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Blue Canyon Technologies	**Technical Report**
Title: Orbital Debris Analysis for RAVAN	**Prepared By:** John Carvo

Summary:

Rev B Update:

- Total RAVAN mass reduced from 4.15kg to 3.93kg based on measured values.
- Definition of solar array hinges in reentry analysis updated to reflect the final design
- Definition of UHF antenna in reentry analysis updated to reflect the final design
- More fidelity was added to the Instrument door motor/mechanism in the reentry analysis that resulted in elimination of any casualty risk from reentry debris
  - Door motor/mechanism line item split into 3 line items: door stepper motor, door mechanism, door motor bearings

An orbital debris analysis found the RAVAN 3U CubeSat mission to be compliant with the applicable requirements for spacecraft disposal and risk to human casualty contained in NASA STD 8719.14A. The analysis uses Debris Assessment Software provided by the NASA ODPO and follows the requirement structure of the Process for Limiting Orbital Debris, NASA-STD 8719.14A. RAVAN will be launched into a 600 km altitude, 98.8 deg inclination orbit and spacecraft disposal is accomplished through atmospheric reentry. The spacecraft is estimated to reenter in 7.3 years and is compliant with the requirement to reenter within 25 years after mission completion or 30 years after launch.

The inputs to the DAS object tree (spacecraft model) were nested according to the users guide to provide a realistic reentry model and used the standard materials database provided in the application. RAVAN meets all applicable requirements for the process of limiting orbital debris.

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1.0 Scope

This report summarizes the analyses performed to assess orbital debris for the Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) spacecraft and its compliance with requirements established by the NASA Orbital Debris Program Office (NASA ODPO).

The analysis uses Debris Assessment Software provided by the NASA ODPO and follows the requirement structure of the Process for Limiting Orbital Debris, NASA-STD 8719.14A. The RAVAN analysis was performed using version DAS 2.0.2 provided by the Orbital Debris Program Office at NASA's Johnson Space Center (JSC). This analysis complies with the methodology described in section 1.1.3 of NS 8719.14A: "*1.1.3 This document, along with the associated current version of Debris Assessment Software (DAS) or the higher fidelity Object Reentry Survival Analysis Tool (ORSAT), provided by the NASA Orbital Debris Program Office (NASA ODPO) located at Johnson Space Center (JSC), shall be used by the program or project manager as the primary reference in conducting orbital debris assessments (Requirement 56244).*"

2.0 Mission Design

2.1 Mission Description

Blue Canyon Technologies (BCT) is building the spacecraft for the RAVAN project, which is led by the Johns Hopkins University Applied Physics Laboratory (JHU/APL), with partners L-1 Standards and Technology, Inc. and Draper Laboratory, and funded by NASA's Earth Science Technology Office under a government contract.

The objective of the RAVAN project is to demonstrate a radiometer that is compact, low-cost, and low-uncertainty. The radiometer uses a gallium fixed-point black body as a built-in calibration source and a vertically aligned carbon nanotube (VACNT) absorber. VACNTs are the blackest known substance. Neither the VACNT nor gallium black body has ever been used in an orbiting scientific instrument. Successful demonstration will pave the way for a constellation Earth radiation budget mission that can provide valuable measurements needed to significantly advance our understanding of ongoing and future climate change.

2.2 Spacecraft Description

RAVAN is a predominately nadir-pointing, 3-axis controlled, 3U CubeSat configured as shown in Figure 1. The spacecraft is designed for use in a low earth orbit (LEO) with two deployed, non-articulating solar arrays. There is also a deployed UHF monopole antenna. The total spacecraft mass is 3.93 kg with a volume of 10 cm x 34 cm x 10 cm in the stowed configuration. When fully deployed, the UHF monopole antenna extends approximately 15 cm and the total surface area of the solar panels is 866 cm^2.

The 3 axis inertial pointing system contains 3 reaction wheel assemblies, 3 torque rods, two miniaturized star trackers, and a processor board all self contained in a ½ U unit. The RAVAN battery pack is comprised of six 2.8 amp-hour lithium ion battery cells connected in series and parallel to make a 12 Volt battery pack with 5.6 amp-hour capacity.

All sensors on RAVAN are passive and there are no lasers, radiation sources, propellants, pressure vessels, or other hazardous materials on board the spacecraft.

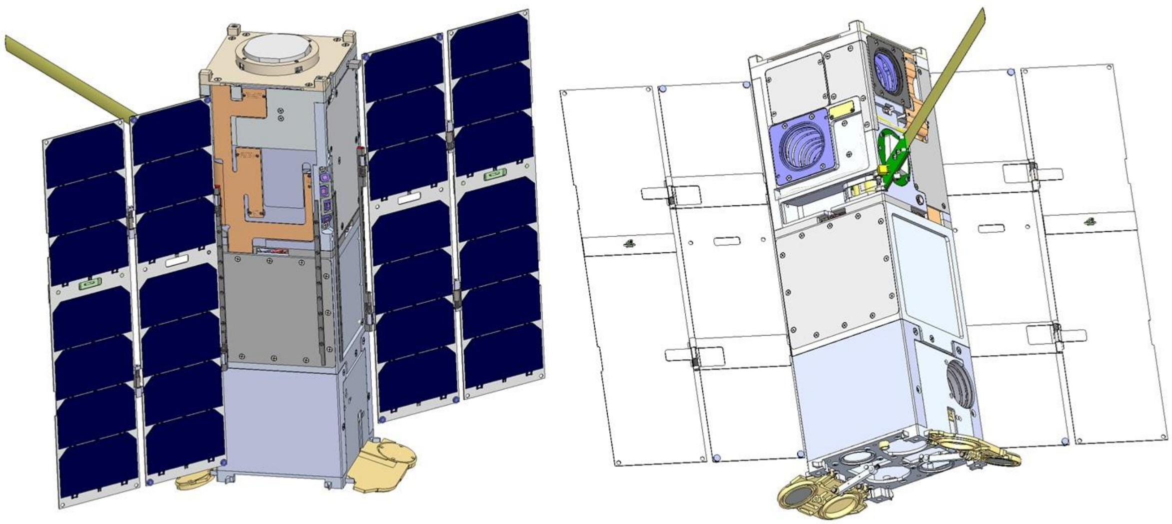

Figure 1. RAVAN Spacecraft with Solar Panels and UHF antenna deployed.

3.0 Orbit Lifetime

NASA requires the disposal of spacecraft through one of three methods; 1) atmospheric reentry within 25 years of Mission completion or 30 years from launch, maneuver the spacecraft for a controlled reentry, 2) maneuver the spacecraft into a storage orbit, or 3) direct retrieval. RAVAN will meet NS 8719.14 through atmospheric reentry within 25 years mission completion *[(Requirement 4.6-1) - Disposal for space structures passing through LEO: A spacecraft or orbital stage with a perigee altitude below 2000 km shall be disposed of by one of three methods:*
a. Atmospheric reentry option:
(1) Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission but no more than 30 years after launch; or…].

For the orbit lifetime analysis, RAVAN analyzed an initial orbit of 600 x 600 km altitude, 98.8 deg inclination. DAS software is used to calculate the cross sectional area of the spacecraft for random tumbling and a detailed mass budget was used to accurately estimate the fully integrated spacecraft mass.

A 0.096 m^2 cross sectional area was estimated using the "Calculate the Cross Sectional Area" in the DAS Science and Engineering toolbox. The spacecraft mass is 3.93 kg. The area-to-mass ratio is then 0.02439 m^2/kg for RAVAN (in the fully deployed configuration, the area-to-mass ratio is 0.009941 with the solar arrays stowed and would reenter in 17.1 years). The inputs to the calculation and the orbit history are shown in Figure 2.

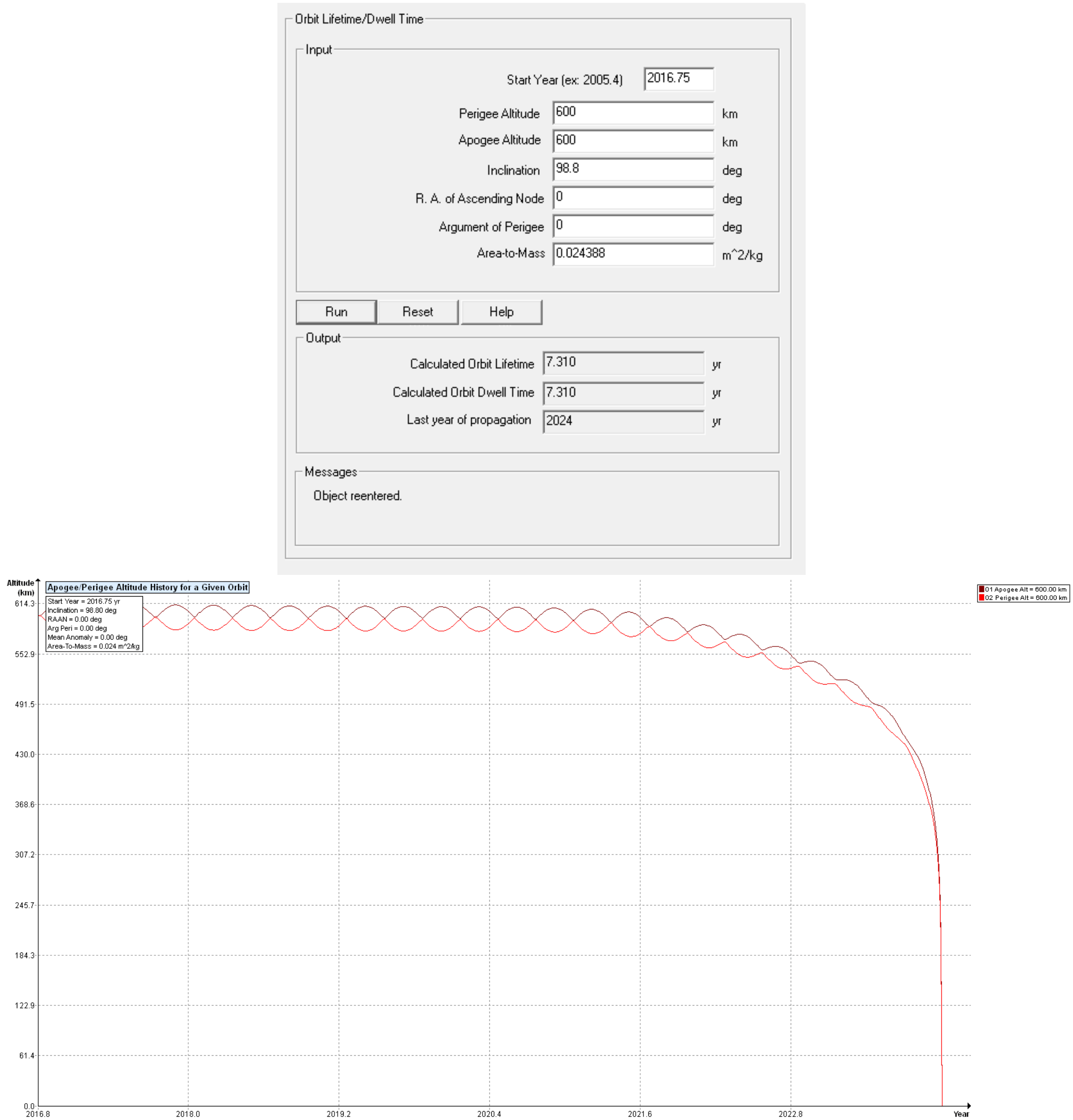

Figure 2. RAVAN Orbit Lifetime/Dwell Time and Orbit Decay

Assuming a September, 2016 launch, the orbit dwell time is 7.3 years, meeting 8719.14 through atmospheric reentry within 25 years of mission completion or 30 years from launch.

4.0 Orbital Debris Requirements

Requirements associated with the risk of human casualty from reentering space hardware are contained in NS 8719.14A, requirement 4.7-1: [*Limit the risk of human casualty: The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 Joules:*

a) For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000)….]

All analyses contained in the DAS 2.0.2 Requirements Assessment tools were successfully performed with the exception of collision hazards from space tethers. There are no tethers on RAVAN.

4.1 Model Construction

In order to calculate the risk of human casualty, the arrangement of each space structure element is defined to assess its reentry survival potential. Based on empirical and theoretical values, the outermost structure (i.e. the “parent” object) is assumed to break apart at an altitude of 78 km. The first level of “child” objects is exposed at this point. The objects are then subjected to the various forces of the reentry model. If a child object is destroyed (“demises”) due to the reentry forces, it does not affect the final casualty area calculation. If a child object contains further levels of children, those children are exposed at the same point at which their immediate parent is exposed.

4.1.1 RAVAN Components and Object Tree

RAVAN components and their physical properties are inserted into the object tree with sub-items (child objects) nested to match the mechanical design of the system. The object tree contains 51 objects and nests to the third level of child objects. The root level (0^{th}) object for the object tree is RAVAN. The first level of child objects contains the RAVAN structure, the ADCS structure, and items that reside on the outside of the spacecraft such as: solar array hinge pieces, solar arrays, and antennas. The second level of child objects contains components inside the five level 1 structures and consists of housings encasing other components, electronics boards, batteries, wire harness, fasteners, and connectors. The third level of child objects contains components housed inside the level 2 cases and consists of reaction wheel components and star tracker optics. Figure 3 shows the major components of the RAVAN spacecraft and Figure 4 shows an exploded view of the RAVAN structure.

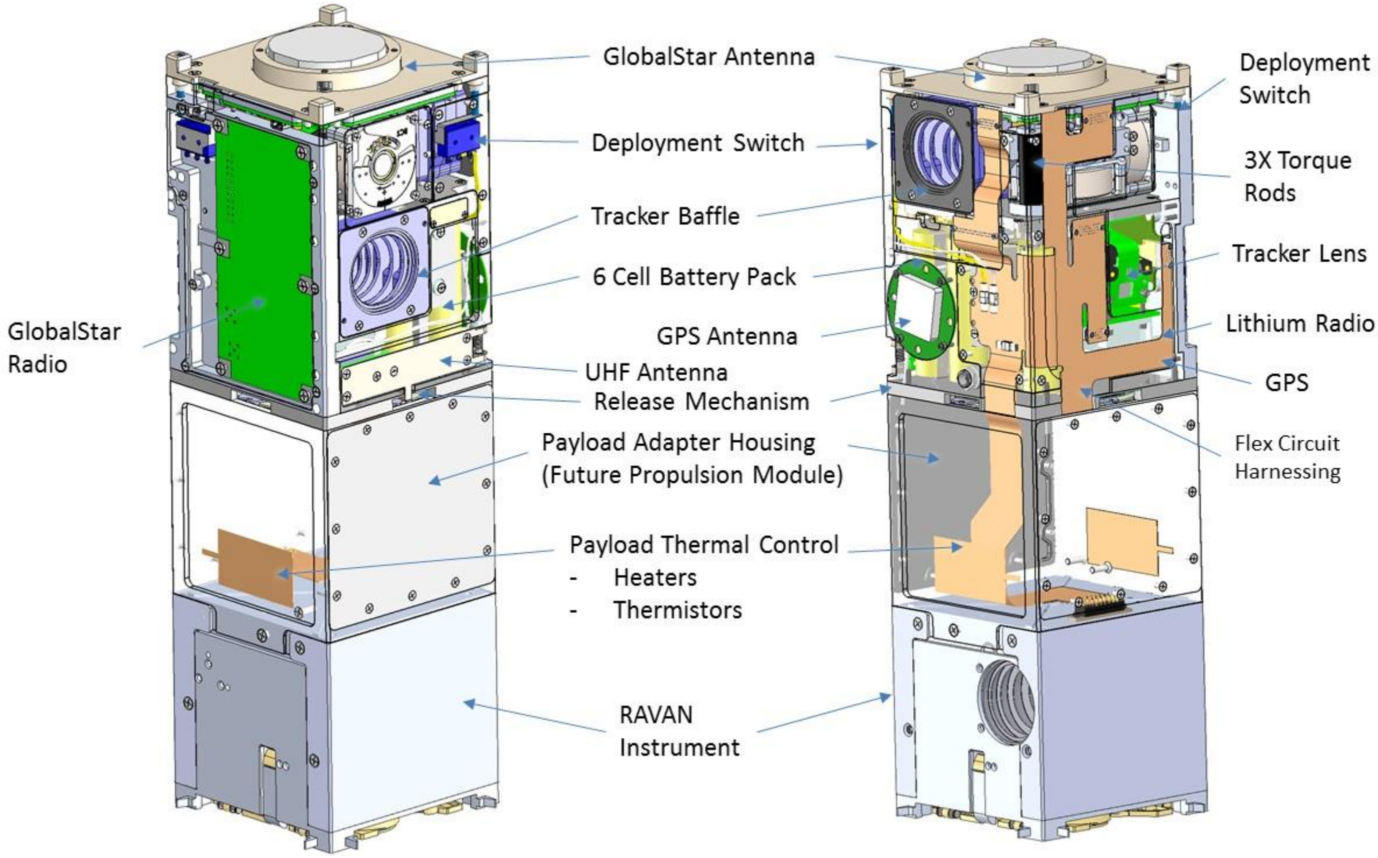

Figure 3. RAVAN Major Components

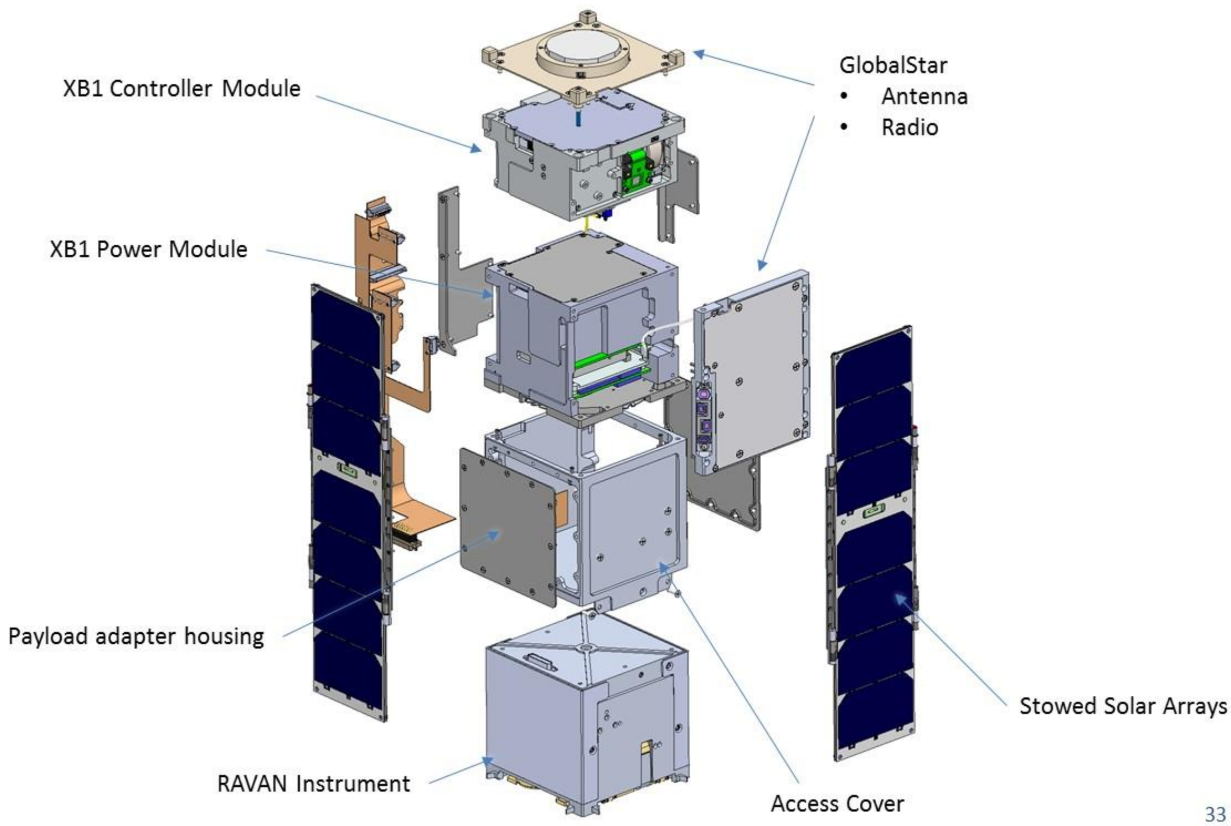

Figure 4. RAVAN Exploded View of Structure

4.1.2 Material Database and Object Parameters

Materials for each object are selected from the standard DAS materials database and no new materials were added. Exact material properties are selected when existing in the database. The material that is closest to the family of the exact material is selected for items not contained in the database. The following properties were applied to RAVAN components:

1. electronic boards – fiberglass
2. wire harness – copper alloy
3. connectors – stainless steel (generic)
4. steel items - stainless steel (generic)
5. torque rods – iron
6. structures – aluminum 6061-T6
7. fasteners - steel A-286
8. solar arrays – fiberglass
9. plastic parts - polymide
10. internal casings - aluminum 6061-T6
11. solar array hinges – titanium (generic)

The analysis uses measured values when available for items and subassemblies contained in the object tree. The mass for all items that were not measured was estimated using the CAD model and the applied material properties. The mass for connectors, wire harness, and fasteners are derived though analysis.

Object sizes are measured values from the CAD model and the thickness of the electronics boards is increased (usually by about a factor of 2 to account for electronic parts) so the volume is consistent with the mass and density of the item.

4.2 Orbital Debris Analysis Results

A summary of the results of orbital debris analyses that were performed are shown in Figure 5. RAVAN is compliant with NS 8719.14A – Process for Limiting Orbital Debris. There are no tethers on RAVAN.

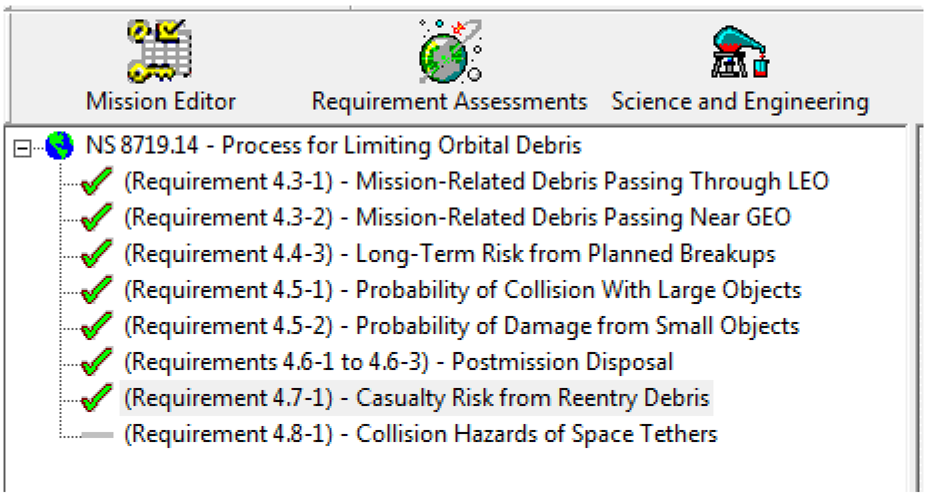

Figure 5. RAVAN Compliance with Orbital Debris Requirements

Numerical results for the risk of human casualty for the total mission is shown in Figure 6. The risk of human casualty is “1:0” and the total casualty area is 0.00m^2. The spacecraft and all of its internal components oblate with no risk to human casualty.

Output

Object Name	Compliance Status	Risk of Human Casualty	SubComponent Object	Demise Altitude (km)	Total Debris Casualty Area ...	Kinetic Energy (J)
RAVAN	Compliant	1:0			0.00	
			Solar Panels	77.3	0.00	0
			Solar Array hi...	0.0	3.02	0
			Solar Array hi...	77.5	0.00	0
			UHF Antenna	0.0	0.40	0
			UHF Antenna ...	77.6	0.00	0

Messages

RAVAN Requirement 4.7-1 Compliant

Figure 6. Risk of Human Casualty

RAVAN is compliant with the requirements contained in NS 8719.14A for orbit lifetime and orbital debris requirements.

5.0 Summary

An orbital debris analysis found the RAVAN 3U CubeSat mission to be compliant with the applicable requirements for spacecraft disposal and risk to human casualty contained in NASA STD 8719.14A. The analysis uses Debris Assessment Software provided by the NASA ODPO and follows the requirement structure of the Process for Limiting Orbital Debris, NASA-STD 8719.14A. RAVAN will be launched into a 600 km altitude, 98.8 deg inclination orbit and spacecraft disposal is accomplished through atmospheric reentry. The spacecraft is estimated to reenter in 7.3 years and is compliant with the requirement to reenter within 25 years after mission completion or 30 years after launch.

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