Laboratory for Atmospheric and Space Physics
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Orbital Debris Analysis for CTIM FD

Document No. – 2120-002
Satellite Primary Serial Number: Flight Model 1

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Revision History

Rev	Date	Change Description	Pages Affected
1	04/07/2020	Initial Release	All

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1. SCOPE

This report summarizes the analyses performed to assess orbital debris for the Compact Total Irradiance Monitor Flight Demonstration (CTIM 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 CTIM analysis was performed using version DAS 3.0.1 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 (CTIM 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.

Current assumed path-to-orbit is transfer to the International Space Station (ISS), followed by deployment to final orbit. CTIM FD is expected to have a 0.659 year mission life with a 450 x 450 km circular orbit at 51.6° inclination. The nominal launch is scheduled on for Spring 2021.

In orbit, CTIM will take daily total irradiance measurements of the sun using an 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. Each instrument package has redundant channels, and the spacecraft mounts two of these instrument packages, leading to quadrupled redundancy.

The mission's ground segment includes mission operations, UHF ground station operating at 437.25 MHz; 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

CTIM 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 circular polarized antenna, and fixed S-band patch antennae. The total spacecraft mass is 11.8 kg with a volume of 22.6 cm x 36.6 cm x 11.8 cm in the stowed configuration. When fully deployed, the spacecraft's four 14.9 cm monopole antennas (together forming a circularly polarized antennae) extend along the diagonals of the +Z face of the spacecraft. All panels are sun facing (minus Z axis). A patch antenna is present for S band transmission, pointing in in the positive Z axis. A star tracker is mounted such that the boresight is 9° off-pointed from the Y-Z plane.

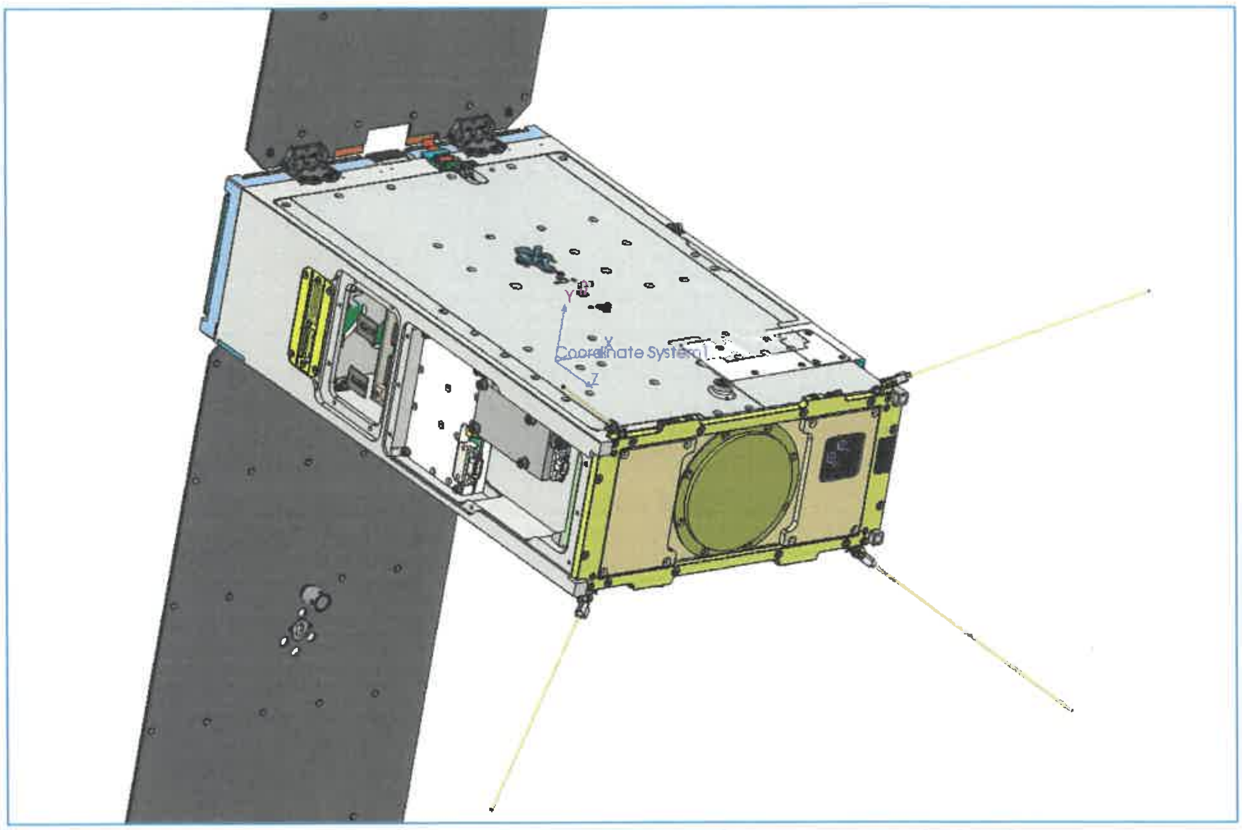


Figure 1 CTIM FD with the solar arrays and antenna arrays deployed.

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 CTIM FD has a two battery packs supplied by the Space Inventors, each 4s2p cell configuration with 15.5V and 75 W-hr.

All sensors and components on CTIM FD 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. CTIM 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, CTIM FD uses the orbital parameters determined by the primary payload – 450 km circular orbit with 51.6° inclination. 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 0.220 m^2 cross sectional area and 11.8 kg result in an area-to-mass ratio of 0.0186 for CTIM FD in the fully deployed configuration The inputs to the calculation and the orbit history are shown in Figure 2, CTIM FD Orbit Lifetime/Dwell Time and Orbit Decay.

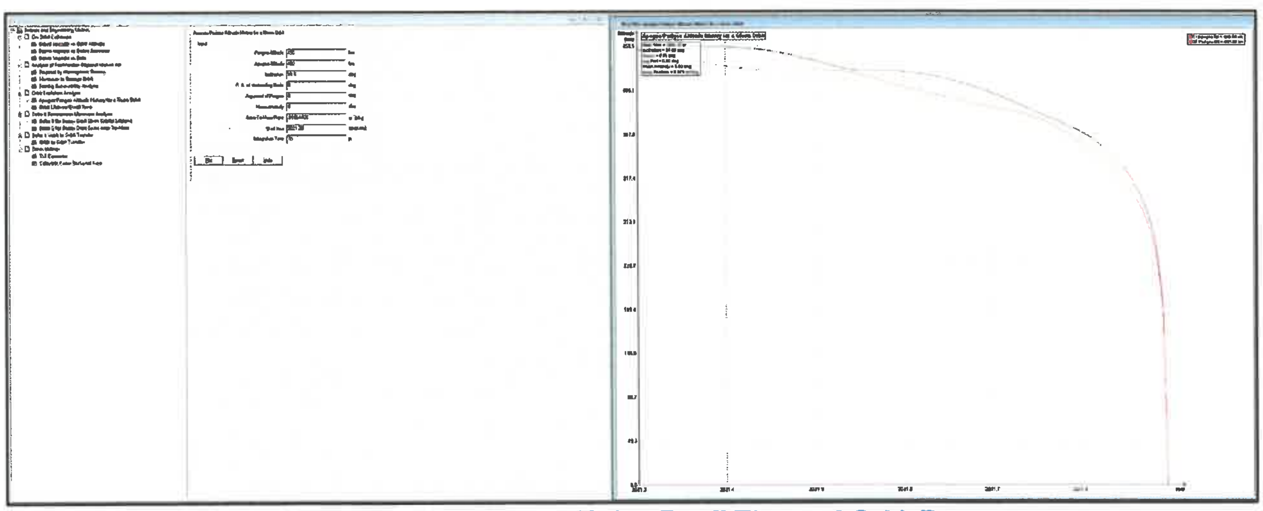


Figure 2 CTIM FD Orbit Lifetime/Dwell Time and Orbit Decay

Assuming an April 2020 launch, the orbit dwell time is 0.695 years and meets the 8719.14 disposal requirements through atmospheric reentry within 25 years of mission completion or 30 years from launch.

On failure to deploy, the area-to-mass ratio is found to be 0.00678 with the solar arrays stowed, and reentry occurs in 1.473 years.

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 3.0.1 Requirements Assessment tools were successfully performed. CTIM FD does not contain any critical surfaces.

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.

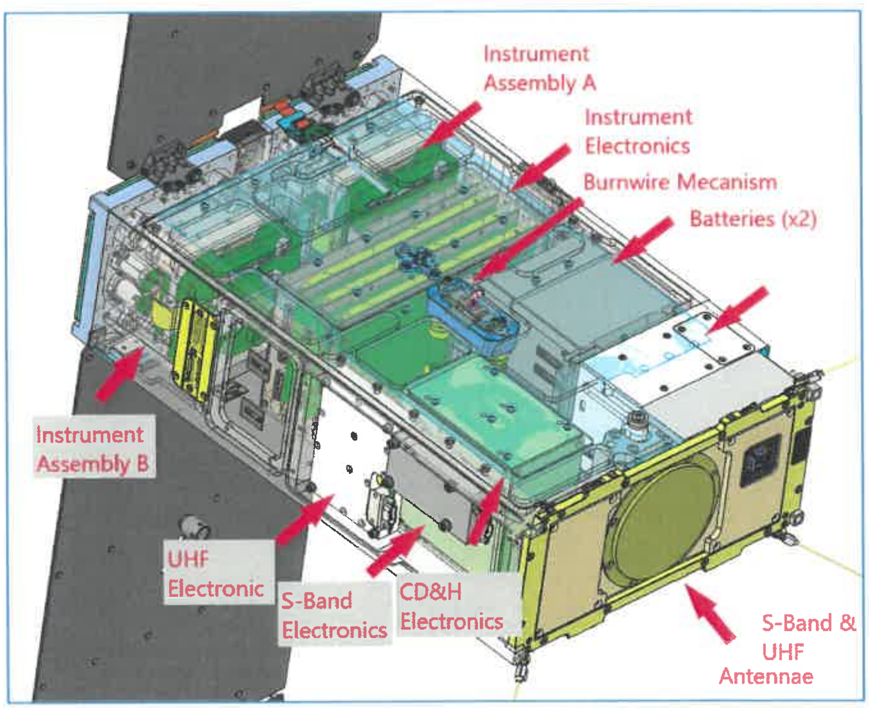


Figure 3 CTIM FD Major Components. The major components and internal location are shown for the CTIM FD spacecraft with solar panels deployed.

4.1.1 CTIM FD Components and Object Tree

CTIM 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 98 objects and nests to the second level of child objects. The root level (0^{th}) object for the object tree is CTIM FD. The first level of child objects contains the CTIM FD subassemblies, the ADCS structure, harnessing, and items that reside on the outside of the spacecraft such as solar array and the antenna. The second level of child objects contains components of the subassemblies, including components, electronics boards, 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, with the addition of custom materials for tantalum and delrin. The following properties were applied to CTIM 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
9. delrin (polyoxymethylene homopolymer)
    a. density: 1435 kg/m^3; melt T: 448 K, specific heat 1425 J/kgK, heat of fusion 236000 J/kg (Ullmann's Polymer's and Plastics: Products and Processes, vol. 2, pg. 913)
10. tantalum
    a. density: 16670 kg/m^3; melt T: 3290 K, specific heat 140 J/kgK, heat of fusion 173528 J/kg (https://www.gordonengland.co.uk/elements/ta.htm)

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

4.2 Orbital Debris Analysis Results

A summary of the results of orbital debris analyses that were performed are shown in Figure 4, CTIM FD Compliance with Orbital Debris Requirements. CTIM FD is compliant with NS 8719.14A – Process for Limiting Orbital Debris. There are no critical surfaces on CTIM FD that would prevent satellite reentry.

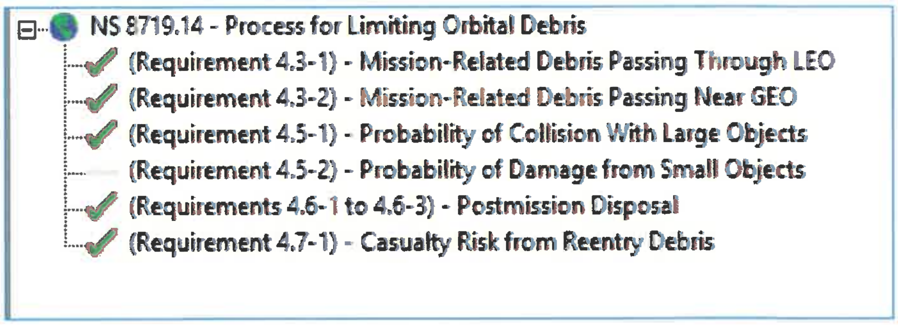
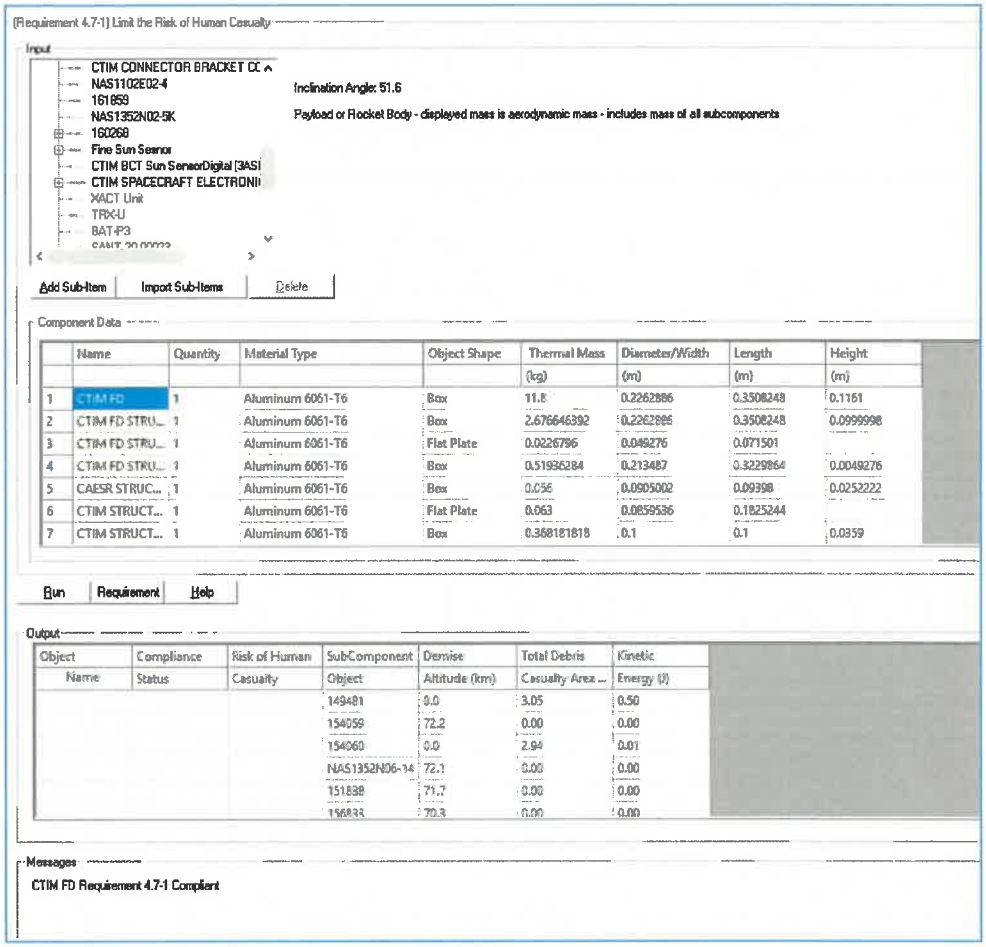


Figure 4 CTIM Compliance with Orbital Debris Requirements. The green checkmarks in the requirements assessment window indicate CTIM FD is compliant with that particular requirement.

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 "1:100000000" and the total casualty area is $0.00 m^2$. The spacecraft and all of its internal components oblate at attitude of approximately 67.8 km with the exception of a number of small titanium and steel components:

- Eight titanium flexures: 3.05 m^2 casualty area, kinetic energies 0.5 J.
- Eight titanium flexure mount plates: 2.94 m^2, kinetic energy 0.01 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 CTIM FD.



	Name	Quantity	Material Type	Object Shape	Thermal Mass (kg)	Diameter/Width (m)	Length (m)	Height (m)
1	CTIM FD	1	Aluminum 6061-T6	Box	11.8	0.2262886	0.3508248	0.1161
2	CTIM FD STRU...	1	Aluminum 6061-T6	Box	2.676646392	0.2262886	0.3508248	0.0999998
3	CTIM FD STRU...	1	Aluminum 6061-T6	Flat Plate	0.0226796	0.049276	0.071501	
4	CTIM FD STRU...	1	Aluminum 6061-T6	Box	0.51936284	0.213487	0.3229864	0.0049276
5	CAESR STRUC...	1	Aluminum 6061-T6	Box	0.056	0.0905002	0.09398	0.0252222
6	CTIM STRUCT...	1	Aluminum 6061-T6	Flat Plate	0.063	0.0859536	0.1825244	
7	CTIM STRUCT...	1	Aluminum 6061-T6	Box	0.368181818	0.1	0.1	0.0359

Object Name	Compliance Status	Risk of Human Casualty	SubComponent Object	Demise Altitude (km)	Total Debris Casualty Area ...	Kinetic Energy (J)
			149481	0.0	3.05	0.50
			154059	72.2	0.00	0.00
			154060	0.0	2.94	0.01
			NAS1352N06-14	72.1	0.00	0.00
			151838	71.7	0.00	0.00
			156833	70.3	0.00	0.00

Figure 5 Risk of Human Casualty

CTIM 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 CTIM 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 CTIM FD is tentatively April 2021 and spacecraft disposal is accomplished through atmospheric reentry. The spacecraft is estimated to reenter in 0.659 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 user's guide to provide a realistic reentry model and used the standard materials database provided in the application. CTIM 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.