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Blue Canyon Technologies	**Technical Report**
Title: Orbital Debris Analysis for TEMPEST-D	**Prepared By:** Matthew Pallas

Summary:

An orbital debris analysis found the TEMPEST-D 6U 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. TEMPEST-D will be launched into a 400 km altitude, 51.6 deg inclination orbit and spacecraft disposal is accomplished through atmospheric reentry. The spacecraft is estimated to reenter in 4.55 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. TEMPEST-D meets all applicable requirements for the process of limiting orbital debris.

Revision B updates:

Payload thermal standoffs were changed from titanium to aluminum. The following sections have changed:
Section 3.0: Mass changed from 11.4kg to 11.2kg. Area-to-mass ratio changed from 0.0019m^2/kg to 0.002 m^2/kg.
Figure 2: Figures updated with new results
Section 4.2: Updated 4.7-1 requirement results to show change from titanium standoffs to aluminum.
Figure 5: Updated with new results
Figure 6: Updated with new results

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1.0 Scope

This report summarizes the analyses performed to assess orbital debris for the TEMPoral Experiment for Storms and Tropical Systems – Demonstration (TEMPEST-D) 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 TEMPEST-D analysis was performed using version DAS 2.1.1 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 TEMPEST-D project, which is led by Colorado State University (CSU), with the Jet Propulsion Laboratory (JPL) as a partner, and funded by NASA's Earth Science Technology Office under a government contract.

The objective of the TEMPEST-D mission is to reduce the risk, cost and development time for a future TEMPEST mission. A future five-satellite TEMPEST mission would provide the first temporal observations of cloud and precipitation processes on a global scale. These observations are important to understanding the linkages in and between Earth's water and energy balance and to the understanding of cloud model microphysical processes that are vital to climate change prediction. This understanding will also have significant impact on agricultural forecasting, forest management and disaster preparedness.

2.2 Spacecraft Description

TEMPEST-D is a predominately nadir-pointing, 3-axis controlled, 6U 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 11.5 kg with a volume of 10 cm x 22 cm x 36 cm in the stowed configuration. When fully deployed, the UHF monopole antenna extends approximately 4 cm and the total surface area of the solar panels is 4087 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 TEMPEST-D battery pack is comprised of six 3.5 amp-hour lithium ion battery cells connected in series and parallel to make a nominally 10.5/max 12 Volt battery pack with 7 amp-hour capacity.

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

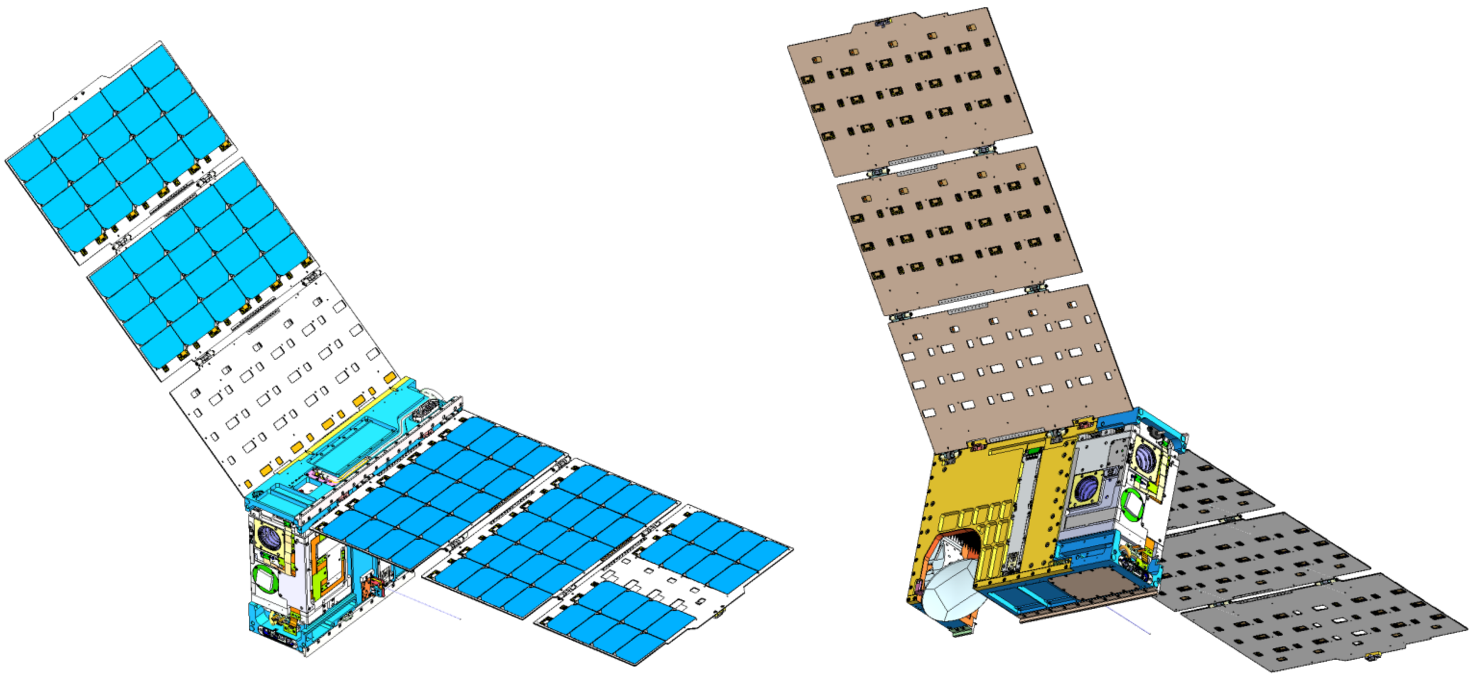

Figure 1. TEMPEST-D Spacecraft with Solar Panels and UHF antenna deployed.

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. TEMPEST-D 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, TEMPEST-D was placed in an initial orbit of 400.2 x 409.5 km altitude, 51.64 deg inclination (i.e. deployed from the International Space Station). 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.

In the nominal operations mode, the spacecraft will have 0.022 m^2 cross sectional area in the orbital velocity vector; this is also the minimum profile/drag area for the spacecraft. The spacecraft mass is 11.5 kg. The area-to-mass ratio is then 0.002 m^2/kg for TEMPEST-D. The inputs to the calculation and the orbit history are shown in Figure 2.

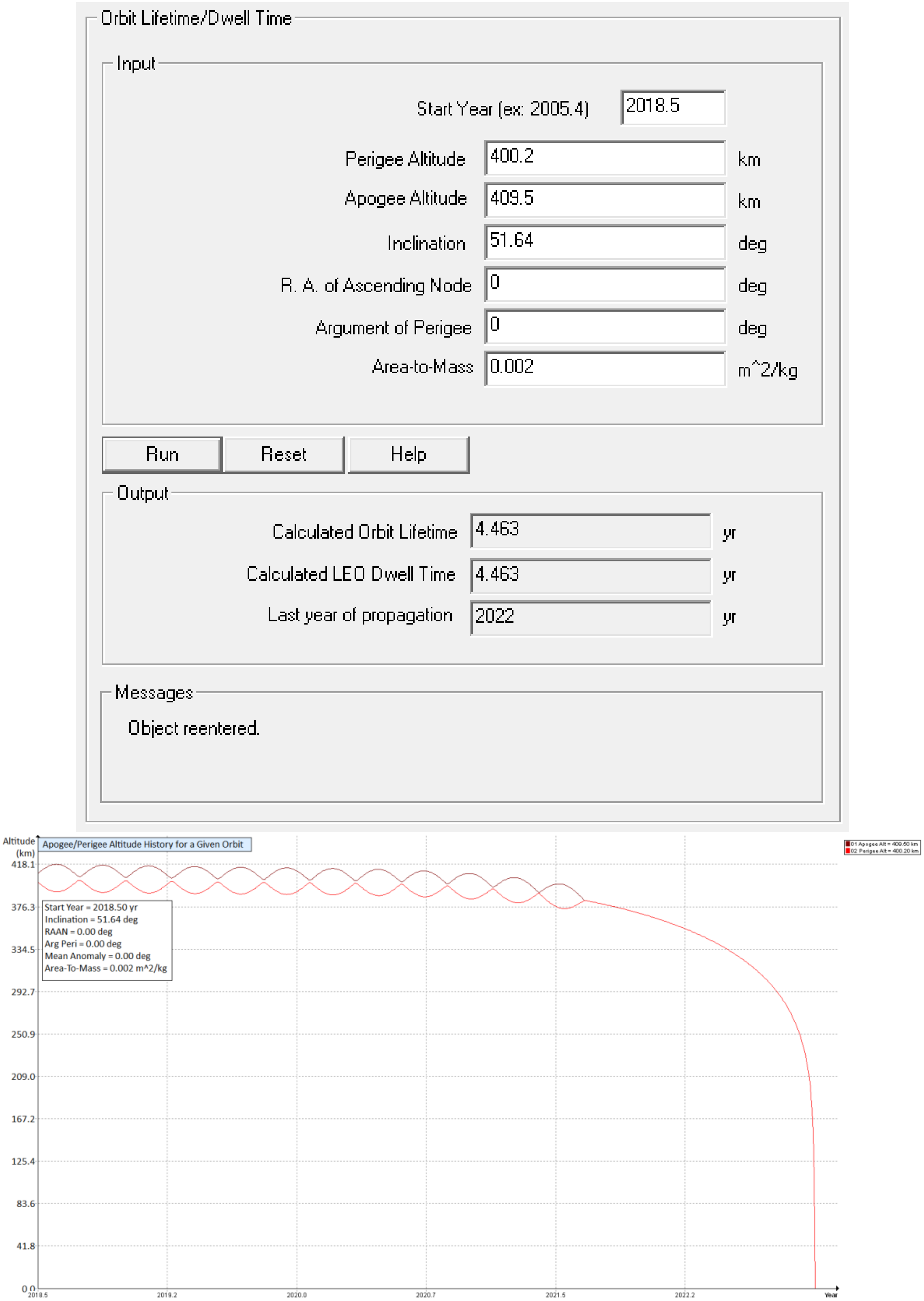

Figure 2. TEMPEST-D Orbit Lifetime/Dwell Time and Orbit Decay

Assuming a June 2018 deployment from the ISS, the orbit dwell time is 4.46 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 2.1.1 Requirements Assessment tools were successfully performed with the exception of collision hazards from space tethers. There are no tethers on TEMPEST-D.

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 TEMPEST-D Components and Object Tree

TEMPEST-D 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 47 objects and nests to the third level of child objects. The root level (0^{th}) object for the object tree is TEMPEST-D. The first level of child objects contains the TEMPEST-D 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 level 1 structures and consists of housings encasing other components. 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 TEMPEST-D spacecraft and Figure 4 shows an exploded view of the TEMPEST-D structure.

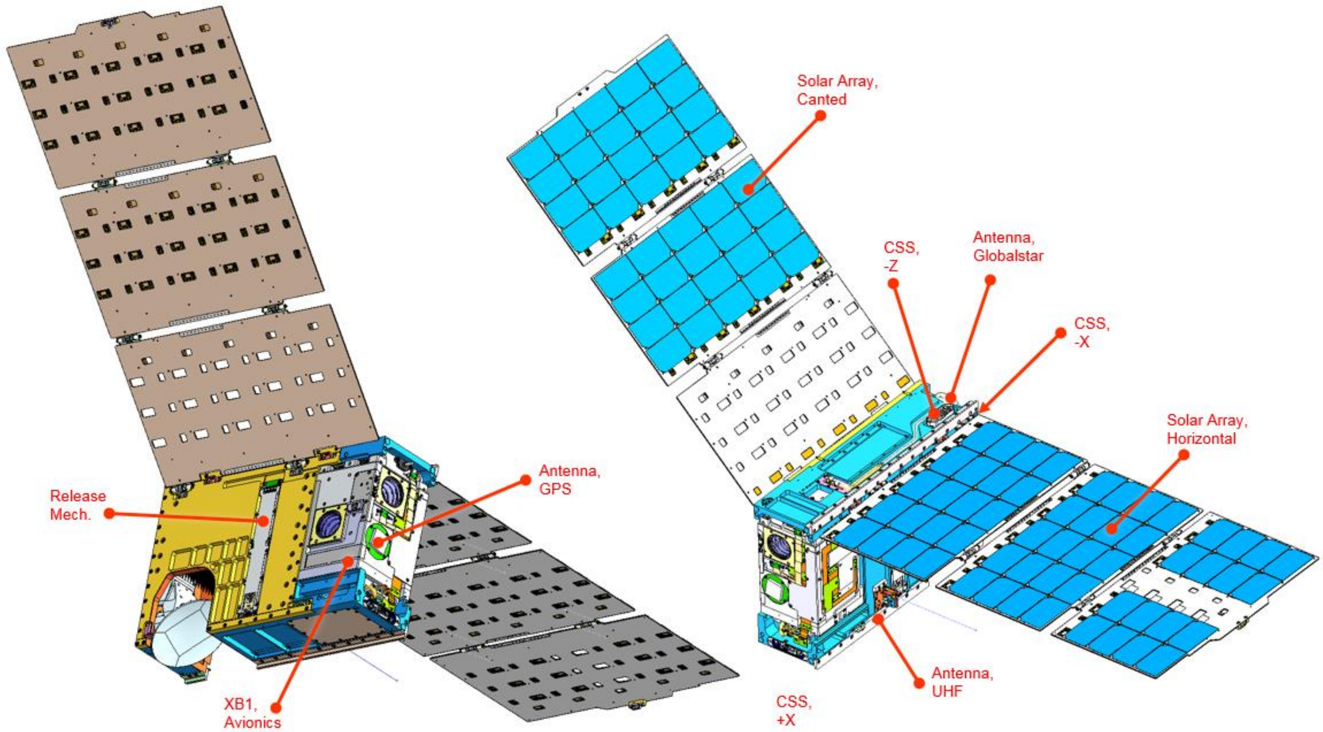

Figure 3. TEMPEST-D Major Components

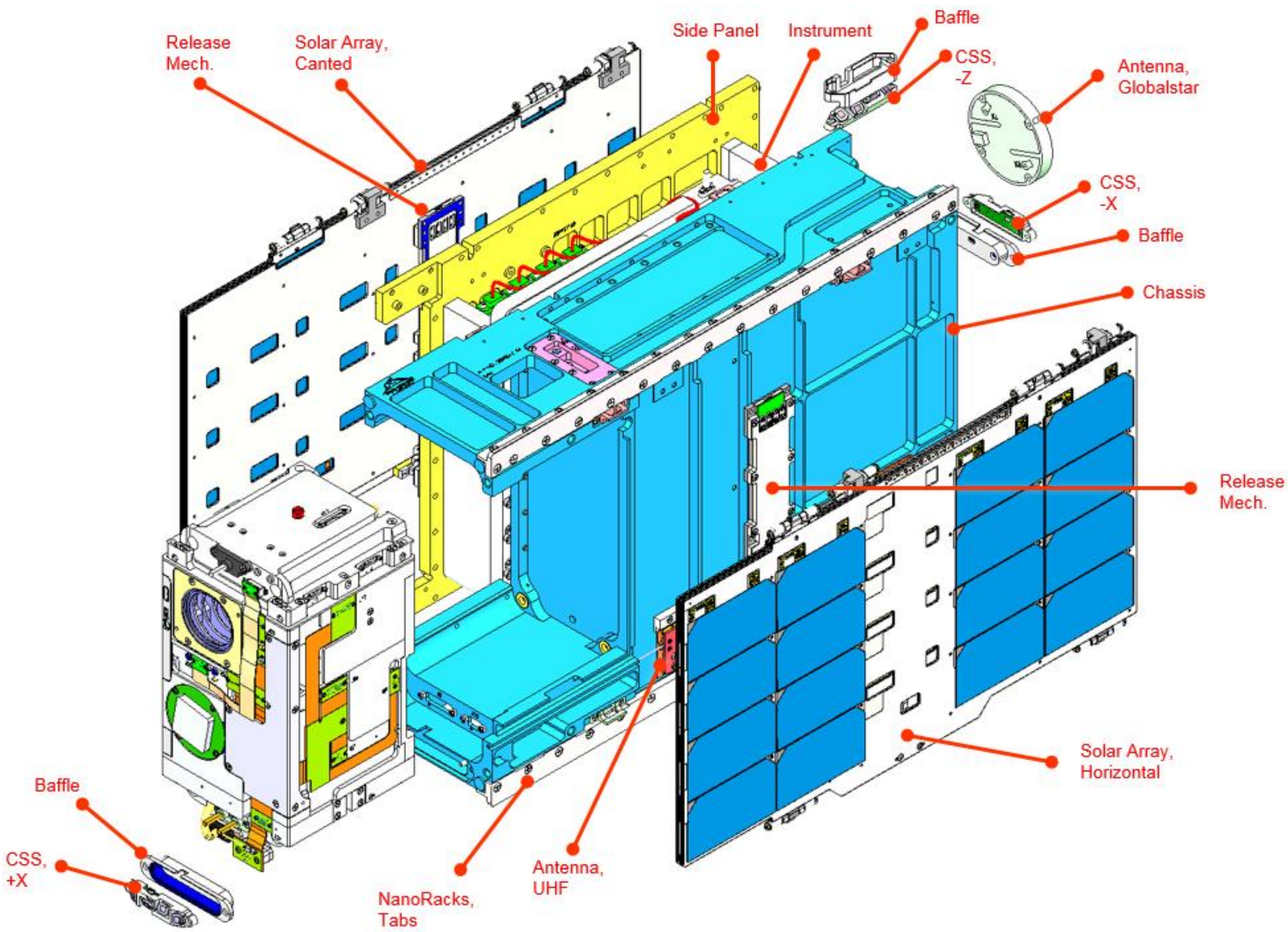

Figure 4. TEMPEST-D Exploded View of Structure

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 TEMPEST-D components:

1. steel items - stainless steel (generic)
2. structures – aluminum 6061-T6
3. rails – aluminum 7075-T6
4. fasteners - steel A-286
5. solar arrays – fiberglass
6. plastic parts - polymide
7. internal casings - aluminum 6061-T6
8. 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.

4.2 Orbital Debris Analysis Results

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

- NS 8719.14 - Process for Limiting Orbital Debris
  - ✓ (Requirement 4.3-1) - Mission-Related Debris Passing Through LEO
  - ✓ (Requirement 4.3-2) - Mission-Related Debris Passing Near GEO
  - ✓ (Requirement 4.4-3) - Long-Term Risk from Planned Breakups
  - ✓ (Requirement 4.5-1) - Probability of Collision With Large Objects
  - ✓ (Requirement 4.5-2) - Probability of Damage from Small Objects
  - ✓ (Requirements 4.6-1 to 4.6-3) - Postmission Disposal
  - ✓ (Requirement 4.7-1) - Casualty Risk from Reentry Debris
  - (Requirement 4.8-1) - Collision Hazards of Space Tethers

Figure 5. TEMPEST-D 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 "1:100,000,000" and the total casualty area is $0.00m^2$. Only one component has a demise altitude of 0km, and the impact kinetic energy is 0J.

Output

Object Name	Compliance Status	Risk of Human Casualty	SubComponent Object	Demise Altitude (km)	Total Debris Casualty Area ...	Kinetic Energy (J)
Tempest-D	Compliant	1:100000000			0.00	
			Chassis	72.3	0.00	0
			Side Panel	74.8	0.00	0
			Rail PSC -1	77.1	0.00	0
			Rail PSC -2	77.3	0.00	0
			Rail PSC -3	77.1	0.00	0

Messages

Tempest-D Requirement 4.7-1 Compliant

Figure 6. Risk of Human Casualty

TEMPEST-D 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 TEMPEST-D 6U 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. TEMPEST-D will be launched into a 400 km altitude, 51.6 deg inclination orbit and spacecraft disposal is accomplished through atmospheric reentry. The spacecraft is estimated to reenter in 4.6 years and is compliant with the requirement to reenter within 25 years after mission completion or 30 years after launch.

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