LNSA-OD-20-0001

Revision -

LINUS-A Orbital Debris Assessment Report (ODAR)

Report Date: January 11, 2021

This report is presented in compliance with NASA-STD-8719.14, APPENDIX A.

Prepared by:
Lockheed Martin Space Systems Company
P.O. Box 179
Denver, CO 80201
CAGE Code 04236

APPROVALS

Prepared by:

	Signature	Date
Jesse Pedroni, Systems Engineering	/S/	11/20/20

Approved by:

Don Waite, LINUS-A Program Manager	/S/	11/20/20

REVISION HISTORY LOG

Revision	Released Date	Change Description / Change Authority / Sections Affected
-	11/20/20	Initial Release for LINUS-A

SUMMARY: LINUS-A ORBITAL DEBRIS ASSESSMENT REPORT

A self-assessment provided below in accordance with the assessment format provided in Appendix A.2 of NASA-STD-8719.14.

Requirement #	Launch Vehicle Compliant	Not Compliant	Incomplete	Standard Non Compliant	Spacecraft Compliant	Not Compliant	Incomplete	Comments
4.3-1.a	☐	☐	☒	☐	☒	☐	☐	No Debris Released in LEO. See note 1.
4.3-1.b	☐	☐	☒	☐	☒	☐	☐	No Debris Released in LEO. See note 1.
4.3-2	☐	☐	☒	☐	☒	☐	☐	No Debris Released in GEO. See note 1.
4.4-1	☐	☐	☒	☐	☒	☐	☐	No Accidental Explosion. See section 4.2.
4.4-2	☐	☐	☒	☐	☒	☐	☐	See section 4.4.
4.4-3	☐	☐	☒	☐	☒	☐	☐	No planned breakups. See section 4.3.
4.4-4	☐	☐	☒	☐	☒	☐	☐	No planned breakups. See section 4.3.
4.5-1	☐	☐	☒	☐	☒	☐	☐	See section 5
4.5-2					☒	☐	☐	See section 5
4.6-1(a)	☐	☐	☒	☐	☒	☐	☐	See section 6
4.6-1(b)	☐	☐	☒	☐	☒	☐	☐	See section 6
4.6-1(c)	☐	☐	☒	☐	☒	☐	☐	See section 6
4.6-2	☐	☐	☒	☐	☒	☐	☐	See section 6
4.6-3	☐	☐	☒	☐	☒	☐	☐	See section 6
4.6-4	☐	☐	☒	☐	☒	☐	☐	See section 6
4.7-1	☐ ☐	☐ ☐	☒ ☒	☐ ☐	☒	☐	☐	No re-entry plans. See section 7
4.8-1					☒	☐	☐	No tethers. See section 8

Note 1: No Debris will be released and no intentional breakups at any point during the lifetime of the vehicle.

Table of Contents

INTRODUCTION

Purpose

This is the Orbital Debris Assessment Report (ODAR) for the LINUS-A Program. The purpose of this report is to assess the debris generation potential and the mitigation options. This ODAR follows the format in NASA-STD-8719.14, Appendix A.1 and includes the content indicated at a minimum in Sections 1 through 8 below for LINUS-A. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered here.

This report will be updated as necessary in accordance with NPR 8715.6B.

A summary of the requirements with their compliance is located in a table in the front of the document.

Scope

This document shows the compliance of LINUS-A with the requirements of NPR 8715.6B, “NASA Procedural Requirements for Limiting Orbital Debris”. The orbital debris assessment covers the following topics according to NASA-STD 8719.14A, and indicates the sections that are not applicable to the LINUS-A mission:

- Program Management and Mission Overview
- Spacecraft Description
- Debris Released During Normal Operations
- Intentional Breakups and Potential for Explosions
- Potential for On-Orbit Collisions
- Post Mission Disposal Plans and Procedures
- Spacecraft Reentry Hazards
- Assessment for Tether Missions

The Launch vehicle assessment (Section 9 – Section 14A of NASA STD 8719.14b) is outside of the scope of this document and will be provided by Space X as the launch vehicle provider for this mission.

Software and Models Used

No specific debris assessment software was used for this assessment.

1 PROGRAM MANAGEMENT AND MISSION OVERVIEW

1.1 Responsible Personnel

LINUS-A Principal Investigator: David Barnhart / Lockheed Martin Space
LINUS-A Program Manager: Don Waite / Lockheed Martin Space
LINUS-A Systems Engineer: Todd McCusker / Lockheed Martin Space
Foreign government or space agency participation: None.

LINUS-A is a Lockheed Martin Space IRAD & CRADA between Lockheed Martin and SSDP and is not part of a NASA program.

1.2 Mission Description

Launch Vehicle: SpaceX Falcon 9 Heavy
Launch Site: KSC **Launch Date (Scheduled):** May 2021
Secondary Payloads (Deployed): LDPE-2 including LINUS-A
LINUS-A Mission Duration: 4 months
Operational Orbit: GEO +300km **Reason:** Mission Augmentation Technologies (MAT) which includes on-orbit upgrades & servicing demonstrations will be used to advance Lockheed Martin technical capabilities to support future on-orbit servicing missions of GEO satellites.

LINUS-A Project Schedule

Contract ATP:	June 2018
Preliminary Design Review:	August 2018
Detail Design Review:	March 2019
Pre-Ship Review	February 2021
Arrival at ASO for LVI Integration:	March 2021
Falcon 9 Heavy Launch	May 2021

The LINUS-A Payload will be one of six payloads installed on the LDPE-2. Following launch of the SpaceX Falcon 9 Heavy. Upon separation of the LDPE-2 from the launch vehicle, the LDPE-2 will transition into a disposal orbit, GEO +300km inclination angle of 2.8° and an Eccentricity of 0, where LINUS-A will begin deployment.

LINUS-A 1 is scheduled to be deployed Launch+57 days and LINUS-A 2 deployed at Launch +59 days after drifting on the LDPE-2 in the disposal orbit (GEO +300km). Upon deployment of each vehicle from the dispensers, the vehicles will power on the components with the radio initializing in a receive only, deploy the Solar Arrays, and point the solar arrays towards the sun for a power positive state. Upon command via communication with the ground, the vehicle will switch the radio into a transmit mode for telemetry downlink. Following the safe mode activity, the vehicle will enter into a checkout state, where the team will verify the vehicle state via telemetry downlink (communication, timing, orbital state, component states, etc). Upon successful completion of the checkout state, the vehicle will then transition into the MAT state functions that will take place over 21 days after both vehicles have been deployed. After MAT functions are complete both vehicles will complete drift for 62 days. During this drift, communication with the vehicles will be infrequent (twice a day for 30 minutes each), where the vehicles will perform the

SmartSat testing. The SmartSat testing consists of taking images of the earth, performing on orbit image processing and downlinking a handful of images to show image processing effectiveness. This mission is represented in Figure 1-1.

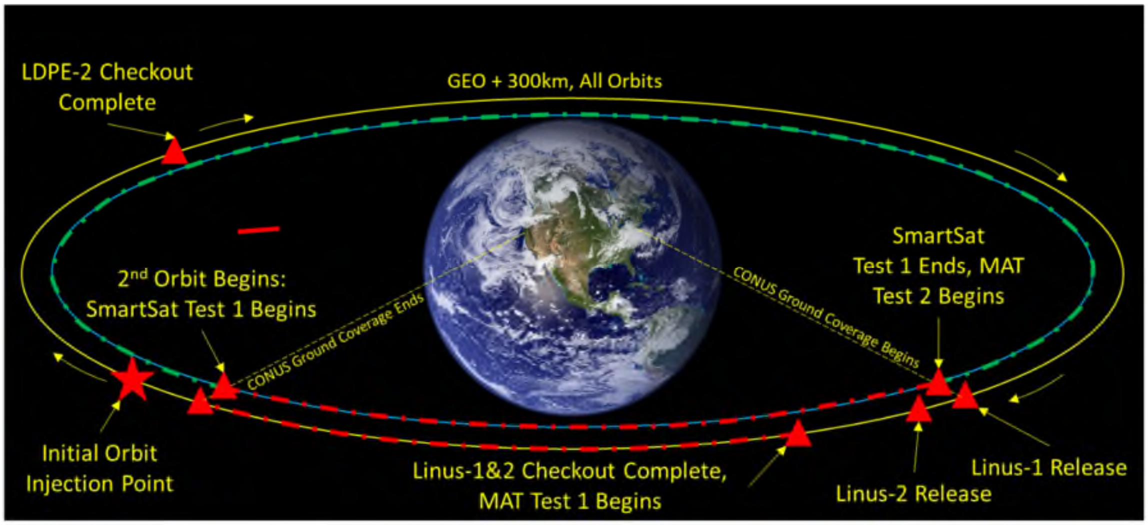

Figure 1-1: Test Mission Overview for LINUS-A

At the end of the first 3 months post deployment, LINUS-A will perform another round of MAT for ~21 days. Following completion of this activity, the vehicles will enter in a disposal state (propellant venting, battery isolation, reaction wheel desaturation, radio power off). LINUS-A will have completed all on-obit activities.

1.3 Launch to Checkout

LINUS-A will be launching on a Falcon 9 Heavy, where it will be ridesharing on the LDPE-2. The LDPE-2 will maneuver the LINUS-A payload into a disposal orbit (GEO +300km). Following arrival at the disposal orbit, LINUS-A will stay on the LDPE-2 until 57 days after launch where a single vehicle will be deployed. The vehicle will be deployed at an approximate velocity of 1 m/s. The initial vehicle will perform all the necessary critical events to achieve safe mode. The critical events entail, initializing the time on the vehicle, capture the vehicle rates, deploy the solar arrays, establish a comm link with ground, and hold on the sun. On day 59 after launch, the second vehicle will be deployed. The second vehicle will perform all necessary critical events to achieve safe mode. The critical events should take approximately 10 minutes.

1.4 Checkout to MAT Functions

Upon reaching safe mode, each vehicle will perform a checkout to verify nominal telemetry from components. This includes verifying communication with ground and data rates, power positive state of the battery, vehicle timing, IMU and Star Tracker measurements for appropriate attitude and rate sensing, reaction wheels damped rates and a vehicle steady state, the prop tank is warming up and pressure is rising, and address any reported faults. This checkout should take no longer than 2 hours.

1.5 MAT Functions

The mission objective for LINUS-A is to perform MAT between the two vehicles. This will be accomplished using relative navigation via on-board GNC algorithms using payload processing. The two vehicles will initially be separated by approximately 500km due to the delay in deployment of each one (2 days). The first deployed vehicle will be identified as the “Chase” vehicle, and the second as the “Resident Space Object (RSO)”. Upon checkout and calibration of each vehicle, the chase will then begin to maneuver towards the RSO. This will be accomplished via lowering the orbit of the chase vehicle. This lowering of the orbit is accomplished by two burns approximately spaced 12 hours apart. Once the chase is approximately 25 km away from the RSO, the chase will enter into a FMC orbit around the RSO, ultimately closing in to reach a separation of 50 m. The chase vehicle will always be in an actively controlled state to avoid collision with the RSO due to any failures/anomalies. If loss of control occurs on the Chase vehicle, LINUS-A can move the RSO for collision avoidance. The initial 25 km point, called Terminal Guidance, is approximately 5 days after the previous burn. The vehicle will then fire the thrusters 17 more times over the course of 5 days. Following MAT operations, the vehicles will egress away from each other prior to entering drift. The MAT phase will take approximately 10 days.

1.6 Drift

Approximately 21 days post deployment, the vehicles will enter into a drift state. This drift phase will last about 62 days. During this drift phase, the vehicles will perform minimal operations and primarily be in a safe mode state. The minimal operations include three 20-minute maneuvers where the vehicle will capture images of earth, perform on-board image processing, and return to a safe mode state. Each vehicle will be in communication with the ground for ~30 minutes twice a day. During this communication, the vehicles will downlink a single image along with any back-orbit telemetry since last communication.

1.7 Decommissioning/End of Life

The LINUS-A space vehicles will perform their primary mission in the GEO Disposal Orbit (GEO +300km). Therefore, there is no need to change the orbit to achieve a disposal orbit. To complete decommission, the vehicles will deplete all propellant, isolate the batteries from Solar Array to prevent charging, Reaction Wheels and transmitters. At this point, the vehicles will be removed from service.

1.8 Other Programmatic Issues

There is currently no foreign government or space agency participation in the LINUS-A mission.

2 SPACECRAFT DESCRIPTION

2.1 Physical Description of the Spacecraft

The LINUS-A payload consists of two (2) 12U CubeSats, two (2) CubeSat Dispensers, and one (1) adapter plate. The entire payload has a mass of 67.8 kg. This translates to a vehicle wet mass of 21.5 kg and a dry mass of 19.2 kg each (two vehicles). The CubeSats will be housed within the dispensers while attached to the host vehicle. Each dispenser will interface with the adapter plate, that will then interface with the host vehicle (LDPE-2) via the four-point mount. The LINUS-A payload is a separable payload occupying one of six possible payload ports on the host vehicle. In the stowed configuration, the dimensions of the Payload are 17.5” x 27.57” x 20.9” (H x W x L). In the deployed configuration, the dimensions are 17.5” x 27.57” x 31.8” (H x W x L). The vehicle components are shown in Figure 2-1. The vehicle dimensions/coordinate system is shown in Figure 2-2.

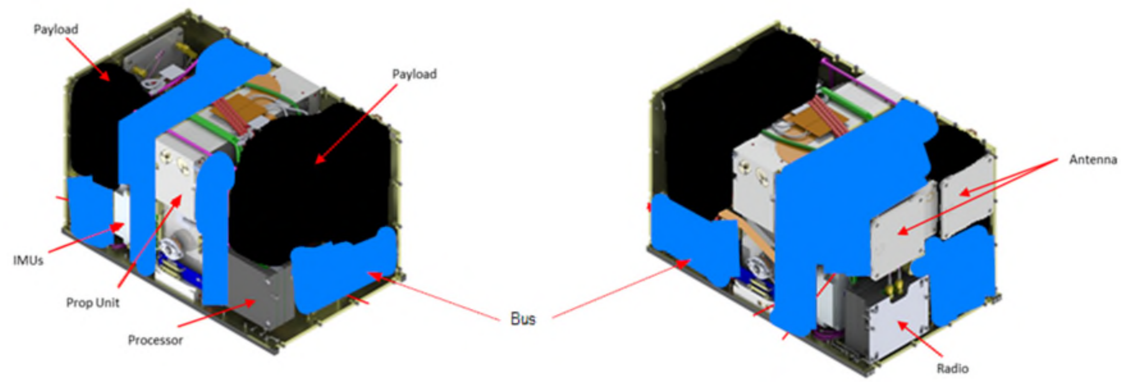

Figure 2-1: LINUS-A Interior Component View

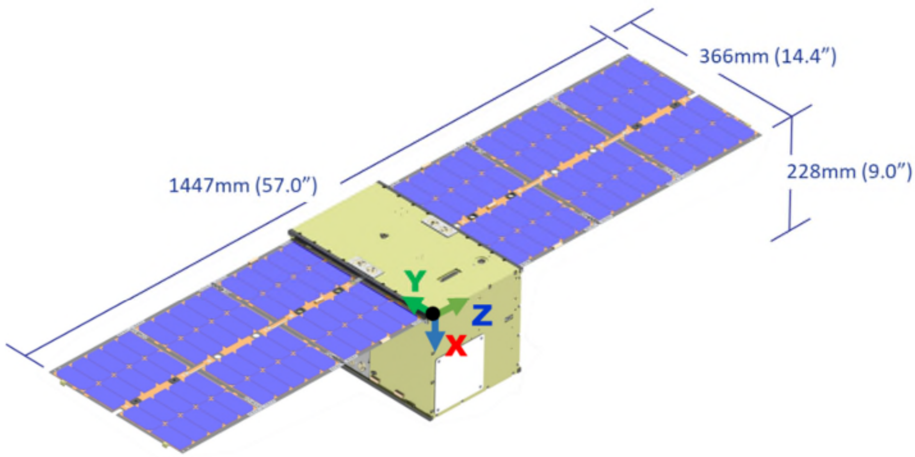

Figure 2-2: LINUS-A dimensions when the solar arrays are deployed

The Dispenser contains the Dispenser pusher plate in a compressed configuration while the vehicles are housed within the Dispenser. Upon actuation of the HDRM, the pusher plate is released to its uncompressed state, deploying the vehicles from the dispensers. The dispenser release mechanisms are burn-wire redundant twin spool release devices provided by Glenair which will be actuated by the launch provider.

2.2 Propulsion System

LINUS-A utilizes a VACCO Shoebox Attitude Control System (ACS) Propulsion System. The ACS provides propulsion for spacecraft maneuvering and station-keeping. The system can provide rotational and translational control of the LINUS-A spacecraft. The ACS thrusters are located on the -X and +/- Z faces of the spacecraft. The tank storing the R236fa propellant is located inside the vehicle housing midway through the Y panel. The unit is mounted to the -X and +/- Z structural panels through a single bulkhead bracket. The Shoebox ACS is a self-contained system housing drive electronics, 8 thrusters, and propellant within a single welded module. Proportional heater and temperature sensors allow for precise control of the propellant pressure. Each thruster can be controlled separately for command-able thrust level and firing times.

The LINUS-A vehicles each have approximately 30 m/s ΔV provided by a VACCO Industries propulsion unit. The entire mission will only utilize approximately 15 m/s for the chase vehicle while the RSO will not utilize any except for desaturation of the wheels.

At the end of mission life, the propulsion system will be vented in a manner to not cause rotational or translation effects on the vehicle.

2.3 Guidance, Navigation & Control System

The LINUS-A guidance, navigation and control (GNC) system consists of two LM50 IMUs, Tyvak IMU module, two Nano Star Trackers, three Tyvak Reaction Wheels and a sun sensor. The IMU module provides accurate inertial measurements to the flight computer for GNC use. The Nano Star Trackers build off flight proven Endeavor class Star Trackers, improving hardware and software components. Each Star Tracker Module (STM) carries a Star Catalog, image storage, and processing. The Tyvak Reaction Wheel provides fine pointing control authority to the spacecraft using a balanced flywheel to induce torque and store momentum. Utilizing three orthogonal reaction wheels, the system can perform fine pointing without other control methods. For majority of the mission, the vehicle will be pointing at the sun for power generation on the solar arrays. The sun sensor is utilized to track the sun during safe mode and is adjacent with the solar arrays.

At the end of mission life, the reaction wheels will be desaturated for vehicle disposal.

2.4 Electrical Power System

LINUS-A contains an electrical power subsystem (EPS), which consists of solar arrays for energy conversion, lithium-ion (Li-ion) batteries for energy storage, Max Power Point Tracker, and EPS control electronics for power switching. The solar arrays are mounted to +Z and -Z faces of the satellite that are deployed by an HDRM. The HDRM is a “debris-less” mechanism that will not produce any debris in orbit. The batteries are part of the Tyvak Mk.II 12V Electrical Power System. The 12V Electrical Power system is comprised of three different battery modules that are together responsible for storing and managing power for a 12V bus. Other than the batteries, there is no other source of stored electrical energy. The Maximum Power Point Tracker (MPPT) maximizes the power draw from a solar array panel into the 12V Battery Module. The MPPT acts as an ideal DC-DC transformer that computes ideal input voltage, setting the maximum power voltage at the “knee” of the solar cell curve. Integrated electronics include: Telemetry collection, Li-Ion safety circuitry, voltage monitoring, cell balancing, temperature monitoring, and cartridge heaters. Tyvak’s Mark II 12V Load Controller collects flight power switching and Torque Rod control elements into a central module. The 12V Load Controller Module delivers power from the 12V Battery Module and maintains the power on-off status of the bus components with 28 state latches. Available fused power rails include 3.3V, 5V, and 12V.

At end of mission life, the batteries will be isolated as to not allow for continual charging of the batteries from Solar Array power.

2.5 Payload System

Each LINUS-A satellite has 4 payloads. The Innoflight Compact Flight Computer 400 (CFC-400) is main payload processor.

2.6 Communication System

An Innoflight SCR-104 radio provides S-band communications via a leased commercial ground entry point (GEP).

2.7 Avionics System

Each vehicle contains a Tyvak MKII dual sided redundant avionics computer. The MKII is the main processor for the vehicle and performs all commanding and processing. The MKII hosts the Tyvak executive software as well as the LM GNC application.

2.8 Fluids and Pressure Vessels / Pressurized Components

The only fluid and pressurized vessel on the vehicle is the propellant tank. The propellant utilized is non-hazardous R236fa.The maximum operating pressure is 97.5 PSIA at 55°C. At nominal temperatures (20°C) the tank will only reach 33 PSI. Although R236fa is a non-hazardous propellant and only requires one inhibit, the ACS has two inhibits to leakage for redundancy. A designated burst test unit passed leakage after a dwell at 2.5 X MEOP and was burst to failure with significant margin in accordance with AIAA S-080-1998.

2.9 Radioactive Material

LINUS-A doesn't have any radioactive materials in its construction.

2.10 Pyrotechnic Devices

LINUS-A doesn't have any range safety or pyrotechnic devices in its construction.

3 ASSESSMENT OF SPACECRAFT DEBRIS RELEASED DURING NORMAL OPERATIONS

3.1 DEBRIS RELEASED DURING NORMAL OPERATIONS

No debris is planned to be released into Earth orbit during launch, or payload deployment.

4 ASSESSMENT OF SPACECRAFT INTENTIONAL BREAKUPS AND POTENTIAL FOR EXPLOSIONS

4.1 INTENTIONAL BREAKUPS AND POTENTIAL FOR EXPLOSIONS

There are no plans for designed spacecraft breakups, explosions, or intentional collisions. The sources of stored energy on-board are the reaction wheels, the batteries, and the propulsion system.

Requirements 4.4-3 and 4.4-4 are not applicable to LINUS-A since there are no planned breakups.

4.2 Accidental Explosions

LINUS-A does not have any system on board that would result in an explosion due to an anomaly or failure. The propellant tank, if over pressurized (as a result of thermal control failure) will result in a ripping or unzipping of the tank. This ripping translates to a venting of the propellant (R236fa) and not an explosion. This is due to the malleable nature of aluminum (tank material). This was observed during the Propulsion tank burst pressure test that LM performed. The batteries on board have a venting technology if over pressurized. The failure case of potential over pressurization of the batteries is a failure of the battery charge controller, specifically overcharging the batteries. If overcharging is performed, the batteries will vent, through the cell wall, any decomposition of the electrolyte and therefore eliminate the pressurization leading to an explosion.

4.3 Passivation of Systems at EOM

At the end of the mission, the system is designed to be left in the following state:

- Disposal orbit (entire mission is in the disposal orbit)
- Propulsion system will be de-pressurized
- Batteries will no longer be charging,
- Reaction wheels desaturated
- RF transmission powered off
- Structure intact, no planned breakups

Upon completion of the mission, both vehicles will desaturate the wheels using the attitude controls of the propulsion system. They will then deplete all propellant by opening all valves appropriately in order to not instill a torque on the vehicle or alter the orbit in such a way as to interfere with other space objects. A command will be sent to the vehicle to prevent the MPPT from charging the batteries from the Solar Arrays. This is an irreversible command sent from the ground. Finally, the radio will be powered off to prevent RF transmission.

5 POTENTIAL FOR ON-ORBIT COLLISIONS

The satellite has a mean cross-sectional area of ~0.22 m2. Using the MEM 3 environment, the weighted cross-sectional area flux was determined to be 3.9 E-11 particles per square meter. The probability of collision was determined using the following equation:

$$P = F * A * T$$

F is the weighted cross-sectional area flux (3.9E-11), A is the mean cross-sectional area (0.22), and T is the orbital lifetime in years (100). The probability comes out to 8.7E-10.

In addition to the small cross-sectional area, the mission is all being performed in the disposal orbit, so the risk of collision is small, and less critical as opposed to operating in a LEO-GEO orbit. Since the vehicles start in a disposal orbit, any failure of the vehicles will not affect the ability to stay in the disposal orbit. There is no planned interference with other operational spacecraft during the LINUS-A mission life.

6 POST-MISSION DISPOSAL PLANS AND PROCEDURES

LINUS-A is operating already in a circular GEO +300 km disposal orbit. The area to mass ratio is 0.01. Based on Figure 6-1 from NASA STD 8719.14b, the altitude of LINUS-A is sufficient for requirements 4.6-1 through 4.6-4. No systems or components are necessary to achieve the disposal orbit. The propulsion unit, radio, and batteries will be passivated appropriately to achieve EOM requirements.

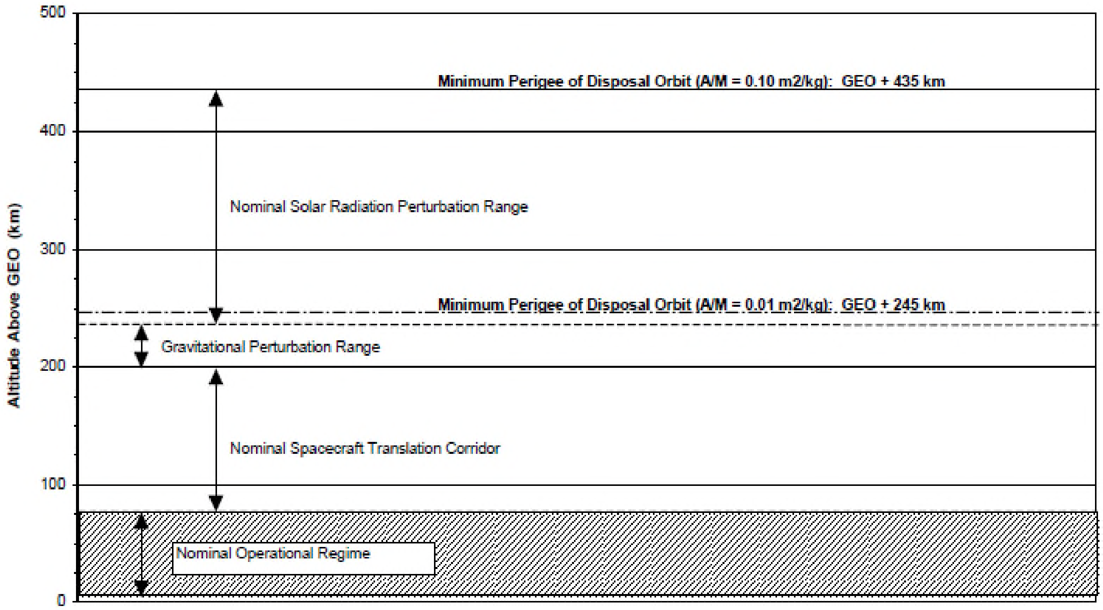

Figure 6-1: NASA STD 8719.14b specifies the minimum perigee altitude for given area to mass ratio spacecrafts

7 ASSESSMENT OF REENTRY HAZARDS

The LINUS-A payload will stay in the GEO disposal orbit and not re-enter the atmosphere. Requirement 4.7-1 is not applicable.

7 A. Hazardous Materials Assessment

The only subsystem containing potentially catastrophic hazards is the Electric Power Subsystems (EPS) due to the batteries on-board each LINUS-A vehicle. The battery modules are housed within the LINUS-A vehicles, which are subsequently housed within a dispenser. The batteries are protected from activation through 2P-2S mechanical switches that prevent the batteries from powering on the vehicle while contained within the dispenser. Other hazards associated with batteries include leakage, thermal runaway, and shock. All batteries on-board are UL Certified, with no additional means of charging while stored in the dispenser. The LG INR18650 part number has undergone JSC 20793 standard testing through NASA for other CubeSat missions. Additionally, no access to the batteries is possible without disassembly of the vehicles, thus mitigating any risk of shock to personnel. The battery modules and vehicle provide sufficient venting for any buildup of hazardous vapors. Cell puncture is a potential hazard associated with handling of battery cells and modules. The LINUS-A battery cells are in a permanent module configuration, with no intention of modifying or removing the module at the range.

If the battery terminals have contact with other metals, that may cause heat generation or electrolyte leakage. The electrolyte is flammable. In case of electrolyte leakage, move the battery from fire immediately. Vapor generated from burning batteries may make eyes, skin, and throat irritated.

If the batteries get punctured through the cell casing, a thermal runaway is possible. If the battery is in a thermal runaway state, move away immediately and do not contact the battery until the thermal event has concluded. The battery cells are in a permanent module configuration once installed in the vehicles, with no intent to modify or remove any battery module or cells. Minimized handling of batteries reduces the risk of puncture. The LINUS-A payload will also undergo TVAC and vibration testing prior to arrival at the range. Table 7-1 provides a hazardous description of the battery as per NASA STD 8719.14b.

Table 7-1: Description of Hazardous material as per NASA STD 8719.14b

Chemical Name	Description	Material State @ Launch	Material State on Orbit	Material State at EOM	Material State @ Passivation	Material State @ Re-entry
Li-Ion Battery	A thermal runaway (flammable) can happen due to mishandling of battery	Solid/18 Cells/Vacuum	Solid/18 Cells/Vacuum	Solid/18 Cells/Vacuum	Solid/18 Cells/Vacuum	None

8 ASSESSMENT FOR TETHER MISSIONS

This does not apply to LINUS-A. The mission does not employ any tethers in the design.