University of Colorado at Boulder

Orbital Debris Analysis for Challenger

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Revision History

Rev	Date	Change Description	Pages Affected
1	1/12/15	Initial Release	All

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1. SCOPE

This report summarizes the analyses performed to assess orbital debris for the QB-50 Challenger Cubesat 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 Challenger 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. MISSION DESIGN

2.1 MISSION DESCRIPTION

The QB-50 Challenger mission is 2U CubeSat mission, developed by the University of Colorado Aerospace Engineering Department.

2.2 SPACECRAFT DESCRIPTION

Challenger is a solar-pointing, 3-axis-controlled, 2U CubeSat that observes neutral molecules and ions using a mass spectrometer. The spacecraft is designed for use in low earth orbit (LEO) with two deployable solar panels and a deployable UHF monopole antenna. There is a single, fixed solar array panel along the plus X axis. The total spacecraft mass is 1.94 kg with a volume of 10 cm x 25 cm x 10 cm in the stowed configuration. When fully deployed, the spacecraft's monopole antenna extends 72.5cm along the minus Z axis and all three solar panels are sun facing. Sun sensors cover the surface of the spacecraft and provide the primary method of attitude determination.

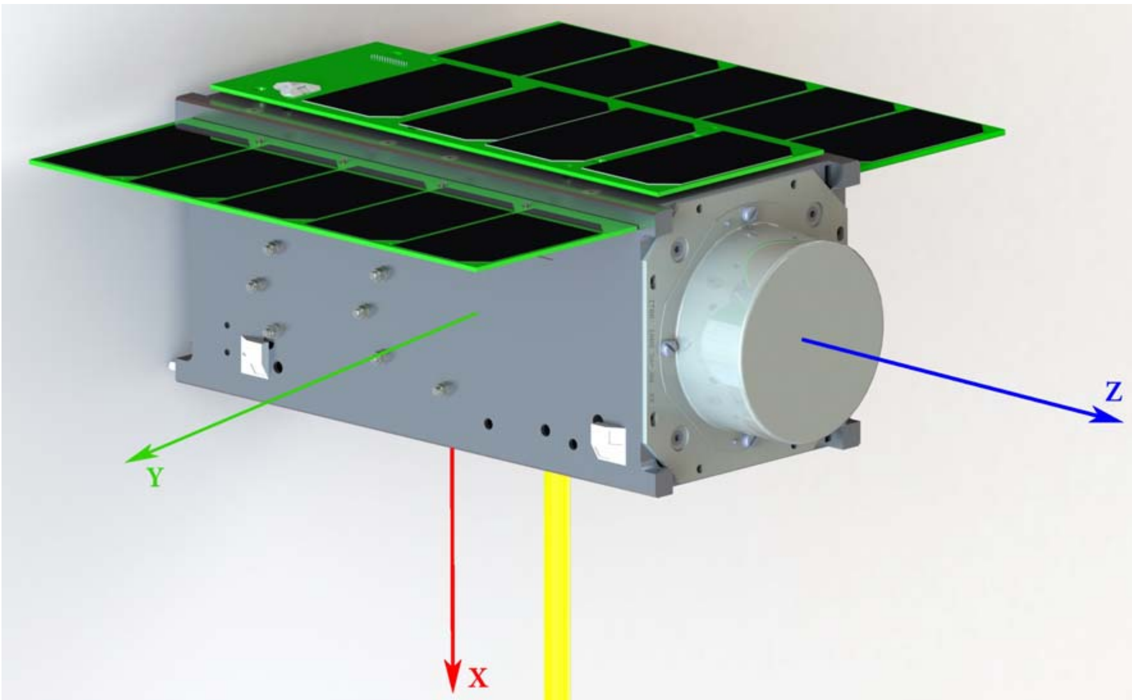


Figure 1, Challenger with the solar arrays and monopole antenna deployed.

Challenger's attitude system is custom designed and includes three torque rods, magnetometers, gyroscopes, and sun sensors. The spacecraft also has a GPS for position and time knowledge. The Challenger battery pack is comprised of four 2 amp-hour lithium polymer batteries connected in series and parallel to make an 8.4 Volt battery pack with 4 amp-hour capacity.

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

3. ORBIT LIFETME

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. Challenger 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, Challenger adopts the initial orbit parameters recommended by NASA's Kennedy Spaceflight Center (KSC) for CubeSats being deployed from the ISS: 399 x 408 km altitude, 51.6° inclination. DAS software is used to calculate the cross sectional area of the spacecraft for random tumbling and the solid model of the spacecraft used to predict its mass.

A 0.04 m^2 cross sectional area was estimated using the “Calculate the Cross Sectional Area” in the DAS Science and Engineering toolbox.

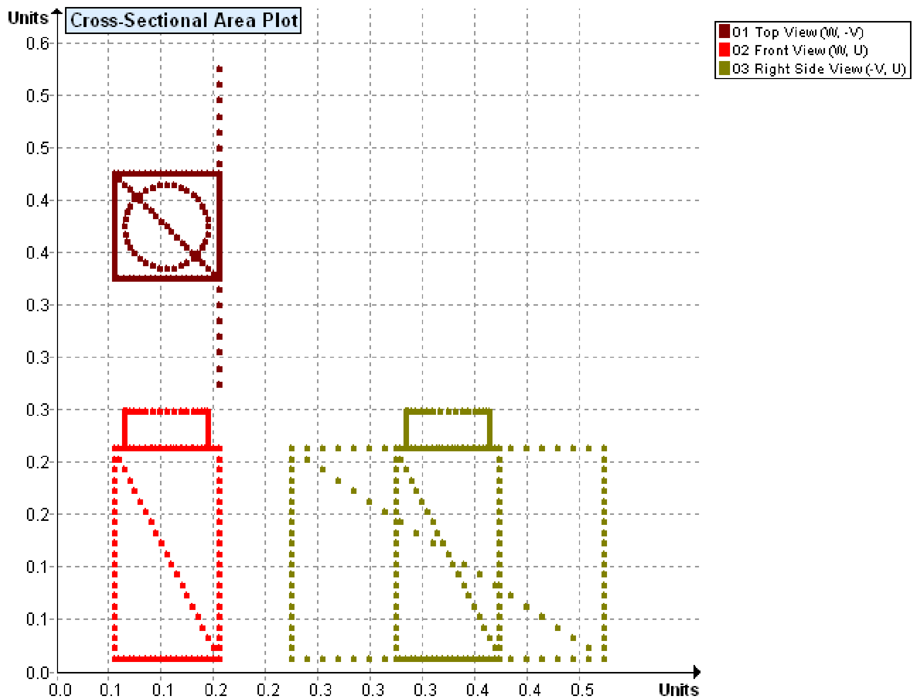


Figure 2, Challenger Cross Sectional Area Plot

The measured mass is 1.94 kg. The area-to-mass ratio is then 0.0206 for Challenger in the fully deployed configuration. The inputs to the calculation and the orbit history are shown in Figure 3, Challenger Orbit Lifetime/Dwell Time and Orbit Decay.

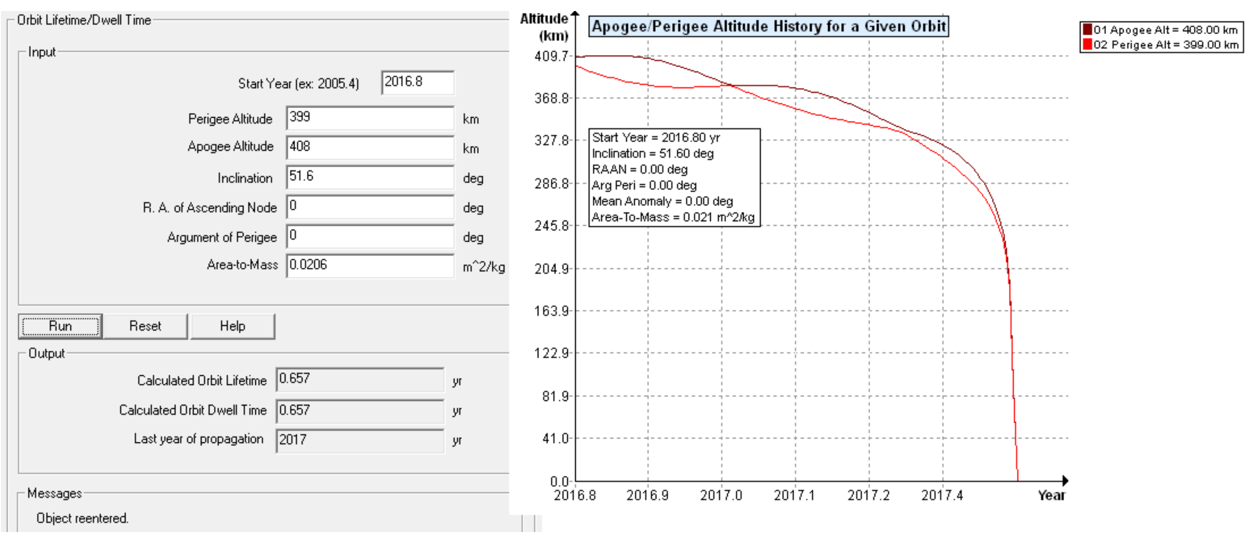


Figure 3, Challenger Orbit Lifetime/Dwell Time and Orbit Decay

Assuming an August, 2016 deployment from the International Space Station (ISS), the orbit dwell time is 0.66 years (7.9 months), meeting 8719.14 through atmospheric reentry within 25 years of mission completion or 30 years from launch.

4. 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 Challenger.

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 76 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 Challenger Components and Object Tree

Challenger 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 21 objects and nests to the third level of child objects. The root level (0^{th}) object for the object tree is Challenger. The first level of child objects contains the Challenger structure, the global star antenna, and items that reside on the outside of the spacecraft such as: solar array hinge pieces, and solar arrays. The second level of child objects contains components inside the level one structures and consists of housings encasing other components, electronics boards, batteries, wire harness, fasteners, and connectors. Finally on the third level are only the torque rods connected to the EPS board.

4.1.2 Material Data Base and Object Parameters

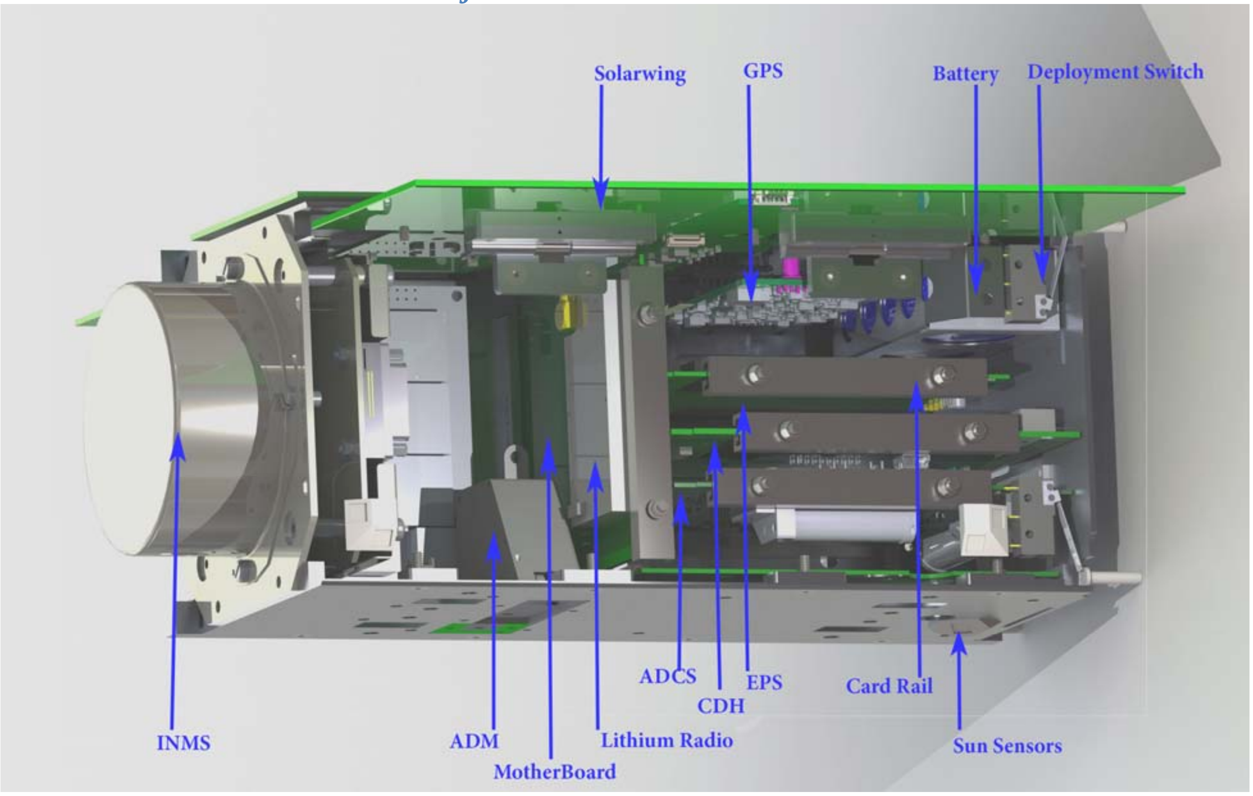


Figure 4, Challenger Major Components

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 Challenger components:

1. electronic boards – fiberglass
2. wire harness – copper alloy
3. connectors – polyimide
4. steel items - steel AISI 321
5. torque rods – copper alloy
6. structures – aluminum 6061-T6
7. fasteners - steel AISI 316
8. solar arrays – fiberglass
9. plastic parts - polyimide
10. internal casings - aluminum 6061-T6
11. INMS - aluminum 6061-T6
12. Global Star Antenna – Macor Ceramic

The analysis uses measured values for most items and subassemblies contained in the object tree. The mass for all major structures, electronics boards, and the science instrument are measured values. The mass for connectors, wire harness, and fasteners are derived though analysis.

Object sizes are measured values 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, Challenger Compliance with Orbital Debris Requirements. Challenger is compliant with NS 8719.14A – Process for Limiting Orbital Debris. There are no tethers on Challenger.

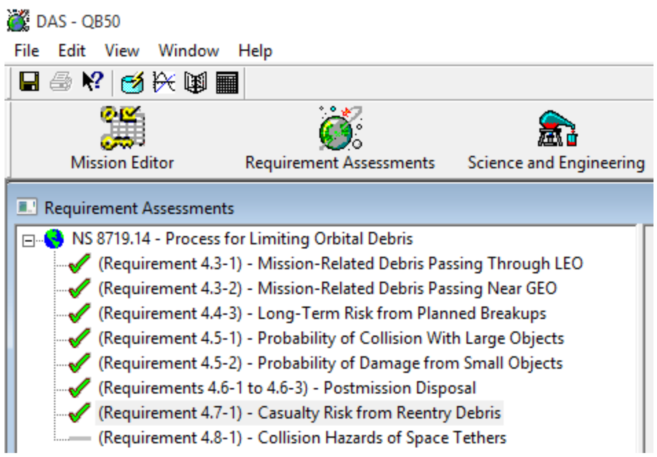
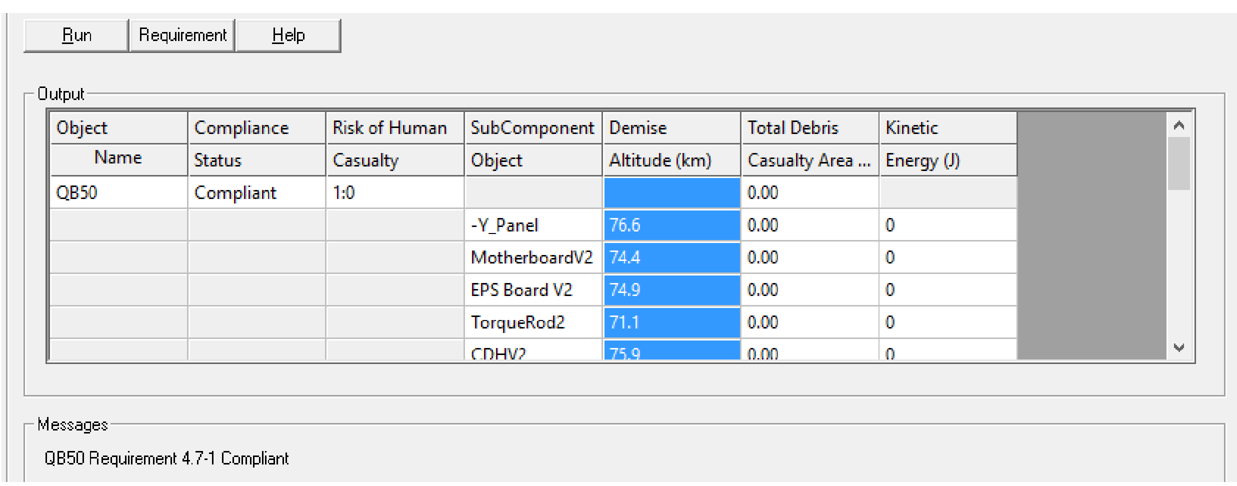


Figure 5, Challenger Compliance with Orbital Debris Requirements

Numerical results for the risk of human casualty for the total mission is shown in Figure 6, Risk of Human Casualty. The risk of human casualty is "1:0" (or zero) and the total casualty area is $0.00 m^2$. The spacecraft and all of its internal components ablate at approximately 69 km in altitude. The last component to ablate is the lithium polymer battery as it has the largest thermal density.



Object Name	Compliance Status	Risk of Human Casualty	SubComponent Object	Demise Altitude (km)	Total Debris Casualty Area ...	Kinetic Energy (J)
QB50	Compliant	1:0			0.00	
			-Y_Panel	76.6	0.00	0
			MotherboardV2	74.4	0.00	0
			EPS Board V2	74.9	0.00	0
			TorqueRod2	71.1	0.00	0
			CDHV2	75.9	0.00	0

Figure 6, Risk of Human Casualty

Challenger 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 Challenger 2U 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. Challenger will be deployed from the ISS and spacecraft disposal is accomplished through atmospheric reentry. The spacecraft is estimated to reenter in 0.66 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 the users guide to provide a realistic reentry model and used the standard materials database provided in the application. Challenger meets all applicable requirements for the process of limiting orbital debris. The total risk of human casualty is zero and the total debris casualty area is zero.