

PREPARED BY Grayson Hawkins Systems Engineer	CAGE CODE 6J8J8	NUMBER ECS-0010	
APPROVALS		TYPE Analysis Procedure	
Approved By Adam Thurn Lead Systems Engineer		DATE 02/24/2021	
		SUPERSEDES SPEC DATED NA	
		REV 00	
TITLE: EchoStar (EG-3) Orbital Debris Assessment Report (ODAR) / End of Mission Plan (EOMP)			
<p>The supporting data for many requirements was calculated using DAS 3.1.1.</p>			

All future revisions to this document shall be approved by the controlling organization prior to release.

Orbital Debris Self-Assessment

Requirement	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant	Not Compliant	Incomplete	
4.3-1.a			X		X			No debris released in LEO
4.3-1.b			X		X			No debris released in LEO
4.3-2			X		X			No debris released in GEO
4.4-1			X		X			Low pressure fuel system, battery module design limit chance of explosion
4.4-2			X		X			Design to passivate propulsion, electrical power system, and reaction wheels
4.4-3			X		X			No planned breakups
4.4-4			X		X			No planned breakups
4.5-1			X		X			Compliant probability of collision.
4.5-2			X		X			No post-mission disposal maneuver required.
4.6-1(a)			X		X			Naturally deorbit after EOM within 25 years.
4.6-1(b)			X		X			N/A
4.6-1(c)			X		X			N/A
4.6-2			X		X			N/A – Not GEO
4.6-3			X		X			N/A – Not between LEO and GEO
4.6-4			X					N/A – Not using PMD maneuver
4.7-1			X		X			No component survives reentry
4.8-1					X			No tethers used

REVISION SUMMARY

REV NO.	RELEASE DATE	BRIEF DESCRIPTION/REASON FOR CHANGE	EFFECTIVE PAGES
01	02/23/21	Initial submission	All
02	02/24/21	Incorrect reference to EG-1 and 2, clarification on 4.7-1 method selected	18, 21

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1.0 PROGRAM MANAGEMENT AND MISSION OVERVIEW

Table 1-1: Summary of Program Management Personnel

Parameter	Value
Program Executive	Marco Villa (Tyvak)
Program/Project Manager	Tristan Latchu (Tyvak)
Senior Scientist	Adam Thurn (Tyvak)

Table 1-2: Summary of EG-3 Mission Parameters

Parameter	Value
Launch vehicle and launch site	SpaceX Falcon 9 Block 5 “Transporter 2” at KSC LC-39A
Launch date	NET June 15, 2021
Mission duration	36 months
Launch and deployment profile	The SpaceX launch vehicle will deliver the spacecraft to an initial orbit of 525 km +/- 25 km circular orbit with a 97.5° +/- 0.1° inclination.
Potential physical interference	Analysis through DAS v3.1.1 does not establish a probability of interaction or physical interference with other operational spacecraft in excess of NASA-STD-8719.14B requirements.

The goal of the EchoStar mission is to perform commercial operations utilizing S-Band, C-Band and X-Band radios. The exact frequencies involved are pursuant to EchoStar’s ITU filing.

2.0 SPACECRAFT DESCRIPTION

The EG-3 vehicle has been designed to support a 36-month mission in LEO and designed to the requirements in the CubeSat Design Specification (CDS). The EG-3 vehicle is a modified 12U CubeSat.

The vehicle design uses subsystem modules built from printed circuit boards (PCB) or miniature enclosures secured to a primary structure consisting of panels and rails. The panel and railed open structure permits the vehicle to be built incrementally with access for integrating subsystem modules and securing interconnect harnessing. The subsystems are placed within the vehicle to optimize mass properties, radiation protection, thermal heat rejection, power handling, vehicle orientation, and cabling length. The deployable solar arrays attach to the primary structure via a fixed mount. Two of the bus side-panels are dedicated as radiators for thermal management and can be easily removed to get access to the interior of the vehicle. The vehicle is primarily constructed out of aluminum and PCB materials.

Additionally, there is a low-pressure monopropellant propulsion system onboard.

Table 2-1: Summary of Spacecraft Parameters

Parameter	Value
Total satellite mass at launch, including all propellants and fluids	23 kg
Dry Mass of satellite at launch, excluding solid rocket motor propellants	17 kg

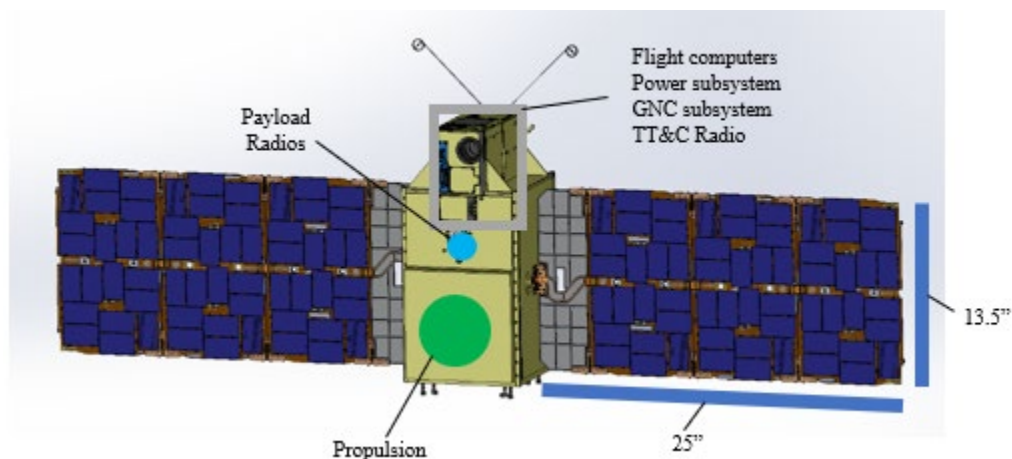


Figure 1. Subsystem locations and deployed panel dimensions

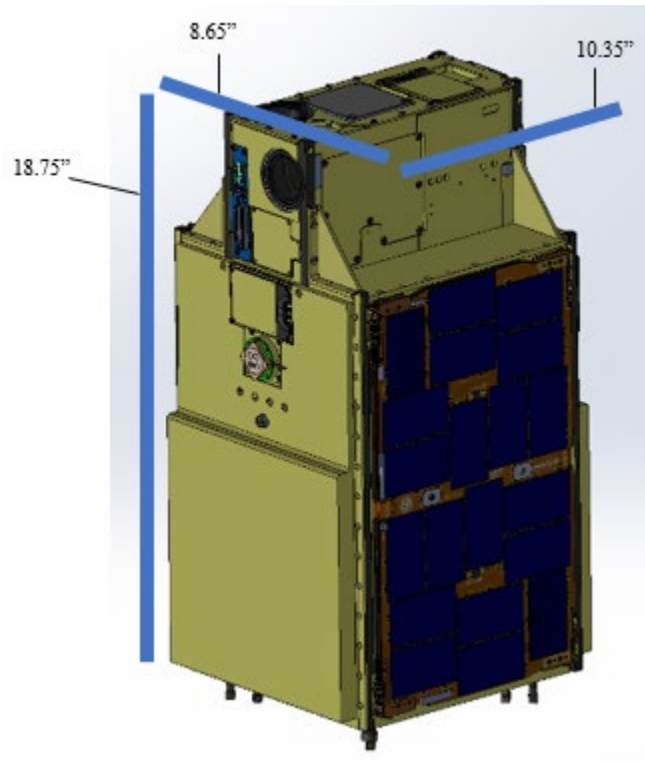


Figure 2. Stowed envelope

2.1 Propulsion System

The propulsion system consists of eight 0.25N high purity hydrazine monopropellant thrusters. Four of the thrusters will be oriented to provide translational thrust from the four corners along the Z-axis of the spacecraft. The table below lists the operating pressure and design pressure for each compartment of the propulsion system, tested in accordance with AFSPCMAN 91-710V3.

2.2 Attitude Control System

The attitude control system for EG-3 consists of three reaction wheels with three independent torque rods to dump momentum.

2.3 Electrical Generation and Storage System

Energy generation is accomplished using two deployable solar array wings. Energy storage is accomplished using standard COTS Li-ion battery cells.

3.0 ASSESSMENT OF SPACECRAFT DEBRIS RELEASED DURING NORMAL OPERATIONS

N/A. No objects are intentionally released during the EG-3 mission, which is inherently compliant with requirements 4.3-1 and 4.3-2.

4.0 ASSESSMENT OF THE POTENTIAL FOR EXPLOSIONS

There are no planned breakups for the EG-3 mission beyond natural atmospheric entry after EOM passivation. Additionally, all items that are required to be passivated are capable of doing so.

4.1 Potential Causes of Spacecraft Breakup During Deployment and Mission Operations

There are two distinct potential causes of an explosion or breakup during deployment and mission operations, a catastrophic failure in the batteries *or* a catastrophic failure in the propulsion system. Failure of either system would have to consist of multiple independent failure modes occurring at the same time.

4.2 FMEA for Credible Failure Modes

4.2.1 Hydrazine Tank Structural Failure

Explosion within the propulsion system would result from an over-pressurization event caused by an electric spark ignition, out of operational range temperatures reaching the autoignition temperature of hydrazine, weakening of tank or tubing structure due to corrosion, or unintended decomposition. If the burst pressure were to be exceeded, the tank would rupture and leak hydrazine within the spacecraft.

Probability: Extremely low.

Failure Mode 1: Poorly built tank ruptures below burst pressure

Mitigation 1: All acceptance testing passed under each relevant standard in AFSPCMAN 91-710V3.

Failure Mode 2: Hydrazine undergoes combustion

Mitigation 2: Hydrazine can undergo combustion in the presence of an ignition source. Possible ignition sources while in orbit are electric sparks and high temperature surfaces.

Failure Mode 3: Overpressurization due to unintended decomposition

Mitigation 3: The interaction of hydrazine with various materials can promote a decomposition reaction to occur. The propulsion system uses materials that do not promote a decomposition reaction to occur within the spacecraft operational temperature range. The table below outlines the materials used and their respective decomposition on-set temperatures.

Failure Mode 4: Hydrazine corrodes tank material

Mitigation 4: Due to the corrosive properties of hydrazine, the propulsion system chose materials that have a low corrosion rate.

4.2.2 Battery Failure

Effect: 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 eliminate a single event occurrence of a battery cell explosion and combined faults must occur for any of the independent, mutually exclusive failure modes to lead to explosion. The battery safety systems include circuitry for over-voltage protection, under-voltage protection, over-current protection and enable cell balancing. Due to the low energy of each individual battery cell, should a single cell fail explosively, the chances of debris being created is small.

Probability: Extremely low.

Failure mode 1: Internal short circuit.

Mitigation 1: Sine and random vibration testing in three axes, thermal vacuum cycling and functional testing followed by charge and discharge cycles to prove that no internal short circuit sensitivity exists.

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

Mitigation 2: Battery cells were tested in lab for high load discharge rates 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. The battery system also includes over-current circuit protection to prevent high discharge events due to short circuits or other failures within the space vehicle. No failures were observed or identified.

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 3: This failure mode is negated by:

- a) qualification tested short circuit protection on each external circuit,
- b) design of battery packs such that no contact with nearby board traces is possible,
- c) observation of such other mechanical failures by environmental tests

Failure Mode 4: Battery venting

Mitigation 4: Battery venting is not inhibited by the battery holder design or the spacecraft design. The battery can vent gases to the external environment.

Failure Mode 5: Crushing

Mitigation 5: This mode is negated by spacecraft design.

Failure Mode 6: Excess temperatures due to orbital environment and high discharge combined.

Mitigation 6: 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.

4.3 End-of-Mission Passivation

The reaction wheels will be passivated at end-of-mission through a series of commands to reduce wheel momentum to a minimum level and then to transition the vehicle to free drift mode.

The batteries will be passivated by discharging the cells to a minimum state and then setting the MPPT output current to 0 Amps to prevent charging of the battery cells.

The fuel in the propulsion system will be completely spent, within mechanical limits, at EOM by firing rotational thrusters simultaneously in conjunction with the GNC subsystem. This results in a minimum-spin free-drift mode at passivation.

4.4 Compliance Statements: 4.4-1 through 4.4-4

Requirement 4.4-1: Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon:

For each spacecraft and launch vehicle orbital stage employed for a mission, 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

The propulsion system has a factor safety >2.5 MEOP for every pressurized volume. Additionally, its testing is compliant with AFSPCMAN 91-710V3. The Tyvak battery modules have flight heritage and have never experienced a critical failure leading to rupture or venting. The propulsion system and the battery modules are contained within the spacecraft structure. Each cell and each module go through extensive environmental testing.

Required probability: 0.001

Expected probability: 0.000 **COMPLIANT**

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 can not cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft (Requirement 56450).

Compliance statement

The batteries will be passivated by discharging the cells to a minimum state and then setting the MPPT output current to 0 Amps to prevent charging of the battery cells. In the unlikely event that a battery cell does explosively rupture, the small size, mass, and potential energy of these batteries is such that while the spacecraft could be expected to vent gases, most debris from the battery rupture would be contained within the vehicle due to lack of penetration energy and also from the battery cells being contained within the module aluminum housing.

The reaction wheels will be passivated at end-of-mission through a series of commands to reduce wheel momentum to a minimum level and then to transition the vehicle to free drift mode.

At EOM, the propulsion unit's fuel reserves will be completely spent by simultaneously firing rotational thrusters that results in no net movement.

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

Compliance statement

This requirement is not applicable. There are no planned breakups.

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

Compliance statement

This requirement is not applicable. There are no planned breakups.

5.0 ASSESEMENT OF SPACECRAFT POTENTIAL FOR ON-ORBIT COLLISIONS

These requirements were assessed through the DAS v3.1.1 software.

5.1 Debris Avoidance Capabilities

The EG-3 vehicle has an onboard propulsion system with some margin of fuel that can be spent in the case of a major collision being predicted. This was not included in our calculations for compliance with requirements 4.5-1 or 4.5-2.

5.2 Compliance Statements: 4.5-1 and 4.5-2

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

For each spacecraft and launch vehicle orbital stage in or passing through LEO, the program or project shall demonstrate that, during the orbital lifetime of each spacecraft and orbital stage, the probability of accidental collision with space objects larger than 10 cm in diameter is less than 0.001 (Requirement 56506).

Compliance statement

Required probability: 0.001

Expected probability: 0.00003 **COMPLIANT**

Requirement 4.5-2: Limiting debris generated by collisions with small objects when operating in Earth or lunar orbit:

For each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and meteoroids sufficient to prevent compliance with the applicable post-mission disposal requirements is less than 0.01 (Requirement 56507).

Compliance statement

The EG-3 vehicle will deorbit within 25 years without needing a post-mission disposal maneuver. In the event an impact does affect spacecraft capability, there is no risk of long-term debris being generated. See section 6 for the orbital lifetime simulations.

Required probability: 0.01

Expected probability: 0.00000 **COMPLIANT**

5.3 DAS Log for Requirement 4.5-1

Listed below is the complete DAS v3.1.1 log for (Requirement 4.5-1) - Probability of Collision with Large Objects.

02 22 2021; 17:31:06PM Activity Log Started

02 23 2021; 08:35:42AM Processing Requirement 4.5-1: Return Status : Passed

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

****INPUT****

Space Structure Name = EG-3
Space Structure Type = Payload
Perigee Altitude = 650.000 (km)
Apogee Altitude = 650.000 (km)
Inclination = 96.000 (deg)
RAAN = 0.000 (deg)
Argument of Perigee = 0.000 (deg)
Mean Anomaly = 0.000 (deg)
Final Area-To-Mass Ratio = 0.0134 (m²/kg)
Start Year = 2021.500 (yr)
Initial Mass = 23.500 (kg)
Final Mass = 18.000 (kg)
Duration = 5.000 (yr)
Station-Kept = False
Abandoned = True

****OUTPUT****

Collision Probability = 3.2598E-05
Returned Message: Normal Processing
Date Range Message: Normal Date Range
Status = Pass

=====

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

Figure 3. DAS log for Requirement 4.5-1

6.0 ASSESEMENT OF SPACECRAFT POSTMISSION DISPOSAL PLANS AND PROCEDURES

EG-3 currently simulates a 23-year lifetime in orbit after the mission ends. Thus, method a. Atmospheric reentry option was selected to fulfill requirements 4.6-1 through 4.6-4.

This was based on an averaged cross-sectional area and a final mass including a conservative ~1 kg of fuel remaining due to surface wetting and mechanical limits.

6.1 Compliance Statements: 4.6-1 through 4.6-4

Requirement 4.6-1. Disposal for space structures passing through LEO: A spacecraft or orbital stage with a perigee altitude below 2000 km shall be disposed of by one of three methods:
(Requirement 56557)

a. 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 but no more than 30 years after launch; or Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission.

b. Storage orbit option:

Maneuver the space structure into an orbit with perigee altitude greater than 2000 km and apogee less than GEO - 500 km.

c. Direct retrieval:

Retrieve the space structure and remove it from orbit within 10 years after completion of mission

Compliance statement

Method a. was selected. The orbital lifetime is predicted to be approximately 26 years total, or approximately 23 years after the end of mission; **COMPLIANT**

Requirement 4.6-2. Disposal for space structures near GEO.

Compliance statement:

Not applicable. EG-3 mission orbit is LEO.

Requirement 4.6-3. Disposal for space structures between LEO and GEO.

Compliance statement:

Not applicable. EG-3 mission orbit is LEO.

Requirement 4.6-4. Reliability of post-mission disposal maneuver operations in Earth orbit: NASA space programs and projects shall ensure that all post-mission disposal operations to meet Requirements 4.6-1, 4.6-2, and/or 4.6-3 are designed for a probability of success as follows:

a. Be no less than 0.90 at EOM, and

b. For controlled reentry, the probability of success at the time of reentry burn must be sufficiently high so as not to cause a violation of Requirement 4.7-1 pertaining to limiting the risk of human casualty.

Compliance statement

N/A. The spacecraft will reenter without the need for a post-mission disposal maneuver.

6.2 DAS Logs for Requirements 4.6-1 through 4.6-4

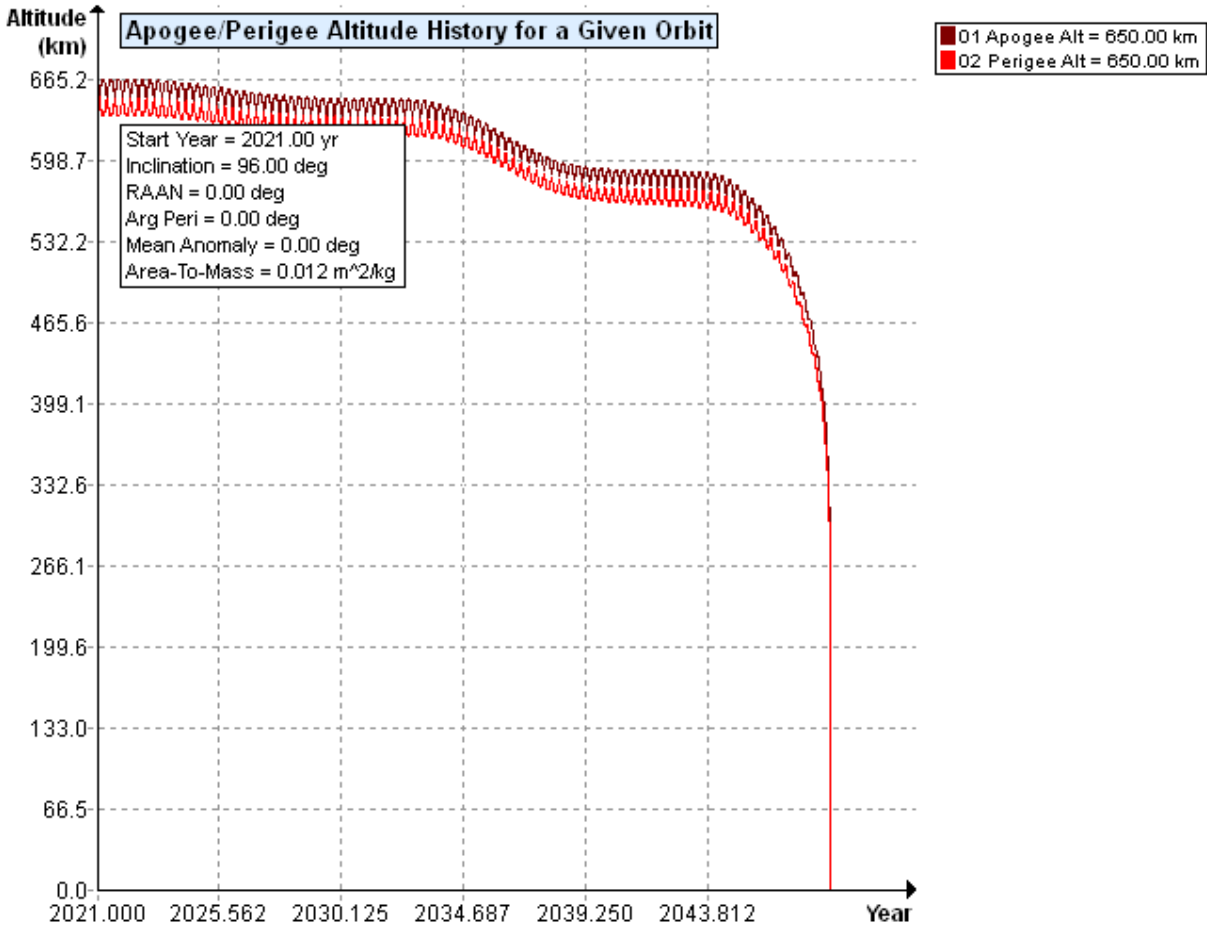


Figure 4. Altitude vs Time plot for EG-3

12 22 2021; 12:59:55PM Processing Requirement 4.6

Return Status : Passed

=====
Project Data
=====****INPUT****

Space Structure Name = EG-3
Space Structure Type = Payload

Perigee Altitude = 650.000000 (km)
Apogee Altitude = 650.000000 (km)
Inclination = 96.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Area-To-Mass Ratio = 0.013400 (m²/kg)
Start Year = 2021.500000 (yr)
Initial Mass = 23.500000 (kg)
Final Mass = 18.000000 (kg)
Duration = 5.000000 (yr)
Station Kept = False
Abandoned = True
PMD Perigee Altitude = 639.734785 (km)
PMD Apogee Altitude = 643.512676 (km)
PMD Inclination = 96.026733 (deg)
PMD RAAN = 274.078918 (deg)
PMD Argument of Perigee = 6.199057 (deg)
PMD Mean Anomaly = 0.000000 (deg)

****OUTPUT****

Suggested Perigee Altitude = 639.734785 (km)
Suggested Apogee Altitude = 643.512676 (km)
Returned Error Message = Passes LEO reentry orbit criteria.

Released Year = 2047 (yr)
Requirement = 61
Compliance Status = Pass

=====

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

Figure 5. DAS log for Requirement 4.6

7.0 ASSESSMENT OF SPACECRAFT REENTRY HAZARDS

A detailed description of spacecraft components is listed in section 7.2 as the DAS v3.1.1 input file for simulating Requirement 4.7-1. No components are expected to survive reentry.

7.1 Compliance Statement: 4.7-1

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:

- a. For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000).
- b. For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica.
- c. For controlled 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

Method a. was selected.

Required probability: 0.0001

Expected probability: 0.0000 **COMPLIANT**

8.0 ASSESMENT FOR TETHER MISSIONS

Not applicable. No tethers are being used on EG-3.