2014

LEMUR-1 Orbital Debris Assessment Report

NANOSATISFI MARKET MISSION PROFILE

PREPARED BY: NANOSATISFI INC

Summarized List of Compliance Status to Orbital Debris Requirements

For convenience, below is a summarized list of the compliance status to orbital debris requirements. Detailed explanations for each of these compliance statements are available in ODAR Sections 1 through 8.

4.3-1, Mission-Related Debris Passing Through LEO:	COMPLIANT
4.3-2, Mission-Related Debris Passing Near GEO	COMPLIANT
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
4.4-2, Design for passivation after completion of mission operations while in orbit about Earth or the Moon:	N/A
4.4-3, Limiting the long-term risk to other space systems from planned breakups:	COMPLIANT
4.4-4, Limiting the short-term risk to other space systems from planned breakups:	COMPLIANT
4.5-1, Probability of Collision with Large Objects:	COMPLIANT
4.5-2, Probability of Damage from Small Objects:	COMPLIANT
4.6-1, Disposal for space structures passing through LEO:	COMPLIANT
4.6-2, Disposal for space structures passing through GEO:	N/A
4.6-3, Disposal for space structures between LEO and GEO:	N/A
4.6-4, Reliability of postmission disposal operations:	N/A
4.8-1, Collision Hazards of Space Tethers	N/A

ODAR Section 1: Program Management and Mission Overview

Program / Project Manager	Peter Platzer
Mission Description	The purpose of the ForeSight CubeSat market study is to evaluate the commercial viability of a low-Earth orbiting constellation of nanosatellites providing both a platform for high school STEM education and for generating high-revisit Earth observation data. As a part of this study, NanoSatisfi will be launching the LEMUR-1 satellite to perform technology demonstration of several spacecraft modules required for the constellation
Project Milestones:	• The development of LEMUR-1 began in Q3 2013, LEMUR-1 is currently undergoing subsystem integration in San Francisco. • LEMUR-1 will be delivered to the launch service provider in early April 2014, to be integrated in the launch vehicle in mid April 2014. • LEMUR-1 will be deployed from a P-POD as a secondary payload on the UniSat-6 mission, currently scheduled for no earlier than May 1 2014. • LEMUR-1 is part of an ongoing market study, which will conclude at the end of 2015.
Foreign Government Involvement	None
Proposed Launch Date:	No earlier than May 1, 2014
Proposed Launch Vehicle:	Dnepr, UniSat-6 mission
Proposed Launch Site:	Yasny Launch Base, Orenburg, Russia
Launch Vehicle Operator:	International Space Company (ISC) Kosmotras
Mission Duration:	June 2014 – Dec 2015
Launch / Deployment Profile:	**Launch** LEMUR-1 will be inserted directly into a circular sun-synchronous orbit at an altitude of 600km. **Operations** The operational phase of the satellite begins following the successful deployment of the satellite from the launch vehicle, at which point its solar panels and antennae deploy. The operational phase continues until the end of the market study in December 2015. .

	Postmission Disposal Following the end of the operational phase, the orbit of the satellite will passively decay, until the satellite reenters the atmosphere and disintegrates. The satellite is nominally expected to reenter the atmosphere 10 years following deployment from the launch vehicle, as detailed in Appendix B: LEMUR1 Orbit Lifetime
Selection of Orbit:	The selection of the chosen orbit was made due to available launch opportunities.
Potential Physical Interference with Other Orbiting Object:	As the satellite does not have any propulsion systems, its orbit will naturally decay following deployment from the launch vehicle. As detailed in Section 5, the probability of physical interference between the satellites and other space objects is sufficiently unlikely that the satellite complies with Requirement 4.5.

ODAR Section 2: Spacecraft Description

Physical Description:

Property	Value
Total Mass at Launch	4kg
Dry Mass at Launch	4kg
Form Factor	3U CubeSat
COG	<3cm radius from geometric center
Envelope (stowed)	100mm x 100mm x 340.5mm (excluding dynamic envelope)
Envelope (deployed)	1m x 1m x 300mm
Propulsion Systems	None
Fluid Systems	None
AOCS	Stabilization/pointing with 3x orthogonal reaction wheels, desaturation + coarse pointing with magnetorquers
Range Safety / Pyrotechnic Devices	None
Electrical Generation	Triple-junction GaAs solar panels
Electrical Storage	Rechargable lithium-ion battery pack
Radioactive Materials	None

ODAR Section 3: Assessment of Debris Released During Normal Operations

Objects larger than 1mm expected to be released during orbit:	**None**
Rationale for release of each object:	N/A
Time of release of each object:	N/A
Release velocity of each object:	N/A
Expected orbital parameters of each object:	N/A
Calculated orbital lifetime of each object:	N/A

Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2:	
4.3-1, Mission-Related Debris Passing Through LEO:	**COMPLIANT**
4.3-2, Mission-Related Debris Passing Near GEO:	**COMPLIANT**

A DAS 2.0.2 log demonstrating the compliance to the above requirements is available in Appendix A – “DAS 2.0.2 Log”.

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

Potential causes for spacecraft breakup:

There are only two plausible causes for breakup of the satellites:

- energy released from onboard batteries, and
- mechanical failure of the reaction wheels

Summary of failure modes and effects analysis of all credible failure modes which may lead to an accidental explosion:

The batteries aboard the satellites are 2600mAh Lithium-Ion cells, and represent the only credible failure mode during which stored energy is released. The main failure modes associated with Lithium Ion batteries result from overcharging, overdischarging, internal shorts, and external shorts.

The battery pack onboard ArduSat-2 and the ArduSat-2X is in compliance with NASA's Crewed Space Vehicle Battery Safety Requirements (JSC-20793), and complies with all controls / process requirements identified in JSC-20793 Section 5.4.3 to mitigate chance of any accidental venting / explosion caused by the above failure modes.

The only failure mode of the reaction wheel assemblies that could lead to creation of debris would be breakup of the wheels themselves due to mechanical failure while operating at a high angular rate. Risk mitigation strategies for breakups due to the reaction wheels includ limiting the maximum rotational speed of the wheels, and containing them within a sealed compartment.

Detailed Plan for any designed spacecraft breakup, including explosions and intentional collisions:

There is no planned breakup the satellites on-orbit.

List of components passivated at EOM:

At the end of mission, the only components that will require passivation are the reaction wheels. At the end of the mission, the reaction wheels will be de-spun to passivate.

Rationale for all items required to be passivated that can not be due to design:

N/A

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4:	
4.4-1, Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon	**COMPLIANT**
4.4-2, Design for passivation after completion of mission operations while in orbit about Earth or the Moon	**COMPLIANT**

4.4-3, Limiting the long-term risk to other space systems from planned breakups: There are no planned breakups of any of the satellites.	**COMPLIANT**
4.4-4, Limiting the short-term risk to other space systems from planned breakups There are no planned breakups of any of the satellites.	**COMPLIANT**

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

Probability for Collision with Objects >10cm:

The probability of a collision of any of the satellites with an orbiting object larger than 10cm in diameter was sufficiently small that the simulation performed using DAS 2.0.2 software returned a probability value of 0.

Assessment of spacecraft compliance with Requirement 4.5-1 and 4.5-2:	
4.5-1, Probability of Collision with Large Objects:	**COMPLIANT**
4.5-2, Probability of Damage from Small Objects:	**COMPLIANT**

A DAS 2.0.2 log demonstrating the compliance to the above requirements is available in Appendix A – “DAS 2.0.2 Log”.

ODAR Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

Description of Disposal Option Selected:

Following its deployment, the satellite’s orbit will naturally decay until it reenters the atmosphere. As detailed in Section 7, the satellites will completely disintegrate during reentry, with no components surviving reentry to the ground.

Identification of Systems Required for Postmission Disposal: None

Plan for Spacecraft Maneuvers required for Postmission Disposal: N/A

Calculation of final Area-to-Mass Ratio if Atmospheric Reentry Not Selected: N/A

Assessment of Spacecraft Compliance with Requirements 4.6-1 through 4.6-4:	
4.6-1, Disposal for space structures passing through LEO All of the satellites will reenter the atmosphere within 25 years of mission completion and 30 years of launch.	**COMPLIANT**
4.6-2, Disposal for space structures passing through GEO:	**N/A**
4.6-3, Disposal for space structures between LEO and GEO:	**N/A**
4.6-4, Reliability of postmission disposal operations:	**COMPLIANT**

ODAR Section 7: Assessment of Spacecraft Reentry Hazards

Detailed description of spacecraft components by size, mass, material, shape, and original location on the space vehicle:

A system-level mass breakdown and primary materials list included in the generic satellite bus is available in the table below:

Subsystem	Materials	Quantity	Mass (g)	Shape	Size (mm)
Solar Panels (long)	Glass, GaAs, FR4 PCB	6	150	Flat Plate	100 x 300
GPS Antenna	Aluminum	2	150	Box	56 x 80 x 20
Subsystem PCBs	FR4 PCB	10	60	Flat Plate	90 x 90
Primary Structure	Aluminum	1	560	Box	100 x 100 x 300
Optical Camera	Aluminum, FR4 PCB, Glass	1	350	Cylinder	60 x 70
Reaction wheel assembly + enclosure	Aluminum, copper, FR4 PCB	1	600	Box	100 x 100 x 56
Battery pack	Li-Ion, aluminum	1	470	Box	100 x 100 x 40

Summary of objects expected to survive an uncontrolled reentry (using DAS 2.0.2 software): None

Calculation of probability of human casualty for expected reentry year and inclination: 0%

Assessment of spacecraft compliance with Requirement 4.7-1:	
4.7-1, Casualty Risk from Reentry Debris:	**COMPLIANT**

A DAS 2.0.2 log demonstrating the compliance to Requirement 4.7-1 is available in Appendix A – “DAS 2.0.2 Log”.

ODAR Section 7A: Assessment of Spacecraft Hazardous Materials

Summary of Hazardous Materials Contained on Spacecraft: None

ODAR Section 8: Assessment for Tether Missions

Type of tether: N/A

Description of tether system: N/A

Determination of minimum size of object that will cause the tether to be severed: N/A

Tether mission plan, including duration and postmission disposal: N/A

Probability of tether colliding with large space objects: N/A

Probability of tether being severed during mission or after postmission disposal: N/A

Maximum orbital lifetime of a severed tether fragment: N/A

Assessment of compliance with Requirement 4.8-1:	
4.8-1, Collision Hazards of Space Tethers:	**N/A**

Appendix A: DAS 2.0.2 Log

Below is the log of the DAS 2.0.2 simulation performed to demonstrate compliance to the above requirements.

```
01 28 2014; 15:31:06PM     DAS Application Started
01 28 2014; 15:31:07PM     Opened Project C:\Program Files
(x86)\NASA\DAS 2.0\ArduSat2\
01 28 2014; 15:31:11PM     Processing Requirement 4.3-1:    Return
Status :  Not Run

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

=============== End of Requirement 4.3-1 ===============
01 28 2014; 15:31:13PM     Processing Requirement 4.3-2: Return Status
: Passed

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

=============== End of Requirement 4.3-2 ===============
01 28 2014; 15:31:14PM     Requirement 4.4-3:  Compliant

=============== End of Requirement 4.4-3 ===============
01 28 2014; 15:31:18PM     Processing Requirement 4.5-1:    Return
Status :  Passed

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

**INPUT**

      Space Structure Name = LEMUR1
      Space Structure Type = Payload
      Perigee Altitude = 600.000000 (km)
      Apogee Altitude = 600.000000 (km)
      Inclination = 98.900000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass Ratio = 0.026310 (m^2/kg)
      Start Year = 2014.000000 (yr)
      Initial Mass = 4.000000 (kg)
      Final Mass = 4.000000 (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)

OUTPUT

Collision Probability = 0.000002
Returned Error Message: Normal Processing
Date Range Error Message: Normal Date Range
Status = Pass

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

=============== End of Requirement 4.5-1 ===============
01 28 2014; 15:31:23PM   Requirement 4.5-2: Compliant
01 28 2014; 15:31:23PM   Processing Requirement 4.6 Return Status : Passed

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

INPUT

Space Structure Name = LEMUR1
Space Structure Type = Payload

Perigee Altitude = 600.000000 (km)
Apogee Altitude = 600.000000 (km)
Inclination = 98.900000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.026310 (m^2/kg)
Start Year = 2014.000000 (yr)
Initial Mass = 4.000000 (kg)
Final Mass = 4.000000 (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)

OUTPUT

```
      Suggested Perigee Altitude = 600.000000 (km)
      Suggested Apogee Altitude = 600.000000 (km)
      Returned Error Message = Reentry during mission (no PMD req.).

      Released Year = 2022 (yr)
      Requirement = 61
      Compliance Status = Pass

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

=============== End of Requirement 4.6 ===============
01 28 2014; 15:31:29PM     *********Processing Requirement 4.7-1
      Return Status :  Passed

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

name = LEMUR1
quantity = 1
parent = 0
materialID = 8
type = Box
Aero Mass = 4.000000
Thermal Mass = 4.000000
Diameter/Width = 0.100000
Length = 0.300000
Height = 0.100000

name = STRUCTURE
quantity = 1
parent = 1
materialID = 9
type = Box
Aero Mass = 0.500000
Thermal Mass = 0.500000
Diameter/Width = 0.100000
Length = 0.300000
Height = 0.100000

name = PCBs
quantity = 10
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.060000
Thermal Mass = 0.060000
Diameter/Width = 0.100000
Length = 0.100000

name = ADCS
quantity = 1
```

```
parent = 1
materialID = 8
type = Box
Aero Mass = 0.600000
Thermal Mass = 0.600000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.050000

name = LENS
quantity = 1
parent = 1
materialID = 8
type = Cylinder
Aero Mass = 0.350000
Thermal Mass = 0.350000
Diameter/Width = 0.060000
Length = 0.070000

name = GPS_ANTENNA
quantity = 2
parent = 1
materialID = 8
type = Box
Aero Mass = 0.150000
Thermal Mass = 0.150000
Diameter/Width = 0.056000
Length = 0.080000
Height = 0.020000

name = BATTERY
quantity = 1
parent = 1
materialID = 9
type = Box
Aero Mass = 0.470000
Thermal Mass = 0.470000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.030000

name = SOLAR_PANELS_LONG
quantity = 6
parent = 1
materialID = 24
type = Flat Plate
Aero Mass = 0.150000
Thermal Mass = 0.150000
Diameter/Width = 0.100000
Length = 0.300000

name = SOLAR_PANELS_SHORT
```

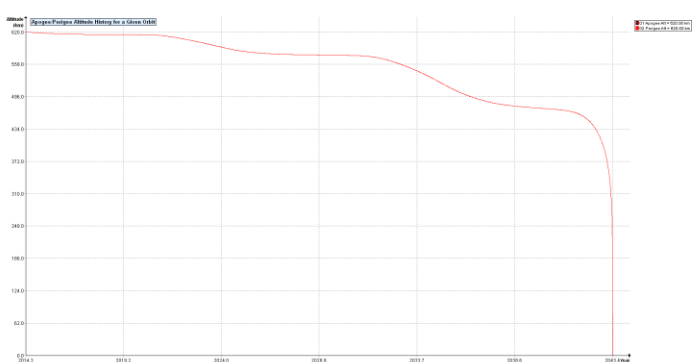
```
quantity = 2
parent = 1
materialID = 24
type = Flat Plate
Aero Mass = 0.060000
Thermal Mass = 0.060000
Diameter/Width = 0.100000
Length = 0.100000

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

name = LEMUR1
Demise Altitude = 77.998504
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = STRUCTURE
Demise Altitude = 76.367371
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = PCBs
Demise Altitude = 77.151676
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = ADCS
Demise Altitude = 71.136496
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = LENS
Demise Altitude = 71.200402
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = GPS_ANTENNA
Demise Altitude = 74.411589
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = BATTERY
Demise Altitude = 71.941042
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

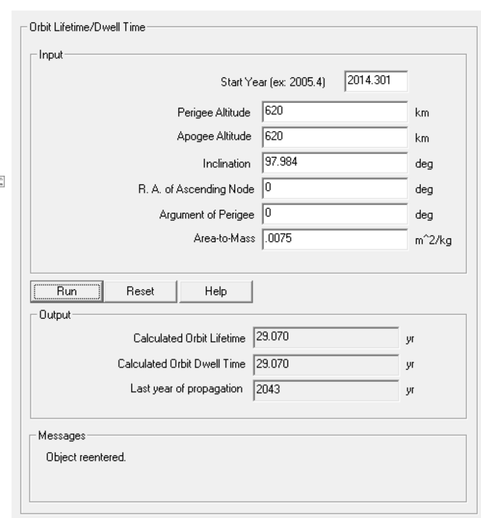
```
************************************
name = SOLAR_PANELS_LONG
Demise Altitude = 77.621574
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = SOLAR_PANELS_SHORT
Demise Altitude = 77.613543
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

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

=============== End of Requirement 4.7-1 ===============
```

Appendix B: LEMUR1 Orbit Lifetime

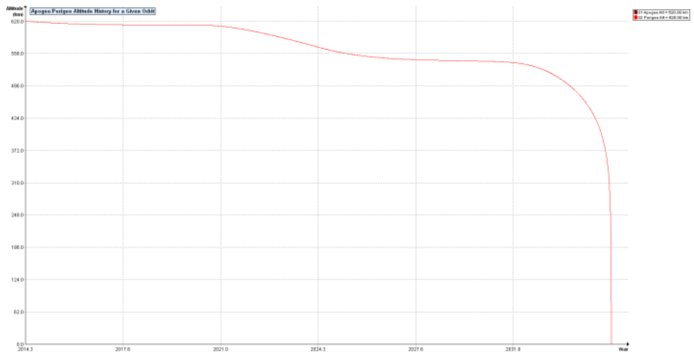
Case	Area	Area/Mass (Mass=4Kg)
1a • CubeSat Z face nadir • Minimum surface area worst case drag	0.0300 (30x10)	0.00750
1b • CubeSat Z face nadir • Nominal drag configuration	0.0424 (30x14.1)	0.01061
2 • CubeSat Z face nadir • Worst case drag config • Antennas deployed (older configuration)	0.0452 (0.01524+0.03)	0.01131
3 • CubeSat Z face nadir • Worst case drag config • Antennas deployed (older configuration) • Solar panels deployed (2 length wise panels)	0.1052 (0.07524+0.03)	0.02631

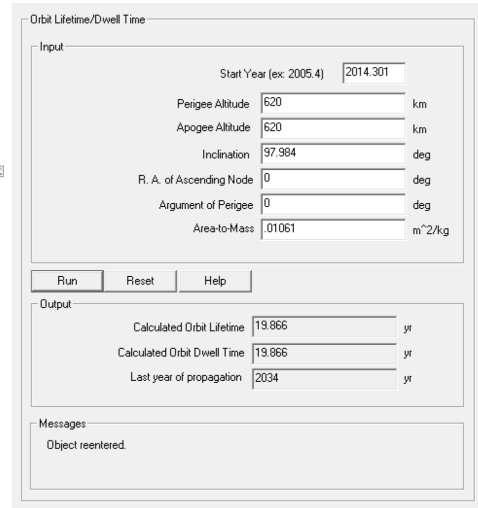
Case 1a:



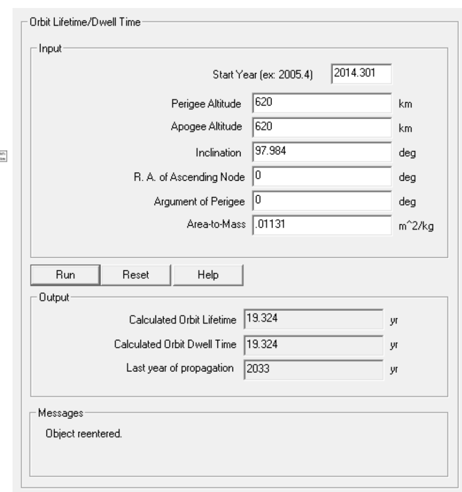


Case 1b:

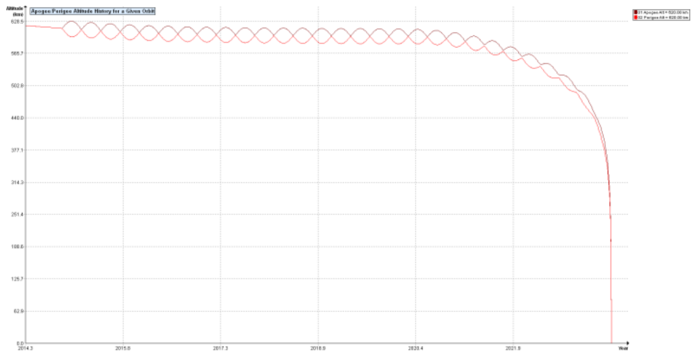


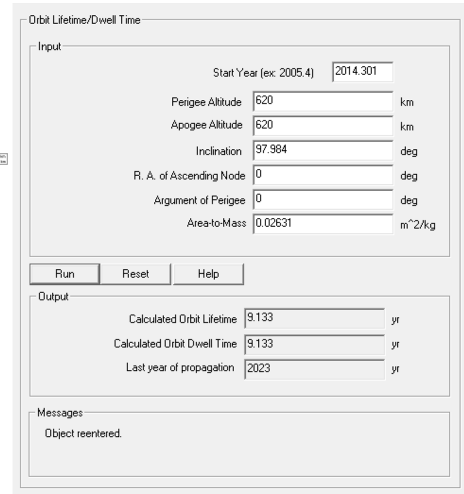


Case 2:



Case 3:


Apogee/Perigee Altitude History for a Given Orbit
Altitude (km)
628.5
565.7
502.8
440.0
377.1
314.3
251.4
188.6
125.7
62.9
0.0
2014.3
2015.8
2017.3
2018.9
2020.4
2021.9
Year


Orbit Lifetime/Dwell Time
Input
Start Year (ex: 2005.4)
2014.301
Perigee Altitude
620
km
Apogee Altitude
620
km
Inclination
97.984
deg
R. A. of Ascending Node
0
deg
Argument of Perigee
0
deg
Area-to-Mass
0.02631
m^2/kg
Run
Reset
Help
Output
Calculated Orbit Lifetime
9.133
yr
Calculated Orbit Dwell Time
9.133
yr
Last year of propagation
2023
yr
Messages
Object reentered.