YORK
SPACE SYSTEMS

HARBINGER
MISSION

Orbital Debris Mitigation Analysis and Plan

REVISION

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Contents

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1 Introduction

The Inter-Agency Space Debris Coordination Committee (IADC) has provided guidelines (IADC-02-01) for mitigating the generation of space debris to reduce the risk for all space assets. They describe existing practices that have been identified and evaluated for limiting the generation of space debris in the environment. These guidelines fall in line with the U.S Government Orbital Debris Mitigation Standard Practices document. See Table 1 for specific relationships between IADC guidelines and U.S Government Orbital Debris Mitigation Standard Practices objectives.

Table 1: Relation between IADC and USG standard guidelines/objectives.

IADC-02-01 Section ID	USG Orbital Debris Mitigation Standard Practices Objective ID	Summary of Section/Objective
Section 5.1	Objective 1	Limit debris released during normal operations
Section 5.2	Objective 2	Minimize potential for on orbit break-ups
Section 5.3	Objective 4	Post Mission Disposal Plan
Section 5.4	Objective 3	Prevention of on-orbit collisions

The Guidelines cover the overall environmental impact of the mission with a focus on the following:

(1) Limitation of debris released during normal operations
(2) Minimization of the potential for on-orbit break-ups
(3) Post-mission disposal
(4) Prevention of on-orbit collisions

1.1 Acronyms and Abbreviations

ACS: Attitude Control Subsystem
EPS: Electrical Power Subsystem
ESA: European Space Agency
FEEP: Field Emission Electric Propulsion
FSW: Flight Software
IADC: Inter-Agency Space Debris Coordination Committee
IF: Interface
LV: Launch Vehicle
NASA: National Aeronautics and Space Administration
RW: Reaction Wheel
Rx: Receiver
SA: Solar Array
SAR: Synthetic Aperture Radar
USG: U.S. Government

2 Applicable/Reference Documents

Agency/Organization	Document Title	Rev.	Release Date	Applicability
IADC	IADC Space Debris Mitigation Guidelines (IADC-02-01)	1	Sept-2007	Document containing referenced guidelines.
NASA	Process for Limiting Orbital Debris (NASA-STD-8719.14A)	A	May-2012	Document containing referenced requirements.
U.S. Government	U.S Government Orbital Debris Mitigation Standard Practices	1	2001	Document containing objectives listed in Table 1.
ESA	DRAMA Final Report	1.1	June-2014	Document containing details on software used (ESA-DRAMA v 2.1.0) to assess debris mitigation compliance.

3 Mission Overview

3.1 Description of Mission

The spacecraft will be the primary payload of a Rocket Lab Electron rocket launched from Rocket Lab Launch Complex 1 in Mahia, New Zealand. The spacecraft will launch into a circular 500 km orbit at a 40-degree inclination. The nominal mission duration is 3 years.

3.2 Mitigation Plan Summary

The results of the analysis were obtained using both NASA and ESA industry standard tools, DAS v2.1.1 and DRAMA v2.2.0 respectively, for a complete and thorough analysis where applicable. Upon completion of this analysis, it has been determined that the spacecraft is compliant with IADC guidelines and NASA requirements and it has been proven that the mission does not have:

(1) Any debris generation as part of normal operations
(2) A considerable probability for on-orbit break-ups
(3) Any probability of impacting the ground upon re-entry
(4) A considerable probability for an on-orbit collision

As such, the mitigation plan includes the following standard mitigation practices:

(1) Spacecraft is designed not to release any debris during normal operations
(2) There is no credible failure mode that results in explosion and all onboard sources of stored energy will be depleted or safed once they are no longer needed for operations
(3) Spacecraft will be disposed of via the atmospheric re-entry method
(4) Spacecraft mission profile inherently limits the probability of on-orbit collision

4 Assessment Report Format

The following report directly addresses each sub-section under section 5 - Mitigation Measures found in IADC-02-01. This report follows the aforementioned guidelines put forth by the IADC in conjunction with requirements presented by NASA (NASA-STD 8719.14) that ensure sufficient compliance with these guidelines. Corresponding NASA requirements that satisfy IADC guidelines are noted where applicable[1].

4.1 Limit Debris Released during Normal Operations

4.1.1 IADC section 5.1 Limit Debris Released during Normal Operations

"…spacecraft and orbital stages should be designed not to release debris during normal operations."

4.1.2 Summary of applicable NASA requirement(s)

4.1.2.1 Requirement 4.3-1. Debris passing through LEO – released debris with diameters of 1mm or larger:

- All released debris shall have a maximum orbital lifetime of 25 years.

4.1.3 Analysis

The spacecraft design does not have any debris generation as part of normal operations. There are two deployment events as part of normal operations. The two deployments are:

(1) The deployment of the solar array panels from the stowed launch configuration to a fixed deployed configuration.
(2) The deployment of the payload radar array from the stowed launch configuration to the fixed deployed state.

Both deployments use non-explosive actuators to affect the release that do not generate debris. All the deployment mechanisms are designed not to generate debris during normal operations. Therefore, the lifetime of any released debris is 0 years.

4.1.4 Assessment of spacecraft compliance

- IADC Section 5.1: COMPLIANT
- NASA Requirement 4.3-1: COMPLIANT

[1] For simplicity, requirements described in NASA-STD 8719.14 and guidelines in IADC-02-01 that are not applicable to this mission have been omitted from this report.

4.2 Minimize the Potential for On-Orbit Break-ups

4.2.1 IADC section 5.2.1 Minimize the potential for post mission break-ups resulting from stored energy

"…all on-board sources of stored energy of a spacecraft or orbital stage, such as residual propellants, batteries, high-pressure vessels, self-destructive devices, flywheels and momentum wheels, should be depleted or safed when they are no longer required for mission operations or post-mission disposal."

4.2.2 Summary of applicable NASA requirement(s)

4.2.2.1 Requirement 4.4-2. Design for passivation after completion of mission operations while in orbit about Earth or the Moon:

- Spacecraft shall have the ability and plan to deplete all onboard sources of energy when they are no longer required.

4.2.3 Analysis

(1) Residual propellants: The spacecraft is equipped with a low thrust propulsion system that uses a solid metal propellant. During normal propulsive operations, the solid metal is heated to a liquid state which becomes the ion source. Ions are then accelerated by an electric field to generate thrust. There are no volatile chemical propellants or pressurants used in the propulsion system design. This system will be powered off, making it inert, during post-mission disposal operations.
(2) Batteries: The battery charge control is maintained to avoid possible over-charge of the battery. The battery cells have individual safety devices to avoid over-charging and have vents to allow each cell to vent rather than rupture or explode.
(3) High-pressure vessels: There are no high-pressure vessels aboard the spacecraft.
(4) Self-destruct devices: There are no self-destruct devices aboard the spacecraft.
(5) Flywheels and momentum wheels: The spacecraft is equipped with 4 attitude control reaction wheels that will be terminated during the disposal phase by being powered off and spun down to remove all stored energy.
(6) Ultracapacitor: During post-mission disposal operations, the ultracapacitor will be discharged and disconnected from its power source (battery).

4.2.4 IADC Section 5.2.2 Minimize the potential for break-ups during operational phases

"…demonstrate, using failure mode and effects analyses or an equivalent analysis, that there is no probable failure mode leading to accidental break-ups."

4.2.5 Summary of applicable NASA requirement(s)

4.2.5.1 Requirement 4.4-1. Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon:

- Demonstrate that the integrated possibility of accidental explosion is less than 0.001.

4.2.6 Analysis

The only spacecraft component that has a remote possibility of causing an accidental break-up is the battery. The Li-Ion battery consists of Sony 18650 HCM cells with strings of 8 series cells and 10 parallel strings. Rigorous testing and safety devices have been put in place to ensure that the probability of accidental explosion is well below 0.001.

The main failure modes associated with these Li-Ion cells that might eventually result in explosion are overcharging of the cells and a short circuit (over-current) external to the cells.

- *Overcharge Mitigation Factors*: At the battery level, battery charge management ensures that the entire overall battery voltage is maintained at or below the maximum allowable voltage. The charge limit voltage is settable by command on-orbit to allow for tailoring as needed.

In addition, at the cell level, each cell is equipped with a Current Interrupt Device (CID) that, if activated, results in a disconnect of current flow within the cell. Activation of the CID occurs when a maximum pressure level is reached. This process ensures that the battery is protected against unsafe overcharge at the cell level.

- *Over-current (short circuit) Mitigation Factors:* Each cell is equipped with a Positive Temperature Coefficient (PTC) Safety Device that, when activated, results in a decrease of the discharge current. Activation of the PTC Safety Device occurs when a short is applied on a cell and the discharge current level increases; this process results in a rise in temperature of the PTC device. In turn, a PTC temperature increase yields a resistance increase. The outcome will be a decrease in discharge current. This process ensures that the battery is protected against short circuit conditions external to the cell that result in unsafe discharge currents and possible battery over-heating.

Other failure modes resulting in battery explosion that have been identified and commonly referenced by industry are inoperable vents, crushing and excess temperatures due to environment. These three failure modes are all mitigated by proper spacecraft design, respectively: vents will not be structurally inhibited, no moving parts are within proximity to battery, spacecraft is thermally designed to maintain safe operating temperatures (10°C to 35°C).

The safety features detailed above are put in place to protect against anomalies and unsafe operation of the battery. For normal and safe operation of the battery, cell reliability has been quantifiably analyzed using publicly available data from ABSL.

Typically, Li-Ion cells have a Mean Time Between Failure (MTBF) anywhere between 2 and 200 million hours. Conservatively assuming that the 18650 HCM cells used in our battery have: (1) an MTBF of 50 million hours and (2) can be modeled by an exponential reliability "bathtub curve" results in a probability of failure of 0.0005. It should be noted that in the improbable case that a random failure does occur during nominal operations, the probability of it resulting in explosion will be less than 0.0005 due to the safety features described in the previous paragraphs.

4.2.7 Assessment of spacecraft compliance

- IADC Section 5.2.1: COMPLIANT
- IADC Section 5.2.2: COMPLIANT
- NASA Requirement 4.4-2: COMPLIANT
- NASA Requirement 4.4-1: COMPLIANT

4.3 Post Mission Disposal

4.3.1 IADC Section 5.3.2 Objects Passing Through the LEO Region

"This IADC and some other studies and a number of existing national guidelines have found 25 years to be a reasonable and appropriate lifetime limit. If a spacecraft or orbital stage is to be disposed of by re-entry into the atmosphere, debris that survives to reach the surface of the Earth should not pose an undue risk to people or property."

4.3.2 Summary of applicable NASA requirement(s)

4.3.2.1 Requirement 4.6-1. Disposal for space structures in or passing through LEO:

- Spacecraft in LEO shall be disposed of within 25 years of completion of mission by one of three methods: atmospheric re-entry, storage orbit or direct retrieval.

4.3.2.2 Requirement 4.6-4. Reliability of post-mission disposal operations in Earth orbit:

- Spacecraft shall ensure that the planned post-mission disposal method has a probability of success no less than 0.90 at EOL.

4.3.2.3 Requirement 4.7-1. Limit the risk of human casualty:

- For uncontrolled re-entry of the spacecraft, the risk of human casualty shall not exceed 0.0001.

4.3.3 Analysis

(1) Spacecraft lifetime: Conservatively assuming a smaller than expected cross-sectional area of 1.3 m^2 and greater than expected mass of 165 kg results in the longest possible lifetime of 5.19 years (average of calculated values from ESA-DRAMA v2.2.0, OSCAR tool and NASA-DAS v2.1.1). This value is well within the suggested 25-year limit. Moreover, the spacecraft will have a greater cross-sectional area and lesser mass than the aforementioned values ensuring that the lifetime will be less than or equal to the calculated value above. It is also important to note that the cross-sectional area used for this computation is an average value of the spacecraft in a randomly tumbling configuration (As per ESA-DRAMA v2.2.0, CROC tool). See Table 2 and Figures 1 and 2 for details regarding this analysis.

Table 2: Orbital parameters at Beginning of Life (BOL) and End of Life (EOL) as well as other input parameters considered in this calculation.

	BOL	EOL (*ESA DRAMA*)
Date	11/15/2018	05/11/2024
Semi-major axis [km]	6878.1	6496.97
Eccentricity	0.000001	0.00018
Inclination [deg]	40	39.96
	Inputs	
Cross sectional area [m²]	1.3	
Dry mass [kg]	165.0	
Area to Mass ratio [m²/kg]	0.00788	
Drag Coefficient	2.2	
Reflectivity Coefficient	1.3	
Solar and Geomagnetic Activity Mode	Latest Prediction	

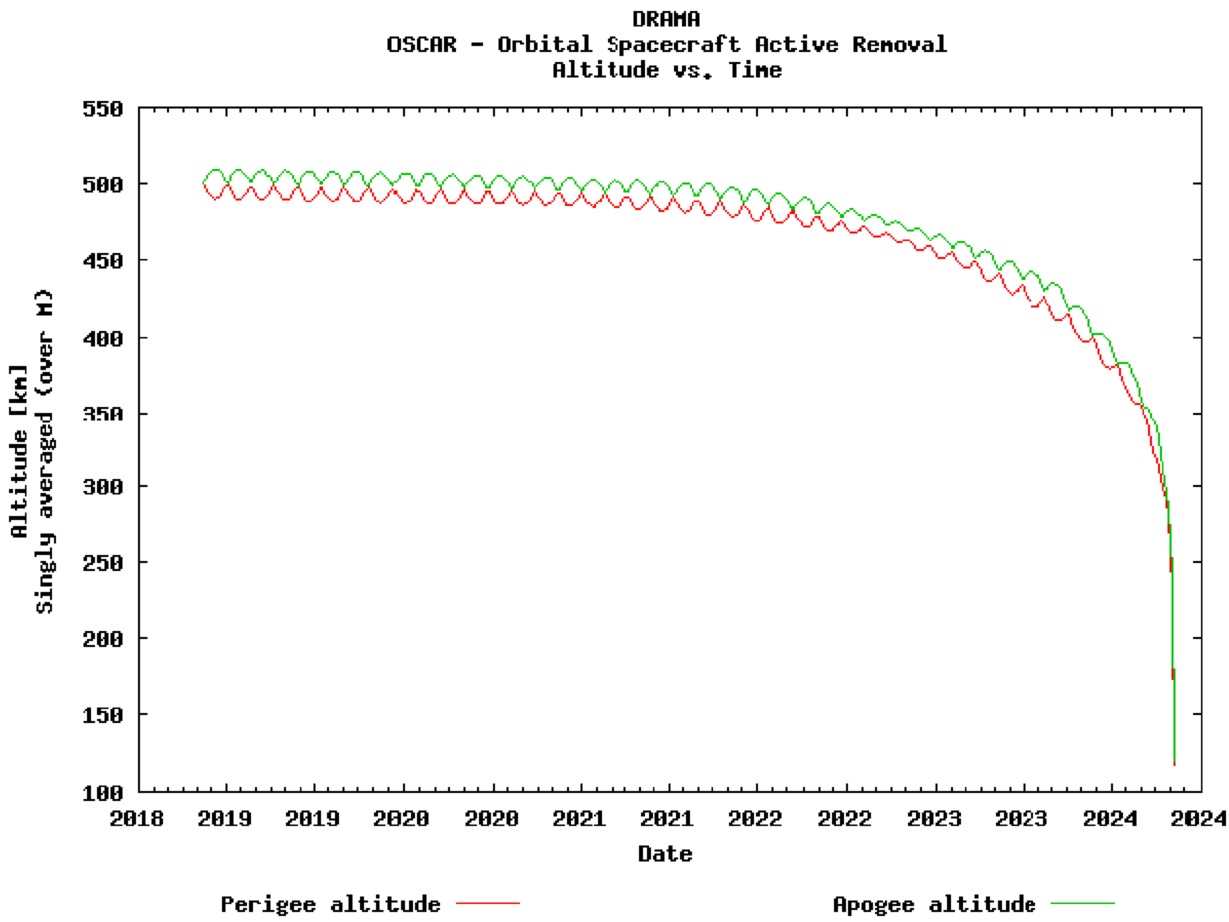

Figure 1: Estimated orbit altitude over time (DRAMA).

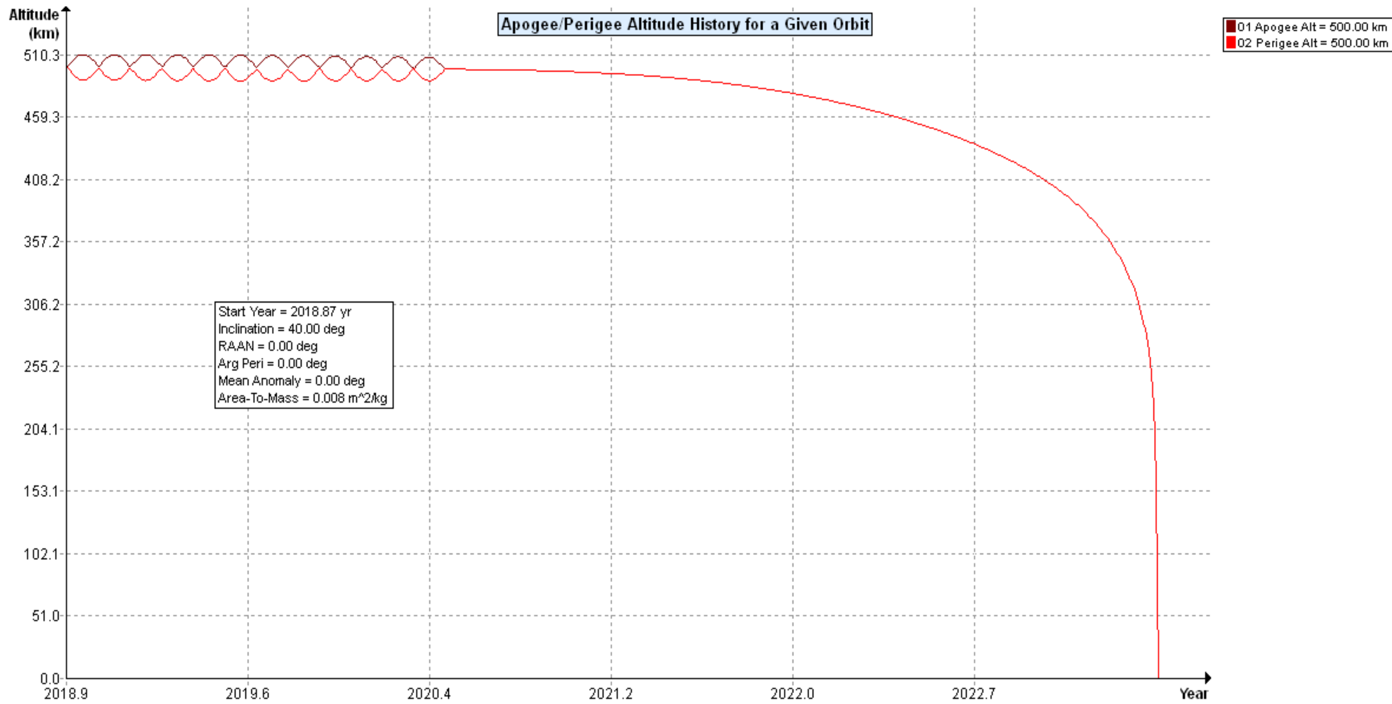

Figure 2: Estimated orbit altitude over time (DAS).

(2) Disposal Plan: Due to our 500 x 500 km orbit and subsequent calculated lifetime, the preferred de-orbit method of direct atmospheric re-entry will be implemented. No propellant is required to maintain a lifetime less than 25 years. As such, this disposal plan is solely dependent on the effects of atmospheric drag and completely independent of the performance of any spacecraft components. Thus, the expected success probability is well above 0.90.

(3) Re-entry Risk: As per ESA-DRAMA v2.2.0 (SARA tool), it has been calculated, using the EOL orbital parameters shown in Table 2, that the risk of human casualty is 0.000 as <u>no</u> spacecraft components are expected to survive a direct re-entry. As per NASA-DAS v2.1.1, it has been calculated that the risk of human casualty is 0.00008 as two spacecraft components are expected to survive a direct re-entry.

Both DRAMA and DAS results have calculated the risk of human casualty to be less than the required value of 0.0001. Results of this analysis are shown in Figure 3 and Table 3[2].

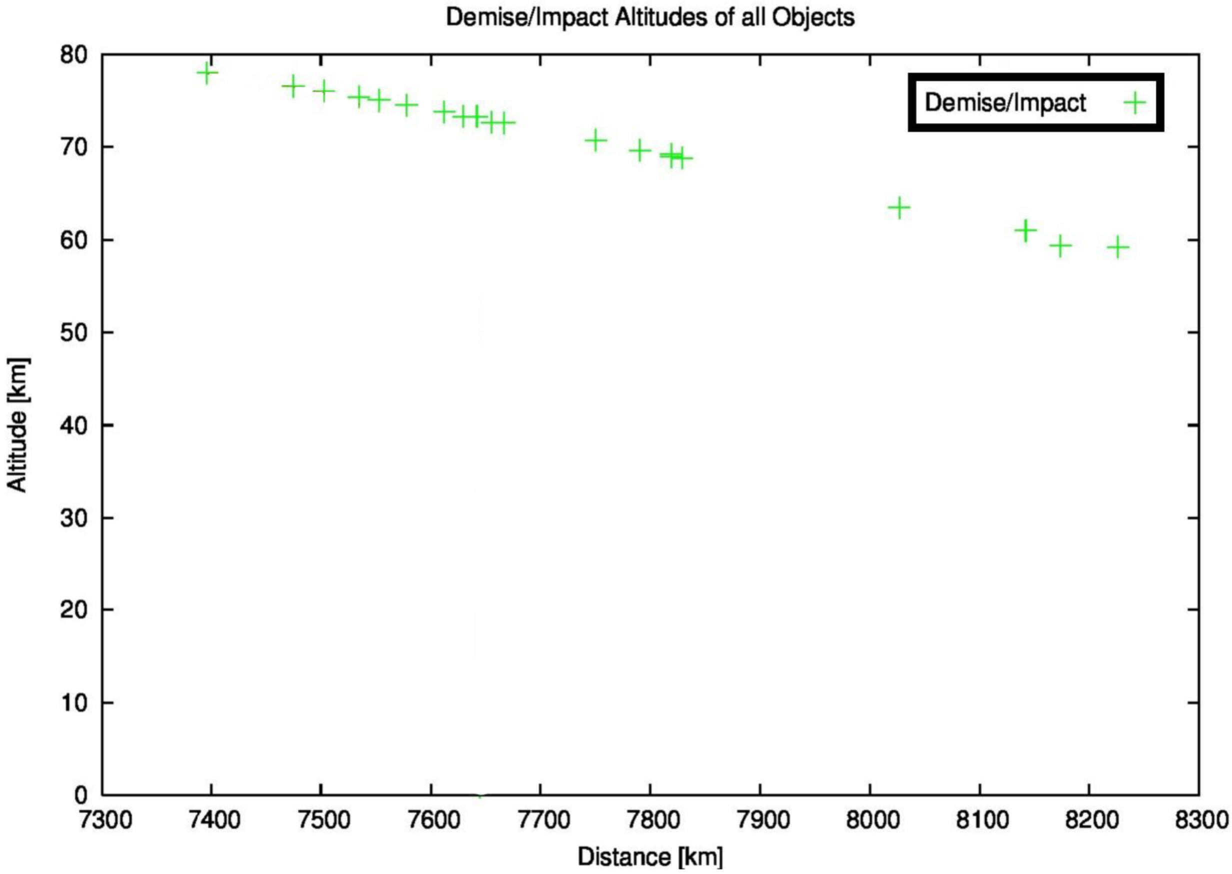

Figure 3: Predict of spacecraft component disintegration altitude (DRAMA).

[2] Break-up altitude (where Parent object decomposes into individual, independent spacecraft components) occurs at an altitude of 78 km. Solar panel break-off occurs at an altitude of 95 km (DRAMA only).

Table 3: Dimensions and associated materials for each component considered in the re-entry analysis with predicted disintegration altitude

Component Name	Shape	Number of Objects	Width/ Diameter	Length	Height	Mass per[3]	Material	Demise Alt. DRAMA	Demise Alt. DAS
-	-	-	*m*	*m*	*m*	*kg*	-	*km*	*km*
Parent	Cylinder	1	1	1		160.0	n/a	77.999	78
Solar Panels	Plate	4	0.826	0.572		3.0	AA6061	95	71.9
Solar Panel Brackets	Plate	4	0.122	0.122		0.17	AA6061	76.3	75.3
Lower Assembly	Cylinder	1	0.546	0.14		12.7	AA6061	61.161	60.1
Upper Assembly	Cylinder	1	0.508	0.54		18.16	AA6061	68.052	69.4
Payload Plate	Plate	1	0.514	0.514		4.66	AA6061	72.414	59.6
ACS – Outer Case	Box	5	0.11	0.11	0.038	0.25	AA6061	76.179	67.1
ACS – RW's	Cylinder	4	0.11	0.038		0.5	AISI316	72.545	60.6
ACS - Torque Rods	Cylinder	2	0.05	0.15		0.15	AISI316	76.130	64.1
Star Trackers	Box	2	0.056	0.102	0.056	0.3	AA6061	74.787	74.2
Battery	Box	1	0.165	0.234	0.097	4.4	AA6061	67.639	50.7
Cable Harnesses	Cylinder	40	0.05	0.4		0.45	Copper	76.589	67.8
Ultracap. – Outer	Cylinder	1	0.457	0.19		10	AA6061	68.606	60.7
Ultracap. – Inner	Cylinder	20	0.1	0.1		1	AA6061	71.916	53.3
Propulsion	Cylinder	1	0.394	0.081		7.6	AA6061	67.243	60.2
Optical Head	Box	1	0.109	0.119	0.102	1.25	AA6061	72.639	69.3
SAR[4]	Box	1	0.41	3.2	0.03	26.75 (1)	AA7075	71.894	77.7
Center Panel (SAR)	Box	1	0.41	0.5	0.03	3.75	AA7075	74.482	68.5
Wing Panel (SAR)	Box	4	0.41	0.66	0.03	5.5	AA7075	72.525	67.2
PL-E. Box	Box	5	0.45	0.45	0.076	3	AA6061	75.179	70.0
PL-Cage	Box	1	0.483	0.483	0.279	3.17	AA6061	75.757	73.0
Total Casualty Area (m^2)								0.0	0.0

[3] It is assumed that the mass values shown are equal to the thermal mass for each component. If this is not the case, then the thermal mass is shown in parenthesis (used in DAS analysis).
[4] All SAR component properties provided by ICEYE.

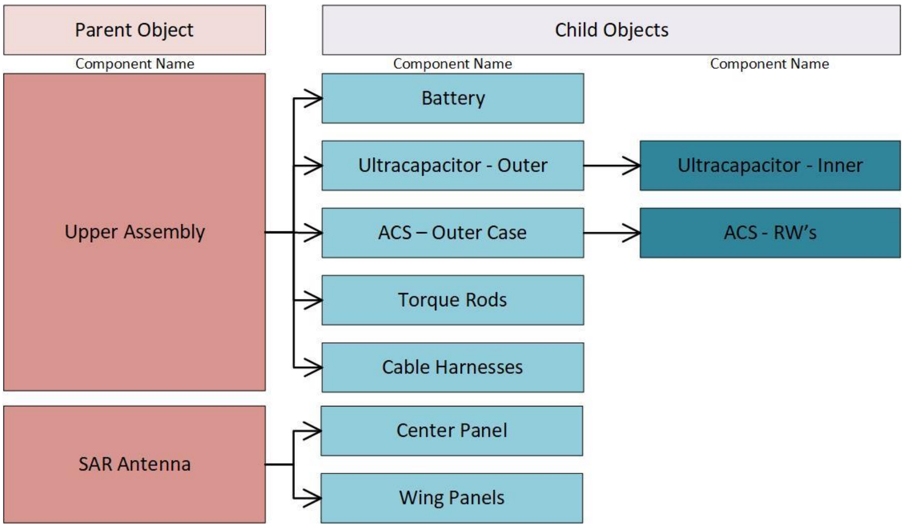

Figure 4: Parent-Child component relationships used in NASA-DAS analysis (only components with children shown).

4.3.4 Assessment of spacecraft compliance

- IADC Section 5.3.2: COMPLIANT
- NASA Requirement 4.6-1: COMPLIANT
- NASA Requirement 4.6-4: COMPLIANT
- NASA Requirement 4.7-1: COMPLIANT

4.4 Prevention of On-Orbit Collisions

4.4.1 IADC Section 5.4 Prevention of On-Orbit Collisions

"In developing the design and mission profile of a spacecraft or orbital stage, a program or project should estimate and limit the probability of accidental collision with known objects during the spacecraft or orbital stage's orbital lifetime."

4.4.2 Summary of applicable NASA requirement(s)

4.4.2.1 Requirement 4.5-1. Limiting debris generated by collisions with large objects when operating in Earth orbit:

- For all spacecraft passing though LEO, the probability of accidental collision with space objects larger than 10 cm in diameter shall be less than 0.001.

4.4.2.2 Requirement 4.5-2. Limiting debris generated by collisions with small objects when operating in Earth or lunar orbit:

- For all spacecraft passing though LEO, the probability of accidental collision with space debris and meteoroids sufficient to prevent compliance with the post-mission disposal plan shall be less than 0.01.

4.4.3 Analysis

This analysis was performed conservatively assuming a larger than expected cross-sectional area of 2.5 m^2, and thus an Area-to-Mass Ratio of 0.0152 m^2/kg (165 kg mass assumed). As per ESA-DRAMA v2.2.0, ARES tool, the Annual Collision Probability due to objects spanning from 0.01 m to 100 m is 0.0002537. This analysis has shown that the spacecraft is compliant with both NASA requirements mentioned above as both small and large objects were considered by the DRAMA tool. As per NASA-DAS v2.1.1, the Probability of Collision with Large Objects is 0.000009 (see Appendix A for further details). Moreover, since the post-mission disposal plan is not reliant on any spacecraft components (see section 4.3.3), the probability of a collision sufficient enough to prevent compliance with said disposal plan is well below the required value of 0.01.

4.4.4 Assessment of spacecraft compliance:

- IADC Section 5.4: COMPLIANT
- NASA Requirement 4.5-1: COMPLIANT
- NASA Requirement 4.5-2: COMPLIANT

5 Conclusion

5.1 Analysis Summary

It has been shown that the Harbinger Mission will be compliant with all four guidelines put forth by the IADC as well as requirements developed by NASA that apply to this mission. Moreover, compliance with each section of IADC-02-01 also assures compliance with the U.S Government Orbital Debris Mitigation Standard Practices objectives.

5.2 Compliance Matrix

Table 4: ASSESSMENT OF COMPLIANCE

Reference Document	Section/ Requirement ID	Section/Requirement Text	Compliance
IADC-02-01	5.1	Limit Debris Release During Normal Operations	COMPLY
IADC-02-01	5.2.1	Minimize the potential for post mission break-ups resulting from stored energy	COMPLY
IADC-02-01	5.2.2	Minimize the potential for break-ups during operational phases	COMPLY
IADC-02-01	5.3.2	Objects Passing Through the LEO Region	COMPLY
IADC-02-01	5.4	Prevention of On-Orbit Collisions	COMPLY
NASA-STD-8719.14	4.3-1	Debris passing through LEO – released debris with diameters of 1mm or larger	COMPLY
NASA-STD-8719.14	4.4-1	Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon	COMPLY
NASA-STD-8719.14	4.4-2	Design for passivation after completion of mission operations while in orbit about Earth or the Moon	COMPLY
NASA-STD-8719.14	4.5-1	Limiting debris generated by collisions with large objects when operating in Earth orbit	COMPLY

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

Appendix A: DAS Activity Log

```
06 22 2018; 15:31:27PM Activity Log Started
06 22 2018; 15:32:25PM Science and Engineering - Orbit Lifetime/Dwell
Time

**INPUT**

      Start Year = 2018.874000 (yr)
      Perigee Altitude = 500.000000 (km)
      Apogee Altitude = 500.000000 (km)
      Inclination = 40.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Area-To-Mass Ratio = 0.007880 (m^2/kg)

**OUTPUT**

      Orbital Lifetime from Startyr = 4.610541 (yr)
      Time Spent in LEO during Lifetime  = 4.610541 (yr)
      Last year of Propagation = 2023 (yr)
      Returned Error Message: Object reentered

06 22 2018; 15:34:11PM Processing Requirement 4.6   Return Status :
Passed

==============
Project Data
==============

**INPUT**

      Space Structure Name = York S-Class
      Space Structure Type = Payload

      Perigee Altitude = 500.000000 (km)
      Apogee Altitude = 500.000000 (km)
      Inclination = 40.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Area-To-Mass Ratio = 0.015200 (m^2/kg)
      Start Year = 2018.874000 (yr)
      Initial Mass = 165.000000 (kg)
      Final Mass = 165.000000 (kg)
      Duration = 3.000000 (yr)
      Station Kept = False
      Abandoned = True
      PMD Perigee Altitude = 447.592578 (km)
      PMD Apogee Altitude = 463.410489 (km)
      PMD Inclination = 39.996380 (deg)
      PMD RAAN = 12.235229 (deg)
      PMD Argument of Perigee = 114.228049 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Suggested Perigee Altitude = 447.592578 (km)
```

Suggested Apogee Altitude = 463.410489 (km)
Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2022 (yr)
Requirement = 61
Compliance Status = Pass

==============

=============== End of Requirement 4.6 ===============
08 27 2018; 09:50:45AM *********Processing Requirement 4.7-1 Return Status : Passed

***********INPUT****
Item Number = 1

name = York S-Class
quantity = 1
parent = 0
materialID = 8
type = Cylinder
Aero Mass = 160.000000
Thermal Mass = 160.000000
Diameter/Width = 1.000000

name = SolarP
quantity = 4
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 3.000000
Thermal Mass = 3.000000
Diameter/Width = 0.527000
Length = 0.830000

name = SolarP - Brack
quantity = 4
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.170000
Thermal Mass = 0.170000
Diameter/Width = 0.122000
Length = 0.122000

name = LowSleeveAssy
quantity = 1
parent = 1
materialID = 8
type = Cylinder
Aero Mass = 12.700000
Thermal Mass = 12.700000
Diameter/Width = 0.140000
Length = 0.546000

name = UpSleeveAssy
quantity = 1
parent = 1

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materialID = 8
type = Cylinder
Aero Mass = 75.320000
Thermal Mass = 18.600000
Diameter/Width = 0.540000
Length = 0.508000

name = UC-Frame
quantity = 1
parent = 5
materialID = 8
type = Cylinder
Aero Mass = 30.000000
Thermal Mass = 10.000000
Diameter/Width = 0.457000
Length = 0.190000

name = UC-Comp
quantity = 20
parent = 6
materialID = 8
type = Cylinder
Aero Mass = 1.000000
Thermal Mass = 1.000000
Diameter/Width = 0.100000
Length = 0.100000

name = RWCase+FlexCore
quantity = 5
parent = 5
materialID = 8
type = Box
Aero Mass = 0.750000
Thermal Mass = 0.250000
Diameter/Width = 0.110000
Length = 0.110000
Height = 0.038000

name = RWs
quantity = 5
parent = 8
materialID = 59
type = Cylinder
Aero Mass = 0.500000
Thermal Mass = 0.500000
Diameter/Width = 0.110000
Length = 0.038000

name = TorRods
quantity = 3
parent = 5
materialID = 59
type = Cylinder
Aero Mass = 0.190000
Thermal Mass = 0.190000
Diameter/Width = 0.020000
Length = 0.130000
```

```
name = Batt
quantity = 1
parent = 5
materialID = 8
type = Box
Aero Mass = 4.400000
Thermal Mass = 4.400000
Diameter/Width = 0.165000
Length = 0.234000
Height = 0.097000

name = CableHarn
quantity = 40
parent = 5
materialID = 19
type = Cylinder
Aero Mass = 0.450000
Thermal Mass = 0.450000
Diameter/Width = 0.050000
Length = 0.400000

name = PL-Plate
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 4.660000
Thermal Mass = 4.660000
Diameter/Width = 0.514000
Length = 0.514000

name = Prop
quantity = 1
parent = 1
materialID = 8
type = Cylinder
Aero Mass = 7.600000
Thermal Mass = 7.600000
Diameter/Width = 0.100000
Length = 0.394000

name = PL-Cage
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 3.170000
Thermal Mass = 3.170000
Diameter/Width = 0.483000
Length = 0.483000
Height = 0.279000

name = ST
quantity = 2
parent = 1
materialID = 8
type = Box
Aero Mass = 0.300000
```

```
Thermal Mass = 0.300000
Diameter/Width = 0.056000
Length = 0.102000
Height = 0.056000

name = Laser
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.250000
Thermal Mass = 1.250000
Diameter/Width = 0.109000
Length = 0.119000
Height = 0.102000

name = PL_EBox
quantity = 5
parent = 1
materialID = 8
type = Box
Aero Mass = 3.000000
Thermal Mass = 3.000000
Diameter/Width = 0.450000
Length = 0.450000
Height = 0.076000

name = SAR-Antenna
quantity = 1
parent = 1
materialID = 9
type = Box
Aero Mass = 26.750000
Thermal Mass = 1.000000
Diameter/Width = 0.410000
Length = 3.200000
Height = 0.030000

name = CenterPanel
quantity = 1
parent = 19
materialID = 9
type = Box
Aero Mass = 3.750000
Thermal Mass = 3.750000
Diameter/Width = 0.410000
Length = 0.500000
Height = 0.030000

name = WingPanel
quantity = 4
parent = 19
materialID = 9
type = Box
Aero Mass = 5.500000
Thermal Mass = 5.500000
Diameter/Width = 0.410000
Length = 0.660000
```

```
Height = 0.030000

*************OUTPUT****
Item Number = 1

name = York S-Class
Demise Altitude = 77.996941
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = SolarP
Demise Altitude = 71.850037
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = SolarP - Brack
Demise Altitude = 75.304092
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = LowSleeveAssy
Demise Altitude = 60.145443
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = UpSleeveAssy
Demise Altitude = 69.355927
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = UC-Frame
Demise Altitude = 60.660938
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = UC-Comp
Demise Altitude = 53.291580
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = RWCase+FlexCore
Demise Altitude = 67.091095
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = RWs
Demise Altitude = 60.579178
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

```
*************************************
name = TorRods
Demise Altitude = 64.119797
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Batt
Demise Altitude = 50.685242
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = CableHarn
Demise Altitude = 67.802345
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = PL-Plate
Demise Altitude = 59.551044
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Prop
Demise Altitude = 60.185749
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = PL-Cage
Demise Altitude = 72.969940
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = ST
Demise Altitude = 74.217567
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Laser
Demise Altitude = 69.295197
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = PL_EBox
Demise Altitude = 69.977554
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = SAR-Antenna
Demise Altitude = 77.656876
Debris Casualty Area = 0.000000
```

```
Impact Kinetic Energy = 0.000000

*************************************
name = CenterPanel
Demise Altitude = 68.470978
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = WingPanel
Demise Altitude = 67.207932
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************

=============== End of Requirement 4.7-1 ===============

06 22 2018; 14:58:28PM Processing Requirement 4.5-1:      Return Status
:  Passed

==============
Run Data
==============

**INPUT**

      Space Structure Name = York S-Class
      Space Structure Type = Payload
      Perigee Altitude = 500.000000 (km)
      Apogee Altitude = 500.000000 (km)
      Inclination = 40.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass Ratio = 0.015200 (m^2/kg)
      Start Year = 2018.874000 (yr)
      Initial Mass = 165.000000 (kg)
      Final Mass = 165.000000 (kg)
      Duration = 3.000000 (yr)
      Station-Kept = False
      Abandoned = True
      PMD Perigee Altitude = -1.000000 (km)
      PMD Apogee Altitude = -1.000000 (km)
      PMD Inclination = 0.000000 (deg)
      PMD RAAN = 0.000000 (deg)
      PMD Argument of Perigee = 0.000000 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Collision Probability = 0.000009
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range
      Status = Pass

==============
```

[illegible]

[illegible]

Appendix B: DRAMA Activity Log

DRAMA v2.2.0

Results

Generated on 2018-06-22 at 15:46 (ARES, OSCAR)

Generated on 2018-08-27 at 09:38 (SARA)

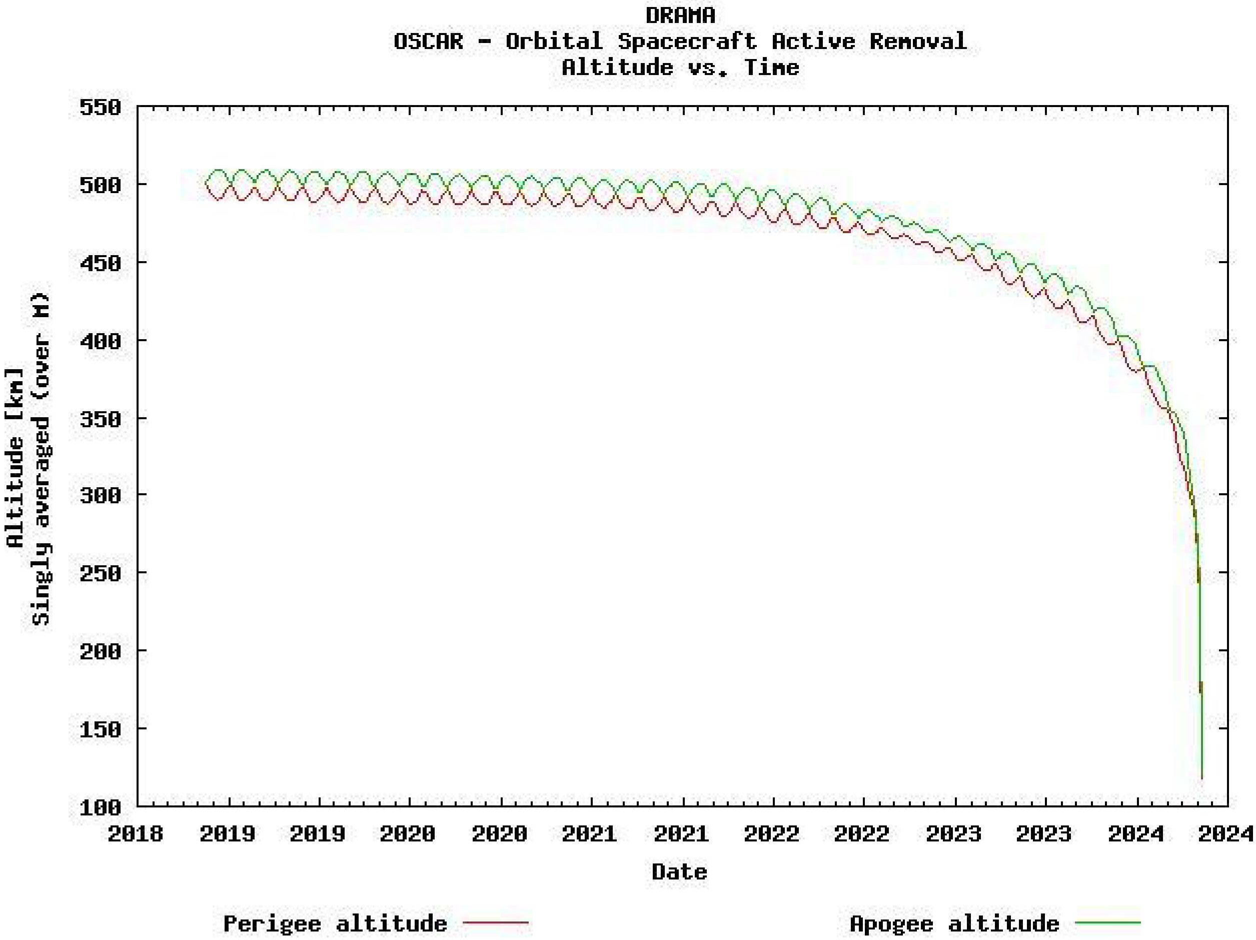
1. ARES
1.1. Results
ares.cp

```
#----------------------------------------------------------------------------
#
#                __/__/    __/_/__/   __/__/__/  _/__/_/
#              __/   __/  __/   __/  __/        __/
#             __/__/__/  __/_/__/   __/__/      __/__/
#            __/   __/  __/   __/  __/             __/
#           __/   __/  __/    __/ __/__/__/  _/__/_/
#
#       Debris Risk Assessment and Mitigation Analysis Tool Suite
#      MASTER(-based) Assessment of Risk Event Statistics Software
#                           (DRAMA-ARES v2.18.3)
#
# ARES version:          2.18.3
# Build date:            30-May-18
# Platform:              i686-w64-mingw32
# Compiler:              GNU Fortran (i686-win32-dwarf-rev3, Built by MinGW-W64 project) 4.9.2
#----------------------------------------------------------------------------
# This file was generated by the ARES tool on:
# 2018/06/22 at 14:38:33
#----------------------------------------------------------------------------
# Comment:
#   DRAMA
#   Assessment of Risk Event Statistics
#
# ARES functionality
#  1: Collision Probability Computation
#
# Analysis epoch (yyyy mm dd):
# 2018/11/15/
#
# Target Orbit:
#   6878.1400000 - semi major axis [km]
#       0.000100 - eccentricity [-]
#      40.000000 - inclination [deg]
#       0.000000 - right ascension of the ascending node [deg]
#       0.000000 - argument of perigee [deg]
#
# Objects considered:
# 0.10000000E-01 - Lower Threshold (m)
#  100.00000- Upper Threshold (m)
#
# Definition of radar equation
# Branch 1: Dmin(h) =        0.320 x  (h/    2000.000)^(  2.0000)
# Branch 2: Dmin(h) =        0.700 x  (h/   36000.000)^( -0.5000)
#
# Population clouds (1 -enabled, 0 -disabled):
# 1 - 25730
# 0 - none
# 0 - none
# 0 - none
# 0 - none
#
# Covariances used for analyses: CSM
#
# Collision probability algorithm: Alfriend-Akella
#
# Collision avoidance strategy:  Target collision probability
#
#----------------------------------------------------------------------------
#
```

```
# title: Annual Collision Probability
#
#-----------------------------------------------------------------------
#
# coltitle: ACP detected population
# coltitle: ACP whole population
# coltitle: Flux due to the detected population [1/km^2/yr]
# coltitle: Flux due to the whole population [1/km^2/yr]
#
#-----------------------------------------------------------------------
#   ACP_d       ACP_w       Flux_d      Flux_w
#-----------------------------------------------------------------------
  0.2537E-03  0.8664E-03  0.1113E+02  0.4217E+02
#
#---eof----------------------------------------------------------eof---
```

2. OSCAR

2.1. Results



3. SARA

3.1. Results

(No objects survived re-entry)