Cesium Mission 1 FCC 442
Orbital Debris Assessment Report

FRN: 0029768140

Rev. D

CesiumAstro, Inc.
13412 Galleria Circle Suite H-100
Austin, Texas 78738

July 13, 2021

Contents

ODAR Signature Approval

Title	Name	Signature	Date
Principal Engineer	Scott Carnahan	Scott Carnahan	7/13/2021
Spacecraft Controls Engineer	Amina Mahrouch	Amina Mahrouch	7/13/2021

Revisions and History

REV.	DESCRIPTION	SUB. DATE
Initial	Initial ODAR submission	02/12/2021
Rev. A	Fixed error in DAS calculation mass parameter, added requested clarification on area-to-mass calculations and propulsion use, battery module FMEA, and solar panel dimensions.	04/27/2021
Rev. B	Adds station keeping tolerances.	05/07/2021
Rev. C	Adds new components (Ballast) to DAS calculation.	06/11/2021
Rev. D	Generated new DAS analysis with updated mass properties and updated area-to-mass, mass, and dimensions to final parameter values and removed Ballast.	07/13/2021

ODAR Self-Assessment per NASA-STD-8719.14B, Process for Limiting Orbital Debris

Table 1 presents the Cesium Mission 1 FCC Orbital Debris Self-Assessment Report Evaluation in accordance with the assessment format provided in Appendix A.2 of NASA-STD-8719.14B. Requirement assessments for 4.3-1/2, 4.5-1/2, 4.6-1 to 4.6-3, and 4.7-1 were analyzed using **NASA's DAS v3.1.0** software.

Table 1: Cesium Mission 1 FCC ODAR self-assessment evaluation per NASA-STD-8719.14B

Reqm't #	Launch Vehicle Compliant / Not Compliant / Std. Non-Compliant / Incomplete	Spacecraft Compliant / Not Compliant / Incomplete	Comments For all incompletes, include risk assessment of non-compliance & Tracking #
4.3-1. a 25-year limit	N/A	Compliant	NASA DAS, no intentional release of debris
4.3-1. b <100 object x year limit	N/A	Compliant	NASA DAS, no intentional release of debris
4.3-2 GEO +/- 200km	N/A	N/A	NASA DAS, LEO orbit
4.4-1 <0.001 Explosive Risk	N/A	Compliant	
4.4-2 Passivate Energy Source	N/A	N/A	
4.4-3 Limit BU Long term Risk	N/A	N/A	
4.4-4 Limit BU Short term Risk	N/A	Compliant	
4.5-1 <0.001 10 cm Impact Risk	N/A	Compliant	NASA DAS v3.1.0
4.5-2 Post mission Disposal Risk	N/A	Compliant	NASA DAS v3.1.0
4.6-1a-c Disposal Method	N/A	Compliant	NASA DAS v3.1.0
4.6-2 GEO Disposal	N/A	N/A	
4.6-3 MEO Disposal	N/A	N/A	
4.6-4 Disposal Reliability	N/A	Compliant	
4.7-1 Ground Population Risk	N/A	Compliant	NASA DAS v3.1.0
4.8-1 Tether Risk	N/A	N/A	Neither CS1 nor CS2 utilize a tether

ODAR Section 1: Program Management and Mission Overview

Purpose: This report is intended to communicate to the Federal Communications Commission (FCC) Cesium Mission 1's probability of generating orbital debris per NASA-STD-8719.14B guidelines to satisfy the requirements concerning the post-mission disposal of commission-licensed satellites.

Program Management: CesiumAstro, Inc.

Clear schedule of mission design and development milestones:

Mission Selection: 01/01/2019

Mission Preliminary Design Review: 10/30/2020

Mission Critical Design Review: 03/01/2021

Pre-Ship Readiness Review: 06/11/2021

Launch: 09/16/2021

Mission Overview: Cesium Mission 1 (CM1) is CesiumAstro's first mission to launch and operate our hardware in space. This is done using two spacecraft, Cesium Satellite 1 (CS1) and Cesium Satellite 2 (CS2). CM1 provides an on-orbit platform for customer experiments that push the boundaries of small satellite communication. In addition, it gives Cesium the capability to demonstrate advanced features of our technology, such as dynamic waveform switching and dynamic link optimization. With the launch of Mission 1, Cesium will have a complete commercial phased array communication system in LEO.

ODAR Summary: No debris released in normal operations; no credible scenario for breakups; the collision probability with other objects is compliant with NASA standards; and the estimated nominal decay lifetime due to atmospheric drag is well under 25 years following operations (< 11 years, as calculated by **DAS 3.1.0**).

Launch Vehicle: Atlas V 401

Launch Site: Vandenberg AFB, CA.

Proposed Launch Date: September 16, 2021

Mission Duration: 5 years

Description of the launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination:

CS1 and CS2 (Cesium Spacecraft) will deploy from an Atlas V 401 upper stage into a sun-synchronous orbit (SSO), from which they will naturally decay due to atmospheric drag. The nominal deployment altitude is 550 km.

- Nominal Insertion Case: Apogee: 550 km, Perigee: 550 km
- Inclination: ~97.6°
- Local Time: 10:30 AM

Between payload experiment operations, the electric thrusters move Cesium Spacecraft to ~96.6° to allow Earth's J_2 effect to rotate the orbit's RAAN relative to SSO. Once the desired MLT is obtained, a second maneuver is used to return the spacecraft to SSO (6:00 AM dawn-dusk), which is the final mission orbit for both spacecraft.

Station-keeping of Cesium Spacecraft will be attempted post-orbital maneuver utilizing the thruster and any remaining propellant. Tolerances for the mission's altitude will be maintained within ± 5% of the initial altitude, which is approximately ± 27.5 kilometers.

Reason for selection of orbit: The dawn-dusk SSO orbit was chosen for the ability to track the Sun and ground simultaneously during operations.

Identification of any interaction or potential physical interference with other operational spacecraft: There are no planned physical interactions with other operational spacecraft.

ODAR Section 2: Spacecraft Description

Physical description of the spacecraft:

CS1 and CS2 are identical 6U CubeSats, each with a launch mass of 12.21 kg. The basic physical dimensions, not including the deployable solar panels, are 239.2 mm × 107.12 mm × 365.01 mm. The structure is mainly comprised of aluminum, with internal rails along four corner edges. The solar arrays are deployable and hinge at the +Z face of the spacecraft. The physical dimensions of the solar arrays at their maximums are presented in Table 2. When deployed, the solar panels are parallel to the +Z face of the spacecraft. Power storage is provided by two 18650 battery modules which are recharged by the solar panels. A render of the spacecraft is depicted in Figure 1.

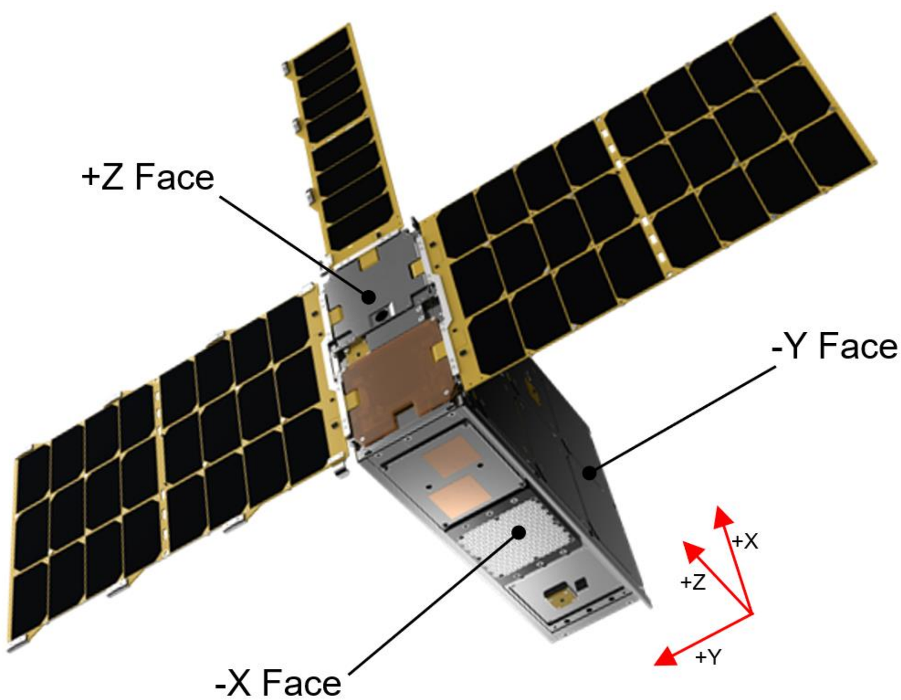

Figure 1: Cesium 6U spacecraft with solar panels deployed

Table 2: Cesium 6U spacecraft solar array dimensions

Solar Array	Dimensions
+X Solar Array	354.2 mm × 88.30 mm × 8.00 mm
+Y Solar Array	354.2 mm × 232.4 mm × 12.1 mm
-Y Solar Array	354.2 mm × 213.9 mm × 3.10 mm

Total spacecraft mass at launch, including all propellants and fluids: 12.21 kg

Dry mass of spacecraft at launch (minus all consumables and propellants): 11.98 kg

Identification, including type, mass, and pressure, of all fluids planned to be on board: The battery modules (BM) are unpressurized standard COTS lithium-ion cells. The Field-Emission Electric Propulsion (FEEP) propellant is solid indium until it is heated to be used.

Description of all propulsion systems: Cesium Spacecraft will each utilize a FEEP thruster with solid indium propellant. There are no moving parts, and the propellant is in its solid state at room temperature.

Description of all active and passive attitude control systems with indications of the normal attitude of the spacecraft with respect to the velocity vector: Cesium Spacecraft maneuver capabilities utilize an Attitude Determination and Control Subsystem (ADACS), which features: three modular reaction wheels (RW), 3-axis magnetometer, a star tracker, six coarse sun sensor inputs, three electromagnet torque rods, 3-axis MEMS accelerometer, 3-axis MEMS gyroscope, and a fully programmed ADACS computer, providing each Cesium Spacecraft with turnkey attitude control capabilities and < 0.1° pointing accuracy. The primary attitude control modes for CM1 comprise of Detumble, Slew, Stabilization, and Pointing.

The Detumble Mode is used after ejection from the launch vehicle, where Cesium Spacecraft slows themselves to a controlled rotation using a B-dot control law, magnetometer (used to sense the rate of change in Earth's magnetic field), and the electromagnet torque rods to damp the Cesium Spacecraft angular rotation. Once the desired rotation rate is achieved, the system transfers to a slew mode to obtain a nadir pointing orientation and link to the ground station (Detumble & Connect operational Mode). The three reaction wheels are used to orient Cesium Spacecraft during slew maneuvers, and the electromagnet rods continuously dump excess momentum. Refer to Figure 2 for an illustration of Cesium Spacecraft with attitude orientations specified.

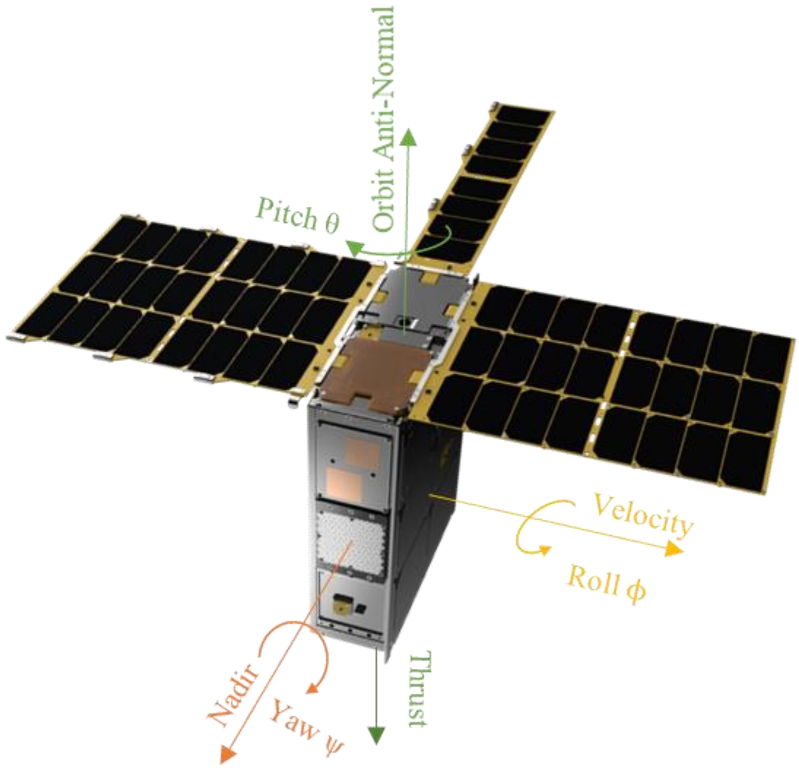

Figure 2: Cesium Spacecraft in normal operation mode

Sun pointing mode provides nadir pointing for the primary axis and rotates about the nadir axes to optimize solar pointing for the secondary axis. Nadir pointing is obtained through magnetic momentum management, sun sensor/magnetometer or star tracker attitude determination, and reaction wheel torque commands computed by a quaternion feedback control law.

Description of any range safety or other pyrotechnic devices: No pyrotechnic devices are used.

Description of the electrical generation and storage system: The solar array system collects solar energy from the Sun. An internal pin puller driver deploys them. The solar arrays can generate up to 56 W instantaneous power at the beginning of the mission.

Cesium Spacecraft Electrical Power System Module (EPSM) accepts input power from the solar panels and arrays, batteries, and external sources and converts it to output power at various voltage levels. Each Battery Module (BM) comprises of eight 18650 lithium-ion cells that provide electrical energy during the mission. In addition, BM electronics provide battery inhibits, first and second-level battery safeties (OV, UV, OC, OT, individual cell over-voltage, and others), a battery heater, and a "gas gauge" to provide up-to-date state-of-charge information on the batteries. The battery cells are recharged by the Electrical Power System (EPS).

Identification of any other sources of stored energy not noted above: N/A

Identification of any radioactive materials on board or make an explicit statement that there are no radioactive materials onboard: CM1 does not have any radioactive materials on board.

ODAR Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions

Potential causes of spacecraft breakup during deployment and mission operations: There are no plausible scenarios that would result in the spacecraft breakup during standard deployments of mission operations. No part of the spacecraft or solar panel deployment will generate debris in nominal operations. In nominal disposal operations, the spacecraft will burn up in the atmosphere. The most significant yet unlikely "breakup" may be caused by a battery explosion, which would still not generate any debris outside the spacecraft. The possibility of this is minimal, as can be seen in the Failure Mode and Effect Analysis (FMEA) below.

Summary of failure modes and effects analyses of all credible failure modes that may lead to an accidental explosion: A potential failure mode that may lead to an unintentional explosion can stem from BM safety protection failure, which would leave the batteries imperiled.

Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions: CM1 has no plans for any intentional collisions and/or explosions.

List of components which are passivated at End of Mission (EOM) including method of passivation and amount which cannot be passivated: No components will be passivated at EOM.

Rationale for all items required to be passivated but cannot be due to their design: The lithium-ion batteries will not be passivated due to the negligible risk of impact/explosion. In addition, the low charges and small battery cells on Cesium Spacecraft power systems deem passivation at EOM redundant.

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:

Compliance statement:

Required Probability: 0.001.

Projected Probability: 0.000.

Supporting Rationale and FMEA details: Battery explosion or failure:

Effect: In the unlikely event that any of the failure modes listed below were to occur, then the possibility of a battery explosion is present. If a battery cell ruptures, the small size, mass, and potential energy of the COTS batteries, most if not all the debris should be contained within the vessel due to the lack of penetration energy.

Probability: Extremely low, less than ~ 0.1%. The BM satisfies the NASA flight safety program and JSC EP-WI-032 for use on the ISS and features over-voltage, over-current, under-voltage, and over-temperature protection.

Failure Mode 1: Short circuit

Mitigation 1: Primary battery protections include: Cell over/under-voltage (OV/UV) protection that inhibits charging/discharging when the cells are in an over or under-voltage condition, Over-current (OC) charge/discharge protection that inhibits predefined charge and discharge limits.

Mitigation 2: Second level battery protection: If/when an over-voltage condition is detected on a cell, in addition to the main circuitry disconnecting the charge, discharge, and/or trickle-charge MOSFETs, the second-level protection discharges the battery pack through a 75 Ω power resistor.

This 2 – 4 W discharge is intended to gradually reduce the affected cell voltage(s) while the cell over-voltage condition exists.

Mitigation 3: BM went through an internal short circuit (cells) testing with upper-temperature limits of +55 °C and lower limits at -15 °C and passed.

Failure Mode 2: Internal thermal rise due to orbital environment and/or high discharge rate

Mitigation 1: Each cell is individually wrapped with a conformal Kapton heater and a thermistor. The individual heaters combine to form a parallel combination of resistive heaters driven by the battery's positive and negative voltage terminals.

Mitigation 2: Over-temperature (OT) charge/discharge protection where charging/discharging inhibit are present if the cell temperature exceeds the predefined limits. Additionally, two heater controllers are present, one in the protection circuitry and one in the SupMCU.

Mitigation 3: Second-level battery protection includes cell balancing. The BM automatically balances the cell voltages during/near the end of charging to maintain the overall cell balance to the pre-determined maximum cell voltage difference.

Failure Mode 3: Inoperative/defect in venting

Mitigation 1: Vent design in cells is constructed to relieve excessive internal pressure at a value and rate that will preclude rupture, explosion, and self-ignition. When evaluated, the BM passed per IEC 6213:2012 standard.

Failure Mode 4: Battery crush

Mitigation 1: The BM has passed crush testing, where crushing force was released upon with a maximum force of 13 kN ± 1 kN has been applied, resulting in no fire or explosion.

4.4-2, Design for passivation after completion of mission operation while in orbit about Earth or the Moon: CM1 does not intend to passivate any components after completing the mission while in orbit about the Earth or Moon.

4.4-3, Limiting the long-term risk to other spaces systems from planned breakups: CM1 does not have any planned breakups; thus, requirement 4.4-3 is not applicable.

4.4-4, Limiting the short-term risk to other space systems from planned breakups: CM1 does not have any planned breakups; thus, requirement 4.4-4 is not applicable.

ODAR Section 5: Assessment of Spacecraft Potential for On-Orbit Collisions

Assessment of spacecraft compliance with Requirements 4.5-1 and 4.5-2 per NASA DAS v3.1.0:

4.5-1, Limiting debris generated by collisions with large objects when operating in Earth orbit: Cesium Spacecraft collision probability per **DAS v3.1.0** is 3.7232 x 10^{-06}.

4.5-2: Limiting debris generated by collisions with smalls object when operating in Earth or Lunar orbit: Cesium Spacecraft collision probability per **DAS v3.1.0** is as follows:

Critical Surface: The FEEP thruster has a probability of penetration of 2.2454 x 10^{-06}.

The critical surface meets the requirement of < 0.001 probability of penetration for large and small orbital debris (Requirement 4.5-1 and 4.5-2), as shown in Figure 3 and Figure 4, respectively.

```
=============== End of Requirement 4.3-2 ===============
07 12 2021; 15:40:36PM  Processing Requirement 4.5-1: Return Status :
Passed

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

**INPUT**

      Space Structure Name = CS1
      Space Structure Type = Payload
      Perigee Altitude = 550.000 (km)
      Apogee Altitude = 550.000 (km)
      Inclination = 97.600 (deg)
      RAAN = 0.000 (deg)
      Argument of Perigee = 0.000 (deg)
      Mean Anomaly = 0.000 (deg)
      Final Area-To-Mass Ratio = 0.0069 (m^2/kg)
      Start Year = 2021.000 (yr)
      Initial Mass = 12.210 (kg)
      Final Mass = 11.980 (kg)
      Duration = 5.000 (yr)
      Station-Kept = True
      Abandoned = True

**OUTPUT**

      Collision Probability = 3.7232E-06
      Returned Message: Normal Processing
      Date Range Message: Normal Date Range
      Status = Pass

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

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

*Figure 3. **NASA DAS v3.1.0** Requirement 4.5-1 Assessment for Cesium Spacecraft, with an area-to-mass ratio of 0.0068647 m^2/kg*

```
==================================================
Spacecraft = CS1
Critical Surface = Thruster
==================================================

**INPUT**

      Apogee Altitude = 550.000 (km)
      Perigee Altitude = 550.000 (km)
      Orbital Inclination = 97.600 (deg)
      RAAN = 0.000 (deg)
      Argument of Perigee = 0.000 (deg)
      Mean Anomaly = 0.000 (deg)
      Final Area-To-Mass = 0.0069 (m^2/kg)
      Initial Mass = 11.980 (kg)
      Final Mass = 11.980 (kg)
      Station Kept = Yes
      Start Year = 2021.000 (yr)
      Duration = 5.000 (yr)
      Orientation = Fixed Oriented
      CS Areal Density = 1.299 (g/cm^2)
      CS Surface Area = 0.0098 (m^2)
      Vector = (-0.186447 (u), 0.635185 (v), 0.749518 (w))
      CS Pressurized = No
      Outer Wall 1   Density: 10.911 (g/cm^2)  Separation: 15.000 (cm)

**OUTPUT**

      Probability of Penetration = 2.2454E-06 (2.2454E-06)
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range

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

*Figure 4. **NASA DAS v3.1.0** Requirement 4.5-2 Assessment for Cesium Spacecraft with an area-to-mass ratio of 0.0068647 m^2/kg*

ODAR Section 6: Assessment of Spacecraft Post Mission Disposal Plan and Procedures

Description of spacecraft disposal options selected & preliminary plan for controlled re-entry: At CM1 EOL, Cesium Spacecraft will de-orbit by atmospheric drag within the 25-year requirement.

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

4.6-1, Disposal for space structures in or passing through LEO: Cesium Spacecraft meets all LEO re-entry orbit criteria per **NASA DAS v3.1.0** as seen in Figure 5.

```
07 12 2021; 15:40:37PM  Processing Requirement 4.6    Return Status :
Passed

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

**INPUT**

      Space Structure Name = CS1
      Space Structure Type = Payload

      Perigee Altitude = 550.000000 (km)
      Apogee Altitude = 550.000000 (km)
      Inclination = 97.600000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Area-To-Mass Ratio = 0.006865 (m^2/kg)
      Start Year = 2021.000000 (yr)
      Initial Mass = 12.209740 (kg)
      Final Mass = 11.979740 (kg)
      Duration = 5.000000 (yr)
      Station Kept = True
      Abandoned = True
      PMD Perigee Altitude = 550.000000 (km)
      PMD Apogee Altitude = 550.000000 (km)
      PMD Inclination = 97.600000 (deg)
      PMD RAAN = 0.000000 (deg)
      PMD Argument of Perigee = 0.000000 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Suggested Perigee Altitude = 550.000000 (km)
      Suggested Apogee Altitude = 550.000000 (km)
      Returned Error Message = Passes LEO reentry orbit criteria.

      Released Year = 2036 (yr)
      Requirement = 61
      Compliance Status = Pass

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

=============== End of Requirement 4.6 ===============
```

*Figure 5. **NASA DAS v3.1.0** Requirement 4.6 assessment for Cesium Spacecraft with an area-to-mass ratio of 0.0068647 m^2/kg*

Moreover, as seen in Figure 6, using the **DAS v3.1.0** Science and Engineering, *Utility for Orbit Lifetime/Dwell Time*, Cesium Spacecraft have an orbital lifetime of 10.984257 years, **satisfying the 25-year requirement.**

```
07 12 2021; 16:39:47PM  Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

      Start Year = 2026.000000 (yr)
      Perigee Altitude = 550.000000 (km)
      Apogee Altitude = 550.000000 (km)
      Inclination = 97.600000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Area-To-Mass Ratio = 0.006865 (m^2/kg)

**OUTPUT**

      Orbital Lifetime from Startyr = 10.984257 (yr)
      Time Spent in LEO during Lifetime  = 10.984257 (yr)
      Last year of Propagation = 2036 (yr)
      Returned Error Message: Object reentered
```

Figure 6. ***DAS v3.1.0*** *Cesium Spacecraft orbital lifetime and dwell time spent in LEO after EOL*

4.6-4, Reliability of post-mission disposal maneuver operations in Earth orbit: Cesium Spacecraft will not perform a post-mission disposal maneuver. Instead, it will de-orbit using atmospheric drag.

ODAR Section 7: Assessment of Spacecraft Re-entry Hazards

Detailed description of spacecraft components by size, mass, material, shape, and original location on the space vehicle if the atmospheric re-entry option is selected: NASA DAS v3.1.0 software analysis for Requirement 4.7-1 confirms the majority of the subcomponents demise before reaching the Earth's surface. The only component that does not demise is the stainless-steel solar panel pin puller which shows a debris casualty area of 0.44 m^2 and an impact kinetic energy of 6.31 J; this **satisfies Requirement 4.7-1**.

Assessment of spacecraft compliance with Requirement 4.7-1:

4.7-1, Assessment of Debris Surviving Atmospheric Reentry: Per **NASA DAS v3.1.0** Cesium Spacecraft risk of human casualties is 1:100000000, which satisfies Requirement 4.7-1. Refer to Table 3 for the material list used and demise altitudes.

ODAR Section 7A: Assessment of Spacecraft Hazardous Materials

Summary of the hazardous materials contained on the spacecraft using all columns and the format in paragraph 4.7.4.10.: There are no hazardous materials onboard Cesium Spacecraft.

Table 3. Material list used in DAS v3.10 Requirement 4.7-1 analysis

Row Number	Name	Qty	Material	Body Type	Mass (kg)	Diameter/Width (m)	Length (m)	Height (m)	Demise Altitude (km)
1	Cesium Satellite 1 6U CubeSat	1	Al-6061	Box	14.000	0.222	0.365	0.106	78
2	Pumpkin ADCS Interface Module Board	1	PCB	Box	0.050	0.097	0.096	0.028	77.2
3	NovAtel OEM917 GPS Receiver	1	PCB/Al	Box	0.031	0.046	0.071	0.011	77.3
4	BeagleBone Black Board	1	PCB	Flat Plate	0.040	0.089	0.055	-	77.2
5	Pumpkin Battery Module	2	Al6061-T6	Box	1.384	0.100	0.100	0.049	64.8
6	Pin Puller Driver	1	SS	Box	0.050	0.096	0.090	0.002	0
7	Enpulsion IFM Nano Thruster	1	PCB	Box	0.670	0.100	0.100	0.083	74.1
8	Pumpkin Battery Switch Module Board	1	Al	Flat Plate	0.026	0.040	0.078	-	76.8
9	Pumpkin Electrical Power System Module 1	1	Al	Box	0.230	0.096	0.090	0.015	73.8
10	EyeStar-D2 Duplex Motherboard/Daughterboard	1	PCB	Box	0.137	0.064	0.119	0.027	76.7
11	EyeStar-S3 Simplex Board	1	PCB	Box	0.022	0.026	0.055	0.015	77.2
12	Adcole ADCS Controller Board	1	PCB	Flat Plate	0.047	0.086	0.088	-	77.2
13	Maryland Aerospace Electromagnet Driver Board	1	PCB	Box	0.024	0.070	0.070	0.011	77.5
14	Adcole Single Axis Reaction Wheel	3	PCB	Box	0.330	0.033	0.033	0.038	73.6
15	Adcole MAI-SS Star Tracker	1	PCB/Al	Box	0.170	0.050	0.050	0.047	71.4
16	ADCS housing	1	Al-6061	box	0.694	0.100	0.100	0.062	77.6
17	Pumpkin Motherboard Module Board	1	PCB	Flat Plate	0.031	0.096	0.090	-	75.3
18	APA 1AT1 Mounting Plate	1	Al-6061	Box	0.148	0.084	0.105	0.013	74.8
19	Cesium Power Conditioning Unit	1	PCB/Al	Box	0.120	0.050	0.084	0.014	75.3
20	Cesium Software Defined Radio	1	PCB/Al	Box	0.100	0.050	0.084	0.013	77.5
21	Cesium Single-Board Computer	1	PCB/Al	Box	0.100	0.050	0.084	0.013	77.2
22	Cesium Up/Down Converter	1	PCB/Al	Box	0.100	0.050	0.086	0.013	76.1
23	Pumpkin Payload Interface Module Board	1	PCB	Box	0.037	0.096	0.090	0.002	77.3
24	Pumpkin Radio Host Module Board	1	PCB	Box	0.056	0.096	0.090	0.002	77.6
25	SUPERNOVA 6U-size top/bottom panel (2x 12S1P)	2	PCB	Flat Plate	0.760	0.214	0.360	-	76.2
26	SUPERNOVA 3U-size side panel (8S1P)	1	PCB	Flat Plate	0.130	0.080	0.360	-	76.1
27	Pumpkin Solar Interface Module Board	1	Al	Flat Plate	0.015	0.087	0.087	-	75.3
28	SUPERNOVA Base Plate	1	Al-7075	Flat Plate	0.564	0.239	0.365	-	77.1

29	SUPERNOVA Top Plate	1	Al-6061	Flat Plate	0.503	0.222	0.348	-	77.4
30	SUPERNOVA Side Plate	2	Al-6061	Flat Plate	0.360	0.088	0.348	-	77.2
31	SUPERNOVA 6U End plate	2	Al-6061	Flat Plate	0.180	0.088	0.206	-	77.3
32	SUPERNOVA Sep Conn Cover	2	Al-6061	Box	0.013	0.018	0.050	0.013	77.5
33	SUPERNOVA Stack Adapter	1	Al-6061	Flat Plate	0.032	0.100	0.100	-	76.9
34	SUPERNOVA 1U -XB3 Cover	1	Al-5052	Flat Plate	0.031	0.082	0.082	-	76.9
35	SUPERNOVA 1U +XA2 Cover	1	Al-5052	Flat Plate	0.023	0.082	0.082	-	75.5
36	SUPERNOVA 1U +XA3 Cover	1	Al-5052	Flat Plate	0.027	0.082	0.082	-	76.9
37	Single SAP End Plate	1	Al-5052	Flat Plate	0.237	0.088	0.206	-	76.9
38	Satlab SRS-3 Radio	1	PCB	Box	0.190	0.087	0.093	0.017	74.5
39	IQ Spacecom Wireless S-Band Antenna	1	Al	Flat Plate	0.049	0.083	0.103	-	76.1
40	SRS-3 enclosure	1	Al	Box	0.190	0.087	0.096	0.017	74.5
41	Hybrid DC-DC Converter	1	Copper Alloy	Box	0.086	0.038	0.076	0.010	76.1

Abbreviations & Acronyms

6U	6-Unit
ADACS	Attitude Determination and Control System
BM	Battery Module
CM1	Cesium Mission 1
COTS	Commercial Off-The-Shelf
CS1	Cesium Satellite 1
CS2	Cesium Satellite 2
EOL	End of Life
EOM	End of Mission
EPS	Electrical Power System
EPSM	Electrical Power System Module
FCC	Federal Communications Commission
FEEP	Field-Emission Electric Propulsion
FMEA	Failure Mode and Effects Analysis
LEO	Low Earth Orbit
MEMS	Micro-Electromechanical System
MLT	Mean Local Time
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
NASA	National Aeronautics and Space Administration
OC	Over-Current
ODAR	Orbital Debris Assessment Report
OT	Over-Temperature
OV	Over-Voltage
RAAN	Right Ascension of the Ascending Node
RW	Reaction Wheel
SSO	Sun Synchronous Orbit
UV	Under-Voltage