PREPARED BY Adam Thurn Systems Engineer	CAGE CODE 6J8J8	NUMBER	
APPROVALS		**TYPE** Analysis Procedure	
Approved By Matt Gann Program Manager		**DATE** 8/2/2020	
Concurrence		**SUPERSEDES SPEC DATED** **NA**	
		REV **01**	

TITLE: EchoStar (EG-1 and EG-2) Orbital Debris Assessment Report (ODAR) / End of Mission Plan (EOMP)

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

REVISION SUMMARY

REV NO.	RELEASE DATE	BRIEF DESCRIPTION/REASON FOR CHANGE	EFFECTIVE PAGES
00	12/9/19	Initial draft for review	All
01	12/10/19	Initial release	All
02	8/3/20	Update per customer needs for FCC submission	All

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ORBITAL DEBRIS SELF-ASSESSMENT: EG-1 AND EG-2 MISSION

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			Less than 0.001 probability
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			Probability 0.00000 (requirement < 0.001)
4.5-2			X		X			Probability 0.00000 (requirement < 0.01)
4.6-1(a)			X		X			Predicted orbital lifetime <3 years
4.6-1(b)			X		X			N/A – using atmospheric entry
4.6-1(c)			X		X			N/A – using atmospheric entry
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		X			Expected probability < 0.001
4.7-1			X		X			Solar Array Wings survive re-entry but human casualty risk < 0.0001
4.8-1					X			No tethers used

1.0 PROGRAM MANAGEMENT AND MISSION OVERVIEW

1.1 Program Management

Parameter	Value
Mission Directorate	N/A
Program Executive	Marco Villa (Tyvak)
Program/project Manager	Matt Gann (Tyvak)
Senior Scientist	Adam Thurn (Tyvak)
Senior Management	N/A

Table 1-1: Summary of Program Management Personnel

1.2 Mission Overview

1.2.1 Mission Design and Development Milestones

The schedule of mission design and development milestones is provided in Table 1.2.

EG-1 Launch	September 2020
EG-2 Launch	August 2020

Table 1.2 – Summary of Mission Design and Development Milestones

1.2.2 Mission Overview

The goal of the EchoStar mission is to perform operations utilizing the provided spectrum in the S-Band, C-Band and X-Bands. The EchoStar spacecraft will operate across the full RF spectrum to satisfy the ITU filing.

Parameter	Value
Launch vehicle and launch site	SpaceX Falcon 9 (EG-1). Arianespace Vega (EG-2)
Launch date	Q3 2020
Mission duration	36 months
Launch and deployment profile	The SpaceX launch vehicle will deliver the EG-1 spacecraft to an initial orbit of 612 km circular orbit with a 97.9° inclination. The Arianespace Vega launch vehicle will deliver the EG-2 spacecraft to an initial orbit of 555 km circular orbit with 97.5° inclination. Both spacecraft will conduct orbit correction maneuvers to get to final orbits of 650 km circular with 96° inclination. Both spacecraft will use their propulsion systems to burn down the orbit altitude to below 500km to allow for natural decay and debris mitigation and will re-enter within 25 years after completion of mission.

Table 1-2: Summary of EchoStar Mission Parameters

2.0 SPACECRAFT DESCRIPTION

2.1 Physical Description of Spacecraft

The EG-1 and EG-2 vehicles have been designed to support a 36 month mission in LEO and designed to the requirements in the CubeSat Design Specification (CDS). The EG-1 and EG-2 vehicles are a 6U CubeSat with the vehicle being 30cm x 20cm x 10cm with a mass of 10.0 kg.

The EG-1 and EG-2 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.

The EG-1 and EG-2 includes an ion propulsion thruster on the Plus-Z panel.

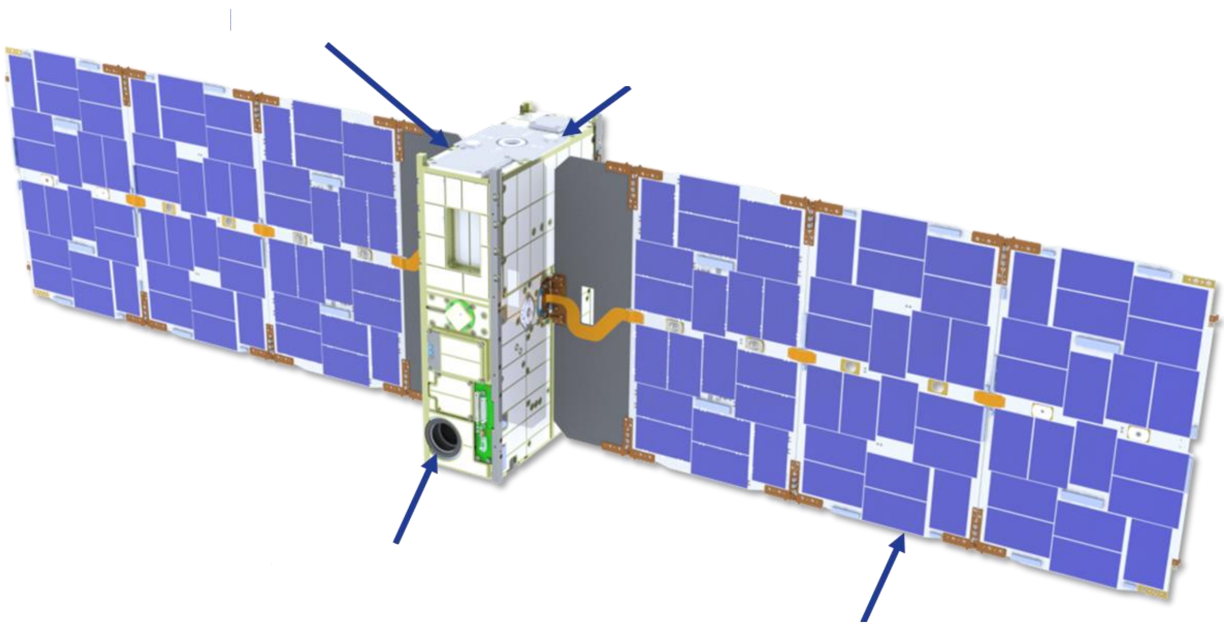

Figure 2-1: Spacecraft Vehicle Layout

Parameter	Value

Total satellite mass at launch, including all propellants and fluids	10.0 kg
Dry Mass of satellite at launch, excluding solid rocket motor propellants	10.0 kg
Identification, including mass and pressure, of all fluids	EG-1 and EG-2 contains a propulsion system that uses indium wire for fuel. The propellant has a mass of 230 grams
Fluids in Pressurized batteries	NONE. EG-1 and EG-2 use unpressurized standard COTS Li-ion battery cells
Identification of any other sources of stored energy	NONE
Identification of any radioactive materials on board	NONE

Table 2-1: Summary of Spacecraft Parameters

2.1.1 Description of Propulsion Systems

The EG-1 and EG-2 payloads consists of an ion propulsion system. The maximum operating thrust is approximately 350 μN.

2.1.2 Description of attitude control system

The EG-1 and EG-2 attitude determination and control system consists of the flight computer, IMU, reaction wheels, GPS receiver, sun sensors, magnetometers, and torque rods.

2.1.3 Description of normal attitude of the spacecraft with respect to the velocity vector

The nominal attitude of the EG-1 AND EG-2 vehicle is in an LVLH orientation with the long axis (Z-axis) facing along the velocity vector and the X-axis aligned towards nadir (earth). The vehicles will rotate about the Z-axis for minimizing Star Tracker sun/earth occlusions, maximizing solar charging and orienting the boresight of the S-band patch antenna towards ground asset(s).

2.1.4 Description of any range safety or other pyrotechnic devices

None.

2.1.5 Description of the 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. The cells are recharged by the solar cells mounted on the deployable solar arrays. The power management and distribution is provided by the electrical power system and battery protection circuitry.

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3.0 ASSESSMENT OF SPACECRAFT DEBRIS RELEASED DURING NORMAL OPERATIONS

No intentional release of any object > 1mm is expected.

Parameter	Value
Identification of any object (>1mm) expected to be released from the spacecraft at any time after launch	**None**
Rationale/necessity for release of object	N/A
Time of release of each object, relative to launch time	N/A
Release velocity of each object with respect to spacecraft	N/A
Expected orbital parameters of each object after release	N/A
Calculated orbital lifetime of each object	N/A
Compliance 4.3-1 Mission related debris passing through GEO	COMPLIANT
Compliance 4.3-2 Mission related debris passing through LEO	COMPLIANT

Table 3-1: Summary of Spacecraft Debris Released During Normal Operations

4.0 ASESSMENT OF SPACECRAFT POTENTIAL FOR EXPLOSIONS AND INTENTIONAL BREAKUPS

4.1 Potential causes of spacecraft breakup during deployment and mission operations

There is no credible scenario that would result in spacecraft breakup during normal deployment and operations.

4.2 Summary of failure modes and effects analysis of all credible failure modes

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 bettery cell explosion and combined faults must occur for any of the independent, mutually exclusive failure modes to lead to explosion.

4.3 Detailed plan for any designed spacecraft breakup

There are no planned breakups.

4.4 List of components which shall be passivated at End-of-Mission (EOM)

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 propulsion system will be left in an unpowered state during passivation.

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

None.

4.6 Assessment of spacecraft compliance with Requirements 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:

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 postmission 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 because the cells are housed in a substantial aluminum bracket.

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.

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 ASSESSMENT OF SPACECRAFT POTENTIAL FOR ON-ORBIT COLLISIONS

5.1 Assessment of spacecraft compliance with Requirements 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: (Large Object Impact and Debris Generation Probability)

Required Probability: 0.001

Expected probability: 0.00000 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 postmission disposal requirements is less than 0.01 (Requirement 56507).*

Compliance statement: (Small Object Impact and Debris Generation Probability)

Required Probability: 0.01

Expected probability: 0.00000 COMPLIANT

6.0 ASSESSMENT OF SPACECRAFT POSTMISSION DISPOSAL PLANS AND PROCEDURES

6.1 Description of spacecraft disposal option selected

The satellites will use the propulsion systems to lower the orbit altitude to below 500 km and then will de-orbit naturally by atmospheric re-entry.

6.2 Plan for any spacecraft maneuvers required to accomplish postmission disposal:

The satellites will use the ion propulsion module to conduct orbit correction maneuvers to lower the apogee of the orbit to less than 500 km.

6.3 Calculation of area-to-mass ratio after postmission disposal:

Spacecraft Mass:	10.00 kg (dry mass)
Cross-sectional Area:	0.2241 m^2
Area to mass ratio:	(0.2241 m^2)/(10.00kg) = 0.02241 m^2/kg

6.4 Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5:

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:

The orbit used for disposal of structure analysis is 500 km. The worst-case orbital lifetime is predicted to be approximately 6 years; COMPLIANT

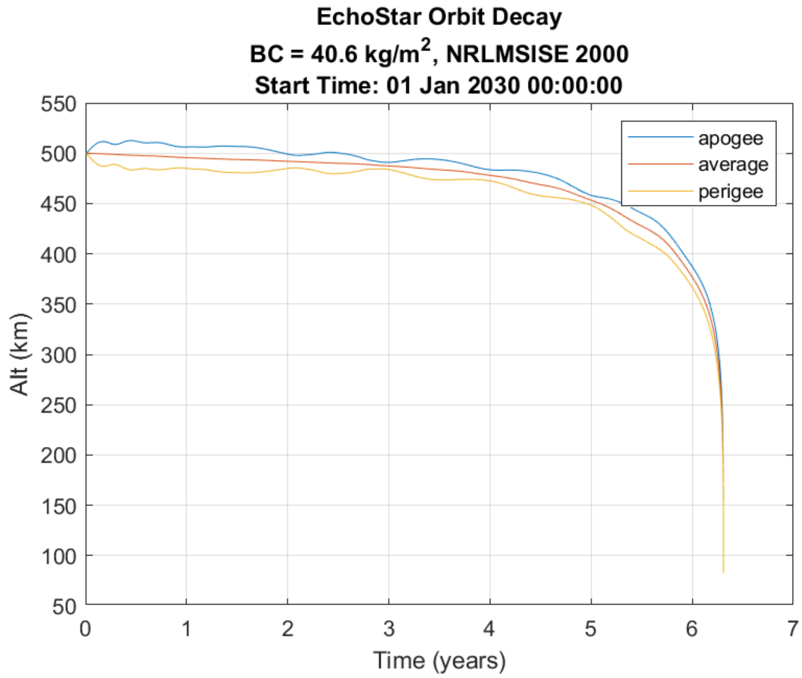

Figure 6-1: EG-1 AND EG-2 Deorbit Lifetime

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

Compliance statement:

Not applicable. EG-1 AND EG-2 mission orbit is LEO.

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

Compliance statement:

Not applicable. EG-1 AND EG-2 mission orbit is LEO.

6.5 Detailed plan for passivating (depleting all energy sources) of the spacecraft:

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 free drift mode does not utilize any attitude control actuators, specifically the reaction wheels. The power service to the reaction wheels will also be deactivated so that no inadvertent switch to another attitude control mode can actuate the reaction wheels.

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

7.0 ASSESSMENT OF SPACECRAFT REENTRY HAZARDS

7.1 Assessment of spacecraft compliance with Requirement 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) (Requirement 56626).

Compliance statement:

DAS v2.0.2 reports that EG-1 AND EG-2 is COMPLIANT with the requirement. The vehicle is primarily composed of Aluminum and PCB (Fiberglass) material and none of the components is expected to survive re-entry. The predicted Total Debris Casualty Area is $1.80m^2$ and the risk of Human Casualty is 1:32,400 below the required 1:10,000 limit.

Requirement 4.7-1., 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 (Requirement 56627).*

Compliance statement:

Not applicable. No controlled reentry planned.

Requirement 4.7-1., c) For controlled reentries, the product of the probability of failure of the reentry burn (from Requirement 4.6-4.b) and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000) (Requirement 56628).

Compliance statement:

Not applicable. No controlled reentry planned.

8.0 ASSESSMENT FOR TETHER MISSIONS

Not applicable. There are no tethers in the EG-1 AND EG-2 mission.