Cislunar Explorers Formal Orbital Debris Assessment Report (ODAR)

Report Version: 1.1

September 21st 2016

The Cislunar Explorers Formal Orbital Debris Assessment Report (ODAR) has been prepared for compliance with NASA-STD 8719.14 and NPR 8715.6A for submittal as part of the Ground Tournament 3 competition of the CubeQuest Challenge.

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DOCUMENT HISTORY LOG

Document Revision	Effective Date	Description
-	09/21/2016	Initial Release

Orbital Debris Assessment Report Self Evaluation								
	Launch Vehicle				Spacecraft			
Requirement #	Compliant	Not Compliant	Incomplete	Standard Non-Compliant	Compliant	Not Compliant	Incomplete	Comments
4.3-1.a	☐	☐	☒	☐	☒	☐	☐	N/A
4.3-1.b	☐	☐	☒	☐	☒	☐	☐	N/A
4.3-2	☐	☐	☒	☐	☒	☐	☐	N/A
4.4-1	☐	☐	☒	☐	☒	☐	☐	See Section 4
4.4-2	☐	☐	☒	☐	☒	☐	☐	See Section 4
4.4-3	☐	☐	☒	☐	☒	☐	☐	N/A
4.4-4	☐	☐	☒	☐	☒	☐	☐	N/A
4.5-1	☐	☐	☒	☐	☒	☐	☐	N/A
4.5-2					☒	☐	☐	See Section 6
4.6-1(a)	☐	☐	☒	☐	☒	☐	☐	N/A
4.6-1(b)	☐	☐	☒	☐	☒	☐	☐	N/A
4.6-1(c)	☐	☐	☒	☐	☒	☐	☐	N/A
4.6-2	☐	☐	☒	☐	☒	☐	☐	N/A
4.6-3	☐	☐	☒	☐	☒	☐	☐	N/A
4.6-4	☐	☐	☒	☐	☒	☐	☐	N/A
4.6-5	☐	☐	☒	☐	☒	☐	☐	N/A
4.7-1	☐	☐	☒	☐	☒	☐	☐	N/A
4.8-1					☒	☐	☐	N/A

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Purpose

This is the Orbital Debris Assessment Report (ODAR) for Cislunar Explorers, a CubeQuest payload. 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 2 through 8 below for Cislunar Explorers. 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 8715.6A.

1.2 Scope

This document shows compliance of Cislunar Explorers with the requirements of NPR 8715.6A, "NASA Procedural Requirements for Limiting Orbital Debris". The orbital debris assessment covers the following five aspects according to NASA-STD 8719.14A:

- Debris generated during normal operations
- Debris generated by explosion or intentional breakup
- Debris generated by on-orbit collisions during and after mission operations
- Reliable disposal of spacecraft and launch vehicle orbital stages after mission completion
- Structural components impacting the Earth following post-mission disposal by atmospheric reentry

1.3 Software and Models Used

No specific debris assessment software was used for this assessment, due to the unusual orbits.

2 PROGRAM MANAGEMENT AND MISSION OVERVIEW

2.1 Personnel and Management

Headquarters Mission Directorate: Space Technology Mission Directorate
Program Executive: Dr. Mason Peck
Lead Engineer: Kyle Doyle
Planetary Protection/Orbital Debris Engineer: Amil Vira
Cube Quest Program Manager: James Cockrell
Secondary Payload Integration Manager: Kevin Sykes

Foreign Government or Space Agency Participation: None

Summary of NASA's responsibility under the governing agreement(s): N/A

2.2 Mission Milestones

- **September 2015:** CubeQuest Ground Tournament 1
- **October 2015:** Phase 0 Safety Review
- **February 2016**: CubeQuest Ground Tournament 2
- **May 2016:** Phase I Safety Review
- **June 2016:** Final preparations for internal CDR.
    - Life cycle testing of propulsion subsystem.
    - Upgrades to ground station.
    - Optical navigation system simulated mission.
    - “software flatsat” debugging.
- **July 1st 2016:** Internal critical design review prior to fabrication of EDU
- **July-August 2016:** Engineering Development Unit fabrication.
- **“August 5th” 2016:** Submittals for CubeQuest Ground Tournament 3 due
    - Several sources have said this is delayed until at least September.
- **“September 7th” 2016:** CubeQuest Ground Tournament 3 Face to Face
    - Would be delayed until at least October.
- **August-October 2016:** EDU testing.
- **October 2016:** Testing of EDU completed.
    - Fabrication of flight units commences.
- **October 2016:** Phase II Safety Review.
- **December 2016:** Fabrication of flight units complete.
- **February 3rd, 2017:** Submittals for CubeQuest Ground Tournament 4 due
- **March 1st, 2017:** CubeQuest Ground Tournament 4 Face to Face
- **March-July 2017:** Development of mission products.
- **July 2017-Launch:** Mission rehearsals.
- **2017:** Integration with dispenser.
- **NLT 30 days prior to next level integration:** Phase III Safety Review
    - CubeQuest in space portion begins. Present final safety analysis with all verification methods and status.
    - Obtain final panel endorsement.
- **February 1st, 2018:** Integrated payload-dispenser delivery to KSC
- **February 2017-Launch:** Integration of stack at KSC, storage, pre-launch.
- **Fall 2018:** EM-1 Launch
    - CubeQuest in space portion begins.
- **T+1 year:** Competition ends

2.3 Mission Description

Cislunar Explorers is competing in the CubeQuest Challenge, which is sponsored by NASA's Space Technology Mission Directorate as a part of the Centennial Challenge Program. The team plans to compete in the Lunar Derby in pursuit of the Lunar Propulsion and Spacecraft Longevity prizes. For the Lunar Propulsion Prize, the Cislunar Explorers spacecraft must achieve a verifiable lunar orbit. The Spacecraft Longevity Prize will be judged based on the number of elapsed days between the first and last confirmed reception of a 1024-bit data block from the spacecraft.

Cislunar Explorers also aims to demonstrate the viability of electrolysis propulsion for spacecraft with a special emphasis on application in nanosatellites. The electrolysis propulsion system will separate water into hydrogen and oxygen gas, which will then be combusted resulting in a Δv between 650 and 800 m/s. Other goals include the demonstration of passive spin stabilization, optical navigation, and a 3D printed nozzle for Technology Readiness Level advancement. In order to operate, the two halves of the spacecraft will spin about their major axes, and the water in the propellant tank will provide a viscous damping effect, passively stabilize the satellites' spins. The satellites will be able to determine its position optically by taking photographs of the Sun, Earth, and Moon. Flight software will analyze the appearance of these bodies in the photographs and use the data in conjunction with data regarding their instantaneous positions to triangulate the position of the satellite.

The Cislunar Explorers spacecraft will be launched as one of several secondary payloads on the Space Launch System (SLS) Block I from Kennedy Space Center. The spacecraft will be launched during the SLS Exploration Mission 1, which is scheduled to take place in 2018. The mission to achieve lunar orbit is just over one month in duration, with an extended mission in lunar orbit lasting no longer than one year before controlled impact into the lunar surface.

Following SLS launch, the upper stage performs a Trans Lunar Injection (TLI) burn placing the upper stage on a Trans Lunar trajectory. The Multi-Purpose Crewed Vehicle (MPCV) then separates from Interim Cryogenic Propulsion Stage (ICPS) to continue its lunar flyby. Once the MPCV is clear of the ICPS, the ICPS will perform a disposal maneuver. At this point, the Secondary Payload Deployer System (SPDS) sequencer system is activated and will deploy Cislunar Explorers from the Dispenser at the deployment interval negotiated ahead of time. Once Cislunar Explorers is clear of ICPS, it will begin a preprogramed activation and deployment sequence of its onboard systems.

Cislunar Explorers will tweak its trajectory to perform a gravitational swingby of the Moon, with the intent to facilitate a second lunar encounter. While beyond the orbit of the Moon, Cislunar Explorers will perform additional course corrections followed by a lunar orbit injection. The spacecraft will eventually circularize to a lunar orbit of no greater than 10,000 km apogee. The precise orbit is not important to the mission as the goal is to achieve lunar orbit within 10,000 km; there is no scientific component of the mission.

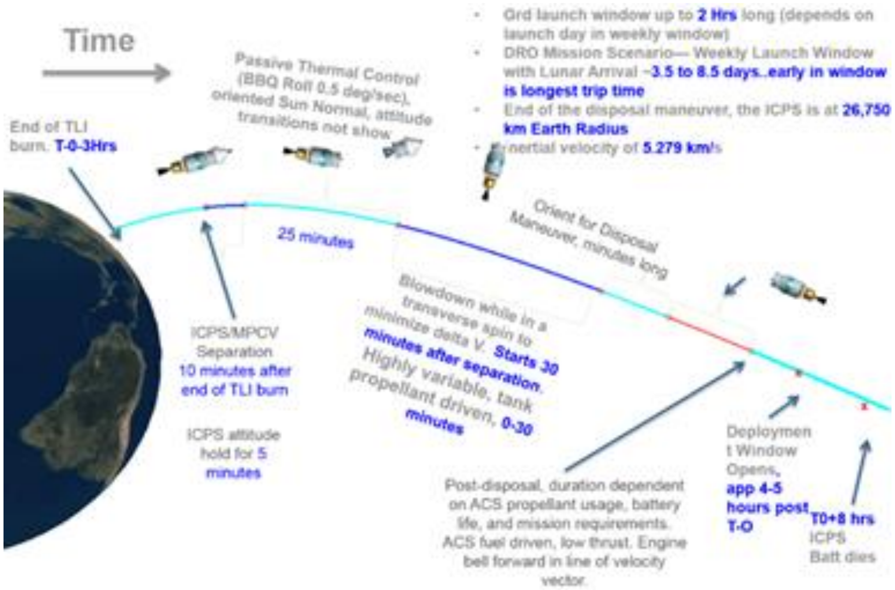


Figure 1: Deployment Overview.

There is concern over potential inadvertent interaction with the SLS second stage or other secondary payloads immediately after deployment. For this reason, the spacecraft will inhibit its boot up for a short time after deployment from the secondary payload dispenser. Cislunar Explorers team has submitted a Safety Data Package to and is preparing for a Phase II Safety Review with the SLS Payload Safety Review Panel, to assure that there will be no potential for inadvertent, hazardous interactions with SLS or other secondary payloads.

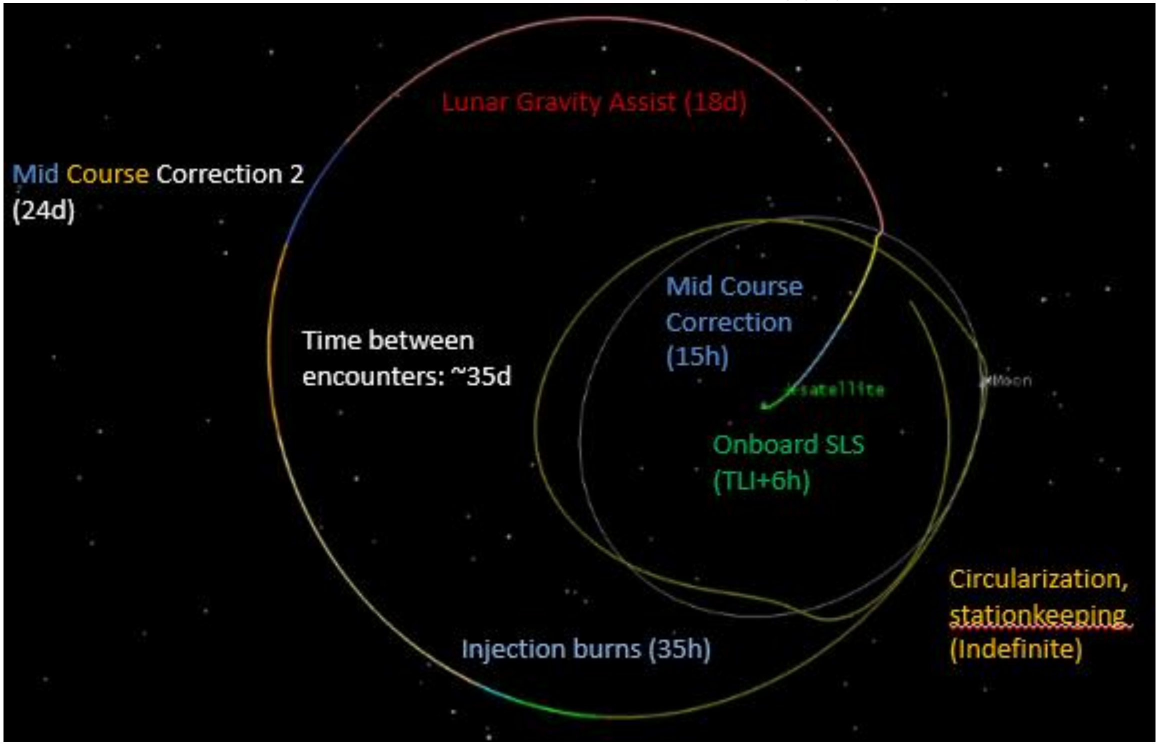


Figure 2: Post-Deployment Trajectory

3 SPACECRAFT DESCRIPTION

3.1 Physical Description

The Cislunar Explorers spacecraft is a 6U cubesat which splits into two L shaped 3U spacecraft after separation from the launch vehicle. The spacecraft are called Cislunar Explorer 1 and Cislunar Explorer 2 (CE-1 and CE-2). The total mass of spacecraft at launch is 14 and the total dry mass of the spacecraft at launch is 11 kg. The mass of propellant on each 3U spacecraft is 1.5 kg. CE-1 weighs 7 kg and CE-2 weighs 7 kg.

Each spacecraft has a full set of all subsystems and operates independently of the other after splitting. The splitting mechanism consists of a release mechanism held in unstable equilibrium by a burn wire. Once the release mechanism is triggered, CE-1 and CE-2 will be separated by springs. The Spacecraft will deploy radio antennas after splitting. The spacecraft will have solar panels on approximately 80 percent of their surfaces. Figures 3 – 5 show up to date models of the Cislunar Explorers Spacecraft.

Figure 3: 6U Storage Configuration

Release Mechanism

Combustion Chamber

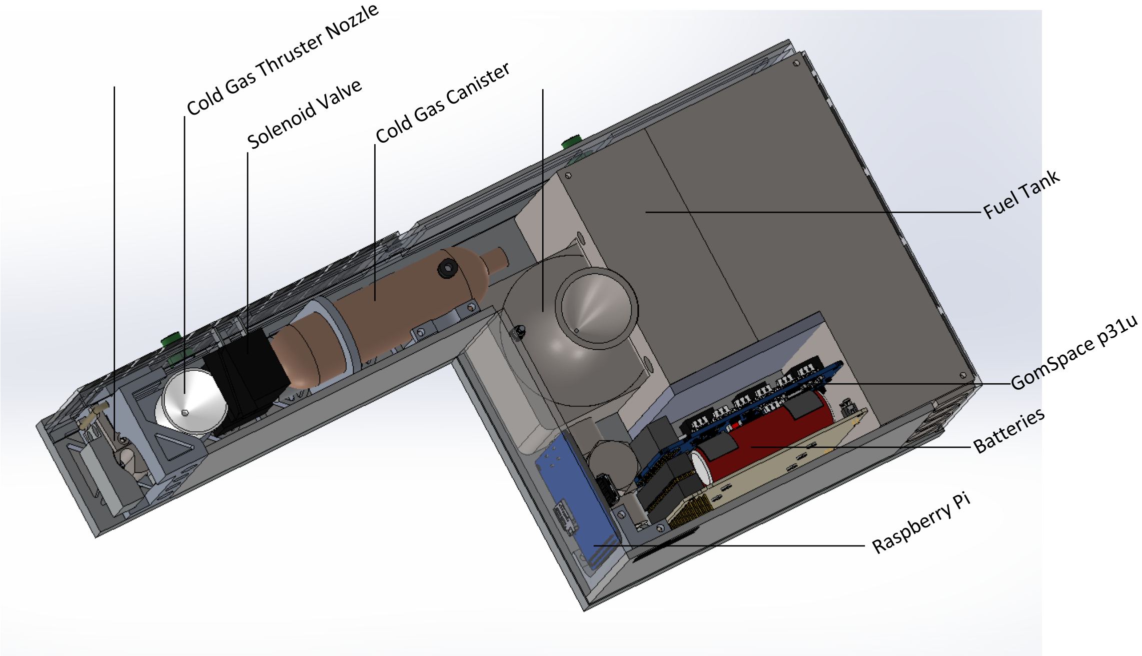


Figure 4: 3U Internal Layout of Components

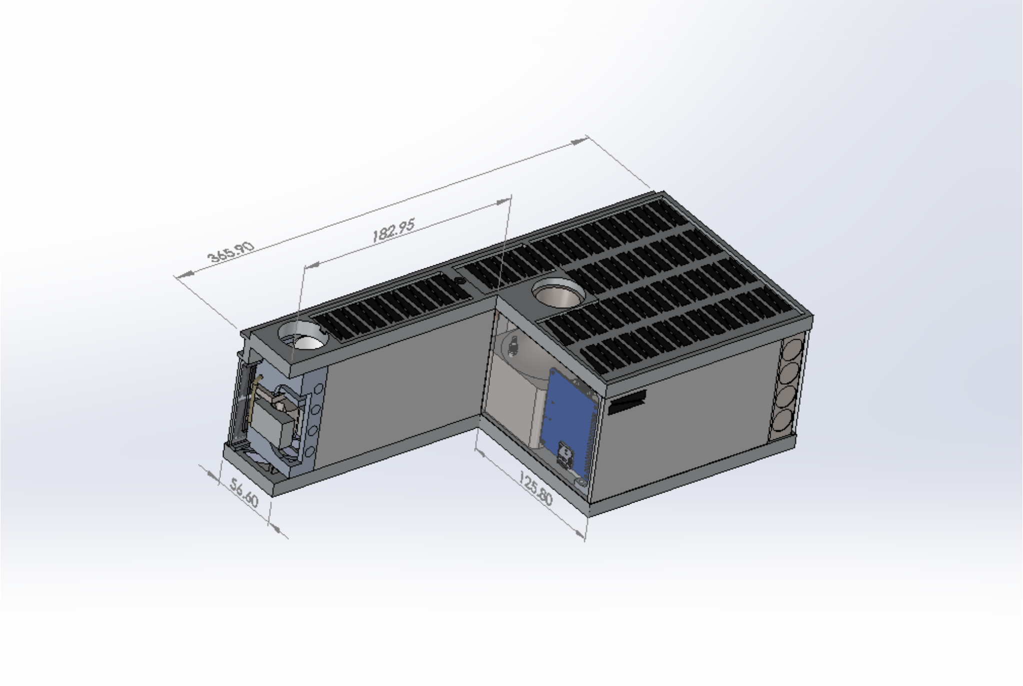


Figure 5: 3U Spacecraft Dimensions

3.2 Release Mechanism

Once ejected from the dispenser the satellite shall not deploy any mechanisms for a minimum of 30 minutes. After this time the single 6U CubeSat shall split into two 3U CubeSats that each have the ability to complete the mission. The driving force behind this deployment is a set of four conical springs in compression located between the two 3U satellites. A release mechanism holds the satellites together during storage, launch, and deployment. This mechanism then releases the two satellites when a command is received from the flight computer.

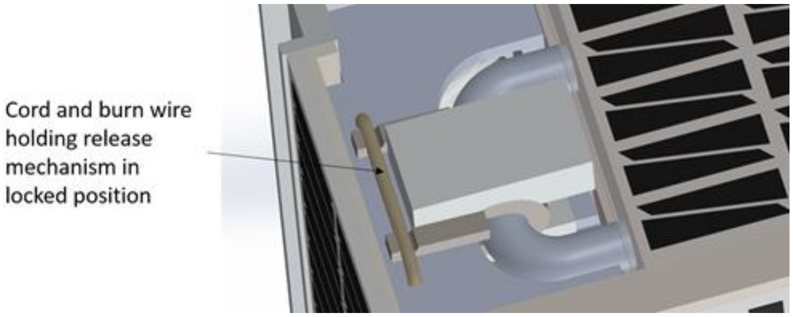


Figure 6: Mechanism Locked

Figure 6 shows the release mechanism in the locked position. A single length of high-strength cord holds the arms shown. A burn wire circuit shall be wrapped around this length of cord to sever it when prompted by the flight computer. To avoid a single point of failure scenario, multiple burn wire circuits shall be attached to the length of cord to ensure it is severed. The individual burn wire circuits shall be designed to run using the batteries on either of the satellites in the event that one of the batteries fails. The cord represents a single point of failure for this system, which is why it and all other components of this mechanism have been designed with a factor of safety of at least 3 for the expected conditions; this is more than double the factor of safety of 1.4 required in the Secondary Payload User's guide.

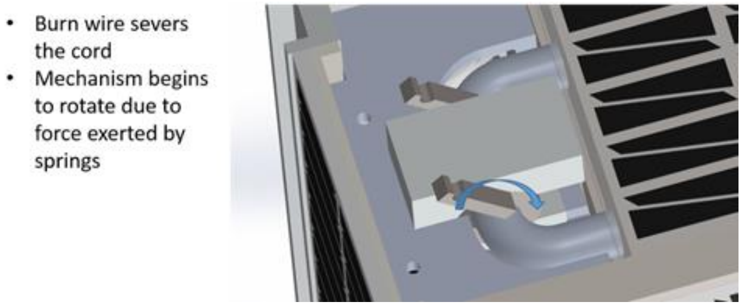


Figure 7: Unlocking

Once the burn wire holding the release mechanism in the locked position is severed, the mechanism shall begin to rotate to the unlocked position. The force causing this rotation is provided by the springs that are also responsible for the separation.

- Satellites begin spin-up at desired rotational velocity

Figure 8: Separation

After the satellites are no longer attached by the release mechanism, they shall pivot about each other at the end of the satellites furthest away from the release mechanism as shown in Figure 8 This allows the satellites to both separate as well as spin-up to the desired angular velocity required for the spin-stabilization of the satellite. By using the energy stored in the springs, the satellite is able to spin-up without using propellant, therefore saving it for use later on in the mission.

The reliability and safety of the release mechanism has been evaluated using the finite element method. The results from the analysis are shown below in Figures 9 and 10. The release mechanism exceeds the desired factor of safety of 3.

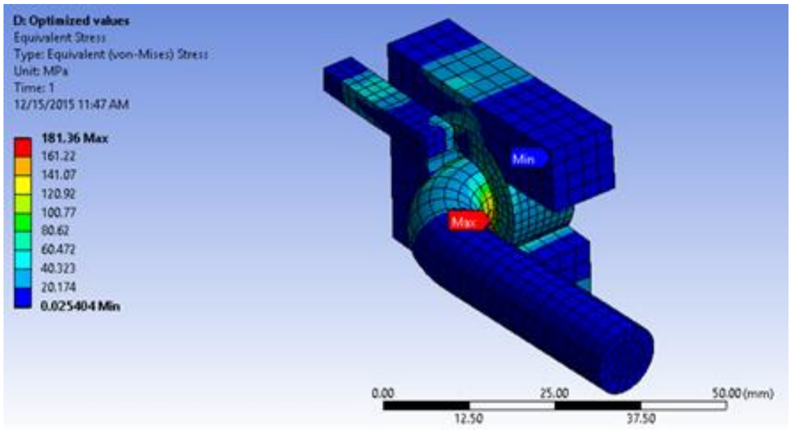


Figure 9: Stresses on Release Mechanism

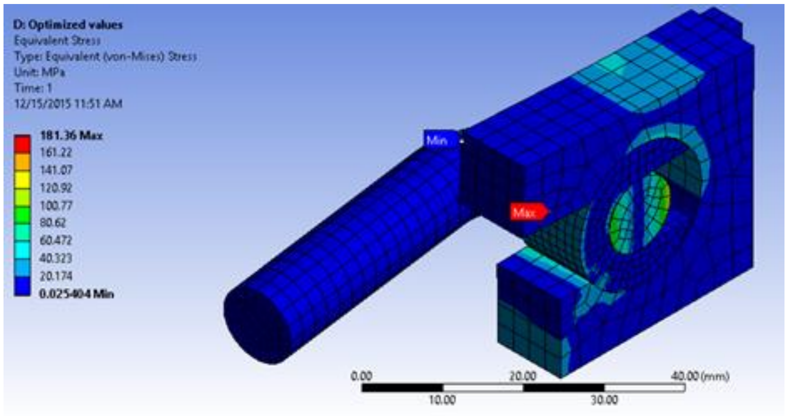


Figure 10: Stresses on Release Mechanism

3.3 Propulsion and Attitude Control

3.3.1 Propulsion System

The Cislunar Explorers spacecraft will make use of an electrolysis propulsion system to provide the necessary Δv. The propulsion system will produce thrust by separating water into a combustible mixture of hydrogen and oxygen gas and then combusting the gaseous mixture. Both spacecraft include a propellant tank that holds 1.5 kg of inert liquid water which is at 1 atm at launch and deployment. This much propellant is expected to produce a Δv of 650 m/s and only 417 m/s is required to achieve lunar orbit. The tank is made of two Ti-6Al-4V halves welded together with the electrolyzers inside. It is designed to hold a maximum pressure of 150 psi with a factor of safety of 2.17. We consider the potential hazard of propellant leakage mitigated by the design in which the propellant is stored inertly and at low pressure until after deployment.

The combustion chamber is 3D printed titanium and can hold a maximum pressure of 1000 psi with a factor of safety of 2.06. The propulsion system also includes two electrolyzes, two pressure transducers, a solenoid valve, a detonation flame arrestor, and a 3D printed titanium nozzle. The fluid loading plan for this system consists solely of filling the propellant tank with liquid water prior to the commencement of the mission.

Attitude control is done primarily by the Reaction Control System. Undesirable nutation of the spin axis is cause by the imperfect alignment of the main thruster firing axis and the center of mass. This problem is addressed by the water in the propellant tank, which provides passive spin-stabilization by damping theis nutation.

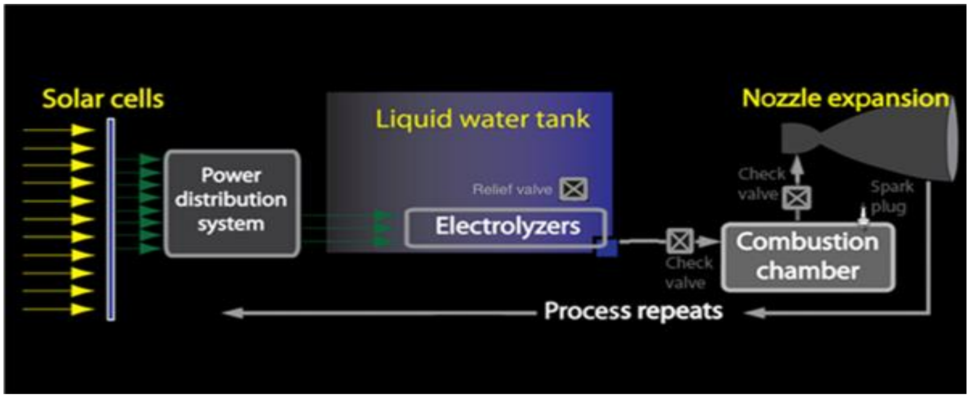


Figure 11: Schematic of Propulsion Subsystem

3.3.2 Attitude Determination, Control, and Navigation System

The Cislunar Explorers' ADCNS system is composed of three Raspberry Pi camera modules and a gyroscope for position and attitude determination, one cold-gas pulse thruster for reorientation maneuvers, and a single electrolysis engine for navigation. The image processing required to extract apparent sizes and centroids of the celestial bodies is performed on the Raspberry Pi, which also stores an onboard ephemerides table and the spacecrafts' control logic. The optical navigation process is visually depicted in Figure 12, and a block diagram of operations is in Figure 13. The Raspberry Pi flight computer relays this data along with the telemetry via the communication subsystem, which provides health and navigation information to flight controllers and receives reorientation and navigation commands.

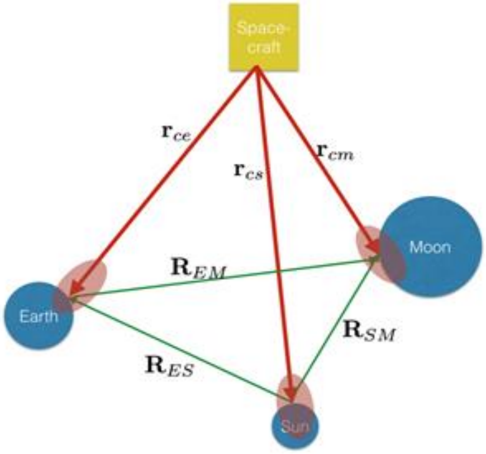


Figure 12: Optical Navigation Geometry

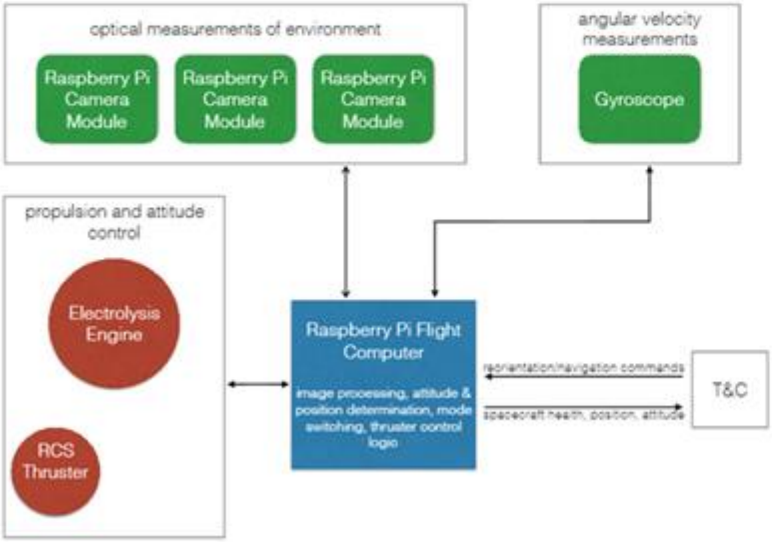


Figure 13: Attitude Control Block Diagram

3.3.3 Spin Stabilization

The spacecraft are passively spin-stabilized by propellant sloshing after deployment from SLS and separation of the 3U spacecraft. There are no rotating parts onboard. Instead, due to the separation mechanism, the spacecraft spins about its major axis. Reorientation is achieved with a single cold gas thruster that exerts a torque affecting the spin axis depending on when during a spin cycle it is pulsed. Nutation caused by the reorientation (or by any other disturbance such as an electrolysis thruster burn) damps out due to the influence of propellant sloshing in the tank.

3.3.4 Reaction Control System

The Reaction Control System (RCS) is the primary means actuating attitude control. It consists of a single cold gas thruster with 38 grams of carbon dioxide in a COTS cylinder manufacture by Leland Ltd. 38g of carbon dioxide can provide up to 2200 degrees of reorientation, a margin of 5.1 times the 360 degrees we require. Details are provided below and the system is pictured in Figure 14. The MDP is 955 psi at the greatest anticipated stowed temperatures (over 140°C)

- Leland Limited 86121z co_2 gas cylinder contains 38.0g of co_2
  - Pressure vessel at 850 psi at 21°C
  - Burst pressure of 7840 psi - factor of safety of 8.2 MDP.
  - Certified mil-i-45208a
- Lee IEPA1221141H valve, factor of safety 1.67 MDP proof, 2.51 MDP ultimate
  - Failure mode is leakage through seal after elastomer extrudes through seal, not burst
- Stainless steel tubing with a maximum pressure of 3900 psi for a factor of safety of 4.08 MD
- Puncture device with a hydrostatic minimum test of 7850 psi for a factor of safety of 8.22 MDP
- Well tested prototype, see Section 4.4.7 of the CubeQuest Design Document.
- Flight heritage expected before EM-1
- Flight heritage expected before EM-1

Figure 14: Cold Gas Thruster Assembly

3.4 Power Management System

Power will be supplied by two main components, Emcore ZTJ Photovoltaic Cells and a commercial battery pack of 18650 batteries. The batteries will be managed using a GomSpace p31u. For the vast majority of the mission life, the net power will remains positive and will keep the battery fully charged.

3.4.1 Solar Panels

Each 3U CubeSat will have 578 cubic centimeters of solar cell coverage with cells on each surface. The two terminal triple junction GaAs cells are almost twice as efficient (29.5 percent) as silicon cells. They are also capable of delivering 4 times the voltage when compared to silicon cells. The solar cells also offer an extremely low solar cell density of 84 mg/square cm. They are arranged with blocking and bypass diodes as shown in Figure 15. Characteristics of solar cell performance are provided in Figure 16.

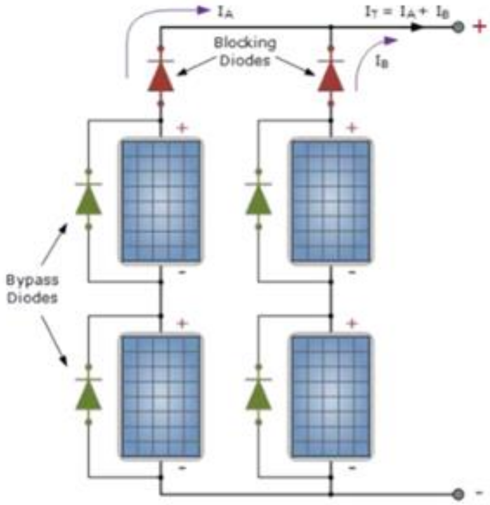
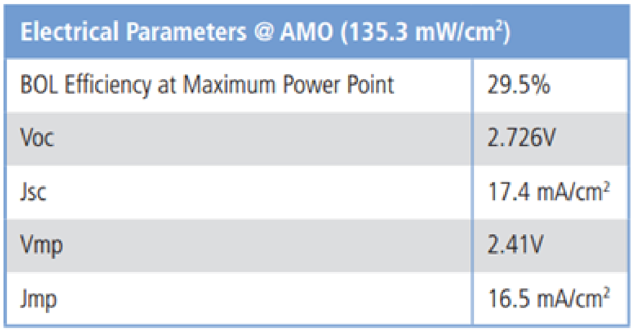


Figure 15: Solar Cell and Diode Arrangement



Electrical Parameters @ AMO (135.3 mW/cm²)	
BOL Efficiency at Maximum Power Point	29.5%
Voc	2.726V
Jsc	17.4 mA/cm²
Vmp	2.41V
Jmp	16.5 mA/cm²

Figure 16: Solar Cell Performance

3.4.2 Batteries

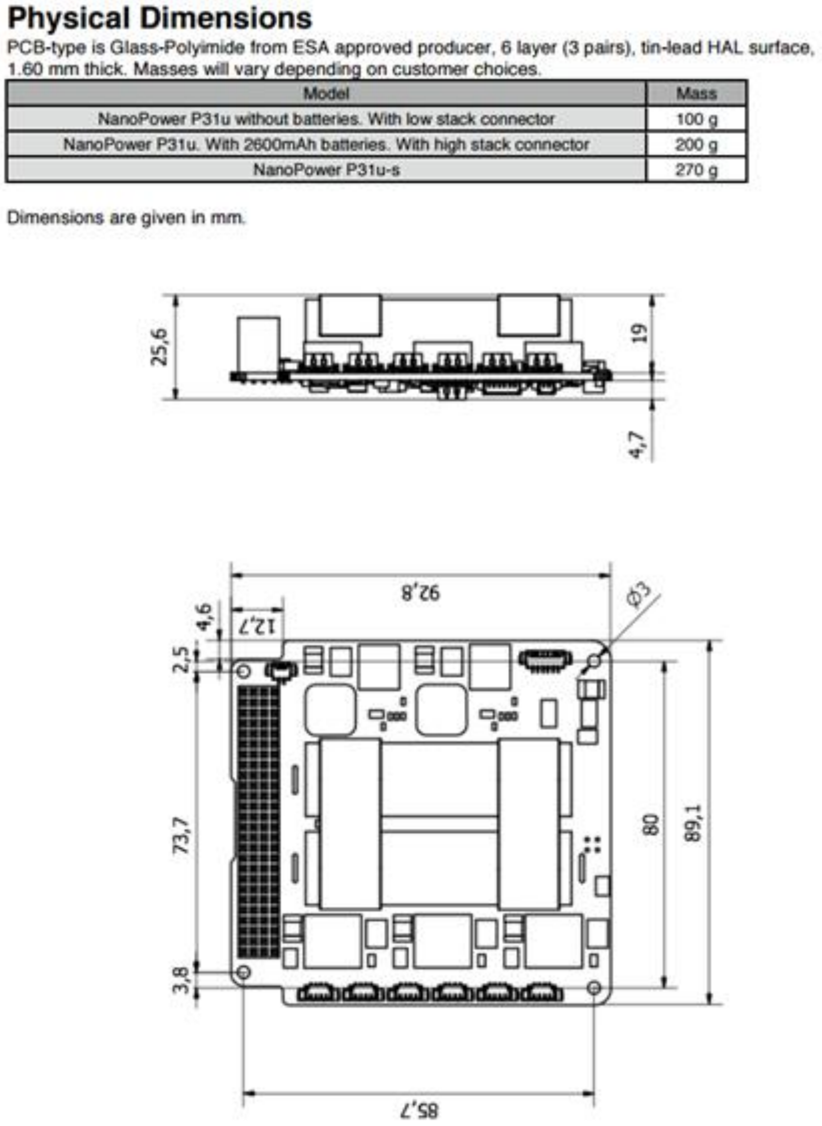
18650 cells are used as the battery source for each 3U CubeSat. Each 18650 cell is rated for 3.7V with a capacity of 2600 mAh. The batteries have a heritage on several CubeSat space missions speaking to their ability as space rated batteries. They are configured as a 7.4V, 2600 mAh stack, and have built in protection against over-temperature, over-current draw, and over-charge. The batteries are stored open to the CubeSat environment, on the controller shown in Figure 4-21. It is grounded and bonded to the CubeSat structure, specifically, to one side of the water propellant tank for the dual purpose of acting as a heat sink for the power system and helping keep the water liquid during the mission.

A potential hazard would be overcharging or overheating of the batteries while onboard SLS/ICPS. This is mitigated by using the recommended 18650 cells, which can survive the storage and pre-deployment environments described in the SPUG and have internal protection against overcharging and overheating due to charging. The NASA-provided trickle charging will be carefully monitored for charge and thermal status, including the use of a thermistor and a diode on the positive circuit leg. Only one of the two 3U spacecraft is to be trickle charged, using the provided trickle charging apparatus.

The batteries have been qualified by NASA, ESA, and JAXA for the ISS. Qualification included abuse testing as well as destructive testing. The batteries have internal PTC rings, CID, and pressure relief disks. In the event of overpressure, the CID interrupts the battery current flow and causes the venting disk to open. Vented products are primarily carbon dioxide. Overcharge, overdischarge (cell reversal), overheating, and overcurrent are prevented by BPS circuitry.

3.4.3 Controller

The batteries interface with a GOM Space P31u power board. Battery power is fed through two buck-converters that supply a 3.3V at 5A and 5V at 4A output bus. Both the battery and power board are from GOMspace and as such will not have any interface issues. The board contains 3 photo-voltaic inputs that allow for conversion of GaAs solar cell power of up to 30W. Low and high voltage protection is embedded to protect the battery as it charges. The power board can also operate up to 6 configurable output switches and has interfaces for a remove-before-flight-pin and separation-switch. It includes heaters to keep the batteries within operational temperature ranges. The system is inhibited from activating during ground loading and flight by the aforementioned separation switches as well as a pre-flight activation switch. The controller is interfaced using I2C to an onboard microcontroller. It provides onboard housekeeping measurements such as temperature, battery voltage, and current draw. A functional block diagram and a physical description can be found below in Figure 17.



Physical Dimensions

PCB-type is Glass-Polyimide from ESA approved producer, 6 layer (3 pairs), tin-lead HAL surface, 1.60 mm thick. Masses will vary depending on customer choices.

Model	Mass
NanoPower P31u without batteries. With low stack connector	100 g
NanoPower P31u. With 2600mAh batteries. With high stack connector	200 g
NanoPower P31u-s	270 g

Dimensions are given in mm.

Figure 17: Physical Description and Block Diagram

3.5 Other

Other than the power system, the main source of stored energy is potential energy stored in the springs used by the splitting mechanism. This energy will be expended after the splitting mechanism is triggered. Kinetic or potential kinetic energy is not stored anywhere else on the spacecraft as there are no reaction wheels.

There are no range safety or pyrotechnic devices. There are no radioactive materials on board either CE-1 or CE-2.

4 ASSESSMENT OF SPACECRAFT DEBRIS RELEASED DURING NORMAL OPERATIONS

The Cislunar Explorers spacecraft will not release any debris larger than 1 mm during normal operations. They will split apart from a single 6U unit into two 3U spacecraft. However, we do not consider this a debris release as both are functional spacecraft and no other components separate. If one spacecraft is inactive it will not be separated but retained in a 6U configuration; the other will continue to operate with the defunct 3U unit attached. Requirements 4.3-1 and 4.3-2 in NASA-STD-8719.14A do not apply because the spacecraft will not enter a Low Earth Orbit or a Geosynchronous Earth Orbit during the mission.

5 ASSESSMENT OF SPACECRAFT INTENTIONAL BREAKUPS AND POTENTIAL FOR EXPLOSIONS

The only intentional break up designed is splitting of the 6U unit into two 3U spacecraft. This event will occur 30 minutes after separation from the launch vehicle. The release mechanism, how it functions, and its factor of safety are all described in section 3.2 of this document. This break up will not produce any debris.

Failure Mode 1: Explosion of Pressurized Vessels
The cold gas thruster system contains 38 g of CO_2 stored at a designed-and-tested margin of safety of >2.5 against maximum expected pressure, and is thus a low risk for explosion. The electrolysis propulsion system never contains more than a small amount of combustible propellant at any time. The propellant is stored as inert, liquid water. Small amounts up to 1 g are electrolyzed at any time, up to a pressure of 150 psi with a factor of safety greater than 2. We therefore consider this to have a very low risk of any explosion and a low amount of energy for a potential explosion in any case.

Failure Mode 2: Failure of Splitting Mechanism
The splitting mechanism springs do not store energy after deployment and prior to activation the mechanism stores at a factor of safety greater than 3.2 over maximum design stress.

Failure Mode 3: Batteries
Because of the above points, we consider the batteries to pose the most significant risk of explosion. This could be due to overcharge, overheating, or short-circuit. The risk of this is considered minimal because the batteries have internal protection against overheating, pressure relief disks, and current interruption devices. Additionally, danger from overheating, cell reversal, overcurrent and overcharge/discharge are prevented by the power system circuitry. This system is described in section 3.4 of this document.

Because the Cislunar Explorers are a secondary payload, NASA SLS will be responsible for calculating the integrated probability of explosion for the launch vehicle. The Cislunar Explorers' probability of explosion has been assessed to be very low.

Passivation at end of mission:

There are no components that are required to be passivated but cannot be passivated due to their design. The Cislunar Explorers are compliant with requirement 4.4-1 and 4.4-2. Stored sources of energy to be passivated include:

- Batteries, to be passivated by opening the solar array switches and run the flight computer and communications until the batteries are drained.
- Cold gas pressure vessel, to be passivated by opening the thruster valve until expended.
- Water propellant tank with any remaining water propellant and electrolyzed gas. Energy is stored here in the form of low pressure gas as well as the potential combustion of the electrolyzed oxyhydrogen mixture. To be passivated by firing the electrolysis propulsion thruster several times to reduce the pressure of electrolyzed gas remaining in the propellant tank. Only a small amount is ever present at any one time. Any remaining water can be left as it does not pose a stored energy hazard without being electrolyzed.
- There are no other sources of stored energy (e.g. no reaction wheels) onboard.

Requirement 4.4-3 is not applicable because no debris larger than 10 cm will be created and no debris will be released in Earth orbit. Requirement 4.4-4 is not applicable because no debris will be produced by the splitting of the Cislunar Explorers spacecraft; they split into two separate, functional, independent spacecraft.

6 ASSESSMENT OF SPACECRAFT POTENTIAL FOR ON-ORBIT COLLISIONS

The spacecraft are 3U CubeSats, which are very small. Additionally they will be in lunar orbit where there is practically no man-made debris presence and only a few ongoing missions compared to the crowded space in Earth orbit. Hence, the risk of collision with a large object is extremely small. The launch vehicle will pass through LEO very briefly, resulting in practically no exposure to orbital debris still in orbit. Prior to launch a Collision On Launch Avoidance (COLA) analysis of the launch trajectory will be performed by the SLS EM-1 mission to ensure that it does not intersect with existing satellites or debris objects tracked by the US Space Surveillance Network.

Using the Micrometeoroid Engineering Model supplied by the NASA Micrometeoroid Environment Office, it was determined that the probability of a damaging collision with small objects is extremely low. As shown in Figure 18, the flux of milligram or greater micrometeorites capable of preventing postmission disposal is well below 0.01 over the course of the one year mission. The probability of 0.1 milligram and larger micrometeorites is shown below in Figure 19 and is also below 0.01. The flux in both of these figures is per square meter of surface area; the combined surface area of the Cislunar Explorers is approximately 0.3 square meters, further reducing the probability of collision.

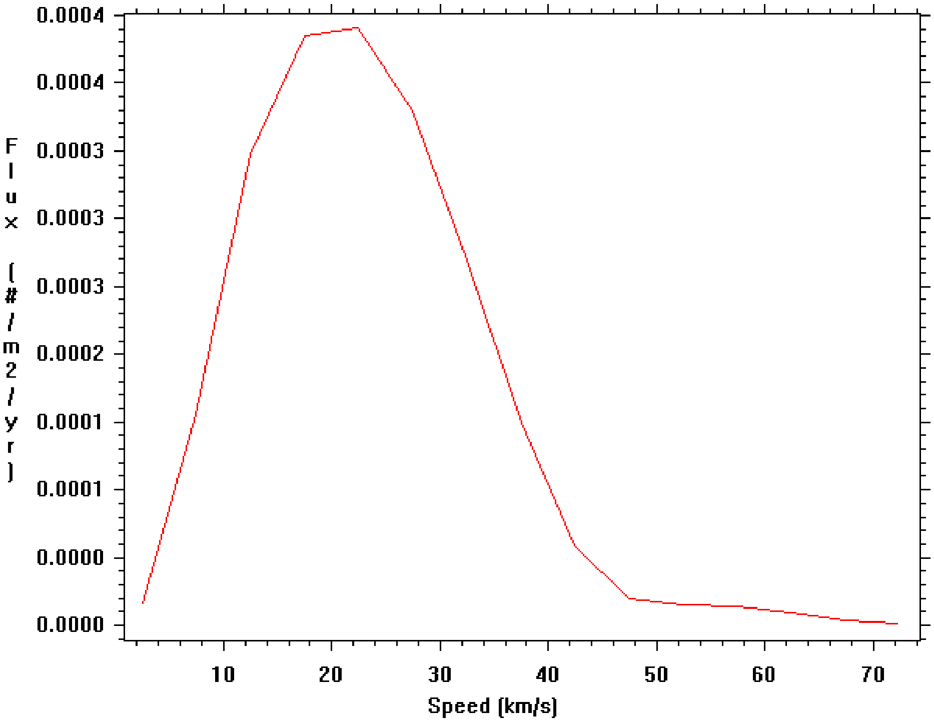


Figure 18: Flux of milligram and greater sized micrometeoroids on Cislunar Explorers

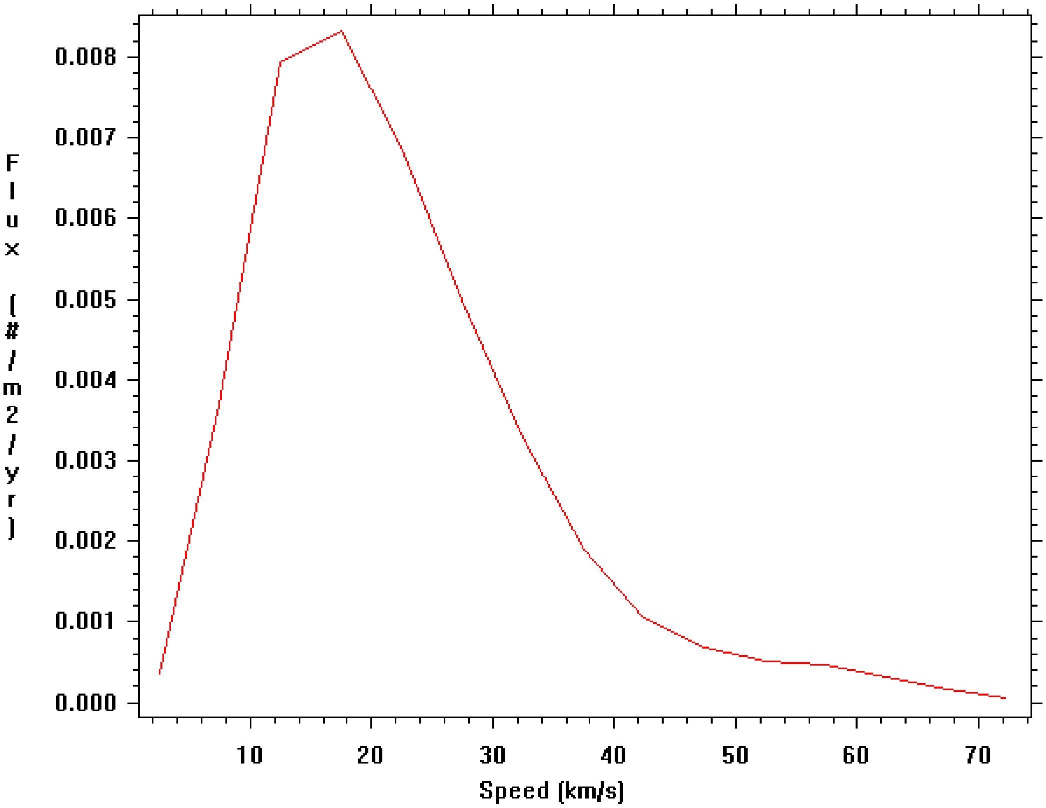


Figure 19: Flux of 0.1 milligram and greater sized micrometeoroids on Cislunar Explorers

Requirement 4.5-1 is not applicable because the Cislunar Explorers spacecraft will not be in Lower Earth Orbit. The Cislunar Explorers are compliant with requirement 4.5-2.

7 ASSESSMENT OF SPACECRAFT POSTMISSION DISPOSAL PLANS AND PROCEDURES

Requirements in section 4.6 of NASA-STD-8719.14A do not apply to this mission because the Cislunar Explorers spacecraft will not be in Earth orbit. The spacecraft will orbit the moon until they have ran out of the allotted amount of propellant and then will be disposed upon the surface of the Moon through a controlled collision. If needed, course corrections will be made to avoid any historically significant sites on the Moon.

8 ASSESSMENT OF SPACECRAFT REENTRY HAZARDS AND HAZARDOUS MATERIALS

This section addresses ODAR sections 7 and 7A as outlined in Appendix A of NASA-STD-8719.14A. There will be no procedures for mitigating reentry hazards for the Cislunar Explorers mission. The Cislunar Explorers spacecraft will not be reentering the Earth's atmosphere at any point in its mission and poses no human casualty risk. Assessment of hazardous materials for the purpose of measuring risk to humans will also not be necessary. Requirements in section 4.7 of NASA-STD-8719.14A do not apply to this mission.

9 ASSESSMENT FOR TETHER MISSIONS

The Cislunar Explorers spacecraft does not include any tethers in its design. Requirements in section 4.8 of NASA-STD-8719.14A do not apply to this mission.

10 LAUNCH VEHICLE DESCRIPTION AND ASSESSMENT

This section addresses ODAR sections 9 through 14 as outlined in Appendix A of NASA-STD-8719.14A. The Cislunar Explorers spacecraft will be launched as a secondary payload to NASA's Exploration Mission 1 which is scheduled to launch in 2018. The launch vehicle for this mission is the SLS Block 1 rocket. Since the Cislunar Explorers spacecraft is a secondary payload, NASA SLS will be responsible for the launch vehicle orbital debris assessment.