Tomorrow.io Weather Radar Spacecraft Demonstration

Orbital Debris Assessment Report (ODAR)

DOC 1000155

Version Log

Version	Date	Updating Author	Description
1.0	10/07/2021	D. Thorn	Initial Release
2.0	01/21/2022	D. Thorn	Updated spacecraft mass to CBE and re-ran DAS
3.0	03/25/2022	D. Thorn	Added Driver to reentry.csv, updated masses to reflect margin in reentry.csv, updated total mass, added section 8 on tether tape.
4.0	5/13/2022	S. Luther	Added DEP/DEM description, area to mass ratio, design for demise description, and Appendix B
A	**9/8/2022**	**S. Luther**	**Transitioned to Tomorrow.io document ownership and formatting. Re-run of model in DAS 3.2.3 See Appendix E for summary of full version details**

Document Approval Page:

X *John Springmann*
box SIGN 1337KLR1-1X9W2L34

John Springmann
VP, Space & Sensors

X *Shaun Luther*
box SIGN 15YLVXW1-1X9W2L34

Shaun Luther
Program Chief Engineer

Table of Contents

Self-Assessment per NASA-STD-8719.14

A self-assessment in accordance with the format provided in Appendix A.2 of NASA-STD-8719.14 is shown below in Table 1.

Table 1: Assessment Report Format

Section	Status	Section
4.3-1: Mission-Related Debris Passing Through LEO	**Compliant**	3.7.1
4.3-2: Mission-Related Debris Passing Near GEO	**N/A**	3.7.2
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	**Compliant**	4.6.1
4.4-2: Design for passivation after completion of mission operations while in orbit about Earth or the Moon	**Compliant**	4.6.2
4.4-3: Limiting the long-term risk to other space systems from planned breakup	**N/A**	4.6.3
4.4-4: Limiting the short-term risk to other space systems from planned breakup	**N/A**	4.6.4
4.5-1: Probability of Damage from Small Objects	**Compliant**	5.1.1
4.5-2: Probability of Damage from Small Objects	**Compliant**	5.1.2
4.6-1: Disposal for space structures passing through LEO	**Compliant**	6.4.1
4.6-2: Disposal for space structures passing through GEO	**N/A**	6.4.2
4.6-3: Disposal for space structures between LEO and GEOs	**N/A**	6.4.3
4.6-4: Reliability of post-mission disposal operations	**Compliant**	6.4.4
4.7-1: Limit the risk of human casualty	**Compliant**	7.1.1
4.8-1: Collision Hazards of Space Tether	**Compliant**	8.2.1

Assessment Report Format

This ODAR follows the format in NASA-STD-8719.14, Appendix A.1 and includes the content indicated as a minimum, in each of sections 2 through 8 below. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered here. Tomorrow.io and Astro Digital US, Inc are US companies.

1 Program Management and Mission Overview

Table 2: List of Key Personnel

Responsibility	Name	Company
Program Chief Engineer	Shaun Luther	Tomorrow.io
T.io Management	John Springmann	Tomorrow.io
T.io Regulatory	Kristina Hloptsidis	Tomorrow.io
System Engineer	David Thorne	Astro Digital
Program Manager	Timothy Cole	Astro Digital
AD Management	Chris Biddy	Astro Digital

Foreign Government or Space Agency Participation: **None**

Summary of NASA's Responsibility Under the Governing Agreement(s): **N/A**

1.1 Schedule of upcoming mission milestones

- Shipment of First Spacecraft: **Q4 CY2022**
- First launch: **Q1 CY2023**
- Shipment of Second Spacecraft: **Q1 CY2023**
- Second Launch: **Q2 CY2023**

1.2 Mission Overview

The Tomorrow.io Weather Radar Spacecraft Demonstration is a remote sensing mission consisting of two satellites, Tomorrow-R1 and -R2, that will demonstrate a weather radar testbed on orbit. The primary application of the system is precipitation monitoring. The radar testbed payload is manufactured by Tomorrow.io and consists of a Ka-band radar integrated into a spacecraft bus based on Astro Digital's standardized Corvus -XL design.

1.3 Launch Vehicles and Launch Sites

Tomorrow-R1 is scheduled to launch on SpaceX's Transporter-7 rideshare mission, currently planned in early Q1 2023, and Tomorrow-R2 is scheduled for to launch on Transporter-8, currently planned for Q2 2023. The planned launch location for both launches is Cape Canaveral, Florida.

1.4 Mission Duration

Total duration to complete the scientific mission is projected to be 6 months. The maximum nominal operations and design lifetime of the spacecraft hardware is 3 years.

1.5 Launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination

Table 3: Tomrorow-R1 on Transporter-7 Q1 2023

Parameter	Value	Status
Orbital Altitude	500 ± 20 km	Final Value per LV Provider
Eccentricity	< 0.004	Final Value per LV Provider
Inclination	97.4° – 97.8°	Min/Max value per LV Provider
MLTAN	10:30 AM ± 30 min	Final Value per LV Provider

Table 4: Tomrorow-R2 on Transporter-8 Q2 2023

Parameter	Value	Status
Orbital Altitude	500 – 600 km	Min/Max value per LV Provider
Eccentricity	0.0000 – 0.0033	Min/Max value per LV Provider
Inclination	97.4° – 97.8°	Min/Max value per LV Provider
MLTAN	10:00 AM – 11:00 AM	Min/Max value per LV Provider

Each spacecraft will be delivered to their respective final circular polar orbit as described in **Table 3** and **Table 4**. Each Tomorrow Spacecraft will operate for a duration of six (6) months. After the spacecraft has demonstrated all relevant technologies and completed payload operations, the spacecraft will be decommissioned in a safe state, batteries will be discharged, and the vehicles will deorbit passively as further detailed in 6.4.1 below.

2 Spacecraft Description

2.1 Physical description of the spacecraft

Each of the two identical Tomorrow.io weather radar satellites are based on Astro Digital's standard Corvus-XL bus and have a current best estimate (CBE) mass of 85.8 kg with 4.2kg of mass growth allowance (MGA) for a worst-case mass of 90 kg. Each satellite has dimensions of 120cm x 78.2cm x 104.3cm. Each of the satellite's structures includes five aluminum iso-grid plates, in which all components are mounted on the inner and outer faces. All structural panels are referenced against the body frame of the spacecraft, as depicted in Figure 1. A main structural panel in the -Z axis, two side plates on the +Y axis a base plate on the +X and a payload deck on the -X/+Z axis. The primary payload deck is tilted 38° from the base plate in the +X axis.

A total of six Main Solar Panels (MSPs) are used as the primary source of power generation. These MSPs are body mounted in the -Z axis and have dimensions of 45 cm x 32 cm x 0.16 cm. Two additional keep alive panels are mounted on the +/- Y axis of the spacecraft with dimensions of 22.1 cm x 17.1 cm x 0.16 cm. A total of 3 Smart Panels are placed on the +/- Y and -Z axis. The Smart Panels have dimensions of 12.1 cm x 1.3 cm x 0.16 cm, and contain electronics embedded in them such as a sun sensor and magnetometer to enable recovery from a lower power generation scenario.

Each satellite avionics system is enclosed inside the Data Power Module (DPM) which is comprised of a flight computer with integrated IMU, GPS module, TT&C transceiver, charging module, power distribution module, high voltage power board, and two battery packs. An additional battery pack containing four Direct Energy Packs (DEPs) is also used to further supply power to the payload and regulate the high loads. Each satellite includes an eXternal Payload Unit (XPU) which is comprised of a payload computer and ethernet switching board. Note that the DPM, DEP, and XPU are defined as modules with child relationships within the DAS analysis (Appendix A). Components considered internal to each respective module are accounted for with child relationships because of the thin aluminum casing of the parent module.

Each satellite is equipped with a TT&C transceiver call the Turva S-band/UHF. Two UHF antennas are placed on the top corners of the spacecraft -Z axis. Two S-band patch antennas are placed in the lower corners of the +/-Y axis. One XCOM Ka-band transceiver is equipped to provide high payload data downlink. This transceiver is mounted in the interior of the satellite's +Y plate with the antenna mounted on the exterior of that same plate. The GPS is mounted inside the DPM and with its corresponding antenna mounted on the -Z axis.

The Attitude Determination and Control System (ADCS) consists of flight proven externally sourced hardware including two-star trackers, a gyroscope, three reaction wheels and torque rods. A torque rod control module and a reaction wheel control module are included to regulate the high load required by these components. Both star trackers are located external to the structural panels, specifically mounted to the payload deck.

The weather radar payload components are mounted on the inside of the payload deck enclosed on a 53 cm diameter ring where the antenna interface is located. All radar subsystems are bolted to the payload deck using their casing. The radar antenna is mounted externally to the payload deck ring interface using eight 5/16-24 bolts.

A 15-inch Planetary Systems Lightband on the +X panel of the satellite will be used to deploy each spacecraft from the launch vehicle.

A NanoSat Termination Tape (NSTT) is equipped on the spacecraft as a secondary, experimental, and completely optional payload. The NSTT is mounted inside the Planetary Systems Lightband on the +X panel. Use of the NSTT is optional and experimental, and allowance of such experimental use may prove useful in the future to assist Tomorrow assess options for de-orbit.

2.2 Detailed illustration of the spacecraft

An illustration of the spacecraft is shown in Figure 1 below.

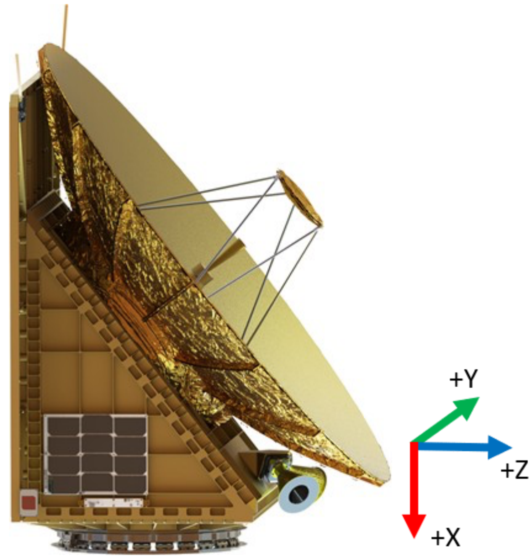

Figure 1: Tomorrow.io Weather Radar Spacecraft

2.3 Total Satellite Mass

The spacecraft have a (CBE) mass of 85.8 kg with 4.2kg of mass growth allowance (MGA) for a max mass of 90 kg.

2.4 Dry Mass of the Satellite

N/A: Neither Spacecraft has any propellent or fuel therefore dry mass is identical to total mass.

2.5 Identification of All Fluids On-board

N/A: There are no fluids on-board the spacecraft.

2.6 Description of Propulsion System

N/A: No propulsive devices.

2.7 Description of Attitude Control System

After separation from the launch vehicle, each spacecraft will wait 30 minutes prior to autonomously turning on. It will then autonomously de-tumble and enter a safe sun tracking mode. All attitude modes use a combination of the following sensors and actuators to perform maneuvers. One (1) magnetometer, one (1) gyroscope, three (3) sun sensors, three (3) reaction wheels, three (3) torque rods and two (2) star trackers are used to orientate the spacecraft correctly. Attitude modes are described in Table 5, below.

Table 5: Spacecraft ADCS Modes

ADCS Mode	Description
Nominal	The spacecraft will be tracking the sun vector on its -Z body axis to generate sufficient power to charge up the batteries.
TT&C	During TT&C mode the spacecraft can perform a slew to track the ground station but may not be required based on the antenna placement and attitude of the spacecraft.
Downlink	The spacecraft will perform a slew to track the corresponding ground station as long as line of sight is available. The antenna is located on its +Y body axis.
Radar Operations	During nominal payload operations the spacecraft will hold the specified attitude for the allowed duty cycle per orbit before slewing into sun tracking mode to recharge the batteries. The spacecraft will track the radar boresight within 20 degrees of nadir, with various scan angles used to complete the test and demonstration mission.

2.8 Fluids in Pressurized Batteries

None: Each Tomorrow.io Weather Radar spacecraft uses unpressurized standard lithium-ion battery cells, which include two battery packs variants. The single DPM battery pack contains a set of 8 Lithium-Ion battery cells in parallel with a capacity of 144 W-hrs. The DEP packs contain a set of 7 Lithium-Ion battery cells in series, with a capacity of 126 W-hrs. Four DEPs are included in the spacecraft and provide a total capacity of 504 W-hrs.

2.9 Description of Pyrotechnic Devices

N/A: No pyrotechnic devices.

2.10 Description of Electrical and Power System

Power is generated by the 6 Main Solar Panels (MSP) mounted on the -Z body axis of the spacecraft. Each MSP is comprised of 14 cells in series with 3 strings for a total of 42 cells per panel. The MSPs peak power generation is 46 W per panel. Two keep alive panels are located on the +/- Y body axis to serve as backup power generators in the event of an uncontrolled tumble. These keep alive panels are comprised of 12 cells in series witha maximum power generation of 26 W per panel.

Each satellite includes a total of five battery packs, one DPM and four DEPs. The DPM battery pack is enclosed inside its own module and then mounted inside the DPM. Total capacity of each battery pack variant have been described in section 2.8. The battery packs are all equipped with power regulation ICs which regulate the discharge state of the individual battery cells. All the power regulation required for operating the bus is via the DPM. The DEP batteries function as the primary source of energy storage while DPM batteries are used as backup. All battery packs are charged through the solar panels.

Each satellite bus, not including payload operations, nominally consumes 18W of power with some modes reducing or increasing the load. The payload is expected to consume a maximum of 220W. The charge/discharge cycle is managed by a power management system overseen by the Flight Computer and Electrical Power Subsystem.

2.11 Identification of Other Stored Energy

N/A: No other stored energy devices.

2.12 Identification of Any Radioactive Materials

N/A: No radioactive materials.

3 Assessment of Debris Released During Normal Operations

3.1 Identification of Objects Expected to be Released at Any Time

N/A: There will be no intentional releases of objects at any time by either spacecraft.

3.2 Rationale for Release of Objects

N/A: See Section 3.1

3.3 Time of Release of Objects

N/A: See Section 3.1

3.4 Release Velocity

N/A: See Section 3.1

3.5 Expected Orbital Parameters After Object Release

N/A: See Section 3.1

3.6 Calculated Orbital Lifetime of Release Objects

N/A: See Section 3.1

3.7 Assessment of Compliance with Requirement 4.3-1 and 4.3-2

3.7.1 Requirements 4.3-1: Planned debris release passing through LEO

"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. The total object-time product shall be no larger than 100 object-years per mission. For the purpose of this standard, satellites smaller than a 1U standard CubeSat are treated as mission-related debris and thus are bound by this definition to collectively follow the same 100 object-years per mission deployment limit"

Compliance Statement: **Compliant**, there will be no intentional objects released.

3.7.2 Requirements 4.3-2: Planned debris release passing near GEO

N/A: Neither spacecraft will pass near GEO.

4 Assessment of Spacecraft Intentional Breakups and Potential for Explosions

4.1 Identification of all potential causes of spacecraft breakup during deployment and mission operation

N/A: There are no known scenarios or occurrences where the spacecraft will breakup during normal deployment or mission operation.

4.2 Summary of failure modes and effects analyses of all credible failure modes which may lead to an accidental explosion

In mission failure of a battery cell protection circuit could lead to a short circuit resulting in overheating and a very remote possibility of battery cell explosion. The battery safety systems discussed in the FMEA (see requirement 4.4-1 below) describe the combined faults that must occur for any of seven (7) independent, mutually exclusive failure modes to lead to such an explosion.

4.3 Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions

N/A: The spacecraft does not include any designed or planned breakup.

4.4 List of components which shall be passivated at End of Mission (EOM) including method of passivation and amount which cannot be passivated

After the satellite has reached its End of Lifetime (EOL) all of the 36 Lithium-Ion Battery Cells (8 DPM & 28 DEP) will be passivated. This is accomplished by disabling the solar array charging circuit. With no ability to charge, all cells will fully discharge within a roughly 3 days due to the inherent power draw of the bus. Once cells are fully discharged the spacecraft does not have any capability to be revived.

4.5 Rationale for all items which are required to be passivated, but cannot be due to their design

N/A: The spacecraft does not have any components which cannot be passivated.

4.6 Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4

4.6.1 Requirement 4.4-1: Limiting the risk to other space systems from accidental explosions during deployment and mission operations

"For each spacecraft and launch vehicle orbital stage employed for a mission, the program or project shall demonstrate, via failure mode and effects analyses or equivalent analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle is less than 0.001 (excluding small particle impacts) (Requirement 56449)."

Compliance Statement

- Required Probability: 0.001

- Expected Probability: 0.000

Supporting Rationale and FMEA Details

4.6.1.1 Battery Explosion

- Effect: All failure modes below could theoretically result in battery explosion with the possibility of orbital debris generation. However, in the unlikely event that a battery cell does explosively rupture, the small size, mass, and potential energy, of these small batteries is such that while the spacecraft could be expected to vent gases, most debris from the battery rupture should be contained within the spacecraft due to the lack of penetration energy to the multiple enclosures surrounding the batteries.

- Probability: Extremely Low. Multiple independent faults must occur for each failure to cause an explosion. Each battery cell is UL/UN certified with individual over-voltage and over-currentprotection internal to the cell in the form of a physical Current Interrupt Device (CID). CIDs are physical pressure valve that permanently deform to prevent potential thermal runaway conditions if the current exceeds limitations. This yields the cell as inoperable but prohibits the change of explosion. The battery data sheet provides a list of standardized tests such as drop test, vibration test, overcharge test, short circuit, forced discharge and heating which correlate to some of the failure modes described below. All batteries also are subjected to a rigorous inspection regime including long duration electrical testing to assure that no physical, electrical abnormalities are present.

4.6.1.1.1 Failure Mode 1: Internal short circuit

- Mitigation: Protoflight level sine burst, sine and random vibration in three axes of both spacecraft, thermal vacuum cycling of both spacecraft and extensive functional testing followed by maximum system rate-limited charge and discharge cycles were performed to prove that no internal short circuit sensitivity exists. Additional environmental and functional testing of the batteries at the power subsystem vendor facilities were also conducted on the batteries at the component level.
- Combined faults required for realized failure: Environmental testing AND functional charge/discharge tests must both be ineffective in discovery of the failure mode.

4.6.1.1.2 Failure Mode 2: Internal thermal rise due to high load discharge rate

- Mitigation: Battery cells were tested in lab for high load discharge rates in a variety of flight-like configurations to determine if the feasibility of an out-of-control thermal rise in the cell. Cells were also tested in a hot, thermal vacuum environment (5 cycles at 50° C, then to -20°C) in order to test the upper limit of the cells capability. No failures were observed or identified via satellite telemetry or via external monitoring circuitry.
- Combined faults required for realized failure: Spacecraft thermal design must be incorrect AND external over-current detection and disconnect function must fail to enable this failure mode.

4.6.1.1.3 Failure Mode 3: Excessive discharge rate or short-circuit due to external device failure or terminal contact with conductors not at battery voltage levels (due to abrasion or inadequate proximity separation).

- Mitigation: This failure mode is negated by:
    - Qualification tested short circuit protection on each external circuit,
    - Design of battery packs and insulators such that no contact with nearby board traces is possible without being caused by some other mechanical failure,
    - Observation of such other mechanical failures by protoflight level environmental tests (sine burst, random vibration, thermal cycling, and thermal-vacuumtests).

- <u>Combined faults required for realized failure</u>: An external load must fail/short-circuit AND external over-current detection and disconnect function must all occur to enable this failure mode.

4.6.1.1.4 Failure Mode 4: Inoperable vents

- <u>Mitigation</u>: Battery venting is not inhibited by the battery holder design or the space- craft design. The battery is capable of venting gases to the external environment.
- <u>Combined faults required for realized failure</u>: The cell manufacturer OR the satellite integrator fails to install proper venting.

4.6.1.1.5 Failure Mode 5: Crushing

- <u>Mitigation</u>: This mode is negated by spacecraft design. There are no moving parts in the proximity of the batteries.
- <u>Combined faults required for realized failure</u>: A catastrophic failure must occur in an external system AND the failure must cause a collision sufficient to crush the batteries leading to an internal short circuit AND the satellite must be in a naturally sustained orbit at the time the crushing occurs.

4.6.1.1.6 Failure Mode 6: Low level current leakage or short-circuit through battery pack case or due to moisture-based degradation of insulators.

- <u>Mitigation</u>: These modes are negated by:
  - Battery holder/case design made of non-conductive plastic, and
  - Operation in vacuum such that no moisture can affect insulators.
- <u>Combined faults required for realized failure</u>: Abrasion or piercing failure of circuit board coating or wire insulators AND dislocation of battery packs AND failure of battery terminal insulators AND failure to detect such failures in environmentaltests must occur to result in this failure mode.

4.6.1.1.7 Failure Mode 7: Excess temperatures due to orbital environment and high discharge combined.

- <u>Mitigation</u>: The spacecraft thermal design will negate this possibility. Thermal rise has been analyzed in combination with space environment temperatures showing that batteries do not exceed normal allowable operating temperatures under a variety of modeled cases, including worst case orbital scenarios. Analysis shows these temperatures to be well below temperatures of concern for explosions.
- <u>Combined faults required for realized failure</u>: Thermal analysis AND thermal design AND mission simulations in thermal-vacuum chamber testing AND over-current monitoring and control must all fail for this failure mode to occur.

4.6.2 Requirement 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 to 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 control to a level which cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft (Requirement 56450)."

Compliance Statement: **Compliant**, each spacecraft includes the ability to fully disconnect the Lithium Ion cells from the charging current of the solar arrays. Once the satellite reaches its End of Life (EOL), this feature will be used to completely passivate the batteries by removing all energy from them. In the unlikely event that a battery cell does explosively rupture, the small size, mass, and potential energy, of these small batteries is such that while the spacecraft could be expected to vent gases, the debris from the battery rupture should be contained within the spacecraft due to the lack of penetration energy to the multiple enclosures surrounding the batteries.

4.6.3 Requirement 4.4-3: Limiting the long-term risk to other space systems from planned breakup

N/A: The nominal spacecraft mission does not include a planned breakup event.

4.6.4 Requirement 4.4-4: Limiting the short-term risk to other space systems from planned breakup

N/A: The nominal spacecraft mission does not include a planned breakup event.

5 Assessment of Potential for On-Orbit Collisions

5.1 Assessment of Compliance with Requirement 4.5-1 and 4.5-2

Collision with small and large objects was assessed for the full duration of the mission, including the nominal 6-month operational lifetime phase and the decommission phase in which the spacecraft will be fully passivated and the orbit will naturally decay until disposal. The area to mass ratio remains the same throughout the mission and is 0.0089 m^2/kg.

Note: The experimental and optional NSTT termination tape payload is presented in Section 8.

5.1.1 *Requirement 4.5-1: Probability of Damage from Large Objects*

"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"

Compliance Statement: **Compliant**, all altitudes meet the probability requirement considering the vehicle lifetime of a 6-month operational mission, as well decommissioning and disposal of the spacecraft. Probability of damage from large objects per DAS v 3.2.3 is listed for multiple orbital altitudes, as shown in Table 6. Rationale for the altitude ranges is as follows:

- The Tomorow-R1 spacecraft will be on SpaceX's Transporter-7 launch which has a confirmed deployment altitude of 500 km ± 20 km, therefore scenarios for 480 km, 500 km, and 520 km were analyzed.
- The Tomorrow-R2 spacecraft will be on SpaceX's Transporter-8 launch. The Transporter-8 deployment altitude has not been confirmed but is bound to an altitude range requirement between 500 km and 600 km. The worst-case altitude of 600 km the mid-point altitude of 550 km, and the minimum altitude of 500 km are included.

Table 6: Probability of Damage from Large Objects at Relevant Mission Altitudes

Altitude	Inclination	Probability Of Collision
480	97.4	6.8629E-06
500	97.4	7.9356E-06
520	97.4	9.5929E-06
550	97.4	2.4095E-05
600	97.4	6.9721E-05

Note: The experimental and optional NSTT termination tape payload is presented in Section 8.

5.1.2 Requirement 4.5-2: Probability of Damage from Small Objects

"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"

Compliance Statement: **Compliant**, DAS analysis confirmed that the system is compliant over the mission lifetime including operations, decommissioning and disposal of the spacecraft.

Note: The experimental and optional NSTT termination tape payload is presented in Section 8.

5.2 Identification of all systems or components required to accomplish any post-mission disposal operation, including passivation and maneuvering

The Flight Computer, Telemetry Transceiver and Electrical Power Subsystem are required to complete passivation operations. The only device that requires specific passivation activity is the solar array charge circuit to fully discharge all battery cells.

6 Assessment of Post-Mission Disposal Plans and Procedure

6.1 Description of Spacecraft Disposal Option Selected

After completing its planned operations, each satellite will de-orbit naturally and re-enter due to atmospheric drag.

6.2 Plan for any spacecraft maneuvers required to accomplish post- mission disposal

N/A: The spacecraft does not require any maneuvers post mission disposal.

6.3 Calculation of area-to-mass ratio after post-mission disposal if the controlled reentry option is not selected

- Spacecraft maximum mass: 90 Kg (CBE+MGA)

- Current best estimate plus margin is used to assess reentry criteria giving a lower area to mass ratio which in turn increases the orbit dwell time.
- Worst case Area-to-Mass ratio: 0.0089 m^2/kg assuming uncontrolled tumbling case

6.4 Assessment of Compliance with Requirement 4.6-1 Through 4.6-4

6.4.1 Requirement 4.6-1: Disposal for space structures passing through LEO

"A spacecraft or orbital stage with a perigee altitude below 2,000 km shall be disposed of by one of the following three methods:"

- Atmospheric reentry option: Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission; or maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission
- Storage orbit option: Maneuver the space structure into an orbit with perigee altitude above 2000km and ensure its apogee altitude will be below 19,700 km, both for a minimum of 100 years
- Direct retrieval: Retrieve the space structure and remove it from orbit within 10 years after completion of mission

Compliance Statement: **Compliant**, orbit lifetime was assessed using the DAS Orbit Evolution Analysis tool version 3.2.3. Analysis was performed at multiple altitudes to confirm compliance for the full range of potential orbital scenarios, showing that both spacecraft meet the required orbit dwell time. The results of this analysis are summarized in Table 7.

Table 7: Disposal for space structures in LEO at Relevant Mission Altitudes

Altitude	Inclination	RAAN	Arg. Of Perigee	Area-To-Mass	Orbit Lifetime	Decay Year
480	97.4065	187.7	0	0.0082	2.604	2025.694
500	97.4065	187.7	0	0.0082	3.513	2026.603
520	97.4065	187.7	0	0.0082	5.12	2028.21
550	97.4065	187.7	0	0.0082	11.351	2034.441
600	97.4065	187.7	0	0.0082	19.121	2042.211

The Tomorow-R1 spacecraft will be on SpaceX's Transporter-7 launch which has a confirmed deployment altitude of 500 km ± 20 km. The deorbit scenario for 500 km is shown in Figure 2, yielding an estimated time of reentry of 3.857 years. Additional deorbit scenarios for 480 km and 520 km are shown in Appendix C, both meeting the timeframe requirement.

The Tomorrow-R2 spacecraft will be on SpaceX's Transporter-8 launch. The Transporter-8 deployment altitude has not been confirmed but is bound to an altitude range requirement between 500 km and 600 km. The worst case deorbit scenario for 600 km is shown in Figure 3, yielding an estimated time of reentry of 21.955 years. An additional deorbit scenario for 550 km is shown in Appendix C and meets the timeframe requirement.

<u>Note</u>: This analysis was performed assuming all spacecraft parameters described in Section 6.3 and does not include the deployment of the optional and experimental NSTT payload.

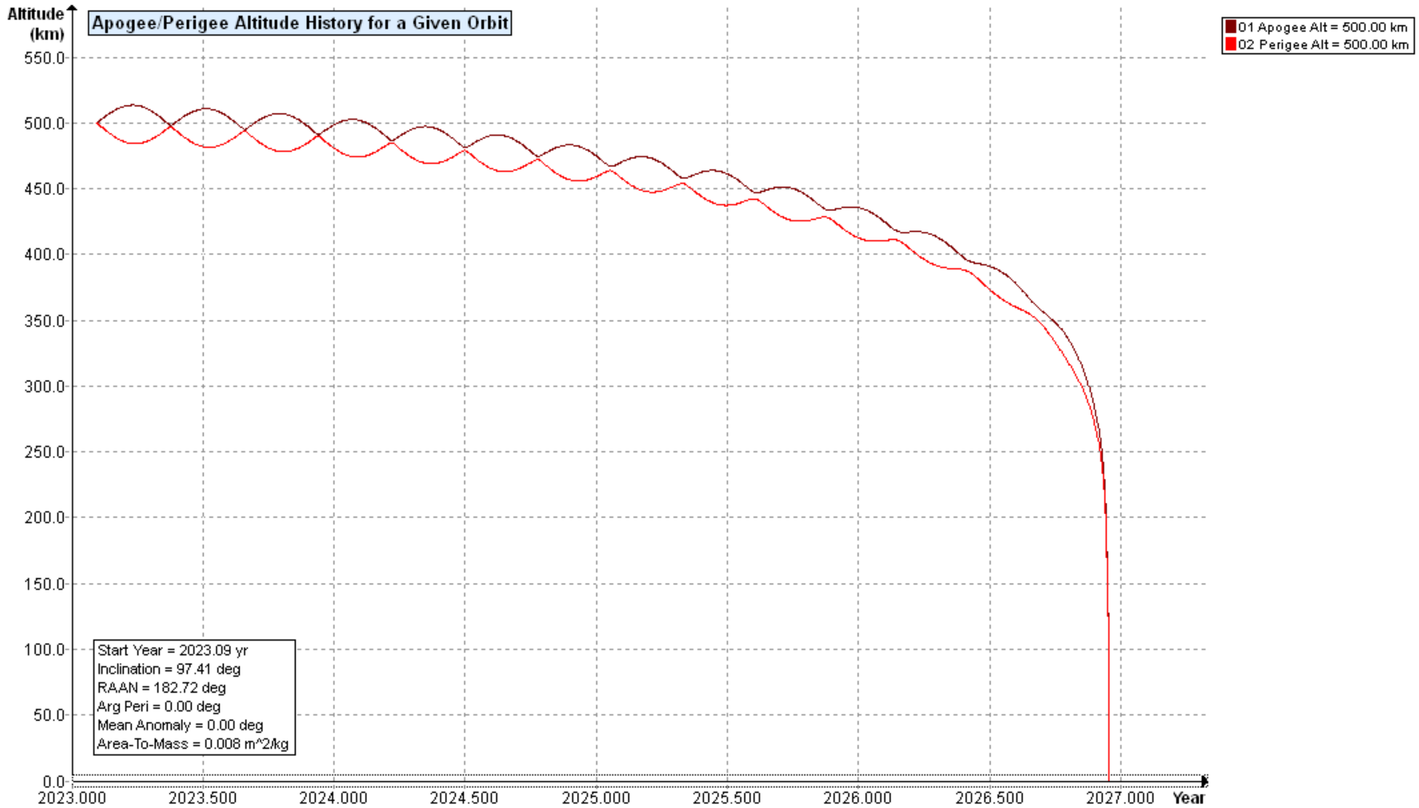

Figure 2: Orbital History at a 500km Starting Altitude, 3.857 year deorbit timeframe

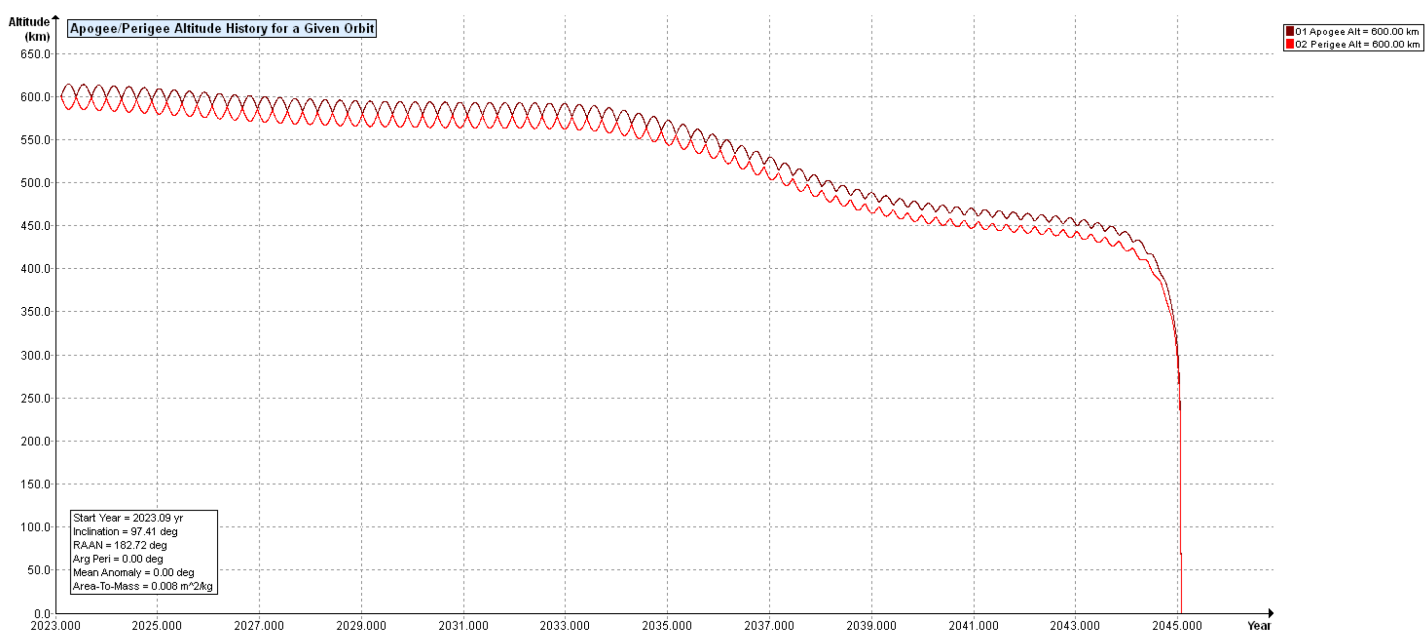

Figure 3: Orbital History at a 600km Starting Altitude, 21.955 year deorbit timeframe

6.4.2 Requirement 4.6-2: Disposal for space structures passing through GEO

N/A: Neither spacecraft will pass through GEO.

6.4.3 Requirement 4.6-3: Disposal for space structures between LEO and GEOs

N/A: Neither spacecraft will pass through GEO

6.4.4 Requirement 4.6-4: Reliability of post-mission disposal operations

Compliance Statement: **Compliant,** each spacecraft will satisfy the requirement of deorbiting within 25 years after deployment as discussed in Section 6.4.1. Reliability of passive deorbit has been validated through different missions in which the accuracy of the orbit's dwell time has a small variation on the order of months.

7 Assessment of Reentry Hazards

The major subsystems and components within each spacecraft bus are nested inside the main body structure such that upon breakup of the body structure, all subsystems and components are directly exposed to the environment. This design intentionally subjects all internal subsystems and components to the maximum atmospheric thermal loading to facilitate an efficient demise. All structural panels consist of an iso grid design to attain a relatively higher surface area to mass ratio and decreased mass, which drastically enhances likelihood of demise. This design was chosen to employ the minimum amount of material possible while still maintaining structural integrity. Similarly, while the antenna diameter was driven by mission requirements, it was designed with the minimum thickness as verified by structural analysis to maximize area to mass ratio and still maintain structural integrity.

Each spacecraft is also designed for demise in that all material selections are prioritized to have a low melting point and density. Any materials known to survive re-entry have been excluded from the design, such as tungsten or titanium. Specifically, all bus structural support members solely consist of aluminum which has of a low melting point and high heat transfer properties. In addition to aluminum, other materials are used in very small quantities including FR4 for PCB boards and Copper Alloy for components such as torque rods and harnessing. Table 8 shows the thermo-physical properties that influence atmospheric reentry thermal load for all major components on board the spacecraft. Given the material properties, FR4 has no risk of reentry and is therefore not included in the table.

Table 8: Material Properties Considering for Design for Demise

Material	Melting Temp (K)	Specific Heat (J/kg-K)	Heat Capacity (J/kg)
Aluminum	850	1110	390000
Copper	1356	389.4<Cp<471.8	204921

The Tomorrow-R1 & Tomorrow-R2 vehicles do not incorporate any new development materials or design architectures as compared with heritage Astro Digital designs that have previously flown and successfully met deorbit and human casualty requirements.

7.1 Assessment of Compliance with Requirement 4.7-1

7.1.1 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:"

- For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001(1:10,000)
- 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
- For controlled reentries, the product of the probability of failure to execute the reentry burn and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000)

Compliance Statement: **DAS version 3.2.3 calculates the risk of human casualty at zero (0) which meets the limit the risk of human casualty requirement.** All components are listed in detail in the full DAS results, as shown in appendix A. The results provided on this analysis are on a per spacecraft basis. All components demise upon reentry. DAS analysis for previous revisions of this document were performed in DAS v3.2.1. DAS v3.2.2 and v3.2.3 have since incorporated multiple changes including temperature-varying specific heats, temperature-varying emissivity values, and updated drag and heating models for cylinders and flat plates. These updates to the reentry survivability modules are the driving rationale behind the difference between values in previous versions of this ODAR, compared to the current zero-value for risk of human casualty.

Note: DPM, DEP, and XPU were modeled with child parent relationship within DAS, as reflected in their design described in Section 2.1.

Table 9: Risk of Human Casualty

Satellite	Risk of Human Casualty	Compliance Status
Tomorrow R-1	0	Compliant
Tomorrow R-2	0	Compliant

8 Assessment for Tether Missions

Each spacecraft includes a secondary and optional payload call a NanoSat Terminator Tape (NSTT). Although the satellite will meet all deorbit and reentry requirements without use of the NSTT, the device is intended to accelerate the process of reentry by deploying a conductive tether which generates neutral particle drag and passive electromagnetics drag. If any conditions occurring throughout the nominal mission which result in unfavorable rationale to active the NSTT, then it will not be deployed and the spacecraft will deorbit within the required timeframe.

The NSTT is mounted inside the spacecraft's light band through four #4-40 SHCS bolts. Its mass is 0.8 kg and the undeployed module dimensions are 180 mm x 180 mm x 18 mm. Once deployed, the terminator tape has dimensions of 70 m x 150 mm.

If utilized, the effective area of the NSTT after deployment is 3.37 +/- 0.56 m^2, which translates into a total "post deployment" spacecraft area to mass ratio of 0.04643m^2/kg. The corresponding cross-sectional area of the spacecraft in a random tumbling attitude with NSTT deploy is estimated at 4.17m^2.

8.1 Assessment for Compliance with Requirements 4.5-1, 4.5-2, and 4.6-1

The following sections reference DAS output logs as shown in appendix D

8.1.1 Requirement 4.5-1 & 4.5-2: Probability of Damage from Large & Small Objects

Probability of damage from large objects was also analyzed with DAS v 3.2.3 over multiple orbital altitudes and assuming NSTT deployment. As shown in Table 9, all altitudes meet the probability requirement. DAS analysis also confirmed probability of collision with small space objects is compliant over the mission lifetime including operations, decommissioning and disposal of the spacecraft. In the unlikely event that there is a collision event with the tether, the vehicle will still de-orbit and re-enter within the required timeframe as discussed in section 6.4.1.

Table 10: Probability of Damage from Large Objects at Relevant Mission Altitudes

Altitude	Inclination	Probability Of Collision
480	97.4	1.0301E-05
500	97.4	1.3163E-05
520	97.4	1.2549E-05
550	97.4	2.0610E-05
600	97.4	4.4851E-05

8.1.2 Requirement 4.6-1: Disposal for space structures passing through LEO

Analysis was performed with DAS v3.2.3 for the disposal for space structures in LEO at multiple altitudes. As shown in Table 10, the deployment of the NSTT is projected to drastically reduce total deorbit time, as compared to the timeframes discussed in Section 6.4.1. It is understood that this analysis is not definitive considering the experimental nature of the NSTT payload.

Table 11: Disposal for Space Structures in LEO at Relevant Mission Altitudes

Altitude	Inclination	RAAN	Arg. Of Perigee	Area-To-Mass	Orbit Lifetime	Decay Year
480	97.4065	187.72	0	0.0464	0.578	2023.668
500	97.4065	187.72	0	0.0464	0.786	2023.876
520	97.4065	187.72	0	0.0464	1.051	2024.141
550	97.4065	187.72	0	0.0464	1.593	2024.683

600	97.4065	187.72	0	0.0464	3.179	2026.269

8.2 Assessment of Compliance with Requirement 4.8-1

8.2.1 Requirement 4.8-1: Collision Hazards of Space Tether

"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."

Compliance Statement: **Compliant**: If deployed, probability of success during deployment and through the deorbit phase has historically been >.90 probability of success from publicly available data. The tether system is intended to remain deployed until removal from Earth orbit by means of atmospheric reentry. In the unlikely event that there is a collision event with the tether, the vehicle will still de-orbit and re-enter within the required timeframe as discussed in section 6.4.1.

Appendix A: DAS Output Log – No NSTT Deployment

```
DAS323 LOG
Processing Requirement 4.3-1:              Return Status :  Not Run

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

=============== End of Requirement 4.3-1 ===============
Processing Requirement 4.3-2: Return Status : Passed

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

=============== End of Requirement 4.3-2 ===============
Processing Requirement 4.5-1:              Return Status :  Passed

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

**INPUT**

        Space Structure Name = Fuji480
        Space Structure Type = Payload
        Perigee Altitude = 480.000 (km)
        Apogee Altitude = 480.000 (km)
        Inclination = 97.406 (deg)
        RAAN = 0.000 (deg)
        Argument of Perigee = 0.000 (deg)
        Mean Anomaly = 0.000 (deg)
        Final Area-To-Mass Ratio = 0.0089 (m^2/kg)
        Start Year = 2023.090 (yr)
        Initial Mass = 90.000 (kg)
        Final Mass = 90.000 (kg)
        Duration = 0.500 (yr)
        Station-Kept = False
        Abandoned = True
        Long-Term Reentry = False

**OUTPUT**

        Collision Probability = 6.8629E-06
        Returned Message: Normal Processing
        Date Range Message: Normal Date Range
        Status = Pass

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

**INPUT**

        Space Structure Name = Fuji500
        Space Structure Type = Payload
        Perigee Altitude = 500.000 (km)
        Apogee Altitude = 500.000 (km)
```

```
        Inclination = 97.406 (deg)
        RAAN = 0.000 (deg)
        Argument of Perigee = 0.000 (deg)
        Mean Anomaly = 0.000 (deg)
        Final Area-To-Mass Ratio = 0.0089 (m^2/kg)
        Start Year = 2023.090 (yr)
        Initial Mass = 90.000 (kg)
        Final Mass = 90.000 (kg)
        Duration = 0.500 (yr)
        Station-Kept = False
        Abandoned = True
        Long-Term Reentry = False

**OUTPUT**

        Collision Probability = 7.9356E-06
        Returned Message: Normal Processing
        Date Range Message: Normal Date Range
        Status = Pass

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

**INPUT**

        Space Structure Name = Fuji520
        Space Structure Type = Payload
        Perigee Altitude = 520.000 (km)
        Apogee Altitude = 520.000 (km)
        Inclination = 97.406 (deg)
        RAAN = 0.000 (deg)
        Argument of Perigee = 0.000 (deg)
        Mean Anomaly = 0.000 (deg)
        Final Area-To-Mass Ratio = 0.0089 (m^2/kg)
        Start Year = 2023.090 (yr)
        Initial Mass = 90.000 (kg)
        Final Mass = 90.000 (kg)
        Duration = 0.500 (yr)
        Station-Kept = False
        Abandoned = True
        Long-Term Reentry = False

**OUTPUT**

        Collision Probability = 9.5929E-06
        Returned Message: Normal Processing
        Date Range Message: Normal Date Range
        Status = Pass

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

**INPUT**

        Space Structure Name = Fuji550
        Space Structure Type = Payload
        Perigee Altitude = 550.000 (km)
        Apogee Altitude = 550.000 (km)
        Inclination = 97.406 (deg)
```

RAAN = 0.000 (deg)
Argument of Perigee = 0.000 (deg)
Mean Anomaly = 0.000 (deg)
Final Area-To-Mass Ratio = 0.0089 (m^2/kg)
Start Year = 2023.090 (yr)
Initial Mass = 90.000 (kg)
Final Mass = 90.000 (kg)
Duration = 0.500 (yr)
Station-Kept = False
Abandoned = True
Long-Term Reentry = False

OUTPUT

Collision Probability = 2.4095E-05
Returned Message: Normal Processing
Date Range Message: Normal Date Range
Status = Pass

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

INPUT

Space Structure Name = Fuji600
Space Structure Type = Payload
Perigee Altitude = 600.000 (km)
Apogee Altitude = 600.000 (km)
Inclination = 97.406 (deg)
RAAN = 0.000 (deg)
Argument of Perigee = 0.000 (deg)
Mean Anomaly = 0.000 (deg)
Final Area-To-Mass Ratio = 0.0089 (m^2/kg)
Start Year = 2023.090 (yr)
Initial Mass = 90.000 (kg)
Final Mass = 90.000 (kg)
Duration = 0.500 (yr)
Station-Kept = False
Abandoned = True
Long-Term Reentry = False

OUTPUT

Collision Probability = 6.9721E-05
Returned Message: Normal Processing
Date Range Message: Normal Date Range
Status = Pass

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

=============== End of Requirement 4.5-1 ===============
Requirement 4.5-2: Compliant

=============== End of Requirement 4.5-2 ===============
Processing Requirement 4.6   Return Status : Passed

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

```
==============

**INPUT**

	Space Structure Name = Fuji
	Space Structure Type = Payload

	Perigee Altitude = 500.000000 (km)
	Apogee Altitude = 500.000000 (km)
	Inclination = 97.600000 (deg)
	RAAN = 0.000000 (deg)
	Argument of Perigee = 0.000000 (deg)
	Mean Anomaly = 0.000000 (deg)
	Area-To-Mass Ratio = 0.008600 (m^2/kg)
	Start Year = 2023.090000 (yr)
	Initial Mass = 90.000000 (kg)
	Final Mass = 90.000000 (kg)
	Duration = 0.500000 (yr)
	Station Kept = False
	Abandoned = True
	PMD Perigee Altitude = 485.022825 (km)
	PMD Apogee Altitude = 504.838579 (km)
	PMD Inclination = 97.618461 (deg)
	PMD RAAN = 184.594244 (deg)
	PMD Argument of Perigee = 41.030712 (deg)
	PMD Mean Anomaly = 0.000000 (deg)
	Long-Term Reentry = False

**OUTPUT**

	Suggested Perigee Altitude = 485.022825 (km)
	Suggested Apogee Altitude = 504.838579 (km)
	Returned Error Message = Passes LEO reentry orbit criteria.

	Released Year = 2026 (yr)
	Requirement = 61
	Compliance Status = Pass

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

=============== End of Requirement 4.6 ===============
Processing Requirement 4.7-1
	Return Status :  Passed

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

name = Fuji
quantity = 1
parent = 0
materialID = 8
type = Box
Aero Mass = 90.000000
Thermal Mass = 90.000000
Diameter/Width = 1.000000
Length = 1.000000
Height = 0.700000
```

```
name = Structural Panel +X
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 8.210000
Thermal Mass = 8.210000
Diameter/Width = 0.500000
Length = 0.680000
Height = 0.040000

name = Harness
quantity = 52
parent = 1
materialID = 19
type = Cylinder
Aero Mass = 0.150000
Thermal Mass = 0.150000
Diameter/Width = 0.020000
Length = 0.300000

name = Reaction wheel
quantity = 3
parent = 1
materialID = 8
type = Box
Aero Mass = 1.400000
Thermal Mass = 1.400000
Diameter/Width = 0.146000
Length = 0.154000
Height = 0.045000

name = Torque board
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.030000
Thermal Mass = 0.030000
Diameter/Width = 0.030000
Length = 0.090000
Height = 0.010000

name = Torque Rod
quantity = 1
parent = 1
materialID = 19
type = Box
Aero Mass = 0.500000
Thermal Mass = 0.500000
Diameter/Width = 0.050000
Length = 0.300000
Height = 0.020000

name = Gyro
quantity = 1
```

```
parent = 1
materialID = 8
type = Box
Aero Mass = 0.080000
Thermal Mass = 0.080000
Diameter/Width = 0.038000
Length = 0.045000
Height = 0.022000

name = Reaction wheel bracket
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.380000
Thermal Mass = 1.380000
Diameter/Width = 0.100000
Length = 0.160000
Height = 0.040000

name = Termination tape
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.810000
Thermal Mass = 0.810000
Diameter/Width = 0.180000
Length = 0.180000
Height = 0.018000

name = DPM
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 2.690000
Thermal Mass = 1.110000
Diameter/Width = 0.150000
Length = 0.220000
Height = 0.100000

name = DPM Backplane
quantity = 1
parent = 10
materialID = 23
type = Flat Plate
Aero Mass = 0.200000
Thermal Mass = 0.200000
Diameter/Width = 0.150000
Length = 0.220000

name = Flight Computer
quantity = 1
parent = 10
materialID = 8
type = Box
```

```
Aero Mass = 0.130000
Thermal Mass = 0.130000
Diameter/Width = 0.700000
Length = 0.800000
Height = 0.010000

name = GPS radio
quantity = 1
parent = 10
materialID = 8
type = Box
Aero Mass = 0.120000
Thermal Mass = 0.120000
Diameter/Width = 0.700000
Length = 0.800000
Height = 0.010000

name = TTC Radio
quantity = 2
parent = 10
materialID = 8
type = Box
Aero Mass = 0.110000
Thermal Mass = 0.110000
Diameter/Width = 0.700000
Length = 0.800000
Height = 0.010000

name = I/O Board
quantity = 1
parent = 10
materialID = 8
type = Box
Aero Mass = 0.130000
Thermal Mass = 0.130000
Diameter/Width = 0.700000
Length = 0.800000
Height = 0.010000

name = Power Board
quantity = 2
parent = 10
materialID = 8
type = Box
Aero Mass = 0.120000
Thermal Mass = 0.120000
Diameter/Width = 0.700000
Length = 0.800000
Height = 0.010000

name = High Voltage Power Board
quantity = 1
parent = 10
materialID = 8
type = Box
Aero Mass = 0.110000
Thermal Mass = 0.110000
```

```
Diameter/Width = 0.700000
Length = 0.800000
Height = 0.010000

name = Charging Board
quantity = 1
parent = 10
materialID = 8
type = Box
Aero Mass = 0.130000
Thermal Mass = 0.130000
Diameter/Width = 0.700000
Length = 0.800000
Height = 0.010000

name = Battery Board
quantity = 2
parent = 10
materialID = 8
type = Box
Aero Mass = 0.150000
Thermal Mass = 0.150000
Diameter/Width = 0.700000
Length = 0.800000
Height = 0.020000

name = DEP
quantity = 4
parent = 1
materialID = 8
type = Box
Aero Mass = 1.200000
Thermal Mass = 0.950000
Diameter/Width = 0.100000
Length = 0.190000
Height = 0.040000

name = Battery Bracket
quantity = 4
parent = 20
materialID = 8
type = Box
Aero Mass = 0.050000
Thermal Mass = 0.050000
Diameter/Width = 0.100000
Length = 0.190000
Height = 0.030000

name = BMS Board
quantity = 4
parent = 20
materialID = 23
type = Flat Plate
Aero Mass = 0.080000
Thermal Mass = 0.080000
Diameter/Width = 0.100000
Length = 0.150000
```

```
name = DEP Board
quantity = 4
parent = 20
materialID = 23
type = Flat Plate
Aero Mass = 0.120000
Thermal Mass = 0.120000
Diameter/Width = 0.100000
Length = 0.170000

name = XPU
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.510000
Thermal Mass = 0.220000
Diameter/Width = 0.100000
Length = 0.120000
Height = 0.090000

name = XPU Backplane
quantity = 1
parent = 24
materialID = 23
type = Flat Plate
Aero Mass = 0.050000
Thermal Mass = 0.050000
Diameter/Width = 0.100000
Length = 0.120000

name = NX Board
quantity = 1
parent = 24
materialID = 8
type = Box
Aero Mass = 0.130000
Thermal Mass = 0.130000
Diameter/Width = 0.700000
Length = 0.800000
Height = 0.010000

name = HVPB Board
quantity = 1
parent = 24
materialID = 8
type = Box
Aero Mass = 0.110000
Thermal Mass = 0.110000
Diameter/Width = 0.700000
Length = 0.800000
Height = 0.010000

name = Structural Panel +Y
quantity = 1
parent = 1
```

```
materialID = 8
type = Box
Aero Mass = 3.480000
Thermal Mass = 3.480000
Diameter/Width = 0.450000
Length = 0.450000
Height = 0.020000

name = XCOM
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 2.000000
Thermal Mass = 2.000000
Diameter/Width = 0.120000
Length = 0.120000
Height = 0.110000

name = HPA
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.210000
Thermal Mass = 0.210000
Diameter/Width = 0.050000
Length = 0.070000
Height = 0.030000

name = Ka antenna
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.290000
Thermal Mass = 0.290000
Diameter/Width = 0.080000
Length = 0.080000
Height = 0.050000

name = XMSP pY
quantity = 1
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.230000
Thermal Mass = 0.230000
Diameter/Width = 0.170000
Length = 0.220000

name = ADS pY
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.030000
```

```
Thermal Mass = 0.030000
Diameter/Width = 0.020000
Length = 0.150000
Height = 0.010000

name = Structural Panel -Y
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 3.240000
Thermal Mass = 3.240000
Diameter/Width = 0.480000
Length = 0.480000
Height = 0.020000

name = TRQ nY
quantity = 2
parent = 1
materialID = 19
type = Box
Aero Mass = 0.500000
Thermal Mass = 0.500000
Diameter/Width = 0.050000
Length = 0.300000
Height = 0.020000

name = SRX nY
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.030000
Thermal Mass = 0.030000
Diameter/Width = 0.040000
Length = 0.060000
Height = 0.010000

name = XMSP nY
quantity = 1
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.230000
Thermal Mass = 0.230000
Diameter/Width = 0.170000
Length = 0.220000

name = ADS nY
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.030000
Thermal Mass = 0.030000
Diameter/Width = 0.020000
Length = 0.150000
```

```
Height = 0.010000

name = Structural Panel -Z
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 7.080000
Thermal Mass = 7.080000
Diameter/Width = 0.930000
Length = 1.080000
Height = 0.020000

name = SRX nZ
quantity = 2
parent = 1
materialID = 8
type = Box
Aero Mass = 0.030000
Thermal Mass = 0.030000
Diameter/Width = 0.040000
Length = 0.060000
Height = 0.010000

name = Camera bracket
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.070000
Thermal Mass = 0.070000
Diameter/Width = 0.146000
Length = 0.177800

name = ADS nZ
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.030000
Thermal Mass = 0.030000
Diameter/Width = 0.020000
Length = 0.150000
Height = 0.010000

name = MSP
quantity = 6
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.840000
Thermal Mass = 0.840000
Diameter/Width = 0.320000
Length = 0.420000

name = Camera
quantity = 1
```

```
parent = 1
materialID = 5
type = Box
Aero Mass = 0.130000
Thermal Mass = 0.130000
Diameter/Width = 0.037000
Length = 0.072000
Height = 0.037000

name = GPS antenna
quantity = 2
parent = 1
materialID = 8
type = Box
Aero Mass = 0.030000
Thermal Mass = 0.030000
Diameter/Width = 0.030000
Length = 0.030000
Height = 0.020000

name = UHF antenna
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.030000
Thermal Mass = 0.030000
Diameter/Width = 0.030000
Length = 0.050000
Height = 0.010000

name = Structural Panel payload deck
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 9.620000
Thermal Mass = 9.620000
Diameter/Width = 0.760000
Length = 0.820000
Height = 0.090000

name = Thermal strap
quantity = 3
parent = 1
materialID = 19
type = Box
Aero Mass = 0.100000
Thermal Mass = 0.100000
Diameter/Width = 0.040000
Length = 0.040000
Height = 0.030000

name = SDR
quantity = 1
parent = 1
materialID = 8
```

```
type = Box
Aero Mass = 1.110000
Thermal Mass = 1.110000
Diameter/Width = 0.150000
Length = 0.250000
Height = 0.030000

name = FSA
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.970000
Thermal Mass = 1.970000
Diameter/Width = 0.180000
Length = 0.180000
Height = 0.045000

name = PDU
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 2.360000
Thermal Mass = 2.360000
Diameter/Width = 0.190000
Length = 0.190000
Height = 0.030000

name = Upconverter
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.900000
Thermal Mass = 0.900000
Diameter/Width = 0.100000
Length = 0.107000
Height = 0.075000

name = Downconverter
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.900000
Thermal Mass = 0.900000
Diameter/Width = 0.100000
Length = 0.107000
Height = 0.075000

name = SSPA
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.810000
```

```
Thermal Mass = 0.810000
Diameter/Width = 0.120000
Length = 0.160000
Height = 0.030000

name = Duplexer
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.910000
Thermal Mass = 0.910000
Diameter/Width = 0.120000
Length = 0.200000
Height = 0.030000

name = Driver
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.410000
Thermal Mass = 0.410000
Diameter/Width = 0.063500
Length = 0.108000
Height = 0.029500

name = Star tracker bracket
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.270000
Thermal Mass = 0.270000
Diameter/Width = 0.250000
Length = 0.270000
Height = 0.100000

name = Star tracker
quantity = 2
parent = 1
materialID = 8
type = Cylinder
Aero Mass = 0.230000
Thermal Mass = 0.230000
Diameter/Width = 0.150000
Length = 0.330000

name = Antenna
quantity = 1
parent = 1
materialID = 8
type = Cylinder
Aero Mass = 15.000000
Thermal Mass = 15.000000
Diameter/Width = 1.200000
Length = 0.440000
```

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

name = Fuji
Demise Altitude = 77.994667
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Structural Panel +X
Demise Altitude = 74.991271
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Harness
Demise Altitude = 76.535685
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Reaction wheel
Demise Altitude = 74.927558
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Torque board
Demise Altitude = 77.643640
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Torque Rod
Demise Altitude = 75.345501
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Gyro
Demise Altitude = 76.838838
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Reaction wheel bracket
Demise Altitude = 74.616587
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Termination tape
Demise Altitude = 76.246261
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

```
************************************
name = DPM
Demise Altitude = 76.686063
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = DPM Backplane
Demise Altitude = 75.544251
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Flight Computer
Demise Altitude = 76.656008
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = GPS radio
Demise Altitude = 76.655511
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = TTC Radio
Demise Altitude = 76.663074
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = I/O Board
Demise Altitude = 76.656008
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Power Board
Demise Altitude = 76.655511
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = High Voltage Power Board
Demise Altitude = 76.663074
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Charging Board
Demise Altitude = 76.656008
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Battery Board
Demise Altitude = 76.648592
```

```
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = DEP
Demise Altitude = 75.922072
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Battery Bracket
Demise Altitude = 75.803676
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = BMS Board
Demise Altitude = 75.103768
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = DEP Board
Demise Altitude = 74.824388
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = XPU
Demise Altitude = 77.483151
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = XPU Backplane
Demise Altitude = 76.824427
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = NX Board
Demise Altitude = 77.453915
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = HVPB Board
Demise Altitude = 77.454623
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Structural Panel +Y
Demise Altitude = 75.884779
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

```
************************************
name = XCOM
Demise Altitude = 74.140217
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = HPA
Demise Altitude = 76.406629
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Ka antenna
Demise Altitude = 76.625616
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = XMSP pY
Demise Altitude = 76.738770
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = ADS pY
Demise Altitude = 77.277789
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Structural Panel -Y
Demise Altitude = 76.184096
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = TRQ nY
Demise Altitude = 75.345501
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = SRX nY
Demise Altitude = 77.572800
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = XMSP nY
Demise Altitude = 76.738770
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = ADS nY
Demise Altitude = 77.277789
```

```
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Structural Panel -Z
Demise Altitude = 76.575221
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = SRX nZ
Demise Altitude = 77.572800
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Camera bracket
Demise Altitude = 77.801564
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = ADS nZ
Demise Altitude = 77.277789
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = MSP
Demise Altitude = 76.147525
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Camera
Demise Altitude = 75.545991
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = GPS antenna
Demise Altitude = 77.269836
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = UHF antenna
Demise Altitude = 77.413732
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Structural Panel payload deck
Demise Altitude = 75.611360
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

****
name = Thermal strap
Demise Altitude = 75.508564
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = SDR
Demise Altitude = 76.243762
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = FSA
Demise Altitude = 74.513087
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = PDU
Demise Altitude = 73.799685
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Upconverter
Demise Altitude = 75.500237
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Downconverter
Demise Altitude = 75.500237
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = SSPA
Demise Altitude = 75.918329
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Duplexer
Demise Altitude = 76.080701
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Driver
Demise Altitude = 76.060073
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Star tracker bracket
Demise Altitude = 77.747696

```
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Star tracker
Demise Altitude = 77.708351
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Antenna
Demise Altitude = 76.495657
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************

=============== End of Requirement 4.7-1 ===============
Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

        Start Year = 2023.090000 (yr)
        Perigee Altitude = 480.000000 (km)
        Apogee Altitude = 480.000000 (km)
        Inclination = 97.406500 (deg)
        RAAN = 187.720000 (deg)
        Argument of Perigee = 0.000000 (deg)
        Area-To-Mass Ratio = 0.008200 (m^2/kg)

**OUTPUT**

        Orbital Lifetime from Startyr = 2.847365 (yr)
        Time Spent in LEO during Lifetime  = 2.847365 (yr)
        Last year of Propagation = 2025 (yr)
        Returned Error Message: Object reentered
Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

        Start Year = 2023.090000 (yr)
        Perigee Altitude = 500.000000 (km)
        Apogee Altitude = 500.000000 (km)
        Inclination = 97.406500 (deg)
        RAAN = 187.720000 (deg)
        Argument of Perigee = 0.000000 (deg)
        Area-To-Mass Ratio = 0.008200 (m^2/kg)

**OUTPUT**

        Orbital Lifetime from Startyr = 3.857632 (yr)
        Time Spent in LEO during Lifetime  = 3.857632 (yr)
        Last year of Propagation = 2026 (yr)
        Returned Error Message: Object reentered
Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**
```

Start Year = 2023.090000 (yr)
Perigee Altitude = 520.000000 (km)
Apogee Altitude = 520.000000 (km)
Inclination = 97.406500 (deg)
RAAN = 187.720000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.008200 (m^2/kg)

OUTPUT

Orbital Lifetime from Startyr = 5.848049 (yr)
Time Spent in LEO during Lifetime = 5.848049 (yr)
Last year of Propagation = 2028 (yr)
Returned Error Message: Object reentered
Science and Engineering - Orbit Lifetime/Dwell Time

INPUT

Start Year = 2023.090000 (yr)
Perigee Altitude = 550.000000 (km)
Apogee Altitude = 550.000000 (km)
Inclination = 97.406500 (deg)
RAAN = 187.720000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.008200 (m^2/kg)

OUTPUT

Orbital Lifetime from Startyr = 11.816564 (yr)
Time Spent in LEO during Lifetime = 11.816564 (yr)
Last year of Propagation = 2034 (yr)
Returned Error Message: Object reentered
Science and Engineering - Orbit Lifetime/Dwell Time

INPUT

Start Year = 2023.090000 (yr)
Perigee Altitude = 600.000000 (km)
Apogee Altitude = 600.000000 (km)
Inclination = 97.406500 (deg)
RAAN = 187.720000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.008200 (m^2/kg)

OUTPUT

Orbital Lifetime from Startyr = 21.954825 (yr)
Time Spent in LEO during Lifetime = 21.954825 (yr)
Last year of Propagation = 2045 (yr)
Returned Error Message: Object reentered

Appendix B: Miscellaneous Hardware

The following table describes all components that are considered “Misc Hardware” within the DAS output log described in Appendix A. "Misc hardware" is comprised of very small components that are otherwise not contained withing a subsystem or module. Components include items such as socket head cap screws, countersunk screws, hex nuts, standoffs, spacers, gap pads, small brackets, cable/zip ties, etc. These objects are distributed throughout the system.

Table 12: Miscellaneous Hardware Description

Product Reference	Product Name	Quantity
90666A104	M3 X 8L Low Profile SHCS, SS	10
92095A179	M3 x 0.50 mm Thread, 6mm Long	3
92095A182	BHCS, M3x0.5, 10MM LONG, 18-8 SS	1
92095A458	M2.5 x 0.45 mm Thread, 6mm Long	3
92095A460	M2.5 X 10L BHCS, SS	4
92290A055	M2.5 x 5L SHCS, 316SS	14
92290A056	SS Socket Head Screw, M2.5 x 0.45 mm Thread, 6 mm L	4
92290A056	SS Socket Head Screw, M2.5 x 0.45 mm Thread, 6 mm L	16
92290A058	Super-Corrosion-Resistant 316 SSvSocket Head Screw, M2.5 x 0.45 mm Thread, 8 mm Long	3
92290A751	316 SS Socket Head Screw, M2.5 x 0.45 mm Thread, 4 mm L	4
92871A171	M3 Unthreaded Spacer, 3MM LONG, 18-8 SS	1
92871A174	STANDOFF, M2.5 X 5L, SS	4
93395A137	M2 x 0.40mm Thread, 5mm Long	4
93395A174	M2.5 X 6L FHCS, SS	4
93395A176	316 Stainless Steel Hex Drive Flat Head Screw, 90 Degree Countersink, M2.5 x 0.45mm Thread, 8mm Long	1
93395A179	M2.5 X 10L FHCS, SS	4
93935A310	M2.5 THIN HEX NUT, 316SS	4
CSM-02447	Cable Tie Anchor Mount, Size 3	25
CSM-03595	Flight Blue Zip Ties	50
STR-03377-2	Ka Support Bracket, Bottom	1
STR-03378-3	Ka Support Bracket, Top	1
STR-04594-1	CORNER BRACKET, FUJI	1
TIM-00151	GAP PAD 0.10" Thickness 4"X4" sheet	4
TIM-03963	GAP PAD, 0.02INCH THICKNESS 8"x16" Sheet	1
TIM-44589	GAP PAD, 0.04" THICKNESS 4"x4" sheet	1

Appendix C: Additional De-orbit Scenarios

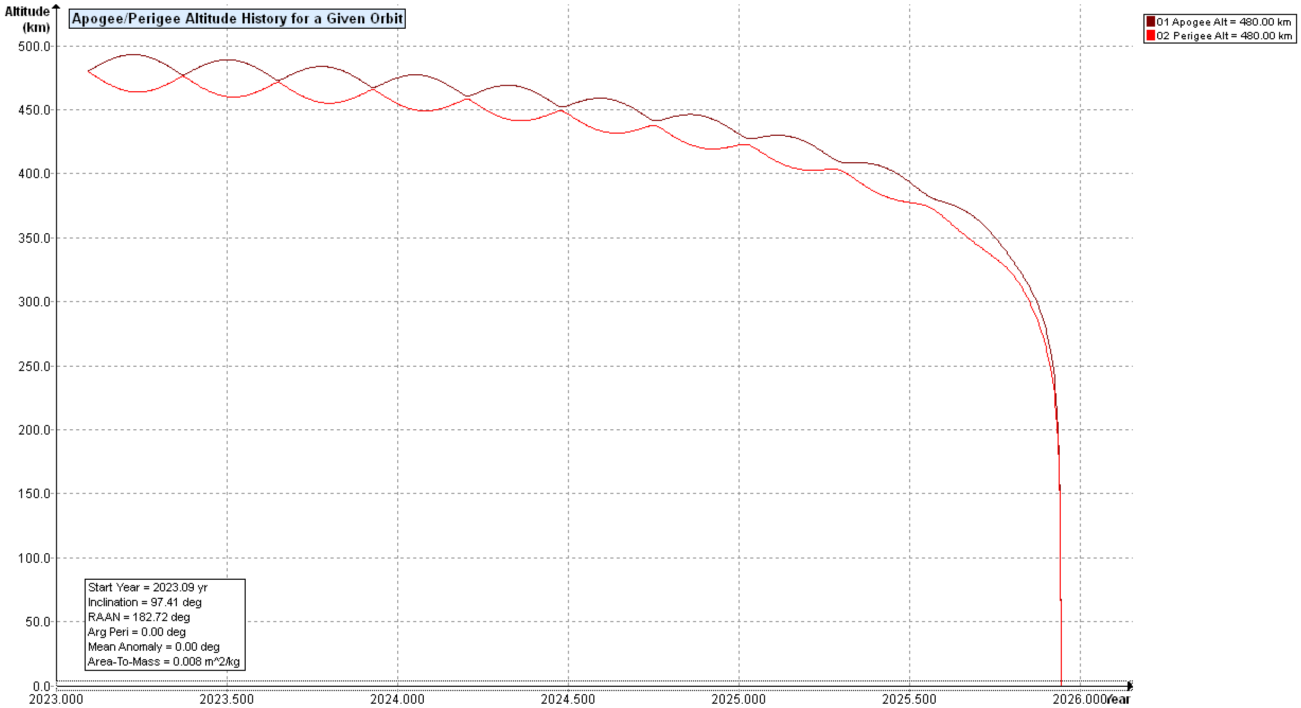

Figure 4: Orbital History at a 480km Starting Altitude, 2.847 year deorbit timeframe

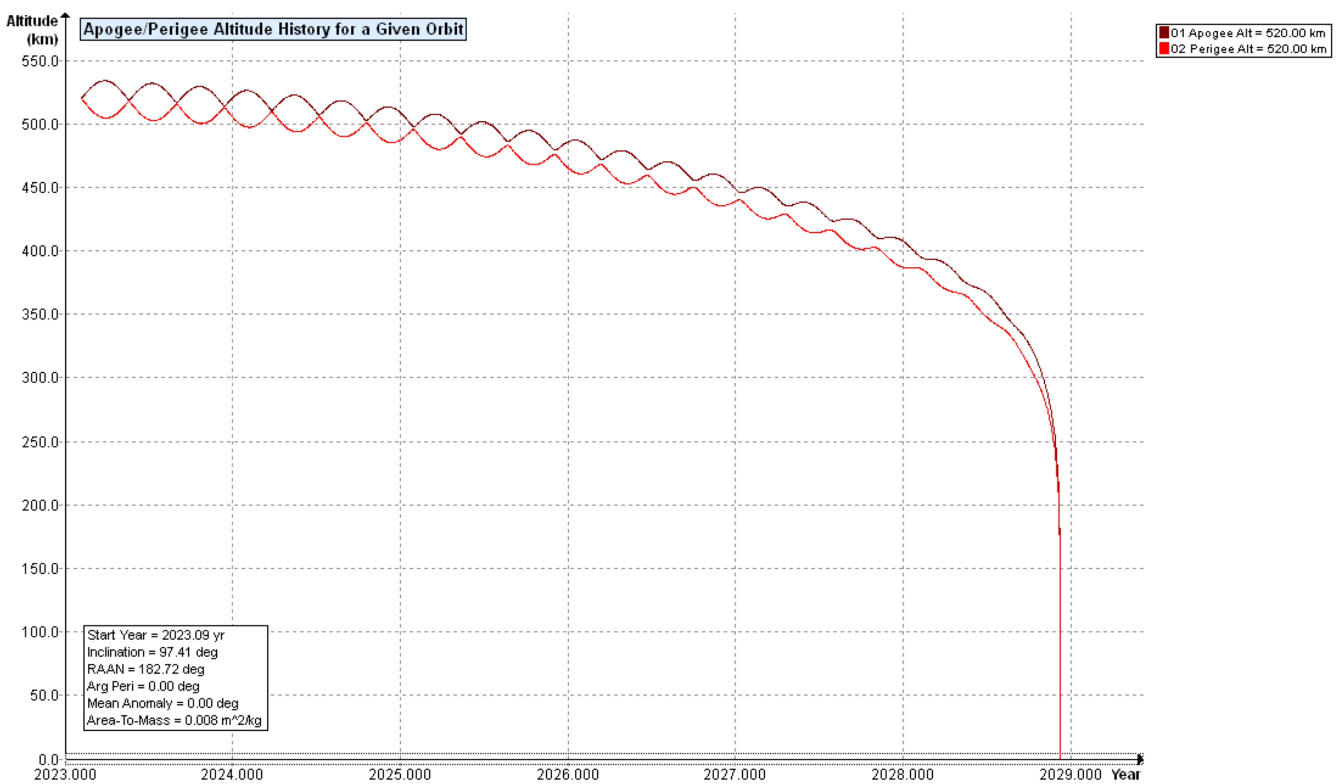

Figure 5: Orbital History at a 520km Starting Altitude, 5.848 year deorbit timeframe

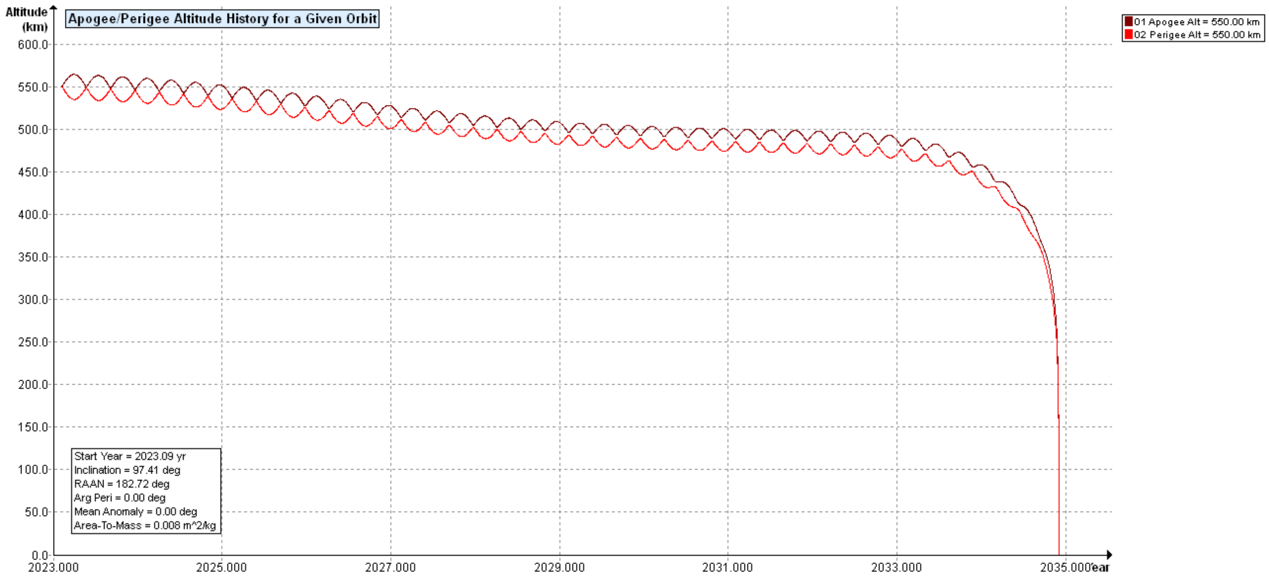

Figure 6: Orbital History at a 550km Starting Altitude, 11.817 year deorbit timeframe

Appendix D: Experimental DAS Output Log – NSTT Deployment

Processing Requirement 4.5-1: Return Status : Passed

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

INPUT

Space Structure Name = Fuji480
Space Structure Type = Payload
Perigee Altitude = 480.000 (km)
Apogee Altitude = 480.000 (km)
Inclination = 97.406 (deg)
RAAN = 0.000 (deg)
Argument of Perigee = 0.000 (deg)
Mean Anomaly = 0.000 (deg)
Final Area-To-Mass Ratio = 0.0464 (m^2/kg)
Start Year = 2023.590 (yr)
Initial Mass = 90.000 (kg)
Final Mass = 90.000 (kg)
Duration = 0.500 (yr)
Station-Kept = False
Abandoned = True
Long-Term Reentry = False

OUTPUT

Collision Probability = 1.0301E-05
Returned Message: Normal Processing
Date Range Message: Normal Date Range
Status = Pass

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

INPUT

Space Structure Name = Fuji500
Space Structure Type = Payload
Perigee Altitude = 500.000 (km)
Apogee Altitude = 500.000 (km)
Inclination = 97.406 (deg)
RAAN = 0.000 (deg)
Argument of Perigee = 0.000 (deg)
Mean Anomaly = 0.000 (deg)
Final Area-To-Mass Ratio = 0.0464 (m^2/kg)
Start Year = 2023.590 (yr)
Initial Mass = 90.000 (kg)
Final Mass = 90.000 (kg)
Duration = 0.500 (yr)
Station-Kept = False
Abandoned = True
Long-Term Reentry = False

OUTPUT

```
            Collision Probability = 1.3163E-05
            Returned Message: Normal Processing
            Date Range Message: Normal Date Range
            Status = Pass

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

**INPUT**

            Space Structure Name = Fuji520
            Space Structure Type = Payload
            Perigee Altitude = 520.000 (km)
            Apogee Altitude = 520.000 (km)
            Inclination = 97.406 (deg)
            RAAN = 0.000 (deg)
            Argument of Perigee = 0.000 (deg)
            Mean Anomaly = 0.000 (deg)
            Final Area-To-Mass Ratio = 0.0464 (m^2/kg)
            Start Year = 2023.590 (yr)
            Initial Mass = 90.000 (kg)
            Final Mass = 90.000 (kg)
            Duration = 0.500 (yr)
            Station-Kept = False
            Abandoned = True
            Long-Term Reentry = False

**OUTPUT**

            Collision Probability = 1.2549E-05
            Returned Message: Normal Processing
            Date Range Message: Normal Date Range
            Status = Pass

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

**INPUT**

            Space Structure Name = Fuji550
            Space Structure Type = Payload
            Perigee Altitude = 550.000 (km)
            Apogee Altitude = 550.000 (km)
            Inclination = 97.406 (deg)
            RAAN = 0.000 (deg)
            Argument of Perigee = 0.000 (deg)
            Mean Anomaly = 0.000 (deg)
            Final Area-To-Mass Ratio = 0.0464 (m^2/kg)
            Start Year = 2023.590 (yr)
            Initial Mass = 90.000 (kg)
            Final Mass = 90.000 (kg)
            Duration = 0.500 (yr)
            Station-Kept = False
            Abandoned = True
            Long-Term Reentry = False

**OUTPUT**

            Collision Probability = 2.0610E-05
```

```
        Returned Message: Normal Processing
        Date Range Message: Normal Date Range
        Status = Pass

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

**INPUT**

        Space Structure Name = Fuji600
        Space Structure Type = Payload
        Perigee Altitude = 600.000 (km)
        Apogee Altitude = 600.000 (km)
        Inclination = 97.406 (deg)
        RAAN = 0.000 (deg)
        Argument of Perigee = 0.000 (deg)
        Mean Anomaly = 0.000 (deg)
        Final Area-To-Mass Ratio = 0.0464 (m^2/kg)
        Start Year = 2023.590 (yr)
        Initial Mass = 90.000 (kg)
        Final Mass = 90.000 (kg)
        Duration = 0.500 (yr)
        Station-Kept = False
        Abandoned = True
        Long-Term Reentry = False

**OUTPUT**

        Collision Probability = 4.4851E-05
        Returned Message: Normal Processing
        Date Range Message: Normal Date Range
        Status = Pass

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

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

Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

        Start Year = 2023.590000 (yr)
        Perigee Altitude = 500.000000 (km)
        Apogee Altitude = 500.000000 (km)
        Inclination = 97.406500 (deg)
        RAAN = 187.720000 (deg)
        Argument of Perigee = 0.000000 (deg)
        Area-To-Mass Ratio = 0.046400 (m^2/kg)

**OUTPUT**

        Orbital Lifetime from Startyr = 0.785763 (yr)
        Time Spent in LEO during Lifetime  = 0.785763 (yr)
        Last year of Propagation = 2024 (yr)
        Returned Error Message: Object reentered
Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**
```

Start Year = 2023.590000 (yr)
Perigee Altitude = 480.000000 (km)
Apogee Altitude = 480.000000 (km)
Inclination = 97.406500 (deg)
RAAN = 187.720000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.046400 (m^2/kg)

OUTPUT

Orbital Lifetime from Startyr = 0.577687 (yr)
Time Spent in LEO during Lifetime = 0.577687 (yr)
Last year of Propagation = 2024 (yr)
Returned Error Message: Object reentered
Science and Engineering - Orbit Lifetime/Dwell Time

INPUT

Start Year = 2023.590000 (yr)
Perigee Altitude = 520.000000 (km)
Apogee Altitude = 520.000000 (km)
Inclination = 97.406500 (deg)
RAAN = 187.720000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.046400 (m^2/kg)

OUTPUT

Orbital Lifetime from Startyr = 1.051335 (yr)
Time Spent in LEO during Lifetime = 1.051335 (yr)
Last year of Propagation = 2024 (yr)
Returned Error Message: Object reentered
Science and Engineering - Orbit Lifetime/Dwell Time

INPUT

Start Year = 2023.590000 (yr)
Perigee Altitude = 550.000000 (km)
Apogee Altitude = 550.000000 (km)
Inclination = 97.406500 (deg)
RAAN = 187.720000 (deg)
Argument of Perigee = 0.000000 (deg)
Area-To-Mass Ratio = 0.046400 (m^2/kg)

OUTPUT

Orbital Lifetime from Startyr = 1.593429 (yr)
Time Spent in LEO during Lifetime = 1.593429 (yr)
Last year of Propagation = 2025 (yr)
Returned Error Message: Object reentered
Science and Engineering - Orbit Lifetime/Dwell Time

INPUT

Start Year = 2023.590000 (yr)
Perigee Altitude = 600.000000 (km)

```
        Apogee Altitude = 600.000000 (km)
        Inclination = 97.406500 (deg)
        RAAN = 187.720000 (deg)
        Argument of Perigee = 0.000000 (deg)
        Area-To-Mass Ratio = 0.046400 (m^2/kg)

**OUTPUT**

        Orbital Lifetime from Startyr = 3.178645 (yr)
        Time Spent in LEO during Lifetime  = 3.178645 (yr)
        Last year of Propagation = 2026 (yr)
        Returned Error Message: Object reentered
```

Appendix E: Change Log

- Table 1: Added reference section
- Section 1: Updated section with key personnel table
- Section 1.1: Updated spacecraft ship/launch dates.
- Section 1.2: Reduced redundant information that is covered in section 2.1.
- Section 1.3: Combined “Launch Vehicles and Launch Sites” sections with “Proposed Initial Launch Date” Section
- Section 1.4: Added tables describing each launch and it’s associated parameters, and included a status column
- Section 2.1: Added paragraph describing Parent/Child subsystems including Data Power Module (DPM), Direct Energy Packs (DEPs), and eXternal Payload UNIT (XPU)
- Section 2.1: Added clarifying statement that the NanoSat Termination Tape (NSTT) is a secondary, experimental, and optional payload.
- Section 4.4: Added clarification that batteries cannot be revived once fully discharged
- Section 4.6.1.1: Added additional description of battery cell Current Interrupt Device (CID)
- Section 5.1.1: Added table to describe full range of probability values based on all possible mission orbital scenarios. All analysis was updated per DAS v3.2.3. Added note about optional NSTT payload.
- Section 5.2: Clarified that only the solar array charge circuit is required for passivation.
- Section 6.1: Clarified that each satellite will de-orbit due to atmospheric drag alone
- Section 6.3: Updated to reflect worst case area-to-mass ratio assuming no NSTT deployment
- Section 6.4.1: Re-wrote section to describe full range of possible orbital scenarios as well as split out the Tomorrow-R1 and R2 spacecraft. All analysis was updated per DAS v3.2.3 and includes parent/child relationships for the DPM, DEP, and XPU.
- Section 7: Included additional details describing the spacecraft design for demise including Table 6, material properties
- Section 7.1: Updated human casualty value per DAS v3.2.3 analysis
- Section 8: Updated section to describe the experimental, optional, and non-mission critical nature of the NSTT payload
- Section 8.1, 8.1.1, and 8.1.2: Split sections out per requirement with similar formatting to non-NSTT analysis.
- Appendix A: Updated per DAS v3.2.3 analysis
- Appendix C: Added to present additional de-orbit scenarios
- Appendix D: Added to present DAS v3.2.3 results of experimental NSTT payload
- Appendix E: Added change log
- General: Added brief description to and requirement where N/A is claimed.