Laboratory for Atmospheric and Space Physics
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Orbital Debris Analysis for CSIM

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1. Scope

This report summarizes the analyses performed to assess orbital debris for the Compact Solar Irradiance Monitor Flight Demonstration (CSIM FD) 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 CSIM 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. Mission design

2.1 Mission Description

The Compact Solar Irradiance Monitor Flight Deployment (CSIM FD) is a 6U CubeSat mission, developed by the Laboratory for Atmospheric and Space Physics (LASP). Its purpose is to better understand the solar spectral irradiance and total solar irradiance.

CSIM FD is expected to have a 2 year mission life. The nominal orbit for CSIM FD is a 575 x 575 km circular sun synchronous orbit with a 10:30 Local Time of Ascending Node (LTAN). The nominal launch is scheduled on approximately October 1st, from Vandenberg Air Force Base. There are two primary science payloads; the first is a custom Electric Substitution Radiometer (ESR) built in cooperation with the National Institute of Standards and Technology (NIST) and mounted in a special housing to isolate it from external vibration and thermal effects. The second is a multichannel spectrometer using a prism and three photodiodes variously responsive at ultraviolet/visible, near infrared and infrared wavelengths.

From the 575 x 575 km, ~97.662° inclination orbit, CSIM FD takes daily measurements of the Sun, alternating between solar spectral irradiance using the spectrometer and total solar irradiance using the ESR, at wavelengths varying from 210 nm to 2400 nm.

The mission's ground segment includes mission operations, the UHF ground station operating at 450 MHz, and a S-band radio operating at 2.4 GHz, science and engineering data processing, and data distribution. These facilities are all located at the Laboratory for Atmospheric and Space Physics (LASP) in Boulder, Colorado, except for the UHF receiving station located in Fairbanks, Alaska.

2.2 SPACECRAFT DESCRIPTION

CSIM FD is a solar-pointing, 3-axis-controlled, 6U CubeSat. The spacecraft is designed for use in low earth orbit (LEO) with two deployable solar panels, a deployable UHF monopole antenna, and fixed S-band patch antennae. The total spacecraft mass is 11.49 kg with a volume of 23.94 cm x 36.58 cm x 14.47 cm in the stowed configuration. When fully deployed, the spacecraft's monopole antenna extends 15.3 cm along the minus Y axis and all panels are sun facing (minus Z axis). A patch antenna is present for S band transmission, pointing in in the positive Z axis.

Two miniaturized star trackers are mounted such that boresight are 10° off-pointed from the perpendiculars to the Y-Z and X-Z planes of the CSIM FD.

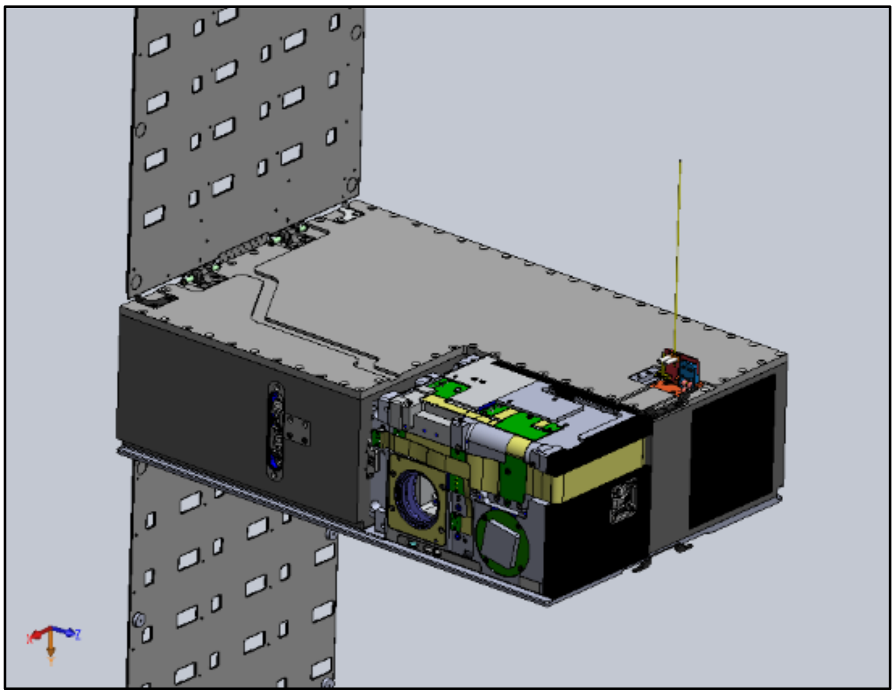

Figure 1 CSIM FD with the solar arrays and monopole antenna deployed.

The 3 axis inertial pointing system (from Blue Canyon Technologies) contains 3 reaction wheel assemblies, 3 torque rods, a miniaturized star tracker, and a processor board all self contained in a 1 U unit that is attached to the plus Z, plus X side of the main body of the spacecraft. The CSIM FD has a battery pack, both supplied by the BCT XB1, comprising 3 cells with 12V and 2.6 A-h.

All sensors and components on CSIM FD are passive. 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. CSIM FD 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, CSIM FD uses the orbital parameters determined by the primary payload - 575 km SSO with and LTAN of 10:30. DAS software is used to calculate the cross sectional area of the spacecraft for random tumbling and mass was determined by mass property calculation in Solidworks CAD software.

A 0.2146 m^2 cross sectional area and 11.49 kg result in an area-to-mass ratio of 0.0187 for CSIM FD in the fully deployed configuration (the area-to-mass ratio is 0.00761 with the solar arrays stowed and would reenter in 14.543 years). The inputs to the calculation and the orbit history are shown in Figure2, CSIM FD Orbit Lifetime/Dwell Time and Orbit Decay.

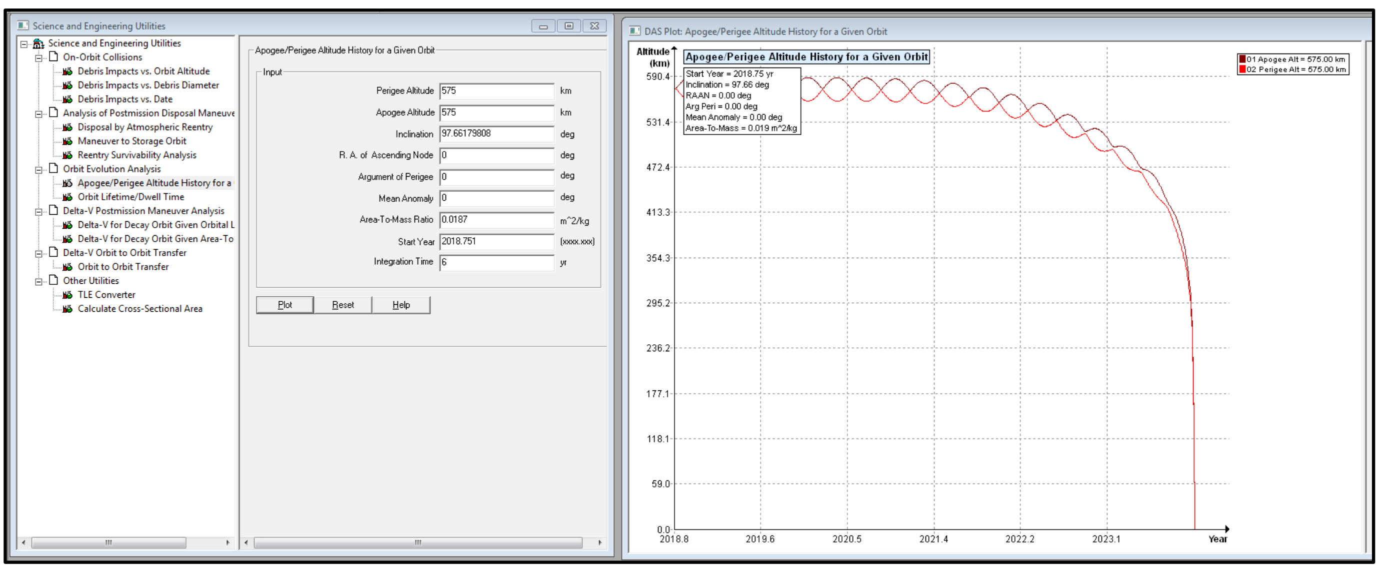

Figure 2 CSIM FD Orbit Lifetime/Dwell Time and Orbit Decay

Assuming an October 2018 launch, the orbit dwell time is 5.207 years and meets the 8719.14 disposal requirements through atmospheric reentry within 25 years of mission completion or 30 years from launch.

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 2.1.1 Requirements Assessment tools were successfully performed. CSIM FD 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 a successive set 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.

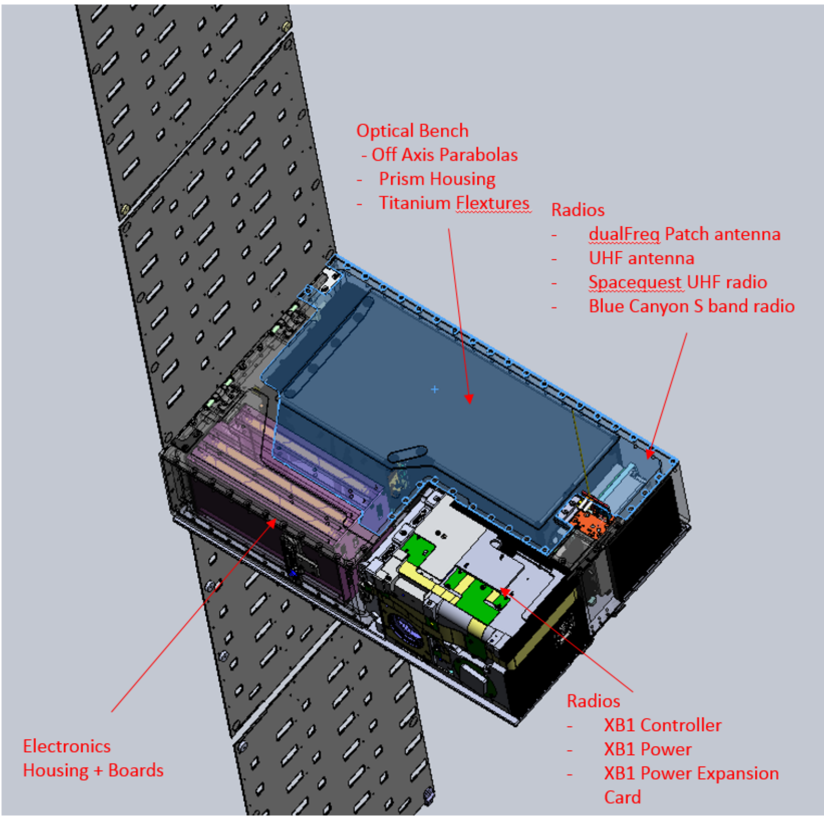

Figure 3 CSIM FD Major Components. The major components and internal location are shown for the CSIM FD spacecraft with solar panel outlines deployed.

x4.1.1 CSIM FD Components and Object Tree

CSIM FD 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 54 objects and nests to the third level of child objects. The root level (0^{th}) object for the object tree is CSIM FD. The first level of child objects contains the CSIM FD structure, the ADCS structure, and items that reside on the outside of the spacecraft such as: solar array hinge pieces, solar arrays, and the antenna. The second level of child objects contains subassembly structures and harnesses. Within these subassemblies are the third level components structures including components, electronics boards, wire harness, fasteners, optical components and connectors.

4.1.2 Material Data Base and Object Parameters

Materials for each object are selected from the standard DAS materials database and no new materials were added. 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 CSIM FD components:

1. electronic boards – fiberglass
2. wire harness – copper alloy
3. aluminum – aluminum 6061-T6
4. steel items – stainless steel (generic)
5. structures – aluminum 6061-T6 or 7075-T6, as appropriate
6. solar arrays – graphite epoxy 1
7. internal casings – aluminum 6061-T6
8. titanium – titanium (6 Al- 4 V) or Titanium (generic), as appropriate

The analysis uses analysis derived values for most items and subassemblies contained in the object tree. The mass for all major structures, electronics boards, the integrated ADCS unit, connectors, wire harness, and total mass of the system, are derived though analysis.

Object sizes are CAD derived 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 4, CSIM FD Compliance with Orbital Debris Requirements. CSIM FD is compliant with NS 8719.14A – Process for Limiting Orbital Debris. There are no tethers on CSIM FD.

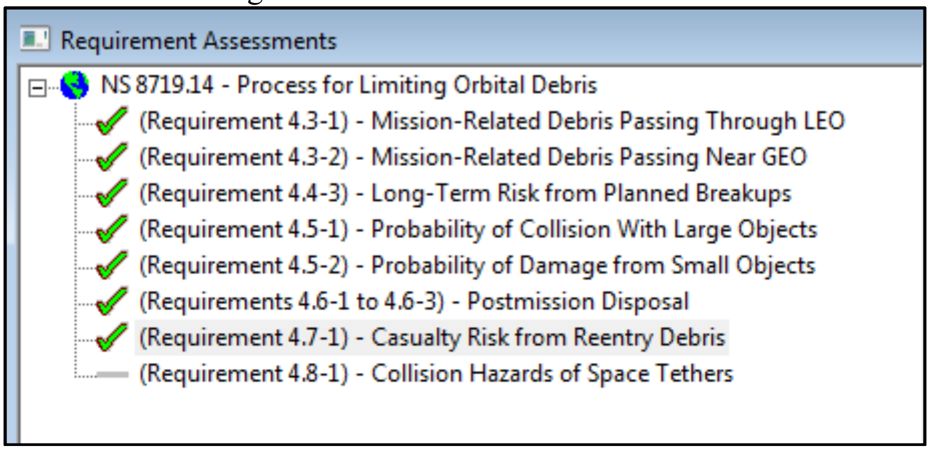

Figure 4 CSIM Compliance with Orbital Debris Requirements. The green checkmarks in the requirements assessment window indicate MinXSS is compliant with that particular requirement.

Numerical results for the risk of human casualty for the total mission is shown in Figure 5, 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 oblate at attitude of approximately 63 km with the exception of a number of small titanium and steel components:

- Two titanium parabolic mirror mounts: 0.39 casualty area, kinetic energies 3 and 6 J.
- Three titanium optical mounting flexures: 1.2 m^2 casualty area, kinetic energy 3 J
- Two titanium solar panel catches: 0.77 m^2 casualty area, kinetic energy <0.1 J
- XB1 (ADCS control box) titanium hinge: 3.14 m^2 casualty area, kinetic energy <0.1 J
- MicroSwitch release switch: 0.76 m^2 casualty area, kinetic energy <0.1 J

The casualty assessment calculated by DAS only considers objects with more than 15 Joules of kinetic energy. The kinetic energies of the above components are individually than 15 Joules, resulting in a total casualty area of 0.00 m^2 for CSIM FD.

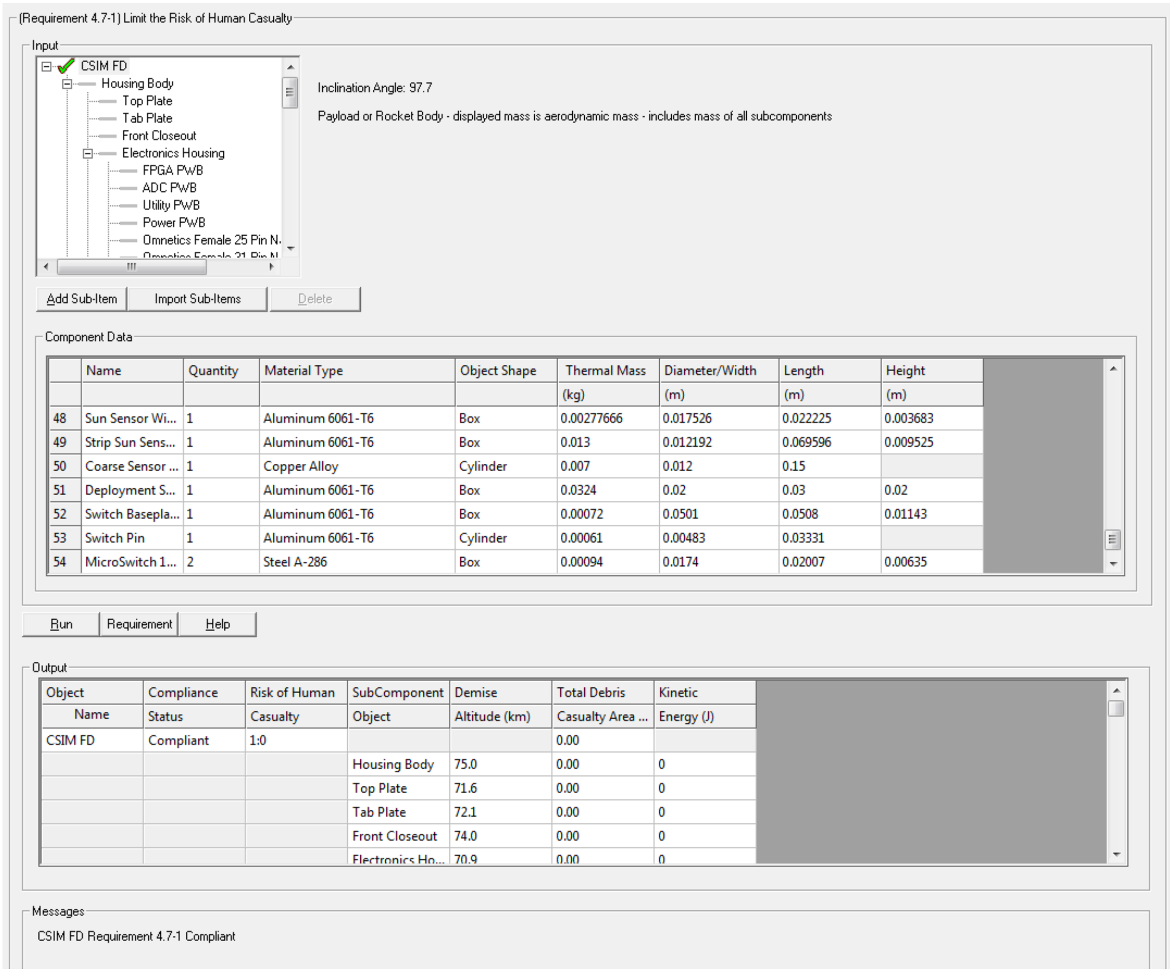

Figure 5 Risk of Human Casualty

CSIM FD 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 CSIM FD 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. The current launch date for CSIM FD is October 2016 and spacecraft disposal is accomplished through atmospheric reentry. The spacecraft is estimated to reenter in 5.21 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. CSIM FD 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.