**Laboratory for Atmospheric and Space Physics**
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# Orbital Debris Analysis Report for CIRBE

**Document No.** 168988, Orbital Debris Analysis Report
**Satellite Primary Serial Number: CIRBE**

| | Title | Name |
|---|---|---|
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## Revision History

| Rev | Date | Change Description | Pages Affected |
|---|---|---|---|
| 1 | 3/18/2021 | Initial Release | All |
| 2 | 6/28/2021 | Added section on large object collision risk, added information on objects that do not demise on reentry, updated software references to DAS 3.1.1 | 6,8,9 |
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# 1. Scope

This report summarizes the analyses performed to assess orbital debris for the Cubesat Inner Radiation Belt Experiment (CIRBE) 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 analysis was performed using version DAS 3.1.1 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. Mission design

## 2.1 Mission Description

The objective of the Colorado Inner Radiation Belt Experiment (CIRBE) is to understand the formation of the inner belt (L<2) electrons (100s of keV to a few MeV), and to determine the source, intensity, and dynamic variations of these electrons using a novel instrument fitted into a 3U (10x10x34 cm3) CubeSat in a highly inclined low earth orbit (LEO). CIRBE's inclination is dictated by the science requirements to reach the L=4 belt, which corresponds to an invariant latitude of 60°. Orbit altitudes greater than 400km and inclinations greater than 50° are the acceptable orbit parameters to meet the science requirements; these parameters are also suitable for using LASP's existing UHF and S-band ground stations (40° N latitude). CIRBE would gather better science data by increasing both altitude and inclination; therefore, a sun-synchronous 550 km and 98° inclination has been identified as CIRBE's optimal orbit. CIRBE's mission life is dependent on altitude and spacecraft longevity, with mission success defined by a minimum 4-month lifetime (1-month commissioning, 3+ months science operations). The mission's ground segment is located at the Laboratory for Atmospheric and Space Physics (LASP) in Boulder, Colorado and includes mission operations, the UHF ground station operating at 437.25 MHz, the S-band ground station operating at 2.402 GHz, science and engineering data processing, and data distribution.

## 2.2 Spacecraft description

CIRBE is a 3-axis-controlled, 3U CubeSat that measures the intensity and spectral distribution of relativistic electrons and protons. CIRBE's science instrument is the Relativistic Electron Proton Telescope integrated little experiment-2 (REPTile-2), which is being designed and built at LASP. The spacecraft bus is 3rd generation XB1 spacecraft being designed and built by Blue Canyon Technologies (BCT) in Boulder, Colorado. The spacecraft is designed for LEO and has two deployable solar panels and a deployable UHF monopole antenna. CIRBE also has antennas for an S-band transmitter and GPS receiver. The total spacecraft mass is 6.0 kg with a volume of 10 cm x 10 cm x 34 cm in the stowed configuration. The CIRBE CubeSat is shown in Figure 1, CIRBE with solar arrays deployed.

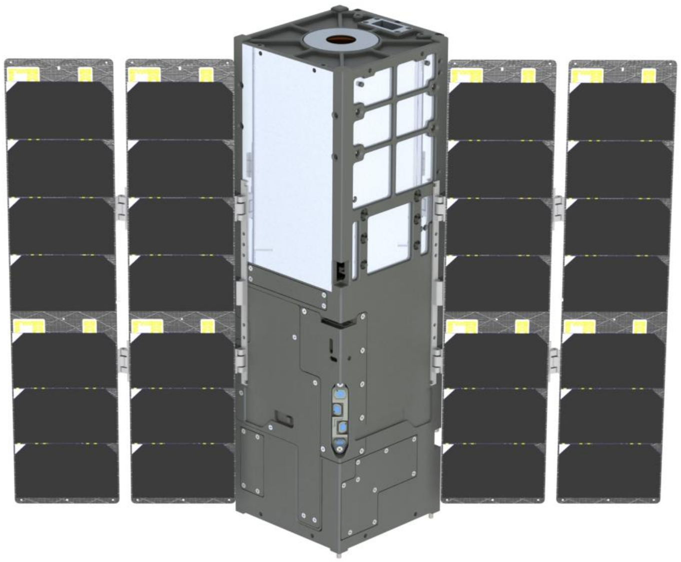

**Figure 1, CIRBE with solar arrays deployed**

The 3-axis inertial pointing system (from BCT) contains 3 reaction wheel assemblies, 3 torque rods, a miniaturized star tracker, and a processor board all contained in a ½ U unit that is attached to the -Z side of the main body of the spacecraft. The CIRBE battery pack made up of six 4.2 V, 3.4 A-hr lithium ion batteries connected in a 3-series, 2-parallel (3S2P) configuration to make a 12.6 V battery pack with a 6.8 A-hr capacity.

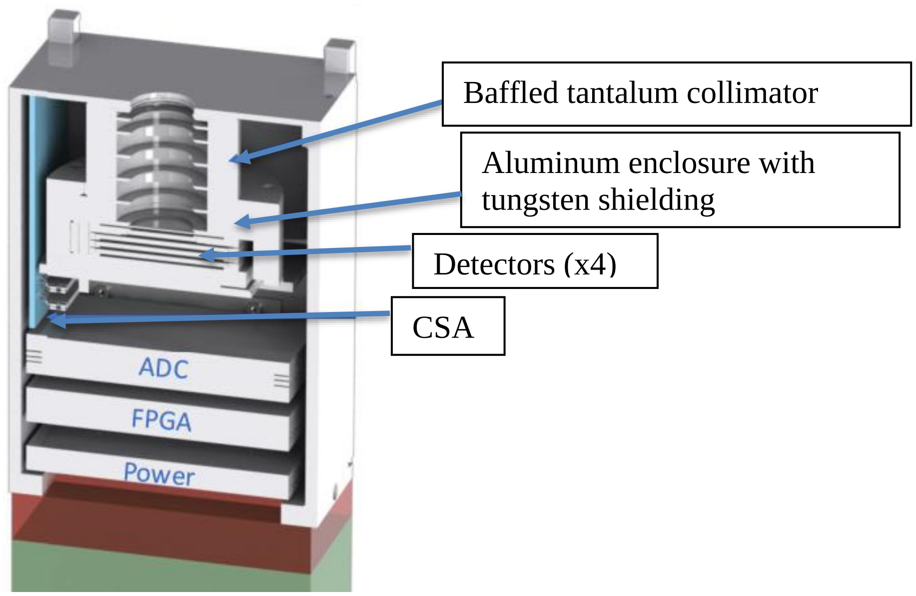


**Figure 2, Payload cutaway showing REPTile-2, heavy metal shielding, and electronics boards**

REPTile-2 contains four silicon detectors housed in tungsten shielding and a baffled tantalum collimator along the instrument's boresight. The tungsten shielding is made from a tungsten-epoxy composite ring around the detectors, with thin tungsten discs stacked at the front and back. The detectors, shielding, and collimator are all contained within an aluminum housing. The instrument has four associated electronics boards: a power board, a processor board with a field programmable gate array (FPGA), an analog-to-digital converter (ADC) board, and a charge sensitive amplifier (CSA) board. Tungsten and tantalum components are only contained in the payload. The payload is shown in Figure 2, Payload cutaway showing REPTile-2, heavy metal shielding, and electronics boards.

With the exception of two transmit antennas, all sensors and components on CIRBE are passive. There are no lasers, radiation sources, propellants, pressure vessels, or other hazardous materials on board the spacecraft.

# 3. 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. CIRBE 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, CIRBE uses the orbital parameters determined by the primary payload - 550 km orbit with an inclination of 98°.

CIRBE has a mass of 6 kg and has an average cross-sectional area of 0.084 $m^2$ as calculated by the DAS random tumbling tool. This results in an area-to-mass ratio of 0.014 $m^2$/kg for CIRBE in the deployed configuration. The inputs to the calculation and the orbit history are shown in Figure 3, CIRBE Orbit Lifetime/Dwell Time and Orbit Decay.

In the fully deployed configuration with a cross-sectional area of 0.084 $m^2$, the orbit lifetime is 6.1 years. In a failure-to-deploy configuration with a cross-sectional area of 0.049 $m^2$, the orbit lifetime is 12.8 years. These analyses meet the 8719.14 disposal requirements through atmospheric reentry within 25 years of mission completion or 30 years from launch.

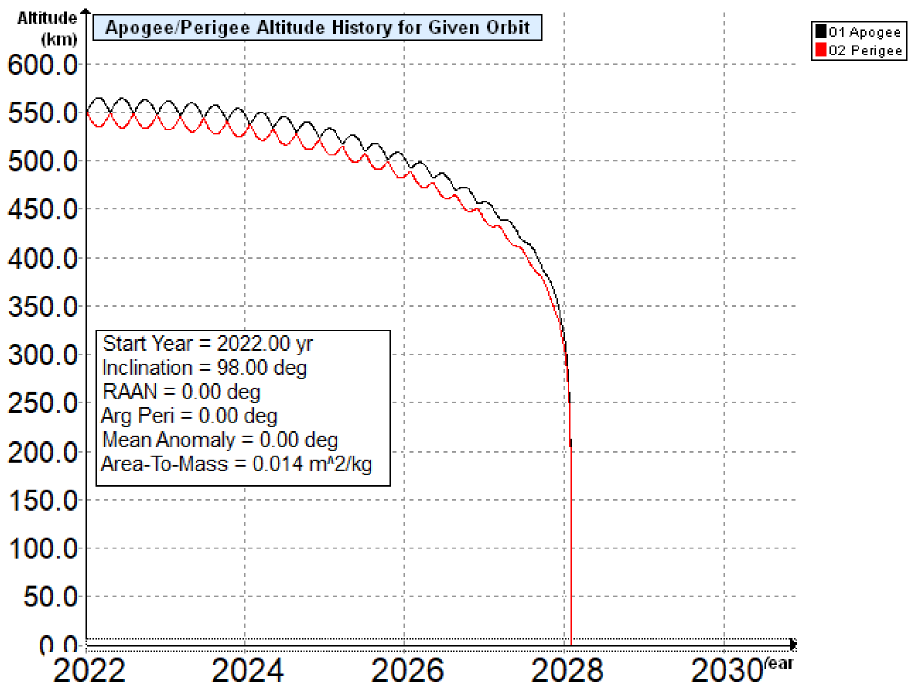


**Figure 3, CIRBE Orbit Lifetime/Dwell Time and Orbit Decay**

# 4. Orbital Debris Requirements

The 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 3.1.1 Requirements Assessment tools were successfully performed. CIRBE does not contain tethers.

## 4.1 Model Construction

In the calculation to determine the risk of human casualty, the arrangement of each space structure element is defined to realistically assess its reentry survival potential. The model is based on successive sets of layered shells with a parent-child relationship. 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 altitude at which their immediate parent is destroyed.

### 4.1.1 CIRBE Components and Object Tree

CIRBE 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 36 objects and nests to the fourth level of child objects. The root level ($0^{th}$) object for the object tree is CIRBE as a whole. The first level of child objects contains the REPTile-2 structure, the ADCS structure, the card-cage structure, and items that reside on the outside of the spacecraft such as: solar arrays, antennas, deployment switches, external mechanical components like solar array release mechanisms. The second level of child objects contains components inside the level-1 structures and consists of housings encasing other components, electronics boards, batteries, radios, reaction wheels, and torque rods. The third level of child objects contains the heavy-metal components housed inside the instrument level-2 housing; this includes tantalum and tungsten shielding. The fourth level of child objects is simply the tungsten powder contained within the tungsten-epoxy composite. An overview of components is shown in Figure 4, CIRBE with callouts for major components.

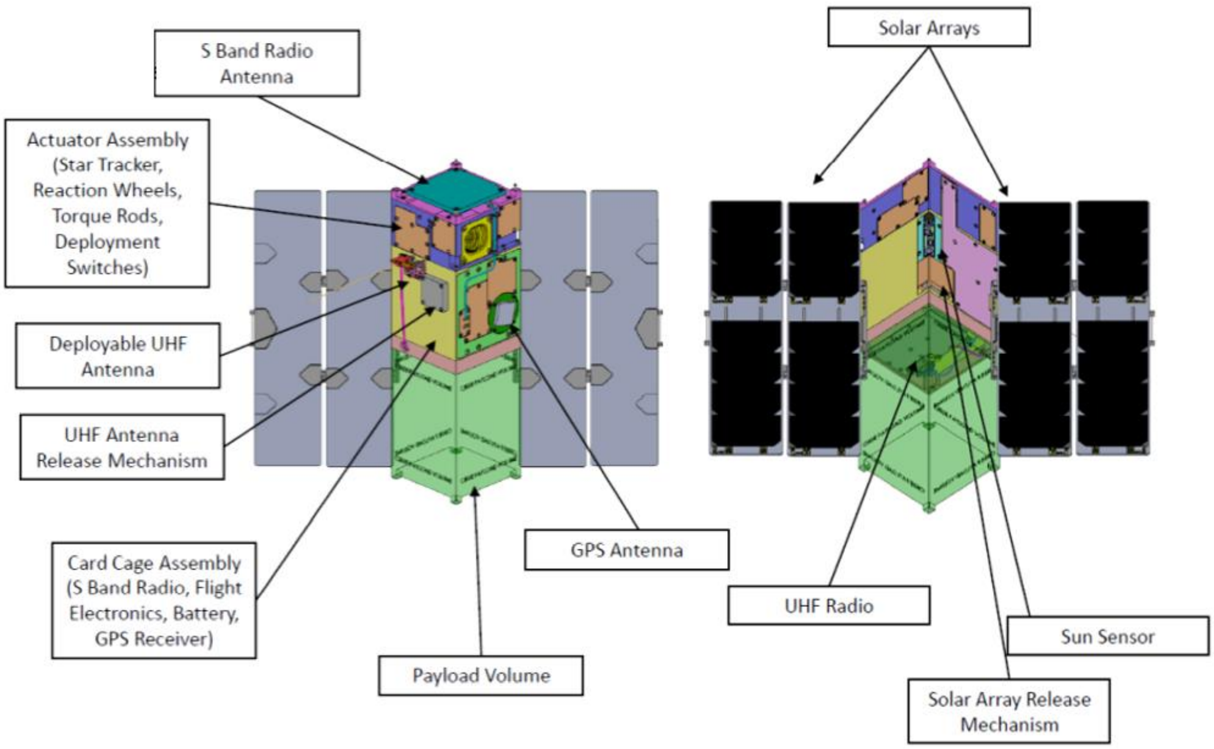


Figure 4, CIRBE with callouts for major components

### 4.1.2 Material Data Base and Object Parameters

Materials for each object are selected from the standard DAS materials database with the exception of tantalum, which was added to the DAS materials database. The following properties were applied to CIRBE components:

1. electronic boards – fiberglass
2. steel items – stainless steel (generic)
3. torque rods – copper alloy
4. reaction wheels – stainless steel (generic)
5. structures – aluminum 6061-T6
6. fasteners – stainless steel (generic)
7. solar arrays – fiberglass
8. internal housings – aluminum 6061-T6
9. instrument shielding– tungsten
10. instrument collimator – tantalum
11. monopole antenna – brass

The analysis uses mass and size values from the CIRBE CAD model. Some object sizes and the thickness of the electronics boards was increased (by a factor of up to 2 to account for electronic parts) so the volume is consistent with the mass and density of the item.

The cylindrical tungsten shielding in REPTile2 is made from a composite mixture of tungsten powder and epoxy resin. Epoxy material properties are not available in DAS software, so this shielding was conservatively modeled using polyamide instead, as polyamide has a slightly higher density and glass transition temperature than epoxy resin. The tungsten powder was modeled with a particle size of 0.15mm to correspond to the maximum particle size.

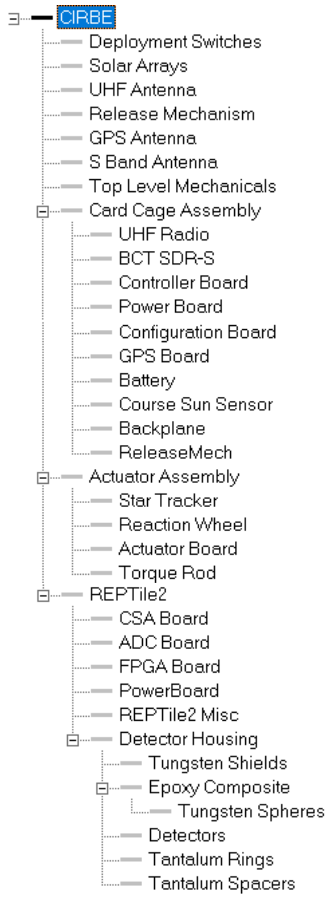


Figure 5, CIRBE object tree

## 4.2 Probability of Collision with Large Objects

CIRBE is compliant with Requirement 4.5-1 *Limiting Debris Generated by Collisions with Large Objects* in both its stowed and deployed configurations. CIRBE's area-to-mass ratio is 0.0082 $m^2$/kg for the stowed configuration and 0.014 $m^2$/kg for the deployed configuration. Results from the DAS 3.1.1 analysis are shown in Figure 6 and Figure 7. These results show that both CIRBE configurations are compliant, with less than 0.001 probability of an accidental collision with large space objects.

| | Space Structure | Compliance Status | Collision Probability |
|---|---|---|---|
| CIRBE | Payload | Compliant | 1.1713E-06 |

Figure 6, Large object collision analysis for deployed configuration

| | Space Structure | Compliance Status | Collision Probability |
|---|---|---|---|
| CIRBE | Payload | Compliant | 1.4646E-06 |

Figure 7, Large object collision analysis for stowed configuration

## 4.3 Orbital Debris Analysis Results

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

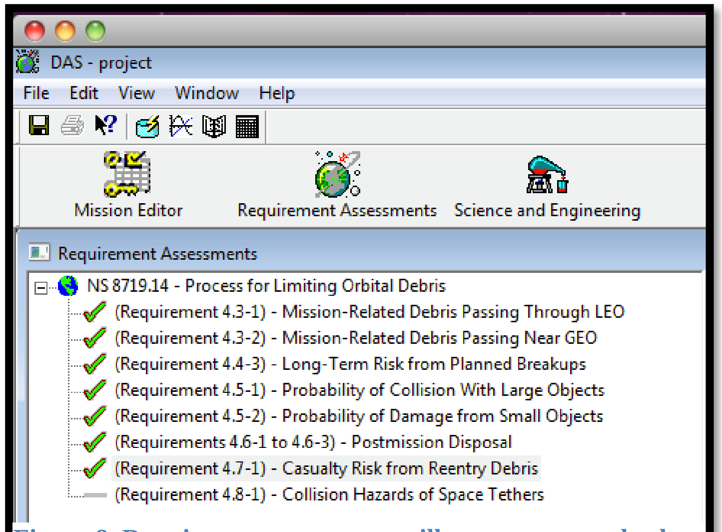

**Figure 8, Requirements assessment illustrates green check marks for compliance with each orbital debris requirement.**

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 0.00m$^2$. The spacecraft and all of its internal components ablate at altitudes between 78 km and 61 km and with the exception of the heavy metal components in REPTile-2 which do not ablate. The casualty assessment calculated by DAS only considers objects with more than 15 Joules of kinetic energy. There are no components that re-entered with greater than 3.5 joules of kinetic energy, resulting in a total casualty area of 0.00 m$^2$ for CIRBE. CIRBE is compliant with the requirements contained in NS 8719.14A for orbit lifetime and orbital debris requirements.

| Object Name | Compliance Status | Risk of Human Casualty | SubComponent Object | Demise Altitude (km) | Total Debris Casualty Area ... | Kinetic Energy (J) |
|---|---|---|---|---|---|---|
| CIRBE | Compliant | 1:100000000 | | | 0.00 | |
| | | | Deployment S... | 75.4 | 0.00 | 0.00 |
| | | | Solar Arrays | 77.2 | 0.00 | 0.00 |
| | | | UHF Antenna | 75.2 | 0.00 | 0.00 |
| | | | Release Mech... | 76.6 | 0.00 | 0.00 |
| | | | GPS Antenna | 77.2 | 0.00 | 0.00 |

**Figure 9, CIRBE is compliant with casualty area debris requirements**

There are no noncompliant reentry objects on the CIRBE spacecraft, all objects are compliant with kinetic energy threshold requirements. The objects that do not demise in the DAS 3.1.1 reentry analysis include twelve pieces of tungsten shielding and eight pieces of tantalum shielding. The reentry energy of these objects given in Figure 10. Objects can be referenced in rows 32 and 35 in the appendix.

| SubComponent Object | Demise Altitude (km) | Total Debris Casualty Area (m**2) | Kinetic Energy (J) |
|---|---|---|---|
| Tungsten Shields | 0.0 | 5.23 | 3.31 |
| Tantalum Spacers | 0.0 | 3.26 | 2.45 |

**Figure 10, Kinetic energy of objects which do not demise during reentry**

# 5.0 Summary

An orbital debris analysis found the CIRBE 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. CIRBE is expected to launch in Q3 2022 and spacecraft disposal is accomplished through atmospheric reentry. The spacecraft is estimated to reenter in 6.1 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, Appendix) were nested according the users guide to provide a realistic reentry model and used the standard materials database provided in the application. CIRBE 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.

# 6.0 APPENDIX

| Row | Name | Parent | Qty | Material | Body Type | Thermal Mass | Diameter/ Width | Length | Height |
|---|---|---|---|---|---|---|---|---|---|
| 1 | CIRBE | 0 | 1 | Aluminum 6061-T6 | Box | 6 | 0.17 | 0.17 | 0.17 |
| 2 | Deployment Switches | 1 | 3 | Stainless Steel (generic) | Box | 0.005 | 0.013 | 0.02 | 0.006 |
| 3 | Solar Arrays | 1 | 2 | Fiberglass | Box | 0.243 | 0.15 | 0.326 | 0.001 |
| 4 | UHF Antenna | 1 | 1 | Brass- Cartridge | Box | 0.049 | 0.025 | 0.031 | 0.006 |
| 5 | Release Mechanism | 1 | 1 | Aluminum 6061-T6 | Box | 0.016 | 0.033 | 0.033 | 0.008 |
| 6 | GPS Antenna | 1 | 1 | Fiberglass | Box | 0.02 | 0.045 | 0.045 | 0.005 |
| 7 | S Band Antenna | 1 | 1 | Fiberglass | Box | 0.049 | 0.076 | 0.076 | 0.0038 |
| 8 | Top Level Mechanicals | 1 | 1 | Aluminum 6061-T6 | Box | 0.242 | 0.12 | 0.12 | 0.05 |
| 9 | Card Cage Assembly | 1 | 1 | Aluminum 6061-T6 | Box | 0.72 | 0.1 | 0.105 | 0.1 |
| 10 | UHF Radio | 9 | 1 | Aluminum 6061-T6 | Box | 0.128 | 0.057 | 0.082 | 0.015 |
| 11 | BCT SDR-S | 9 | 1 | Aluminum 6061-T6 | Box | 0.143 | 0.08 | 0.095 | 0.016 |
| 12 | Controller Board | 9 | 1 | Fiberglass | Box | 0.065 | 0.091 | 0.097 | 0.0075 |
| 13 | Power Board | 9 | 1 | Fiberglass | Box | 0.056 | 0.091 | 0.097 | 0.0075 |
| 14 | Configuration Board | 9 | 1 | Fiberglass | Box | 0.075 | 0.091 | 0.097 | 0.0075 |
| 15 | GPS Board | 9 | 1 | Fiberglass | Box | 0.038 | 0.046 | 0.071 | 0.003 |
| 16 | Battery | 9 | 1 | Aluminum 6061-T6 | Box | 0.461 | 0.076 | 0.097 | 0.038 |
| 17 | Course Sun Sensor | 9 | 1 | Aluminum 6061-T6 | Box | 0.005 | 0.011 | 0.053 | 0.0076 |
| 18 | Backplane | 9 | 1 | Fiberglass | Box | 0.048 | 0.075 | 0.096 | 0.003 |
| 19 | Release Mechanism | 9 | 1 | Aluminum 6061-T6 | Box | 0.016 | 0.033 | 0.033 | 0.008 |
| 20 | Actuator Assembly | 1 | 1 | Aluminum 6061-T6 | Box | 0.4 | 0.1 | 0.1 | 0.055 |
| 21 | Star Tracker | 20 | 1 | Aluminum 6061-T6 | Box | 0.086 | 0.045 | 0.095 | 0.045 |
| 22 | Reaction Wheel | 20 | 3 | Stainless Steel (generic) | Box | 0.119 | 0.042 | 0.042 | 0.019 |
| 23 | Actuator Board | 20 | 1 | Fiberglass | Box | 0.029 | 0.087 | 0.094 | 0.003 |
| 24 | Torque Rod | 20 | 3 | Copper Alloy | Box | 0.028 | 0.013 | 0.04 | 0.013 |
| 25 | REPTile2 | 1 | 1 | Aluminum 6061-T6 | Box | 0.7 | 0.1 | 0.105 | 0.1 |
| 26 | CSA Board | 25 | 1 | Fiberglass | Box | 0.1 | 0.08 | 0.08 | 0.005 |
| 27 | ADC Board | 25 | 1 | Fiberglass | Box | 0.1 | 0.08 | 0.08 | 0.005 |
| 28 | FPGA Board | 25 | 1 | Fiberglass | Box | 0.1 | 0.08 | 0.08 | 0.005 |
| 29 | Power Board | 25 | 1 | Fiberglass | Box | 0.1 | 0.08 | 0.08 | 0.005 |
| 30 | REPTile2 Misc | 25 | 1 | Aluminum 6061-T6 | Box | 0.1 | 0.02 | 0.02 | 0.02 |
| 31 | Detector Housing | 25 | 1 | Aluminum 6061-T6 | Box | 0.25 | 0.06 | 0.08 | 0.06 |
| 32 | Tungsten Shields | 31 | 12 | Tungsten | Flat Plate | 0.027 | 0.06 | 0.06 | 0 |
| 33 | Tungsten Ring | 31 | 1 | Tungsten Composite | Box | 0.159 | 0.05 | 0.05 | 0.01 |
| 34 | Detectors | 31 | 4 | Silicon | Flat Plate | 0.02 | 0.04 | 0.04 | 0 |
| 35 | Tantalum Spacers | 31 | 8 | Tantalum | Flat Plate | 0.015 | 0.015 | 0.1 | 0 |
| 36 | Epoxy Composite | 31 | 1 | Polyamide | Box | 0.065 | 0.05 | 0.05 | 0.01 |
| 37 | Tungsten Spheres | 37 | 750000 | Tungsten | Sphere | 0.0000002 | 0.0003 | 0 | 0 |