Orbital Debris Assessment Report

RAY

per NASA-STD 8719.14A

Signature Page

July 30, 2023

Collin Corey
Inversion Space.

July 26, 2023

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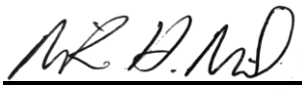
Sterk Solutions Corp.



July 26, 2023

Mike H. Miller, Licensing Analyst
Sterk Solutions Corp.

REFERENCES:

A. *NASA Procedural Requirements for Limiting Orbital Debris Generation,* NPR 8715.6A, *5* February 2008
B. *Process for Limiting Orbital Debris,* NAS A-STD-8719.14A, 25 May 2012
C. International Space Station Reference Trajectory, delivered May 2017
D. McKissock , Barba ra, Patricia Loyselle, and Elisa Vogel. *Guidelines on Lithium-ion Battery Use in Space Applications*. Tech. no. RP-08-75. NASA Glenn Research Center Cleveland, Ohio
E. *UL Standard for Safety.for Lithium Batteries, UL 1642.* 1JL Standard. 4th ed. Northbrook, IL, Underwriters Laboratories, 2007
F. Kwas, Robert. Thermal Analysis of ELaNa-4 CubeSat Batteries, ELVL-2012-0043254; Nov 2012
G. Range Safety User Requirements Manual Volume 3- Launch Vehicles, Payloads, and Ground Support Systems Requirements, AFSCM 91-710 V3.
H. HQ OSMA Policy Memo/Email to 8719.14: CubeSat Battery Non-Passivation, Suzanne Aleman to Justin Treptow, 10, March 2014
I. HQ OSMA Emai1:6U CubcSat Battery Non Passivation Suzanne Aleman to Justin Treptow, 8 August 2017

This report is intended to satisfy the orbital debris requirements listed in *NASA Procedural Requirements for Limiting Orbital Debris Generation,* NPR 8715.6A, *5* February 2008, for the RAY mission.

Sections 1 through 8 of *Process for Limiting Orbital Debris*, NAS A-STD-8719.14A, 25 May 2012, are addressed in this document; sections 9 through 14 are in the domain of the launch provider and are addressed by others.

NASA DAS Software Version 3.2.5 was used to develop the debris assessment values in this report.

RECORD OF REVISIONS		
REV	**DESCRIPTION**	**DATE**
0	Original submission	July 2023

The following table summarizes the compliance status of the RAY spacecraft. The status is fully compliant with all applicable requirements.

Requirements	**Compliance Assessment**	**Comments**
4.3-1a	Not Applicable	No planned debris release
4.3-1b	Not Applicable	No planned debris release
4.3-2	Not Applicable	No planned debris release
4.4-1	Compliant	Batteries incapable of debris producing failure
4.4-2	Compliant	Batteries incapable of debris producing failure
4.4-3	Not Applicable	No planned breakups
4.4.-4	Not Applicable	No planned breakups
4.5-1	Compliant	

Table 1 Compliance Assessment per Requirement

Section 1: Mission Overview

The overall goal of the RAY mission is to test and validate technologies that Inversion is developing for its re-entry vehicles. RAY consists of a service module and a capsule that, at the end of the mission, will detach from the service module, deorbit, and return to Earth.

The satellite will be launched as a rideshare payload aboard a SpaceX Falcon 9, from Cape Canaveral, FL, no earlier than January 1, 2024. It will be inserted into an SSO orbit at 500 km apogee and 500 km perigee, on an inclination from the equator of 97.4 degrees. Transmission will begin upon deploy into orbit and cease upon reentry. Reentry will be initiated between 2 weeks and 5 months after deployment into orbit. A single propellant system burn will put the spacecraft into a controlled reentry trajectory. Immediately following the burn, the capsule detaches from the service module. The service module demises upon reentry. The capsule survives reentry and will be recovered from the Pacific Ocean off the coast of California.

Flight Phase Initiating Event	Apogee / Perigee, km	Duration, Days	Propellant Mass, kg, End of Phase	Comment
Deployment	500 km x 500 km	1	11.33	
Orbit (Idle)	500 km x 500 km	14-60	11.26	
Deorbit	500 km x -111 km	<1	0	

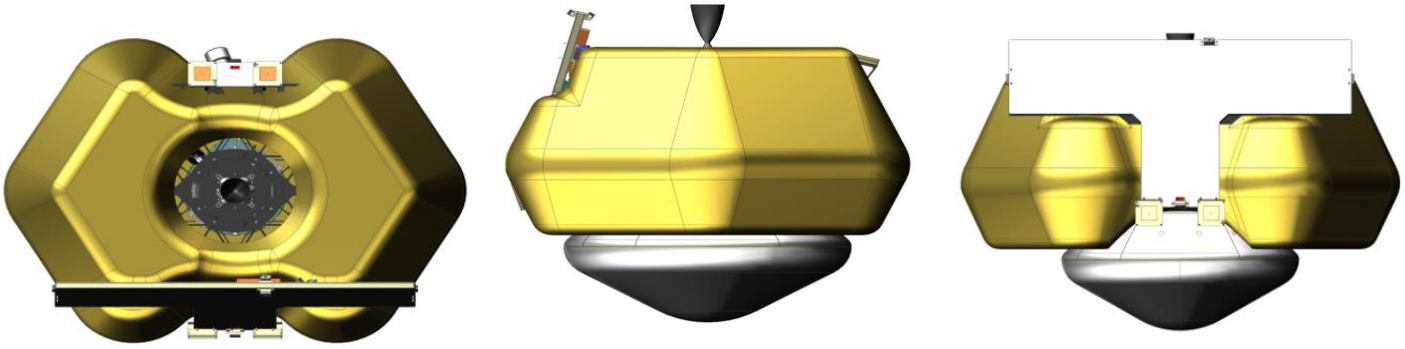
Table 2 Mission Schedule

Section 2: Spacecraft Description

Item	Value
Dry Mass Capsule	19.82kg
Dry Mass Bus	32.26kg
Dry Mass Total	52.08kg
Propellant Mass at Launch	11.33kg
Total Mass at Launch	63.41kg
Cross Section, square meters, in RAM direction, nominal attitude, on orbit in operation.	0.488 m^2

Table 3 Characteristics of Spacecraft

Figure 1 shows the design of the Spacecraft.



X View **Y View** **Z View**

Figure 1 RAY Overview

The Appendix lists all of the components in the spacecraft, with the dimensions, mass, material and shape of each.

Hazards

Pressurized Systems

The propulsion system uses a compressed Helium subsystem (4 tanks) to ensure pressure on the Propylene (C3H6) (2 tanks) and Nitrous Oxide (N2O) (2 tanks). All the tanks are constructed of aluminum. Propylene and Nitrous Oxide are both classified as non-toxic.

The following standards and qualifications have been or will be applied to the pressurized components of the propulsion system:

Tanks will undergo vehicle proto qualification testing as well as separate qualification and acceptance testing at the component level.

Unit test requirements derive from:

- AIAA-S-080A-2018
- AFSPC 91-710 Vol. 3 Section 12 (May 2019 release)
- SMC-S-016 (September 2014 release)
- SpaceX Rideshare Payload User's Guide (October 2022 release)

Tanks are designed for burst at 6ksi and Maximum Expected Operating Pressure at 3ksi.

Batteries

Battery Cells

All batteries use Panasonic NCR18650B cells, with Lithium Ion chemistry. Each cell has a nominal voltage of 3.6V, typical current capacity of 3.35Ah, and power capacity of 12Wh. These cells have significant flight heritage.

This cell is in safety compliance with UL 1642 (file number MH12210 and MH12383), IEC62133, and UN38.3 standards. The cells have been produced in facilities meeting ISO 9001 and ISO 14001 standards.

Ray Return Capsule Primary Bus (EPS) Batteries:

The primary EPS battery uses 14 Panasonic NCR18650B cells built in a 2S7P cell configuration. This configuration has a 168Wh capacity at 7.2V. It utilizes a circuit protection module providing cell-balancing,

over-charge, over-current and over-discharge protection. The full battery system including cells and circuits has been assembled to IPC-A-610 Class 3 Standard and has been tested to NASA GEVS environmental levels, thermal vacuum tested as well as radiation tested to 20 kRad Total Ionizing Dose (TID). This battery system has significant flight heritage.

Ray Buoy Beacon Battery:
The ray buoy beacon uses a single battery composed of 1 Panasonic NCR18650B cell to provide 12Wh capacity at 3.6V.

Ray Splashdown Board Battery:
The ray splashdown board uses a single battery composed of 1 Panasonic NCR18650B cell to provide 12Wh capacity at 3.6V.

Section 3: Assessment of Spacecraft Debris Released during Normal Operations

The assessment of spacecraft debris requires the identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material.

Section 3 requires rationale/necessity for release of each object, time of release of each object, relative to launch time, release velocity of each object with respect to spacecraft, expected orbital parameters (apogee, perigee, and inclination) of each object after release, calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO), and an assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2.

Deployment of the capsule from the bus is treated as a separation of two previously joined spacecraft, not debris release. The behaviors of each of the two spacecraft after separation, are individually analyzed in this report.

No releases of debris are planned, therefore this section is not applicable.

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

There are NO plans for designed spacecraft breakups, explosions, or intentional collisions.

Pressurized Systems
As stated above, comprehensive standards and qualifications have been applied to the design, construction and testing of the system, and as a result the probability of failure and a consequent breach of the pressurized components of the propulsion system is very low.

Batteries
From the battery discussion above, the probability of battery explosion is very low, per the following:

All the battery cells are safety compliant under UL 1642. The battery utilizes a circuit protection module providing over-charge, over-current and over-discharge protection. The cells are pre-screened over temperature, and matched into packs. The batteries are then tested over complete charge and discharge cycles prior to integration into the spacecraft. Each battery pack is physically and thermally isolated from the others.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that the RAY is compliant.

Section 5: Assessment of Spacecraft Potential for On Orbit Collisions

4.5-1 Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft takes into account both the mean cross sectional area (MCSA) and orbital lifetime.

Per NASA STD-8719.14, ".. an object may be considered to be tumbling randomly, or it may be assumed to have a stable attitude relative to the velocity vector." In the longest lifetime scenario, it is assumed to have a stable attitude (minimum cross section relative to the velocity vector).

The mass during the mission until deorbit burns begin at the end of the mission, is 63.41 kg.

In the nominal case, the orbital lifetime will not exceed 5 months, by which time controlled reentry will be performed.

In the worst case (longest lifetime) the spacecraft would remain in orbit in an aerodynamic minimum drag area configuration. The minimum drag area would be 0.302 m^2, and the area to mass ratio will be 0.00476 m^2/kg. Per DAS, after 9.8 years, natural demise would occur.

From DAS, the probability of collision with space objects larger than 10 cm in diameter during the maximum orbital lifetime of the spacecraft, is 5.424E-6

Parameter	Value	Units
Note – there are no deployables		
Mass (Total Wet Mass Before Deorbit Burn)	63.41	kg
Max Area Face (X), Area (RAM Facing Nominal Case)	0.488	m^2
A_1 (Y) Face Area	0.465	m^2
A_2 (Z) Face Area (RAM Facing Aerodynamic Case)	0.302	m^2
Area / Mass Ratio, Aerodynamic Case, No Propellant Expended	0.00476	m^2/kg
Initial Altitude	500	km
Maximum Lifetime until Natural Demise	9.8	Years
Probability of Large Object Collision from DAS, Maximum Life Case 9.8 years	5.424E-6	probability

Table 4 Large Object Collision Probability - Parameters and Results

In summary, the probability of collision with debris or meteoroids greater than 10 cm in diameter is no greater than 5.424E-6, per DAS. This satisfies the 0.001 maximum probability requirement 4.5-l.

Assessment of spacecraft compliance with Requirements 4.5-1 shows the spacecraft to be compliant.

4.5-2 limits the probability of spacecraft being disabled and left in orbit at the end of mission, which would contribute to the long-term growth of the orbital debris environment by subsequent collision or explosion fragmentation.

Requirement 4.5-2 applies only to subsystems that are vital to completing postmission disposal. This would include the propulsion system if a postmission disposal maneuver is required. If no disposal maneuver is required, only subsystems accomplishing passivation of the vehicle should be addressed. The same methodology, however, can be used to evaluate the vulnerability of the spacecraft instruments and mission-related hardware. This information can be used to verify the reliability of the mission with respect to orbital debris and meteoroid hazards.

"If a spacecraft or launch vehicle orbital stage fails to perform its planned postmission disposal operations, it becomes a potential source of debris because a space structure that is abandoned in orbit can subsequently experience catastrophic breakup by collision or explosion. The probability of such an event occurring as a result of a prior damaging impact with small debris is addressed by Requirement 4.5-2."

Per DAS, if there is no postmission disposal activity, the spacecraft will passively deorbit in no more than 9.8 years. So there is no risk that damage to any components would compromise meeting the requirement of demise in less than 25 years.

Assessment of spacecraft compliance with Requirements 4.5-2 shows the spacecraft to be compliant.

Section 6: Assessment of Spacecraft Post Mission Disposal Plans and Procedures

Requirement 4.6 states that "Disposal can be accomplished by one of the following methods: (1) Earth atmospheric natural reentry, (2) direct reentry, (3) maneuvering to a storage orbit, (4) direct retrieval, (5) long-term reentry, or (6) Earth escape. Requirement area 4.6 applies to all space structures when in Earth orbit."

Nominal Plan: As stated above, the nominal post mission disposal plan uses method 2, direct reentry. The spacecraft will be placed in a demising reentry trajectory.. The reentry capsule perigee is suborbital and will disengage from the bus before entering the atmosphere, landing by parachute off the coast of California. The service module will demise upon reentry, above the same location.

See the following Table 5, Post Mission Disposal Schedule. Total mission duration, less than 5 months, or 150 days.

Flight Phase Initiating Event	Apogee / Perigee, km	Duration, Days
Deployment	500km/500km	1
Orbit (Idle)	500km/500km	14-150
Deorbit	Start: 500km/500km End: Earth's Surface	<1

Table 5 Post Mission Disposal Schedule

Contingency Plan: if after the spacecraft is placed in orbit, for an unknown reason no systems function, then in all cases it will demise by method (1) Earth atmospheric natural reentry, in no more than 9.8 years, per DAS.

Discussion of contingency: if the spacecraft attains orbit, does not activate, and assumes an aerodynamic profile with the minimum area face in the RAM direction, then

Effective Area = 0.302 m^2, the minimum face

Mass = 63.41 (total wet mass is retained)

A/M ratio = 0.00476 m2/kg

From DAS, starting with the 500 km circular initial orbit, the lifetime would be 9.8 years until natural demise if all systems were inactive.

The assessment of the spacecraft illustrates it is compliant with Requirements 4.6.

Section 7: Assessment of Spacecraft Reentry Hazards

Requirement 4.7-1 states that the probability of human casualty shall be less than 1:10,000.

Nominal Plan

The return capsule is expected to survive reentry and parachute intact into the Pacific Ocean off the coast of California.

From DAS, it is expected that all of the components of the service module will demise.

The aggregate expectation of human casualty from the controlled reentry, is 0.

Off Nominal Plan

In this case, for some unforeseen reason the mission including the controlled reentry of the return capsule is not executed, then the spacecraft will undergo natural demise. For this situation, a detailed assessment was performed using DAS. See Appendix for the complete DAS Activity Log. The analysis provides a bounding analysis for characterizing the survivability of a component during re-entry. It considers the case where upon deploy from the Falcon 9 second stage, it in inoperable, and it assumes an aerodynamic attitude yielding minimum cross sectional area, and all propellant mass is retained, giving maximum mass. This supports an estimate of maximum lifetime on orbit.

It is conservative in that when it shows terminal energy of a component surviving reentry, it does not consider any loss of material from ablation or charring. Both of these may for some materials decrease the mass and dimensions of the re-entering components, reducing the risk below that calculated.

Per DAS, all of the components of the service module demise upon reentry. The return capsule is estimated to survive reentry intact, yielding a calculated Risk of Human Casualty for natural demise of 1:56800, which is Compliant.

Reentry Hazards Summary

The worst case Risk of Human Casualty is 1:56,800, associated with the off nominal case of mission failure, natural demise, and survival of the return capsule as it deorbits with no parachute.

This is less than the required maximum risk of 1:10,000, so the RAY satellite is in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

The activity log for the DAS reentry hazards calculation is provided in the Appendix at end of report.

Section 8: Assessment for Tether Missions

No tethers are used. Requirement 4.8-1 is satisfied.

Section 9 through 14:

ODAR sections 9 through 14 pertain to the launch vehicle, and are not covered here.

Appendix 1 – DAS Activity Logs

```
07 25 2023; 21:14:54PM Activity Log Started
07 25 2023; 21:14:54PM Opened Project C:\Users\Mike\Documents\All
SatLicensing\RAY\ODAR\DAS\DAS July 25\
07 25 2023; 21:15:01PM Closed Project C:\Users\Mike\Documents\All
SatLicensing\RAY\ODAR\DAS\DAS July 25\
07 25 2023; 21:15:01PM Activity Log Started
07 25 2023; 21:15:01PM Opened Project C:\Users\Mike\Documents\All
SatLicensing\RAY\ODAR\DAS\DAS July 25\
07 25 2023; 21:15:18PM Mission Editor Changes Applied
07 25 2023; 21:15:18PM Project Data Saved To File
07 25 2023; 21:15:18PM Project Data Saved To File
07 25 2023; 22:51:36PM Processing Requirement 4.5-1:     Return Status :  Passed

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

**INPUT**

      Space Structure Name = Ray_1.0
      Space Structure Type = Payload
      Perigee Altitude = 500.000 (km)
      Apogee Altitude = 500.000 (km)
      Inclination = 97.400 (deg)
      RAAN = 0.000 (deg)
      Argument of Perigee = 0.000 (deg)
      Mean Anomaly = 0.000 (deg)
      Final Area-To-Mass Ratio = 0.0048 (m^2/kg)
      Start Year = 2023.900 (yr)
      Initial Mass = 63.440 (kg)
      Final Mass = 63.440 (kg)
      Duration = 10.000 (yr)
      Station-Kept = False
      Abandoned = True
      Long-Term Reentry = False

**OUTPUT**

      Collision Probability = 5.4238E-06
      Returned Message: Normal Processing
      Date Range Message: Normal Date Range
      Status = Pass

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

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

07 25 2023; 22:53:46PM Processing Requirement 4.6   Return Status :  Passed

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

**INPUT**

      Space Structure Name = Ray_1.0
      Space Structure Type = Payload
```

```
      Perigee Altitude = 500.000000 (km)
      Apogee Altitude = 500.000000 (km)
      Inclination = 97.400000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Area-To-Mass Ratio = 0.004760 (m^2/kg)
      Start Year = 2023.900000 (yr)
      Initial Mass = 63.440000 (kg)
      Final Mass = 63.440000 (kg)
      Duration = 10.000000 (yr)
      Station Kept = False
      Abandoned = True
      PMD Perigee Altitude = -1.000000 (km)
      PMD Apogee Altitude = -1.000000 (km)
      PMD Inclination = 0.000000 (deg)
      PMD RAAN = 0.000000 (deg)
      PMD Argument of Perigee = 0.000000 (deg)
      PMD Mean Anomaly = 0.000000 (deg)
      Long-Term Reentry = False

**OUTPUT**

      Suggested Perigee Altitude = 500.000000 (km)
      Suggested Apogee Altitude = 500.000000 (km)
      Returned Error Message = Reentry during mission (no PMD req.).

      Released Year = 2033 (yr)
      Requirement = 61
      Compliance Status = Pass

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

=============== End of Requirement 4.6 ===============
07 25 2023; 22:53:48PM *********Processing Requirement 4.7-1
      Return Status :  Passed

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

name = Ray_1.0
quantity = 1
parent = 0
materialID = 8
type = Box
Aero Mass = 63.439999
Thermal Mass = 63.439999
Diameter/Width = 0.711200
Length = 0.940000
Height = 0.655000

name = Upper_Isogrid_Pieces
quantity = 10
parent = 1
materialID = 8
type = Box
Aero Mass = 0.488600
Thermal Mass = 0.488600
Diameter/Width = 0.162200
Length = 0.241000
```

```
Height = 0.024900

name = Lower_Isigrid_Pieces
quantity = 6
parent = 1
materialID = 8
type = Box
Aero Mass = 0.375400
Thermal Mass = 0.375400
Diameter/Width = 0.232300
Length = 0.292400
Height = 0.025400

name = Center_Supports
quantity = 4
parent = 1
materialID = 8
type = Box
Aero Mass = 0.327000
Thermal Mass = 0.327000
Diameter/Width = 0.063500
Length = 0.114300
Height = 0.019100

name = Lower_Flange
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.394000
Thermal Mass = 0.394000
Diameter/Width = 0.201500
Length = 0.201500
Height = 0.020200

name = Upper_Flange
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.437000
Thermal Mass = 0.437000
Diameter/Width = 0.201500
Length = 0.201500
Height = 0.019050

name = Engine_Mount
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.408000
Thermal Mass = 0.408000
Diameter/Width = 0.129800
Length = 0.129800

name = SS_bolts
quantity = 22
parent = 1
materialID = 57
```

```
type = Cylinder
Aero Mass = 0.006390
Thermal Mass = 0.006390
Diameter/Width = 0.006350
Length = 0.025400

name = Solar_Panel
quantity = 1
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 1.136000
Thermal Mass = 1.136000
Diameter/Width = 0.419100
Length = 0.749300

name = Harness_Pcs-Medium
quantity = 7
parent = 1
materialID = -3
type = Cylinder
Aero Mass = 0.029700
Thermal Mass = 0.029700
Diameter/Width = 0.006350
Length = 0.304800

name = Harness_Pcs-Small
quantity = 18
parent = 1
materialID = -3
type = Cylinder
Aero Mass = 0.009900
Thermal Mass = 0.009900
Diameter/Width = 0.006350
Length = 0.101600

name = Electrical_Connector-Small
quantity = 13
parent = 1
materialID = 54
type = Cylinder
Aero Mass = 0.020000
Thermal Mass = 0.020000
Diameter/Width = 0.012700
Length = 0.025400

name = GPS_Antenna
quantity = 1
parent = 1
materialID = 77
type = Box
Aero Mass = 0.037000
Thermal Mass = 0.037000
Diameter/Width = 0.150800
Length = 0.150800
Height = 0.012300

name = Sun_Sensor
quantity = 6
parent = 1
```

```
materialID = 50
type = Box
Aero Mass = 0.008300
Thermal Mass = 0.008300
Diameter/Width = 0.038100
Length = 0.038100
Height = 0.011250

name = Propellant_Controller_Board
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.125200
Thermal Mass = 0.125200
Diameter/Width = 0.101600
Length = 0.152400
Height = 0.007620

name = Magnetorquer
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.205000
Thermal Mass = 0.205000
Diameter/Width = 0.090500
Length = 0.096900
Height = 0.019050

name = S-Band_Antenna
quantity = 4
parent = 1
materialID = 50
type = Box
Aero Mass = 0.100000
Thermal Mass = 0.100000
Diameter/Width = 0.050800
Length = 0.063500
Height = 0.023370

name = 5MP_Camera
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.055000
Thermal Mass = 0.055000
Diameter/Width = 0.050800
Length = 0.050800
Height = 0.038100

name = Magnetometer
quantity = 2
parent = 1
materialID = 8
type = Box
Aero Mass = 0.000900
Thermal Mass = 0.000900
Diameter/Width = 0.007620
```

```
Length = 0.009910
Height = 0.007620

name = RF_Splitter
quantity = 2
parent = 1
materialID = 8
type = Box
Aero Mass = 0.065300
Thermal Mass = 0.065300
Diameter/Width = 0.044450
Length = 0.045720
Height = 0.016760

name = HV_Transformer
quantity = 1
parent = 1
materialID = -3
type = Box
Aero Mass = 0.249900
Thermal Mass = 0.249900
Diameter/Width = 0.076200
Length = 0.076200
Height = 0.050800

name = Misc_Brackets
quantity = 8
parent = 1
materialID = 8
type = Box
Aero Mass = 0.017460
Thermal Mass = 0.017460
Diameter/Width = 0.038100
Length = 0.063500
Height = 0.025400

name = Marmon_Clamp_Assy
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.982000
Thermal Mass = 0.982000
Diameter/Width = 0.109200
Length = 0.190200
Height = 0.019050

name = CE-1_Engine
quantity = 1
parent = 1
materialID = 37
type = Cylinder
Aero Mass = 0.680400
Thermal Mass = 0.680400
Diameter/Width = 0.076200
Length = 0.193040

name = Zero_Leak_SOV
quantity = 14
parent = 1
```

```
materialID = 54
type = Cylinder
Aero Mass = 0.127000
Thermal Mass = 0.127000
Diameter/Width = 0.025400
Length = 0.031750

name = High_Flow_SOV
quantity = 2
parent = 1
materialID = 54
type = Cylinder
Aero Mass = 0.068000
Thermal Mass = 0.068000
Diameter/Width = 0.025400
Length = 0.027940

name = Helium_Tank_Insulation
quantity = 4
parent = 1
materialID = -2
type = Sphere
Aero Mass = 3.858000
Thermal Mass = 0.176000
Diameter/Width = 0.248920

name = Helium_Tank_Wall
quantity = 4
parent = 27
materialID = 6
type = Sphere
Aero Mass = 3.682000
Thermal Mass = 3.682000
Diameter/Width = 0.241300

name = Nitrous_Oxide_Tank_Insulation
quantity = 2
parent = 1
materialID = -2
type = Sphere
Aero Mass = 2.445000
Thermal Mass = 0.176000
Diameter/Width = 0.239800

name = Nitrous_Oxide_Tank_Wall
quantity = 2
parent = 29
materialID = 6
type = Sphere
Aero Mass = 2.269000
Thermal Mass = 2.269000
Diameter/Width = 0.232200

name = Propylene_Tank_Insulation
quantity = 2
parent = 1
materialID = -2
type = Sphere
Aero Mass = 0.601000
Thermal Mass = 0.050200
```

```
Diameter/Width = 0.142240

name = Propylene_Tank_Wall
quantity = 2
parent = 31
materialID = 6
type = Sphere
Aero Mass = 0.550800
Thermal Mass = 0.550800
Diameter/Width = 0.134620

name = Regulator_Assy
quantity = 1
parent = 1
materialID = 54
type = Cylinder
Aero Mass = 0.943900
Thermal Mass = 0.943900
Diameter/Width = 0.057150
Length = 0.138000

name = Propellant_Tank_Inlet_Manifold
quantity = 1
parent = 1
materialID = 54
type = Box
Aero Mass = 0.363500
Thermal Mass = 0.363500
Diameter/Width = 0.045720
Length = 0.106680
Height = 0.038100

name = Nitrous_Prevalve_Manifold
quantity = 1
parent = 1
materialID = 54
type = Box
Aero Mass = 0.304700
Thermal Mass = 0.304700
Diameter/Width = 0.054860
Length = 0.083820
Height = 0.050800

name = Single_Thruster_Manifold
quantity = 2
parent = 1
materialID = 54
type = Box
Aero Mass = 0.113200
Thermal Mass = 0.113200
Diameter/Width = 0.033020
Length = 0.068580
Height = 0.033020

name = Dual_Thruster_Manifold
quantity = 2
parent = 1
materialID = 54
type = Box
Aero Mass = 0.244300
```

```
Thermal Mass = 0.244300
Diameter/Width = 0.050800
Length = 0.068580
Height = 0.033020

name = Propylene_Prevalve_Manifold
quantity = 1
parent = 1
materialID = 54
type = Box
Aero Mass = 0.172600
Thermal Mass = 0.172600
Diameter/Width = 0.038100
Length = 0.109730
Height = 0.038100

name = Latching_SOV
quantity = 3
parent = 1
materialID = 54
type = Cylinder
Aero Mass = 0.090700
Thermal Mass = 0.090700
Diameter/Width = 0.025400
Length = 0.030480

name = Sensors
quantity = 21
parent = 1
materialID = 54
type = Cylinder
Aero Mass = 0.027700
Thermal Mass = 0.027700
Diameter/Width = 0.015240
Length = 0.031750

name = Fluid_Components
quantity = 2
parent = 1
materialID = 54
type = Cylinder
Aero Mass = 0.045400
Thermal Mass = 0.045400
Diameter/Width = 0.025400
Length = 0.038100

name = ACS_Thrusters
quantity = 6
parent = 1
materialID = 59
type = Box
Aero Mass = 0.004500
Thermal Mass = 0.004500
Diameter/Width = 0.010160
Length = 0.010160
Height = 0.007620

name = Tubing_pcs
quantity = 60
parent = 1
```

```
materialID = 58
type = Cylinder
Aero Mass = 0.033000
Thermal Mass = 0.033000
Diameter/Width = 0.006350
Length = 0.152400

name = Ray_Capsule_TPS
quantity = 1
parent = 1
materialID = -1
type = Sphere
Aero Mass = 19.830100
Thermal Mass = 3.924600
Diameter/Width = 0.640080

name = Ray_Capsule_Shell
quantity = 1
parent = 44
materialID = 9
type = Sphere
Aero Mass = 15.905500
Thermal Mass = 2.482200
Diameter/Width = 0.589280

name = Ballast
quantity = 1
parent = 45
materialID = 67
type = Box
Aero Mass = 5.236000
Thermal Mass = 5.236000
Diameter/Width = 0.175260
Length = 0.175260
Height = 0.015240

name = Mortar_Tube
quantity = 1
parent = 45
materialID = 9
type = Cylinder
Aero Mass = 0.633800
Thermal Mass = 0.633800
Diameter/Width = 0.162560
Length = 0.167640

name = Batteries
quantity = 3
parent = 45
materialID = 46
type = Cylinder
Aero Mass = 0.240900
Thermal Mass = 0.240900
Diameter/Width = 0.022860
Length = 0.071120

name = Reaction_Wheels
quantity = 4
parent = 45
materialID = 57
```

```
type = Box
Aero Mass = 0.237700
Thermal Mass = 0.237700
Diameter/Width = 0.063500
Length = 0.063500
Height = 0.031750

name = Misc_Ray_Internal_Components
quantity = 20
parent = 45
materialID = 8
type = Box
Aero Mass = 0.294000
Thermal Mass = 0.294000
Diameter/Width = 0.063500
Length = 0.076200
Height = 0.025400

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

name = Ray_1.0
Demise Altitude = 77.993547
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Upper_Isogrid_Pieces
Demise Altitude = 77.205755
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Lower_Isigrid_Pieces
Demise Altitude = 77.554619
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Center_Supports
Demise Altitude = 76.319521
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Lower_Flange
Demise Altitude = 77.278809
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Upper_Flange
Demise Altitude = 77.191460
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Engine_Mount
Demise Altitude = 76.366064
Debris Casualty Area = 0.000000
```

```
Impact Kinetic Energy = 0.000000

************************************
name = SS_bolts
Demise Altitude = 75.799754
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Solar_Panel
Demise Altitude = 76.606685
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Harness_Pcs-Medium
Demise Altitude = 77.413063
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Harness_Pcs-Small
Demise Altitude = 77.420989
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Electrical_Connector-Small
Demise Altitude = 73.889415
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = GPS_Antenna
Demise Altitude = 77.918067
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Sun_Sensor
Demise Altitude = 77.747647
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Propellant_Controller_Board
Demise Altitude = 77.544603
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Magnetorquer
Demise Altitude = 76.938473
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = S-Band_Antenna
Demise Altitude = 76.736332
Debris Casualty Area = 0.000000
```

```
Impact Kinetic Energy = 0.000000

************************************
name = 5MP_Camera
Demise Altitude = 77.488426
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Magnetometer
Demise Altitude = 77.831644
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = RF_Splitter
Demise Altitude = 77.034012
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = HV_Transformer
Demise Altitude = 75.542641
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Misc_Brackets
Demise Altitude = 77.823890
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Marmon_Clamp_Assy
Demise Altitude = 75.574200
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = CE-1_Engine
Demise Altitude = 69.885481
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Zero_Leak_SOV
Demise Altitude = 67.698688
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = High_Flow_SOV
Demise Altitude = 71.233781
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Helium_Tank_Insulation
Demise Altitude = 77.775712
Debris Casualty Area = 0.000000
```

Impact Kinetic Energy = 0.000000

****
name = Helium_Tank_Wall
Demise Altitude = 67.714602
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Nitrous_Oxide_Tank_Insulation
Demise Altitude = 77.760156
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Nitrous_Oxide_Tank_Wall
Demise Altitude = 70.197225
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Propylene_Tank_Insulation
Demise Altitude = 77.838258
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Propylene_Tank_Wall
Demise Altitude = 72.559666
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Regulator_Assy
Demise Altitude = 65.432359
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Propellant_Tank_Inlet_Manifold
Demise Altitude = 72.580442
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Nitrous_Prevalve_Manifold
Demise Altitude = 73.280676
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Single_Thruster_Manifold
Demise Altitude = 74.895431
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Dual_Thruster_Manifold
Demise Altitude = 72.473572
Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****
name = Propylene_Prevalve_Manifold
Demise Altitude = 75.082198
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Latching_SOV
Demise Altitude = 69.854691
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Sensors
Demise Altitude = 73.862106
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Fluid_Components
Demise Altitude = 74.032719
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = ACS_Thrusters
Demise Altitude = 75.735111
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Tubing_pcs
Demise Altitude = 75.204548
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Ray_Capsule_TPS
Demise Altitude = 0.000000
Debris Casualty Area = 1.387615
Impact Kinetic Energy = 22546.826092

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

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

****
name = Mortar_Tube
Demise Altitude = 0.000000
Debris Casualty Area = 0.000000

```
Impact Kinetic Energy = 0.000000

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

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

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

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

=============== End of Requirement 4.7-1 ===============
07 25 2023; 22:53:48PM Project Data Saved To File
07 25 2023; 23:01:34PM Science and Engineering - Orbit Lifetime/Dwell Time

**INPUT**

      Start Year = 2023.900000 (yr)
      Perigee Altitude = 500.000000 (km)
      Apogee Altitude = 500.000000 (km)
      Inclination = 97.400000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Area-To-Mass Ratio = 0.004760 (m^2/kg)

**OUTPUT**

      Orbital Lifetime from Startyr = 9.774127 (yr)
      Time Spent in LEO during Lifetime  = 9.774127 (yr)
      Last year of Propagation = 2033 (yr)
      Returned Error Message: Object reentered
07 25 2023; 23:01:42PM Project Data Saved To File
```