X units="km**2">0.000735</CZ_X>
        <CZ_Y units="km**2">0.00153</CZ_Y>
        <CZ_Z units="km**2">0.00327</CZ_Z>
        <CX_DOT_X units="km**2/s">5.86e-05</CX_DOT_X>
        <CX_DOT_Y units="km**2/s">-1.02e-05</CX_DOT_Y>
        <CX_DOT_Z units="km**2/s">5.01e-06</CX_DOT_Z>
        <CX_DOT_X_DOT units="km**2/s**2">4.42e-07</CX_DOT_X_DOT>
        <CY_DOT_X units="km**2/s">-1.77e-05</CY_DOT_X>
        <CY_DOT_Y units="km**2/s">2.9e-06</CY_DOT_Y>
        <CY_DOT_Z units="km**2/s">1.13e-05</CY_DOT_Z>
        <CY_DOT_X_DOT units="km**2/s**2">-7.25e-08</CY_DOT_X_DOT>
        <CY_DOT_Y_DOT units="km**2/s**2">1.26e-08</CY_DOT_Y_DOT>
        <CZ_DOT_X units="km**2/s">6.64e-06</CZ_DOT_X>
        <CZ_DOT_Y units="km**2/s">-1.62e-06</CZ_DOT_Y>
        <CZ_DOT_Z units="km**2/s">2.35e-05</CZ_DOT_Z>
```

```
        <CZ_DOT_X_DOT units="km**2/s**2">5.53e-08</CZ_DOT_X_DOT>
        <CZ_DOT_Y_DOT units="km**2/s**2">-1.15e-08</CZ_DOT_Y_DOT>
        <CZ_DOT_Z_DOT units="km**2/s**2">1.72e-07</CZ_DOT_Z_DOT>
      </covarianceMatrix>
      <spacecraftParameters>
        <COMMENT>Cr is fixed, Cd includes all effects</COMMENT>
        <WET_MASS units="kg">960.0</WET_MASS>
        <DRY_MASS units="kg">410.0</DRY_MASS>
        <SOLAR_RAD_AREA units="m**2">1.0</SOLAR_RAD_AREA>
        <SOLAR_RAD_COEFF>1.2</SOLAR_RAD_COEFF>
        <DRAG_AREA units="m**2">3.9545</DRAG_AREA>
        <DRAG_COEFF>2.3588</DRAG_COEFF>
        <BALLISTIC_COEFF units="kg/m**2">0.009717</BALLISTIC_COEFF>
      </spacecraftParameters>
      <odParameters>
        <COMMENT>two TIRA tracks</COMMENT>
        <TIME_LASTOB_START>2016-10-27T11:54:20.000000</TIME_LASTOB_START>
        <TIME_LASTOB_END>2016-10-28T11:41:00.000000</TIME_LASTOB_END>
        <RECOMMENDED_OD_SPAN units="d">2.0</RECOMMENDED_OD_SPAN>
        <ACTUAL_OD_SPAN units="d">1.0</ACTUAL_OD_SPAN>
        <OBS_AVAILABLE>655</OBS_AVAILABLE>
        <OBS_USED>655</OBS_USED>
        <TRACKS_AVAILABLE>2</TRACKS_AVAILABLE>
        <TRACKS_USED>2</TRACKS_USED>
        <RESIDUALS_ACCEPTED units="%">100.0</RESIDUALS_ACCEPTED>
        <WEIGHTED_RMS>0.0097</WEIGHTED_RMS>
      </odParameters>
    </data>
   &lt;/segment&gt;
  </body>
</ndm:rdm>
```


Figure E-3 ESA/ESOC XML RDM for Test Case #4


```
<?xml version="1.0" encoding="utf-8"?>
<ndm:rdm xmlns:ndm="urn:ccsds:recommendation:navigation:schema:ndmxml"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="../xmlSchema/ndmxml-1.0-rdm-1.0-oneFile.xsd"
id="CCSDS_RDM_VERS" version="0.3">
  <header>
    <COMMENT>Test-case#5: very short term prediction with ground impact location and
uncertainties</COMMENT>
    <CREATION_DATE>2016-11-01T20:14:02.000000</CREATION_DATE>
    <ORIGINATOR>ESA-SDO</ORIGINATOR>
    <MESSAGE_ID>2012-006K_20181109141402_ESA-SDO_E231</MESSAGE_ID>
  </header>
  <body>
```

```
    &lt;segment&gt;
      <metadata>
        <OBJECT_NAME>AVUM (Vega)</OBJECT_NAME>
        <INTERNATIONAL_DESIGNATOR>2012-006K</INTERNATIONAL_DESIGNATOR>
        <CATALOG_NAME>SATCAT</CATALOG_NAME>
        <OBJECT_DESIGNATOR>38086</OBJECT_DESIGNATOR>
        <OBJECT_TYPE>ROCKET BODY</OBJECT_TYPE>
        <CONTROLLED_REENTRY>NO</CONTROLLED_REENTRY>
        <CENTER_NAME>EARTH</CENTER_NAME>
        <TIME_SYSTEM>UTC</TIME_SYSTEM>
        <EPOCH_TZERO>2016-11-01T19:03:00.673920</EPOCH_TZERO>
        <REF_FRAME>EME2000</REF_FRAME>
        <GRAVITY_MODEL>GEM-T1: 8D 8O</GRAVITY_MODEL>
        <ATMOSPHERIC_MODEL>DTM-13</ATMOSPHERIC_MODEL>
        <SOLAR_FLUX_PREDICTION>ESA SOLMAG</SOLAR_FLUX_PREDICTION>
        <N_BODY_PERTURBATIONS>MOON, SUN</N_BODY_PERTURBATIONS>
        <SOLAR_RAD_PRESSURE>CYLINDRICAL SHADOW</SOLAR_RAD_PRESSURE>
        <EARTH_TIDES>NO</EARTH_TIDES>
        <INTRACK_THRUST>NO</INTRACK_THRUST>
        <DRAG_PARAMETERS_SOURCE>CD FITTING WITH FOCUS2</DRAG_PARAMETERS_SOURCE>
        <DRAG_PARAMETERS_ALTITUDE units="km">141.04</DRAG_PARAMETERS_ALTITUDE>
        <REENTRY_UNCERTAINTY_METHOD>EMPIRICAL</REENTRY_UNCERTAINTY_METHOD>
        <REENTRY_DISINTEGRATION>NONE</REENTRY_DISINTEGRATION>
        <IMPACT_UNCERTAINTY_METHOD>EMPIRICAL</IMPACT_UNCERTAINTY_METHOD>
        <PREVIOUS_MESSAGE_ID></PREVIOUS_MESSAGE_ID>
      </metadata>
      <data>
        <atmosphericReentryParameters>
          <COMMENT>Latest prediction</COMMENT>
          <ORBIT_LIFETIME units="d">0.416666666666667</ORBIT_LIFETIME>
          <REENTRY_ALTITUDE units="km">77.046</REENTRY_ALTITUDE>
          <ORBIT_LIFETIME_WINDOW_START
units="d">0.333333333333333</ORBIT_LIFETIME_WINDOW_START>
          <ORBIT_LIFETIME_WINDOW_END units="d">0.5</ORBIT_LIFETIME_WINDOW_END>
          <NOMINAL_REENTRY_EPOCH>2016-11-02T04:57:42.000000</NOMINAL_REENTRY_EPOCH>
          <REENTRY_WINDOW_START>2016-11-02T02:57:42.000000</REENTRY_WINDOW_START>
          <REENTRY_WINDOW_END>2016-11-02T06:57:42.000000</REENTRY_WINDOW_END>
          <ORBIT_LIFETIME_CONFIDENCE units="%">20.0</ORBIT_LIFETIME_CONFIDENCE>
        </atmosphericReentryParameters>
        <groundImpactParameters>
          <COMMENT>Still 3 complete ground tracks around the globe</COMMENT>
          <PROBABILITY_OF_IMPACT>1.0</PROBABILITY_OF_IMPACT>
          <PROBABILITY_OF_BURN_UP>0.0</PROBABILITY_OF_BURN_UP>
          <PROBABILITY_OF_BREAK_UP>0.5</PROBABILITY_OF_BREAK_UP>
          <PROBABILITY_OF_LAND_IMPACT>0.3</PROBABILITY_OF_LAND_IMPACT>
          <PROBABILITY_OF_CASUALTY>1e-05</PROBABILITY_OF_CASUALTY>
```

```
        <NOMINAL_IMPACT_EPOCH>2016-11-02T05:03:42.000000</NOMINAL_IMPACT_EPOCH>
        <IMPACT_WINDOW_START>2016-11-02T03:03:42.000000</IMPACT_WINDOW_START>
        <IMPACT_WINDOW_END>2016-11-02T07:03:42.000000</IMPACT_WINDOW_END>
        <IMPACT_REF_FRAME>WGS84</IMPACT_REF_FRAME>
        <NOMINAL_IMPACT_LON units="deg">113.21</NOMINAL_IMPACT_LON>
        <NOMINAL_IMPACT_LAT units="deg">61.73</NOMINAL_IMPACT_LAT>
        <NOMINAL_IMPACT_ALT units="m">8.22</NOMINAL_IMPACT_ALT>
        <IMPACT_1_CONFIDENCE units="%">10.0</IMPACT_1_CONFIDENCE>
        <IMPACT_1_START_LON units="deg">90.87283</IMPACT_1_START_LON>
        <IMPACT_1_START_LAT units="deg">44.57944</IMPACT_1_START_LAT>
        <IMPACT_1_STOP_LON units="deg">173.20737</IMPACT_1_STOP_LON>
        <IMPACT_1_STOP_LAT units="deg">68.60964</IMPACT_1_STOP_LAT>
        <IMPACT_1_CROSS_TRACK units="km">2.0</IMPACT_1_CROSS_TRACK>
        <IMPACT_2_CONFIDENCE units="%">20.0</IMPACT_2_CONFIDENCE>
        <IMPACT_2_START_LON units="deg">79.61425</IMPACT_2_START_LON>
        <IMPACT_2_START_LAT units="deg">23.03239</IMPACT_2_START_LAT>
        <IMPACT_2_STOP_LON units="deg">-146.30388</IMPACT_2_STOP_LON>
        <IMPACT_2_STOP_LAT units="deg">54.42478</IMPACT_2_STOP_LAT>
        <IMPACT_2_CROSS_TRACK units="km">5.0</IMPACT_2_CROSS_TRACK>
        <IMPACT_3_CONFIDENCE units="%">30.0</IMPACT_3_CONFIDENCE>
        <IMPACT_3_START_LON units="deg">64.09553</IMPACT_3_START_LON>
        <IMPACT_3_START_LAT units="deg">-22.43383</IMPACT_3_START_LAT>
        <IMPACT_3_STOP_LON units="deg">-121.89866</IMPACT_3_STOP_LON>
        <IMPACT_3_STOP_LAT units="deg">12.45417</IMPACT_3_STOP_LAT>
        <IMPACT_3_CROSS_TRACK units="km">10.0</IMPACT_3_CROSS_TRACK>
      </groundImpactParameters>
      <stateVector>
        <COMMENT>epoch of latest TLE (same as epoch_tzero)</COMMENT>
        <EPOCH>2016-11-01T19:03:00.673920</EPOCH>
        <X units="km">4388.70920498928</X>
        <Y units="km">-1149.12118870591</Y>
        <Z units="km">4686.18566939793</Z>
        <X_DOT units="km/s">5.69273208520766</X_DOT>
        <Y_DOT units="km/s">2.59493554481721</Y_DOT>
        <Z_DOT units="km/s">-4.69455708111904</Z_DOT>
      </stateVector>
      <spacecraftParameters>
        <WET_MASS units="kg">960.0</WET_MASS>
        <DRY_MASS units="kg">410.0</DRY_MASS>
        <SOLAR_RAD_AREA units="m**2">1.0</SOLAR_RAD_AREA>
        <SOLAR_RAD_COEFF>1.2</SOLAR_RAD_COEFF>
        <DRAG_AREA units="m**2">3.9545</DRAG_AREA>
        <DRAG_COEFF>2.5388</DRAG_COEFF>
        <BALLISTIC_COEFF units="kg/m**2">0.010458</BALLISTIC_COEFF>
      </spacecraftParameters>
    </data>
```

```
    &lt;/segment&gt;
  </body>
</ndm:rdm>
```

Figure E-4 ESA/ESOC XML RDM for Test Case #5

The following KVN RDMs were produced by the DLR/GSOC prototype.

```
CCSDS_RDM_VERS                = 1.0
CREATION_DATE                 = 2018-11-30T15:30:54.272
ORIGINATOR                    = GSOC
MESSAGE_ID                    = GSOC/2018-11-30T15:30:54UTC

OBJECT_NAME                   = AVUM R/B
INTERNATIONAL_DESIGNATOR      = 2012-006K
CATALOG_NAME                  = SATCAT
OBJECT_DESIGNATOR             = 12345
OBJECT_TYPE                   = UNKNOWN
CONTROLLED_REENTRY            = NO
CENTER_NAME                   = EARTH
TIME_SYSTEM                   = UTC
EPOCH_TZERO                   = 2015-11-01T20:05:40.000

REF_FRAME                     = TOD
GRAVITY_MODEL                 = GGM01S:  08D  08O
ATMOSPHERIC_MODEL             = JACCHIA-GILL
SOLAR_FLUX_PREDICTION         = PREDICTED: MLLRT
N_BODY_PERTURBATIONS          = SUN, MOON
SOLAR_RAD_PRESSURE            = CANNONBALL
EARTH_TIDES                   = MCCARTHY1996
INTRACK_THRUST                = NO
DRAG_PARAMETERS_SOURCE        = OD
DRAG_PARAMETERS_ALTITUDE      =   491.8595                [km]
REENTRY_UNCERTAINTY_METHOD    = EMPIRICAL
REENTRY_DISINTEGRATION        = NONE
ORBIT_LIFETIME                =   385.4993                [d]
REENTRY_ALTITUDE              =   120.0000                [km]
ORBIT_LIFETIME_WINDOW_START   =   308.3994                [d]
ORBIT_LIFETIME_WINDOW_END     =   462.5992                [d]
ORBIT_LIFETIME_CONFIDENCE     =    20.0000                [%]

EPOCH                         = 2015-11-01T20:05:40.000
X                             =     -5925.7575000000      [km]
Y                             =      2969.1288510000      [km]
Z                             =        -9.2273870000      [km]
X_DOT                         =        -1.2300694874      [km/s]
Y_DOT                         =        -2.4793156054      [km/s]
```

```
Z_DOT                          =          7.3849831139      [km/s]

COV_REF_FRAME                  = TOD
CX_X                           = 0.1993482000E+05           [km**2]
CY_X                           = 0.1699190000E+05           [km**2]
CY_Y                           = 0.4277394000E+05           [km**2]
CZ_X                           = -.4360502000E+05           [km**2]
CZ_Y                           = -.8070623000E+05           [km**2]
CZ_Z                           = 0.2763912000E+06           [km**2]
CX_DOT_X                       = -.4341996000E+02           [km**2/s]
CX_DOT_Y                       = 0.1864858000E+02           [km**2/s]
CX_DOT_Z                       = 0.9977287000E+01           [km**2/s]
CX_DOT_X_DOT                   = 0.2541062000E+00           [km**2/s**2]
CY_DOT_X                       = -.7624604000E+02           [km**2/s]
CY_DOT_Y                       = 0.4105582000E+02           [km**2/s]
CY_DOT_Z                       = -.4225089000E+01           [km**2/s]
CY_DOT_X_DOT                   = -.1159934000E+00           [km**2/s**2]
CY_DOT_Y_DOT                   = 0.7962669000E-01           [km**2/s**2]
CZ_DOT_X                       = 0.2537051000E+03           [km**2/s]
CZ_DOT_Y                       = -.1264063000E+03           [km**2/s]
CZ_DOT_Z                       = -.9858566000E+00           [km**2/s]
CZ_DOT_X_DOT                   = -.4018615000E-03           [km**2/s**2]
CZ_DOT_Y_DOT                   = 0.2305920000E-02           [km**2/s**2]
CZ_DOT_Z_DOT                   = 0.1226711000E-01           [km**2/s**2]

WET_MASS                       =       960.0000000000      [kg]
SOLAR_RAD_AREA                 =         1.0000000000      [m**2]
SOLAR_RAD_COEFF                =         1.2000000000
DRAG_AREA                      =         3.9500000000      [m**2]
DRAG_COEFF                     =         2.4108000000
```

Figure E-5 DLR/GSOC KVN RDM for Test Case #2

```
CCSDS_RDM_VERS                 = 1.0
CREATION_DATE                  = 2019-01-10T13:13:24.063
ORIGINATOR                     = GSOC
MESSAGE_ID                     = GSOC/2019-01-10T13:13:24UTC

OBJECT_NAME                    = AVUM R/B
INTERNATIONAL_DESIGNATOR       = 2012-006K
CONTROLLED_REENTRY             = NO
CENTER_NAME                    = EARTH
TIME_SYSTEM                    = UTC
EPOCH_TZERO                    = 2016-10-28T11:41:00.000

REF_FRAME                      = TOD
GRAVITY_MODEL                  = GGM01S:  20D  20O
```

```
ATMOSPHERIC_MODEL           = JACCHIA-GILL
SOLAR_FLUX_PREDICTION       = PREDICTED: MLLRT
N_BODY_PERTURBATIONS        = SUN, MOON
SOLAR_RAD_PRESSURE          = CANNONBALL
EARTH_TIDES                 = MCCARTHY1996
INTRACK_THRUST              = NO
REENTRY_DISINTEGRATION      = NONE
ORBIT_LIFETIME              =     4.8915               [d]
REENTRY_ALTITUDE            =    70.0000               [km]
NOMINAL_REENTRY_EPOCH       = 2016-11-02T09:04:43.000
REENTRY_WINDOW_START        = 2016-11-01T09:35:58.400
REENTRY_WINDOW_END          = 2016-11-03T08:33:27.600
ORBIT_LIFETIME_CONFIDENCE   =    20.0000               [%]

EPOCH                       = 2016-10-28T11:41:00.000
X                           =     -2092.8991170000      [km]
Y                           =     -3048.2867570000      [km]
Z                           =      5455.5699160000      [km]
X_DOT                       =         6.8607473416      [km/s]
Y_DOT                       =         1.4109533544      [km/s]
Z_DOT                       =         3.3712971129      [km/s]

COV_REF_FRAME               = TOD
CX_X                        = 0.3444576000E+04          [km**2]
CY_X                        = 0.2776114000E+04          [km**2]
CY_Y                        = 0.4644814000E+04          [km**2]
CZ_X                        = -.3522417000E+04          [km**2]
CZ_Y                        = -.8150142000E+03          [km**2]
CZ_Z                        = 0.5410610000E+04          [km**2]
CX_DOT_X                    = 0.1716400000E+02          [km**2/s]
CX_DOT_Y                    = 0.1813913000E+02          [km**2/s]
CX_DOT_Z                    = -.2741168000E+02          [km**2/s]
CX_DOT_X_DOT                = 0.1355194000E+00          [km**2/s**2]
CY_DOT_X                    = 0.4100798000E+01          [km**2/s]
CY_DOT_Y                    = 0.2948572000E+02          [km**2/s]
CY_DOT_Z                    = -.1155865000E+02          [km**2/s]
CY_DOT_X_DOT                = 0.3382276000E-01          [km**2/s**2]
CY_DOT_Y_DOT                = 0.1886625000E+00          [km**2/s**2]
CZ_DOT_X                    = -.2658308000E+02          [km**2/s]
CZ_DOT_Y                    = -.6260346000E+01          [km**2/s]
CZ_DOT_Z                    = 0.3835028000E+02          [km**2/s]
CZ_DOT_X_DOT                = -.1992697000E+00          [km**2/s**2]
CZ_DOT_Y_DOT                = -.8625371000E-01          [km**2/s**2]
CZ_DOT_Z_DOT                = 0.3024180000E+00          [km**2/s**2]

WET_MASS                    =       960.0000000000      [kg]
```

```
SOLAR_RAD_AREA              =         1.0000000000      [m**2]
SOLAR_RAD_COEFF             =         1.2000000000
DRAG_AREA                   =         3.9500000000      [m**2]
DRAG_COEFF                  =         2.3588000000
```

Figure E-6 DLR/GSOC KVN RDM for Test Case #3

```
CCSDS_RDM_VERS              = 1.0
CREATION_DATE               = 2019-01-10T13:18:45.160
ORIGINATOR                  = GSOC
MESSAGE_ID                  = GSOC/2019-01-10T13:18:45UTC

OBJECT_NAME                 = AVUM R/B
INTERNATIONAL_DESIGNATOR    = 2012-006K
CONTROLLED_REENTRY          = NO
CENTER_NAME                 = EARTH
TIME_SYSTEM                 = UTC
EPOCH_TZERO                 = 2016-10-28T11:41:00.000

REENTRY_DISINTEGRATION      = NONE
IMPACT_UNCERTAINTY_METHOD   = EMPIRICAL

ORBIT_LIFETIME              =     4.8913              [d]
REENTRY_ALTITUDE            =    70.0000              [km]
ORBIT_LIFETIME_CONFIDENCE   =    20.0000              [%]

NOMINAL_IMPACT_EPOCH        = 2016-11-02T09:04:30.000
IMPACT_WINDOW_START         = 2016-11-01T09:35:48.000
IMPACT_WINDOW_END           = 2016-11-03T08:33:12.000
IMPACT_REF_FRAME            = WGS84
NOMINAL_IMPACT_LON          =     2.3946              [deg]
NOMINAL_IMPACT_LAT          =   -15.6304              [deg]
NOMINAL_IMPACT_ALT          =    70.0000              [m]
```

Figure E-7 DLR/GSOC KVN RDM for Test Case #4

```
CCSDS_RDM_VERS              = 1.0
CREATION_DATE               = 2018-11-30T15:15:51.554
ORIGINATOR                  = GSOC
MESSAGE_ID                  = GSOC/2018-11-30T15:15:51UTC

OBJECT_NAME                 = AVUM R/B
INTERNATIONAL_DESIGNATOR    = 2012-006K
CONTROLLED_REENTRY          = NO
CENTER_NAME                 = EARTH
TIME_SYSTEM                 = UTC
EPOCH_TZERO                 = 2016-11-01T19:03:00.000
```

```
REENTRY_DISINTEGRATION      = BREAK-UP
IMPACT_UNCERTAINTY_METHOD   = MONTE CARLO

ORBIT_LIFETIME              =     0.3758               [d]
REENTRY_ALTITUDE            =    80.0000               [km]
NOMINAL_IMPACT_EPOCH        = 2016-11-02T04:13:13.000
IMPACT_WINDOW_START         = 2016-11-02T04:11:03.000
IMPACT_WINDOW_END           = 2016-11-02T04:14:42.000
IMPACT_REF_FRAME            = WGS84
NOMINAL_IMPACT_LON          =   -85.1700               [deg]
NOMINAL_IMPACT_LAT          =   -27.1000               [deg]
NOMINAL_IMPACT_ALT          =     0.0000               [m]
IMPACT_1_CONFIDENCE         =    66.6667               [%]
IMPACT_1_START_LON          =   -85.9810               [deg]
IMPACT_1_START_LAT          =   -25.0910               [deg]
IMPACT_1_STOP_LON           =   -84.0710               [deg]
IMPACT_1_STOP_LAT           =   -29.7080               [deg]
IMPACT_1_CROSS_TRACK        =     0.7510               [km]
IMPACT_2_CONFIDENCE         =    95.0000               [%]
IMPACT_2_START_LON          =   -86.8830               [deg]
IMPACT_2_START_LAT          =   -22.7720               [deg]
IMPACT_2_STOP_LON           =   -83.0500               [deg]
IMPACT_2_STOP_LAT           =   -32.0050               [deg]
IMPACT_2_CROSS_TRACK        =     1.5020               [km]
IMPACT_3_CONFIDENCE         =    99.7300               [%]
IMPACT_3_START_LON          =   -87.7540               [deg]
IMPACT_3_START_LAT          =   -20.4470               [deg]
IMPACT_3_STOP_LON           =   -81.9780               [deg]
IMPACT_3_STOP_LAT           =   -34.2910               [deg]
IMPACT_3_CROSS_TRACK        =     2.2520               [km]
```

Figure E-8 DLR/GSOC KVN RDM for Test Case #5