Space Telecommunications, Inc.

Orbital Debris Assessment Report (ODAR) for CTC-0[1]

[1]For all calculations, STI used the NASA Debris Assessment Software (DAS) version 3.2.6.

Revision History

Revision	Description of Revisions	Release Date
1	First release	06/05/2024

CONTENTS

SECTION 1. Program Management and Mission Overview

Table 1. CTC-0 Mission Overview

ODAR Authors	Scott Hasbrouck, Chief Technology Officer at Space Telecommunications, Inc., with technical support from Dr. Bogdan Udrea, Independent Consultant.
Mission Description	Space Telecommunications, Inc. ("STI") seeks to deploy one Endurosat 8U CubeSat-class bus with a custom radiofrequency payload for direct-to-5G two-way communications, known as the "CTC-0" satellite. This orbital debris assessment report ("ODAR") covers the CTC-0 spacecraft scheduled to be launched on the SpaceX Falcon 9 Bandwagon-2 rideshare mission, NET November 1, 2024. CTC-0 is owned by STI and will be operated pursuant to a U.S. space station authorization.
Mission Duration	Approximately 3.2 years following deployment from the launch vehicle.
Selection of Orbit	510 km +/- 20 km in a circular orbit of 45° +/- 1.1°.
Potential Physical Interference with Other Orbiting Objects	The satellite does not have any propulsion systems to actively maintain orbital altitude. Therefore, its orbit will naturally decay following deployment from the launch vehicle. As detailed in Section 5, the probability of physical interference between CTC-0 and other space objects complies with Requirement 4.5 of NASA-STD-8719.14C.

SECTION 2. Spacecraft Description

The CTC-0 spacecraft is an 8U CubeSat, measuring 0.245 m × 0.113 m × 0.454 m in its stowed configuration. It has deployable solar arrays and antennas, as shown in Figure 1. The spacecraft includes UHF and S-band communications systems for telemetry and data transmission, as well as a 3-axis attitude determination and control system (ADCS). The spacecraft is compatible with the Exolaunch Nova deployer cubesat dispenser. This dispenser uses the standard cubesat rail spacing, but it has extra volume available between the rails for extra deployable systems. Additional details can be seen in the table and drawings below.

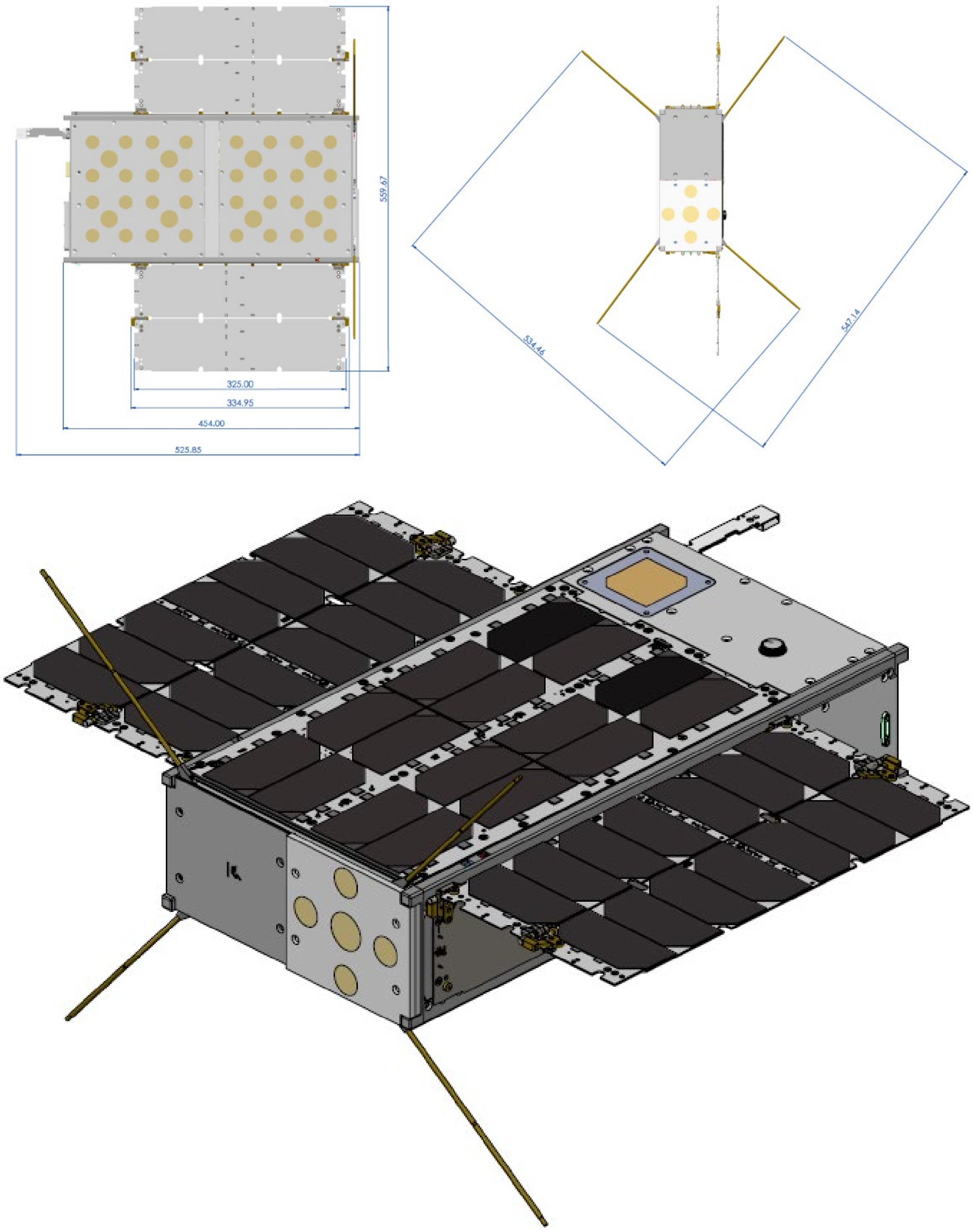

Figure 1. *Overall dimensions of the deployed CTC-0 CubeSat (top) and its 3D rendering (bottom).*

CTC-0 Spacecraft Physical Description	
Property	**Value**
Total Mass at Launch	9.75 kg
Dry Mass at Launch	9.75 kg
Form Factor	8U CubeSat
COG	< 0.05 m radius from the geometric center of the spacecraft box
Envelope (stowed)	0.245 m × 0.113 m × 0.454 m
Envelope (deployed)	Bounding box: 0.525 m ×0.560 m × 0.330 m
Propulsion Systems	None
Fluid Systems	None
Attitude Determination and Control Subsystem (ADCS)	Stabilization/pointing with three (3) reaction wheels, reaction wheel angular momentum desaturation and coarse pointing with magnetic torque bars. Orientation/attitude knowledge through a combination of coarse sun sensors and star trackers
Orbit Determination	On-board Global Navigation Satellite System (GNSS) orbital position and velocity vectors
Range Safety / Pyrotechnic Devices	None
Electrical Generation	Triple-junction GaAs solar panels
Electrical Storage	Two rechargeable lithium-polymer battery packs
Radioactive Materials	None
Proximity Operations Planned	None

SECTION 3. Assessment of Debris Released During Normal Operations

The CTC-0 spacecraft does not release objects either during deployment or operations. Therefore, Requirements 4.3-1 and 4.3-2 of NASA-STD-8719.14C are not applicable.

Assessment of spacecraft compliance with Requirements 4.3-1 through 4.3-2:	
4.3-1a: All debris released during the deployment, operation, and disposal phases shall be limited to a maximum orbital lifetime of 25 years from date of release. 4.3-1b: The total object-time product shall be no larger than 100 object-years per mission	N/A
4.3-2: Debris passing near GEO: For missions leaving debris in orbits with the potential of traversing GEO (GEO altitude +/- 200 km and +/- 15 degrees inclination), released debris with diameters of 5 mm or greater shall be left in orbits which will ensure that within 25 years after release the apogee will no longer exceed GEO - 200 km or the perigee will not be lower than GEO + 200 km, and also ensures that the debris is incapable of being perturbed to lie within that GEO +/- 200 km and +/- 15 degree zone for at least 100 years thereafter.	N/A

SECTION 4. Assessment of Spacecraft Intentional Breakups and Potential for Explosions

Potential causes for spacecraft breakup

The only energy sources (kinetic, chemical, or otherwise) onboard the CTC-0 spacecraft are a Lithium-Polymer battery pack and reaction wheels. Consequently, two plausible causes for breakup of the CTC-0 spacecraft are identified:

1. Energy released from onboard batteries,
2. Mechanical failure of the reaction wheels, and
3. Runaway torque event leading to shedding of deployable components.

The possible failure modes, their analysis, and mitigation plans are detailed in the remainder of this section.

Battery Failure Mode Analysis and Mitigation Plans

The CTC-0 spacecraft contains two (2) EnduroSat battery packs with four (4) cells in series and one (1) parallel string, i.e., a 4S-2P configuration, for a total of 16 cells. The battery cell has a maximum capacity of 10.5 Wh. The total electric energy storage capacity of the two 4S-2P packs is 16×10.5 Wh=168 Wh. The two 4S-2P battery packs represent the only credible failure mode during which stored energy is released. The battery failure modes, their mitigation, and the combined fault analysis are described below.

<u>Failure mode #1:</u> Battery internal short circuit.
<u>Mitigation:</u> A full qualification test campaign has been performed on a qualification model unit and environmental acceptance tests of each flight model unit of the EnduroSat Electric Power Subsystem (EPS) Type II and its battery packs. All EnduroSat components and standard platform configurations undergo qualification based on tailored ESA ECSS-E-ST-10-03 methodology and environmental levels defined as per NASA GEVS GSFC-STD-7000A for random vibrations, shock and thermal vacuum testing at qualification levels that can be found at: https://endurosat.com/space-qualification/
The acceptance tests are shock, vibration, thermal cycling, and vacuum tests followed by maximum system rate-limited charge and discharge to prove that no internal short circuit sensitivity exists. <u>Combined faults required to realize the failure</u>: Environmental testing <u>**AND**</u> functional charge/discharge tests must both be ineffective in discovery of failure mode #1.

<u>Failure Mode #2:</u> Internal thermal rise due to high load discharge rate.
<u>Mitigation:</u> Each 4S-2P battery pack includes a Negative Temperature Coefficient (NTC) thermistor that senses any thermal rise with fast response time and high reliability. Furthermore, the balancer of the battery pack features embedded overtemperature and overcurrent protections during discharge mode.
<u>Combined faults required to realize the failure:</u> The NTC thermistor must fail to provide feedback of the thermal rise **AND** the spacecraft thermal design must be incorrect <u>**AND**</u> the discharge overcurrent protection of the balancer must fail for failure mode #2 to occur.

<u>Failure Mode #3:</u> Overcharging and excessive charge rate.
<u>Mitigation:</u> The satellite bus battery charging circuit design reduces the possibility of the batteries being overcharged if circuits function nominally. This circuit has been proto-qualification tested for survival in shock, vibration, and thermal-vacuum environments. The charger circuit limits the charge current to

zero (0 A) when batteries are charged at 16.2 V. Moreover, the balancer includes charge over voltage, charge overcurrent and charge overtemperature protections. If all the aforementioned circuits fail to operate, continuing to charge the batteries can cause gas generation. The battery packs are not hermetically enclosed and there are gaps that allow gas to escape, thus mitigating any explosion hazard.
Combined faults required to realize the failure:

1) Overcharging: The charge control circuit must fail to function **AND** the NTC thermistor must fail (or temperatures generated must be insufficient to cause the NTC thermistor to register the thermal rise) **AND** charge overvoltage protection circuit **AND** the battery pack must be enclosed in an additional external hermetical enclosure to fail to vent generated gasses at acceptable rates to avoid explosion.
2) Excessive charge rate: The maximum power which can be available from the 6U body-mounted solar panel and the two double deployable solar arrays is up to 53 W and the incoming photovoltaic energy is split between the two battery packs of the CTC-0 spacecraft. The battery cell has a maximum charge rate of 5 A. The total photovoltaic power generated by the body-mounted panel and the deployable arrays is up to 3 A with 19.27 V. Even they if were connected to a single battery pack (eight cells in a 4S-2P configuration) the cell maximum charge rate cannot be physically reached. Moreover, the battery pack has been designed so that the gaps between the cells in the battery pack allow for thermal expansion, in case of excessive charge rate, and prevent the cells from rupturing. For this failure mode to become active the charging circuit must fail **AND** the charge overcurrent protection must fail.

Failure Mode #4: Excessive discharge rate or short circuit due to external device failure or terminal contact with conductors at voltage levels other than battery voltage. For example, such failure can occur due to abrasion or inadequate separation between electrical conductors.
Mitigation: This failure mode is averted by *a)* circuit protection on each external circuit, *b)* the design of battery packs, dedicated aluminum enclosure, and battery cells cage for each battery pack and insulators such that no contact with nearby board traces is possible without some external mechanical failure, *c)* prevention of mechanical failures by qualification and acceptance environmental tests (shock, vibration, thermal cycling, and thermal-vacuum tests).
Combined faults required to realize the failure: The NTC thermistor must fail or the thermal environment of the battery pack must be insufficient to cause the NTC thermistor to register the rise in temperature **AND** an external load must fail/short-circuit **AND** external over-current detection and disconnect function must fail to enable this failure mode.

Failure Mode #5: Inoperable vents in the battery pack.
Mitigation: The battery packs are not hermetically enclosed and there are gaps that allow gas to escape, mitigating any explosion hazard.
Combined effects required to realize the failure: The spacecraft integrator encloses the battery pack in an additional hermetical enclosure without proper venting **AND** the launch vehicle environmental stress screening fails to detect failure in venting.

Failure Mode #6**:** Crushing.
Mitigation: This mode is averted by the appropriate design of the battery pack and spacecraft. Each battery pack features a dedicated aluminum enclosure and battery cells cage. Furthermore, there are no moving parts in the proximity of the batteries.
Combined faults required to realize the failure: A catastrophic failure must occur in an external system **AND** the failure must cause a collision sufficient to crush the battery pack aluminum enclosure, the battery cells cage and the batteries leading to an internal short circuit **AND** the satellite must be in a naturally sustained orbit at the time the crushing occurs.

Failure Mode #7: Low level current leakage or short-circuit through the battery pack case due to moisture-based degradation of insulators.
Mitigation: These modes are averted by *a)* battery holder/case design and assembly of the battery cells and mounting/integration with non-conductive epoxy adhesive to the battery pack cage and *b)* operation in vacuum such that no moisture can affect insulators.
Combined faults required to realize the failure: A catastrophic failure must occur in an external system **AND** the failure must cause a collision sufficient to crush the battery pack aluminum enclosure, **AND** dislocation of battery packs **AND** failure to detect such failures in environmental tests must occur to result in this failure mode.

Failure Mode #8: Excess temperatures due to orbital environment and high discharge combined.
Mitigation: The thermal design of the spacecraft will keep the battery pack within the required temperature ranges during all phases of mission operations. Spacecraft thermal simulations will be performed, and the internal configuration will be selected such that the batteries do not exceed normal allowable operating temperatures, that are well below temperatures of concern for explosions.
Combined faults required to realize the failure: Thermal analysis **AND** thermal design **AND** mission simulations in thermal-vacuum chamber testing **AND** The NTC thermistor must fail or the thermal environment of the battery pack must be insufficient to cause the NTC thermistor to register the rise in temperature **AND** discharge over-current monitoring and control must all fail for this failure mode to occur.

Failure Mode #9: Polarity reversal due to over-discharge caused by continuous load during periods of power-negative operations (power generation is less than power consumption).
Mitigation: In nominal operations, the spacecraft EPS design averts polarity reversal because the EPS microcontroller stops when voltage drops too low, *i.e.*, below the discharge cutoff threshold of 26 V. If the charge circuit does not fail the balancer's undervoltage circuit will disconnect the discharge line from the batteries when the threshold of 24 V is reached. This disables ALL connected loads, creating a guaranteed power-positive charging scenario. The spacecraft will not restart or connect any loads until battery voltage is above the acceptable threshold with a positive margin compared to the discharge cutoff threshold. At this point, only the safe mode processor is enabled (EPS II's own microcontroller) and charging the battery commences. Once the battery reaches 90% of the peak voltage of 31 V, it switches to nominal mode and can receive ground commands.
Combined faults required to realize the failure: The microcontroller of the EPS must stop executing code **AND** significant loads must be commanded/stuck "on" **AND** power margin analysis must be wrong **AND** the balancer undervoltage protection must fail **AND** the charge control circuit must fail for this failure mode to occur.

Failure Mode #10: Excess battery temperatures due to post mission orbital environment and constant solar panel overcharge while spacecraft is powered off.
Mitigation: The DC/DC converters of the battery charging circuit will be commanded permanently OFF to passivate the spacecraft EPS.

Mechanical Failure of the Reaction Wheels

The reaction wheel assemblies could create debris by the disintegration of their rotors (flywheels). Such a failure mode is due to mechanical failure at high angular speed when the hoop stress of the rotor at the outer edge exceeds the yield stress of the rotor material. The CTC-0 spacecraft has three (3) CubeSpace CubeWheel CW0162 reaction wheels with mutually orthogonal axes of rotation. It has been assumed that the reaction wheel rotor is made of brass and has an outer radius of 20 mm and a thickness of 10 mm. The yield tensile strength of brass is assumed 150 MPa. The CW0162 reaction wheel CTC-0 spacecraft has a maximum angular speed of 6 000 RPM and that results in a safety factor of safety of 42 to reaching yield stress at the edge of the rotor. Consequently, the CTC-0 reaction wheels are designed and operated well within the rotor disintegration angular speed. Moreover, the rotors are contained within an aluminum alloy enclosure, thus mitigating the risk of debris release in case of disintegration.

Shedding of Deployables Due to a Runaway Torque

The CTC-0 spacecraft can create debris by shedding its deployable components, the deployable 6U solar arrays (also called 3U double deployable solar arrays) and the four quad rods of the UHF-band antenna. Shedding of the solar panels the UHF-band antenna quad rods occur when the shear stress in the respective hinge pins exceeds the yield stress of the material of the pin. The centrifugal force needed to shed deployables is generated by a runaway torque that has two sources: the pinwheel effect of the quad rods of the UHF-band antenna and the torque generated by out-of-control reaction wheels.

The analysis presented below demonstrates that the risk of a runaway torque causing shedding of CTC=0 spacecraft deployables has been deemed negligible.

Runaway Torque Due to the Pinwheel Effect of UHF-Band Antenna Quad Rods

The pinwheel effect of the UHF-band antenna quad rods is mitigated by the 1) quad rod design that has a circular cross-section rather than the airfoil-like cross-section of measuring tape of some deployable antennas; 2) low atmospheric density of the orbit range of 510 km, +/- 20 km; 3) restorative and damping effect of the 6U (aka double deployable 3U) solar arrays.

Runaway Torque Due to the Out-of-Control Reaction Wheels

The second source of runaway torque generation is the reaction wheels. An analysis was performed to address the feasibility of a runaway torque event and the potential for either the solar panels or the deployable UHF antennas to break away (or shed) from the spacecraft. Given the 1) total maximum stored momentum in the CTC-0 reaction wheels; 2) the shear stress at the pin in the solar array body hinge; and 3) the shear stress at the pin of the deployable UHF antenna hinge, a factor of safety of 5 004 for the solar array and of over 12 507 for the UHF antenna have been found against shedding. Thus, the reaction wheels cannot provide sufficient torque to cause shedding of deployable parts through a runaway torque.

Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions: There is no planned breakup of the spacecraft on-orbit.

Rationale for all items required to be passivated that cannot be due to design: N/A

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4	
4.4-1 Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon: For each spacecraft and launch vehicle orbital stage employed for a mission (i.e., every individual free-flying structural object), the program or project shall demonstrate, via failure mode and effects analyses, probabilistic risk assessments, or other appropriate analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle does not exceed 0.001 (excluding small particle impacts).	COMPLIANT
4.4-2 Design for passivation after completion of mission operations while in orbit about Earth, or the Moon: Design of all spacecraft and launch vehicle orbital stages shall include the ability and a plan to either 1) deplete all onboard sources of stored energy and disconnect all energy generation sources when they are no longer required for mission operations or post mission disposal or 2) control to a level which cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft. The design of depletion burns and ventings should minimize the probability of accidental collision with tracked objects in space.	N/A
4.4-3 Limiting the long-term risk to other space systems from planned breakups for Earth and lunar missions: Planned explosions or intentional collisions shall: a. be conducted at an altitude such that for orbital debris fragments larger than 10 cm the object-time product does not exceed 100 object-years. For example, if the debris fragments greater than 10cm decay in the maximum allowed 1 year, a maximum of 100 such fragments can be generated by the breakup. b. Not generate debris larger than 1 mm that remains in Earth orbit longer than one year.	N/A
4.4-4 Limiting the short-term risk to other space systems from planned breakups for Earth orbital missions: Immediately before a planned explosion or intentional collision, the probability of debris, orbital or ballistic, larger than 1 mm colliding with any operating spacecraft within 24 hours of the breakup shall be verified to not exceed 10^{-6}.	N/A

SECTION 5. Potential for On-Orbit Collisions

This section addresses Requirement 4.5-1 for the probability of collision with objects larger than 10 cm and Requirement 4.5-2 for the probability of collision with debris and meteoroids.

Requirement 4.5-1. Limiting debris generated by collisions with large objects when operating in Earth orbit.

Two scenarios have been considered for this report. Both scenarios assume a worst-case deployment of 530 km. The first scenario assumes that the spacecraft operates nominally upon deployment, deorbiting through atmospheric re-entry in less than three years (`8U_standard_op_life`). The second scenario assumes that, in addition to the worst-case deployment altitude, the CTC-0 spacecraft fails to unstow any of its deployable components, *i.e.*, the two solar arrays and the four UHF antenna rods (`8U_stuck_deployables`). While the unstowed scenarios is highly unlikely, it has been considered in this report, as the worst-case scenario and will still result in complete demise through atmospheric re-entry in less than five years.

The salient "Payload Properties" as input in DAS are tabulated in Table 1.

Table 1. Payload properties input in DAS.

Scenario Name	Mission Duration (yrs)	Op. Perigee (km)	Op. Apogee (km)	Op. Inclination (deg)	Initial Mass (kg)	Final Mass (kg)	Final Area To Mass (m^2/kg)
8U_standard_op_life	2.757	530	530	45	9.75	9.75	0.018
8U_stuck_deployables	4.767	530	530	45	9.75	9.75	0.013

The results of analysis of on-orbit collisions with objects larger than 10 cm are shown in Table 2.

Table 2. *Compliance status output from DAS for Requirement 4.5-1 – probability of collision with objects larger than 10 cm.*

Scenario Name	Compliance Status	Collision Probability
8U_standard_op_life	Compliant	5.5342E-7
8U_stuck_deployables	Compliant	5.8598E-7

Requirement 4.5-2. Limiting damage probability from small objects when operating in Earth or lunar orbit

The CTC-0 satellite does not have a propulsion system and therefore will not have a controlled re-entry. No satellite components are vital to completing post-mission disposal. Under nominal conditions, STI will have the ability to slew the satellite into a maximum drag orientation until entry, however, as demonstrated above, this orientation is not mandatory for safe disposal of the spacecraft.

Assessment of spacecraft compliance with Requirements 4.5-1 and 4.5-2:	
4.5-1 Limiting debris generated by collisions with large objects when in Earth orbit: For each spacecraft and launch vehicle orbital stage in or passing through LEO, the program or project shall demonstrate that, during the orbital lifetime of each spacecraft and orbital stage, the probability of accidental collision with space objects larger than 10 cm in diameter does not exceed 0.001. For spacecraft and orbital stages passing through the protected region +/- 200 km and +/-15 degrees of geostationary orbit, the probability of accidental collision with space objects larger than 10 cm in diameter shall not exceed 0.001 when integrated over 100 years from time of launch.	COMPLIANT
4.5-2 Limiting debris generated by collisions with small objects when operating in Earth orbit: For each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and meteoroids sufficient to prevent compliance with the applicable post mission disposal maneuver requirements does not exceed 0.01. Furthermore, given the vehicle does not have onboard propulsion, and we are limited to only executing orientation maneuvers and minimal delta-V changes with differential drag, the vehicle does not have capable to actuate itself to avoid a collision.	N/A

SECTION 6. Assessment of Spacecraft Post-Mission Disposal Plans and Procedures

Disposal options: The CTC-0 spacecraft will be passivated at the end of its operational life, at which point the spacecraft will randomly tumble until it naturally decays in the atmosphere. For **8U_stuck_deployables** scenario, STI assumed that where the spacecraft failed to unstow any of its deployables, the spacecraft will start to randomly tumble immediately following separation from the launch vehicle.

Orbit lifetime/dwell analysis: Analysis of orbital lifetime/dwell time of both scenarios have been performed with the DAS "Orbit Lifetime/Dwell Time" utility. The results are shown in Table 3. The final area-to-mass ratios are those in Table 1.

Table 3. *Post-mission disposal of space structures results from DAS.*

Scenario Name	Area To Mass (m^2/kg)	Perigee (km)	Apogee (km)	Inclination (deg)	Compliance Status	Orbit Lifetime
8U_standard_op_life	0.018	530	530	45.0	Compliant	2.757
8U_stuck_deployables	0.013	530	530	45.0	Compliant	4.767

The area to mass ratio for **8U_standard_op_life** and **8U_short_op_life** has been calculated under the assumption of random tumble for the unstowed configuration.

Assessment of Spacecraft Compliance with Requirements 4.6-1 through 4.6-4:	
4.6-1 Natural reentry, direct reentry, or direct retrieval shall comply with the following: a. Natural reentry: Leave the space structure in an orbit in which, using conservative projections for solar activity, will limit the orbital lifetime to as short as practicable but no more than 25 years after completion of mission. b. Direct reentry: Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission. c. Direct retrieval: Retrieve the space structure and remove it from orbit preferably at completion of mission, but no more than 5 years after completion of mission.	COMPLIANT
4.6-2 Storage and Earth escape shall comply with the following: a. Storage between LEO and GEO: 1) Maneuver to a highly-eccentric disposal orbit (e.g., GEO transfer orbit) where i. perigee altitude remains above 2000 km for at least 100 years, ii. apogee altitude remains below 35,586 km for at least 100 years, and (iii) the time spent by the space structure between 20,182 +/- 300 km is limited to 25 years or less over 200 years; or, 2) Maneuver to a near-circular disposal orbit to i. avoid crossing 20,182 +/- 300 km, the GEO zone, and the LEO zone for at least 100 years, and ii. limit the risk to other operational constellations, for example, by avoiding crossing the altitudes occupied by known missions of 10 or more spacecraft using near-circular orbits, for 100 years. b. Storage above GEO: Maneuver to a disposal orbit above GEO with a predicted minimum perigee altitude of 35,986 km for a period of at least 100 years after disposal. c. Earth escape: Maneuver to a heliocentric, Earth-escape trajectory.	N/A
4.6-3 Long-term reentry for structures in Medium Earth Orbit (MEO), Tundra orbits, highly inclined GEO, and other orbits shall: a. Maneuver to a disposal orbit where orbital resonances will increase the eccentricity for long term reentry of the structure, b. Limit the postmission orbital lifetime to as short as practicable but not more than 200 years, c. Limit the time spent in the LEO zone, the GEO zone, and between 20,182 +/- 300 km to 25 years or less per zone, and d. Limit the probability of collisions with debris 10 cm and larger to less than 0.001 (1 in 1,000) during orbital lifetime.	N/A

SECTION 7. Assessment of Spacecraft Reentry Hazards

The (re-entry) casualty risk from reentry debris has been analyzed with DAS. A total of 23 component types have been modeled. They range from computer cases and boards to solar panel back and solar cell to reaction wheel cases and rotors to the wire harness. The full DAS log has been provided which includes enumerated data of all of the components modeled.[2]

No objects are expected to survive reentry. The overall probability of human casualty is 0% (1:100000000).

[2] The analysis excludes components and materials such as fasteners and epoxy because their small size and mass ensures complete demise during atmospheric re-entry.

Assessment of spacecraft compliance with Requirement 4.7-1:	
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 be less than 0.0001 (1:10,000). b. For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica. c. For controlled reentry, the product of the probability of failure to execute the reentry burn and the risk of human casualty assuming uncontrolled reentry shall be less than 0.0001 (1:10,000). For long-term reentry of structures in MEO, Tundra orbits, highly inclined GEO, and other orbits: Surviving debris shall have less than 7 m^2 total debris casualty area or 0.0001 (1 in 10,000)	COMPLIANT

SECTION 8. Assessment for Tether Missions

Type of tether: N/A
Description of tether system: N/A
Determination of minimum size of object that will cause the tether to be severed: N/A
Tether mission plan, including duration and post mission disposal: N/A
Probability of tether colliding with large space objects: N/A
Probability of tether being severed during mission or after post mission disposal: N/A
Maximum orbital lifetime of a severed tether fragment: N/A

Assessment of compliance with Requirement 4.8-1:	
4.8-1, Mitigate the collision hazards of space tethers in protected regions of space: Intact and remnants of severed tether systems in Earth orbit shall limit the generation of orbital debris from on-orbit collisions with other operational spacecraft post mission. Tether systems should generally not remain deployed after the completion of their mission objectives. After mission objectives are met, such tethers should have provisions for disposal (full retraction/stowing and/or removal from Earth orbit) with a >0.90 probability of success, including an assessment of the reliability of the disposal system and accounting for the possibility of damage to or cutting of the tether prior to disposal.	N/A

Appendix A – DAS Log

05 14 2024; 07:50:34AM Project Data Saved To File
05 14 2024; 07:50:40AM Processing Requirement 4.3-1: Return Status : Not Run

=====================
No Project Data Available
=====================

=============== End of Requirement 4.3-1 ===============
05 14 2024; 07:50:42AM Processing Requirement 4.3-2: Return Status : Passed

=====================
No Project Data Available
=====================

=============== End of Requirement 4.3-2 ===============
05 14 2024; 08:03:55AM Processing Requirement 4.5-1: Return Status : Passed

==============
Run Data
==============

INPUT

Space Structure Name = 8U_short_op_life
Space Structure Type = Payload
Perigee Altitude = 530.000 (km)
Apogee Altitude = 530.000 (km)
Inclination = 45.000 (deg)
RAAN = 0.000 (deg)
Argument of Perigee = 0.000 (deg)
Mean Anomaly = 0.000 (deg)
Final Area-To-Mass Ratio = 0.0180 (m^2/kg)
Start Year = 2024.874 (yr)
Initial Mass = 9.750 (kg)
Final Mass = 9.750 (kg)
Duration = 3.500 (yr)
Station-Kept = False
Abandoned = True
Long-Term Reentry = False

OUTPUT

Collision Probability = 5.5342E-07
Returned Message: Normal Processing
Date Range Message: Normal Date Range
Status = Pass

==============

INPUT

Space Structure Name = 8U_stuck_deployables
Space Structure Type = Payload
Perigee Altitude = 530.000 (km)
Apogee Altitude = 530.000 (km)
Inclination = 45.000 (deg)
RAAN = 0.000 (deg)
Argument of Perigee = 0.000 (deg)
Mean Anomaly = 0.000 (deg)
Final Area-To-Mass Ratio = 0.0130 (m^2/kg)
Start Year = 2024.874 (yr)
Initial Mass = 9.750 (kg)
Final Mass = 9.750 (kg)
Duration = 0.000 (yr)
Station-Kept = False
Abandoned = True
Long-Term Reentry = False

OUTPUT

Collision Probability = 5.8598E-07
Returned Message: Normal Processing
Date Range Message: Normal Date Range
Status = Pass

==============

=============== End of Requirement 4.5-1 ===============

05 14 2024; 08:04:00AM   Project Data Saved To File
05 14 2024; 08:04:06AM   Requirement 4.5-2: Compliant

=============== End of Requirement 4.5-2 ===============

05 14 2024; 08:04:08AM   Processing Requirement 4.6   Return Status : Passed

==============
Project Data
==============

INPUT

Space Structure Name = 8U_short_op_life
Space Structure Type = Payload

Perigee Altitude = 530.000000 (km)
Apogee Altitude = 530.000000 (km)
Inclination = 45.000000 (deg)
RAAN = 0.000000 (deg)

Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.018000 (m^2/kg)
Start Year = 2024.874000 (yr)
Initial Mass = 9.750000 (kg)
Final Mass = 9.750000 (kg)
Duration = 3.500000 (yr)
Station Kept = False
Abandoned = True
PMD Perigee Altitude = -1.000000 (km)
PMD Apogee Altitude = -1.000000 (km)
PMD Inclination = 0.000000 (deg)
PMD RAAN = 0.000000 (deg)
PMD Argument of Perigee = 0.000000 (deg)
PMD Mean Anomaly = 0.000000 (deg)
Long-Term Reentry = False

OUTPUT

Suggested Perigee Altitude = 530.000000 (km)
Suggested Apogee Altitude = 530.000000 (km)
Returned Error Message = Reentry during mission (no PMD req.).

Released Year = 2027 (yr)
Requirement = 61
Compliance Status = Pass

==============

INPUT

Space Structure Name = 8U_stuck_deployables
Space Structure Type = Payload

Perigee Altitude = 530.000000 (km)
Apogee Altitude = 530.000000 (km)
Inclination = 45.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.013000 (m^2/kg)
Start Year = 2024.874000 (yr)
Initial Mass = 9.750000 (kg)
Final Mass = 9.750000 (kg)
Duration = 0.000000 (yr)
Station Kept = False
Abandoned = True
PMD Perigee Altitude = 529.999997 (km)
PMD Apogee Altitude = 530.000003 (km)
PMD Inclination = 45.000000 (deg)
PMD RAAN = 359.999980 (deg)

PMD Argument of Perigee = 270.261704 (deg)
PMD Mean Anomaly = 0.000000 (deg)
Long-Term Reentry = False

OUTPUT

Suggested Perigee Altitude = 529.999997 (km)
Suggested Apogee Altitude = 530.000003 (km)
Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2029 (yr)
Requirement = 61
Compliance Status = Pass

==============

=============== End of Requirement 4.6 ===============
05 14 2024; 08:04:12AM *********Processing Requirement 4.7-1
Return Status : Passed

***********INPUT****
Item Number = 1

name = 8U_short_op_life
quantity = 1
parent = 0
materialID = 8
type = Box
Aero Mass = 9.750000
Thermal Mass = 9.750000
Diameter/Width = 0.245000
Length = 0.454000
Height = 0.110000

name = bus_box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 9.069900
Thermal Mass = 3.400000
Diameter/Width = 0.245000
Length = 0.454000
Height = 0.110000

name = solar_panel_back
quantity = 4
parent = 2
materialID = 8
type = Box
Aero Mass = 0.310000

Thermal Mass = 0.300000
Diameter/Width = 0.160000
Length = 0.320000
Height = 0.005000

name = solar_panel_cell_surfaces
quantity = 4
parent = 3
materialID = -4
type = Box
Aero Mass = 0.010000
Thermal Mass = 0.010000
Diameter/Width = 0.150000
Length = 0.300000
Height = 0.002000

name = box_cell_surfaces
quantity = 2
parent = 2
materialID = -4
type = Box
Aero Mass = 0.010000
Thermal Mass = 0.010000
Diameter/Width = 0.150000
Length = 0.300000
Height = 0.002000

name = battery_pack_4S-2P_case
quantity = 2
parent = 2
materialID = 8
type = Box
Aero Mass = 0.480200
Thermal Mass = 0.400000
Diameter/Width = 0.080000
Length = 0.100000
Height = 0.080000

name = battery_cell
quantity = 16
parent = 6
materialID = -1
type = Cylinder
Aero Mass = 0.010025
Thermal Mass = 0.009400
Diameter/Width = 0.010000
Length = 0.060000

name = adcs_computer_board
quantity = 1
parent = 7

materialID = -3
type = Box
Aero Mass = 0.010000
Thermal Mass = 0.010000
Diameter/Width = 0.080000
Length = 0.080000
Height = 0.001000

name = adcs_computer_case
quantity = 1
parent = 2
materialID = 8
type = Box
Aero Mass = 0.150000
Thermal Mass = 0.150000
Diameter/Width = 0.080000
Length = 0.100000
Height = 0.080000

name = mag_torque_bar
quantity = 3
parent = 2
materialID = 38
type = Cylinder
Aero Mass = 0.196667
Thermal Mass = 0.090000
Diameter/Width = 0.012000
Length = 0.100000

name = CW0162_RW_rotor
quantity = 3
parent = 10
materialID = 13
type = Cylinder
Aero Mass = 0.106667
Thermal Mass = 0.100000
Diameter/Width = 0.040000
Length = 0.012000

name = on-board_computer_board
quantity = 1
parent = 11
materialID = -3
type = Box
Aero Mass = 0.020000
Thermal Mass = 0.010000
Diameter/Width = 0.080000
Length = 0.080000
Height = 0.002000

name = payload_proc_board

quantity = 1
parent = 12
materialID = -3
type = Box
Aero Mass = 0.010000
Thermal Mass = 0.010000
Diameter/Width = 0.080000
Length = 0.080000
Height = 0.002000

name = CW0162_RW_case
quantity = 3
parent = 2
materialID = 8
type = Box
Aero Mass = 0.140000
Thermal Mass = 0.140000
Diameter/Width = 0.046000
Length = 0.046000
Height = 0.024000

name = on-board_computer_case
quantity = 1
parent = 2
materialID = 8
type = Box
Aero Mass = 0.150000
Thermal Mass = 0.150000
Diameter/Width = 0.080000
Length = 0.100000
Height = 0.080000

name = payload_proc_case
quantity = 1
parent = 2
materialID = 8
type = Box
Aero Mass = 0.150000
Thermal Mass = 0.150000
Diameter/Width = 0.080000
Length = 0.100000
Height = 0.080000

name = payload_patch_antenna
quantity = 2
parent = 2
materialID = 7
type = Box
Aero Mass = 0.605000
Thermal Mass = 0.600000
Diameter/Width = 0.200000

Length = 0.200000
Height = 0.010000

name = S-band_radio_board
quantity = 1
parent = 17
materialID = -3
type = Box
Aero Mass = 0.010000
Thermal Mass = 0.010000
Diameter/Width = 0.080000
Length = 0.080000
Height = 0.002000

name = S-band_radio_case
quantity = 1
parent = 2
materialID = 8
type = Box
Aero Mass = 0.100000
Thermal Mass = 0.100000
Diameter/Width = 0.080000
Length = 0.080000
Height = 0.020000

name = S-band_antenna_patch
quantity = 1
parent = 2
materialID = 8
type = Box
Aero Mass = 0.260000
Thermal Mass = 0.110000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.005000

name = UHF-band_radio_board
quantity = 1
parent = 20
materialID = -3
type = Box
Aero Mass = 0.150000
Thermal Mass = 0.150000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.008000

name = UHF-band_radio_case
quantity = 1
parent = 2
materialID = 7

type = Box
Aero Mass = 0.100000
Thermal Mass = 0.100000
Diameter/Width = 0.080000
Length = 0.080000
Height = 0.020000

name = UHF-band_antenna_rods
quantity = 4
parent = 2
materialID = 19
type = Cylinder
Aero Mass = 0.018000
Thermal Mass = 0.018000
Diameter/Width = 0.004000
Length = 0.163000

name = GPS_antenna_patch
quantity = 1
parent = 2
materialID = 8
type = Box
Aero Mass = 0.037500
Thermal Mass = 0.037500
Diameter/Width = 0.050000
Length = 0.050000
Height = 0.050000

name = harness
quantity = 1
parent = 2
materialID = 19
type = Cylinder
Aero Mass = 0.210000
Thermal Mass = 0.210000
Diameter/Width = 0.012000
Length = 0.200000

*************OUTPUT****
Item Number = 1

name = 8U_short_op_life
Demise Altitude = 77.999266
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = bus_box
Demise Altitude = 76.052557
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = solar_panel_back
Demise Altitude = 75.590946
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = solar_panel_cell_surfaces
Demise Altitude = 75.542896
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = box_cell_surfaces
Demise Altitude = 76.003468
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = battery_pack_4S-2P_case
Demise Altitude = 74.835800
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = battery_cell
Demise Altitude = 73.735923
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = adcs_computer_board
Demise Altitude = 73.686330
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = adcs_computer_case
Demise Altitude = 75.587425
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = mag_torque_bar
Demise Altitude = 69.566068
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = CW0162_RW_rotor

Demise Altitude = 64.657570
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = on-board_computer_board
Demise Altitude = 64.608492
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = payload_proc_board
Demise Altitude = 64.558048
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = CW0162_RW_case
Demise Altitude = 74.324009
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = on-board_computer_case
Demise Altitude = 75.587425
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = payload_proc_case
Demise Altitude = 75.587425
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = payload_patch_antenna
Demise Altitude = 72.990014
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = S-band_radio_board
Demise Altitude = 72.941122
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = S-band_radio_case
Demise Altitude = 75.395992
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = S-band_antenna_patch
Demise Altitude = 75.423997
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = UHF-band_radio_board
Demise Altitude = 74.751852
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = UHF-band_radio_case
Demise Altitude = 74.468876
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = UHF-band_antenna_rods
Demise Altitude = 75.147954
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = GPS_antenna_patch
Demise Altitude = 75.754189
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = harness
Demise Altitude = 72.059335
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****

***********INPUT****
Item Number = 2

name = 8U_stuck_deployables
quantity = 1
parent = 0
materialID = 5
type = Box
Aero Mass = 9.750000
Thermal Mass = 9.750000
Diameter/Width = 0.245000
Length = 0.454000

Height = 0.113000

name = 8
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 9.750000
Thermal Mass = 9.750000
Diameter/Width = 0.245000
Length = 0.454000
Height = 0.113000

**************OUTPUT****
Item Number = 2

name = 8U_stuck_deployables
Demise Altitude = 77.998876
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = 8
Demise Altitude = 64.788404
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****

============== End of Requirement 4.7-1 ==============
05 14 2024; 08:04:12AM Project Data Saved To File