Laser Interconnect & Networking Communications System (LINCS)

Cubesatellite Test Bed Experiment

CTB-14 & CTB-15

Orbital Debris Assessment Report (ODAR)

Revision A
14 February 2020

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NASA Debris Assessment Software (DAS) version 2.1.1 used in preparing this report.

REVISION HISTORY

Revision	Date	Affected Pages	Description of Change	Author
0	1 October 2019		Initial Draft	T. Correa
A	14 February 2020		Final Draft	T. Correa

AUTHORIZATION

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ACRONYMS

Acronym	Definition
AIS	Article Data Sheet
ADACS	Attitude Determination And Control System
BCR	Battery Charge Regulator
CoC	Certificate of Conformity
CTB	Cubesatellite Test Bed
DAS	Debris Assessment Software
EOM	End of Mission
FMEA	Failure Mode and Effects Analysis
GEO	Geostationary Earth Orbit
I2C	Inter-Integrated Circuit protocol
I/O	Input/Output
IRPL	Infra-Red PayLoad
LCT	Laser Communications Terminal
LEO	Low Earth Orbit
LINCS	Laser Interconnect & Networking Communications System
MAI	Maryland Aerospace Inc
MOSFET	Metal Oxide Semiconductor Field-Effect Transistor
mΩ	Mili-Ohm
MΩ	Mega-Ohm
OSMA	Office of Safety and Mission Assurance
SV	Space Vehicle
w.r.t.	with respect to
XEPF	Extra Extended Payload Fairing

SELF-ASSESSMENT AND OSMA ASSESSMENT OF THE ODAR

A self-assessment is provided below in accordance with the assessment format provided in Appendix 2.1 of NASA-STD-8719.14. In the final ODAR document, this assessment will reflect any inputs received from NASA's Office of Safety and Mission Assurance (OSMA).

Table 1: Orbital Debris Self-Assessment Report Evaluation: LINCS Space Vehicle

Requirement #	Launch Vehicle				Space Vehicle			Comments
	Compliant	Non-Compliant	Incomplete	Standard Non-Compliant	Compliant	Non-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			
4.4-2			X		X			
4.4-3			X		X			**No Planned Breakups.**
4.4-4			X		X			**No Planned Breakups.**
4.5-1			X		X			
4.5-2			X		X			
4.6-1(a-c)			X		X			
4.6-2			X		X			
4.6-3			X		X			
4.6-4			X		X			
4.7-1			X		X			
4.8-1			X		X			**No Tethers Used.**

ASSESSMENT REPORT FORMAT

ODAR Technical Sections Format Requirements:
This ODAR follows the format in NASA-STD-8719.14B, Appendix A.1 and includes the content indicated at a minimum in each section 2 through 8 below for the LINCS space vehicles (SV).

Sections **9** through **14** apply to the launch vehicle ODAR and therefore **omitted** from this report.

SECTION 1:
PROGRAM MANAGEMENT AND MISSION OVERVIEW

Mission Description

The LINCS mission will demonstrate initial capabilities for a laser communication terminal and IR sensor payload. The LINCS mission is executed by two identical 12U canister-deployed satellites: **CTB-14 and CTB-15**.

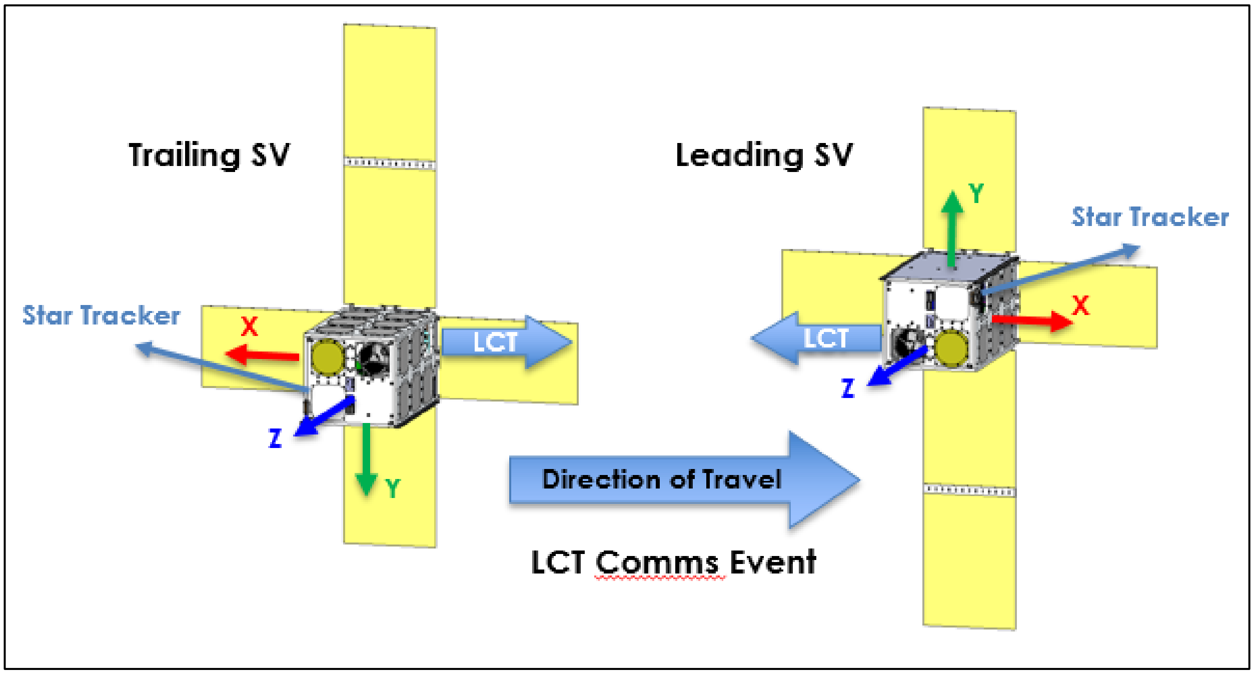


Figure 1: LINCS LCT Event Configuration

The purpose of the Laser Communications Terminal (LCT) is to allow the exchange of information between two orbiting satellites, as described in **Figure 1** or between an orbiting satellite and a ground station (direct-to-earth) as described in **Figure 2**. The information exchange includes data and imagery. The intent is to achieve high data rate information exchange with very low latency.

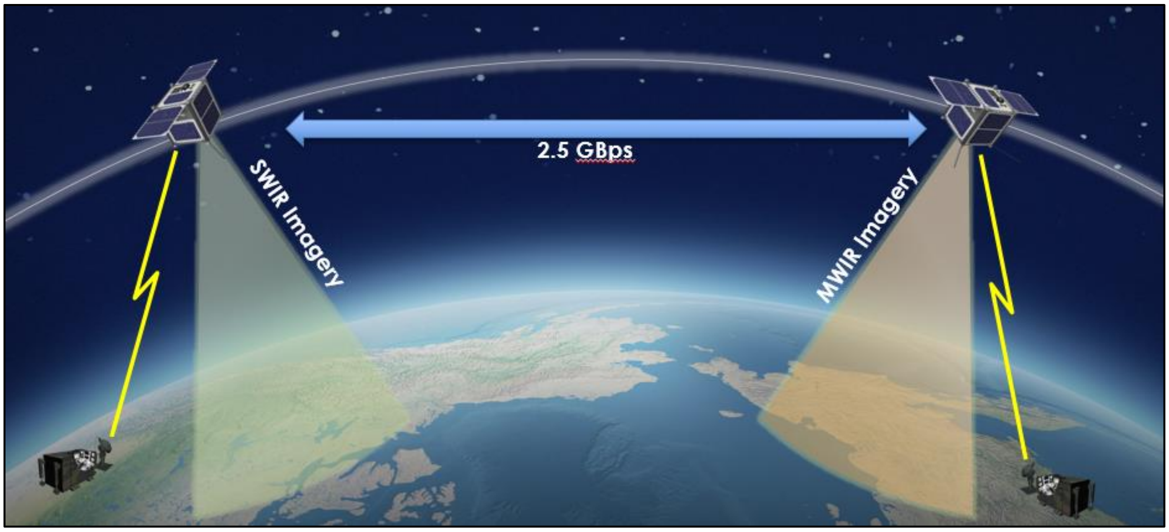


Figure 2: LINCS IRPL Event configuration

The purpose of the Infra-Red Sensor Payload (IRPL) is to capture and store earth imagery for processing and dissemination as depicted in **Figure 2**.

The anchor satellite (primary payload) will be delivered into orbit by a United Launch Alliance Atlas V 401 launch vehicle with the 4-m Extra Extended Payload Fairing (XEPF) with no solid rocket boosters, and a single Centaur engine. LINCS satellites will be inserted into an orbit at 550 km perigee and 550 Km apogee altitude on an inclination from the equator at 97.61degrees. Atmospheric drag will slow the satellite and reduce the altitude of the orbit, until de-orbiting occurs approximately **19 years after launch** and will conclude the mission. The reentry figure was calculated using the smallest (un-deployed solar panels) area-to-mass ratio providing a worst-case reentry scenario.

Launch vehicle: United Launch Alliance Atlas V 401 launch vehicle
Launch site: Vandenberg AFB
Proposed launch date: 2020
Mission duration: 2 years

Launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination:
The LINCS orbital elements are defined as follows:
Apogee: 550 km (+12Km, 3σ)
Perigee: 550 km (-11Km, 3σ)
Inclination: 97.61 deg (TBD deg, 3σ)

LINCS has no propulsion and therefore does not actively change orbits. There is no parking or transfer orbit. At this time, we know of no potential interaction or physical interference between LINCS and any other operational spacecraft.

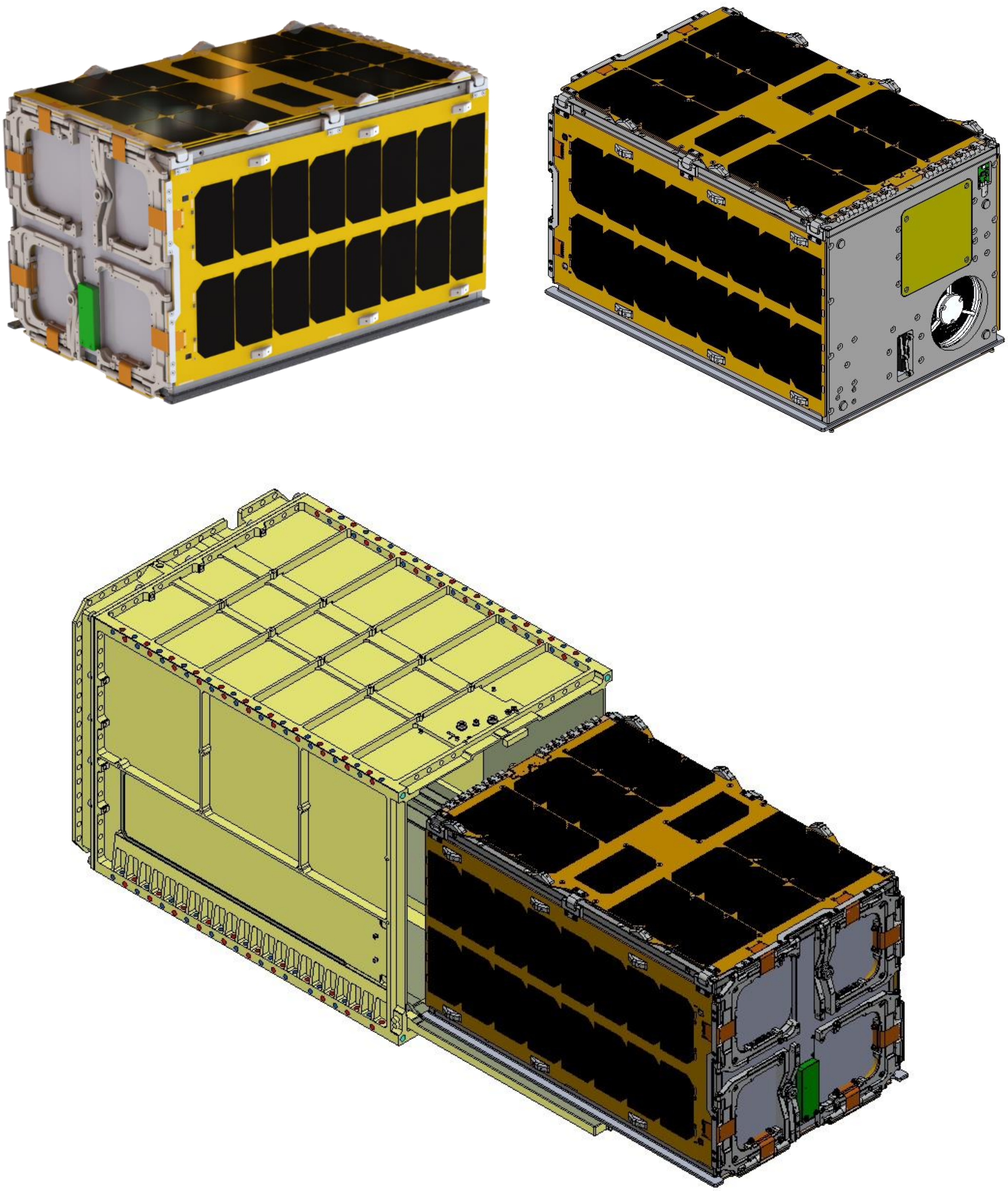


Figure 3: LINCS Stowed Configuration

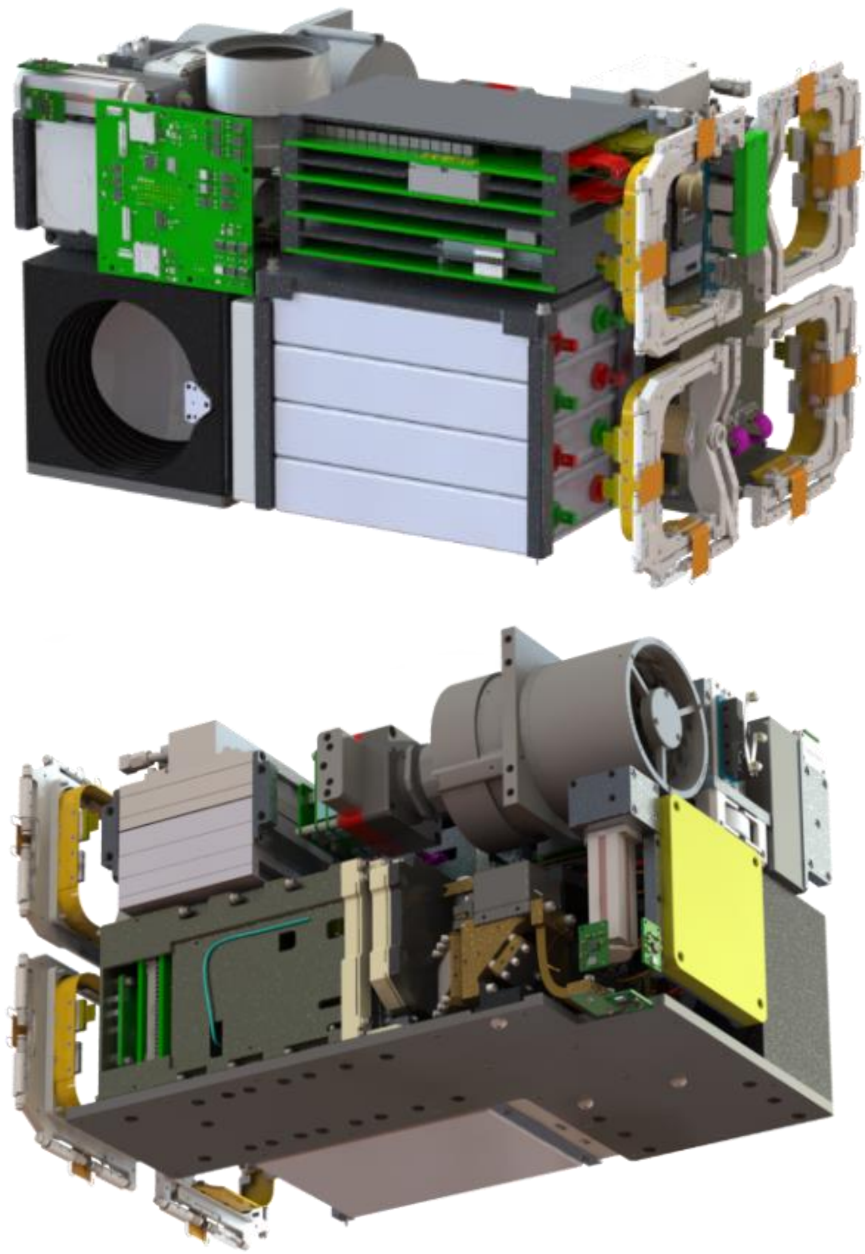


Figure 4: LINCS Internal Views

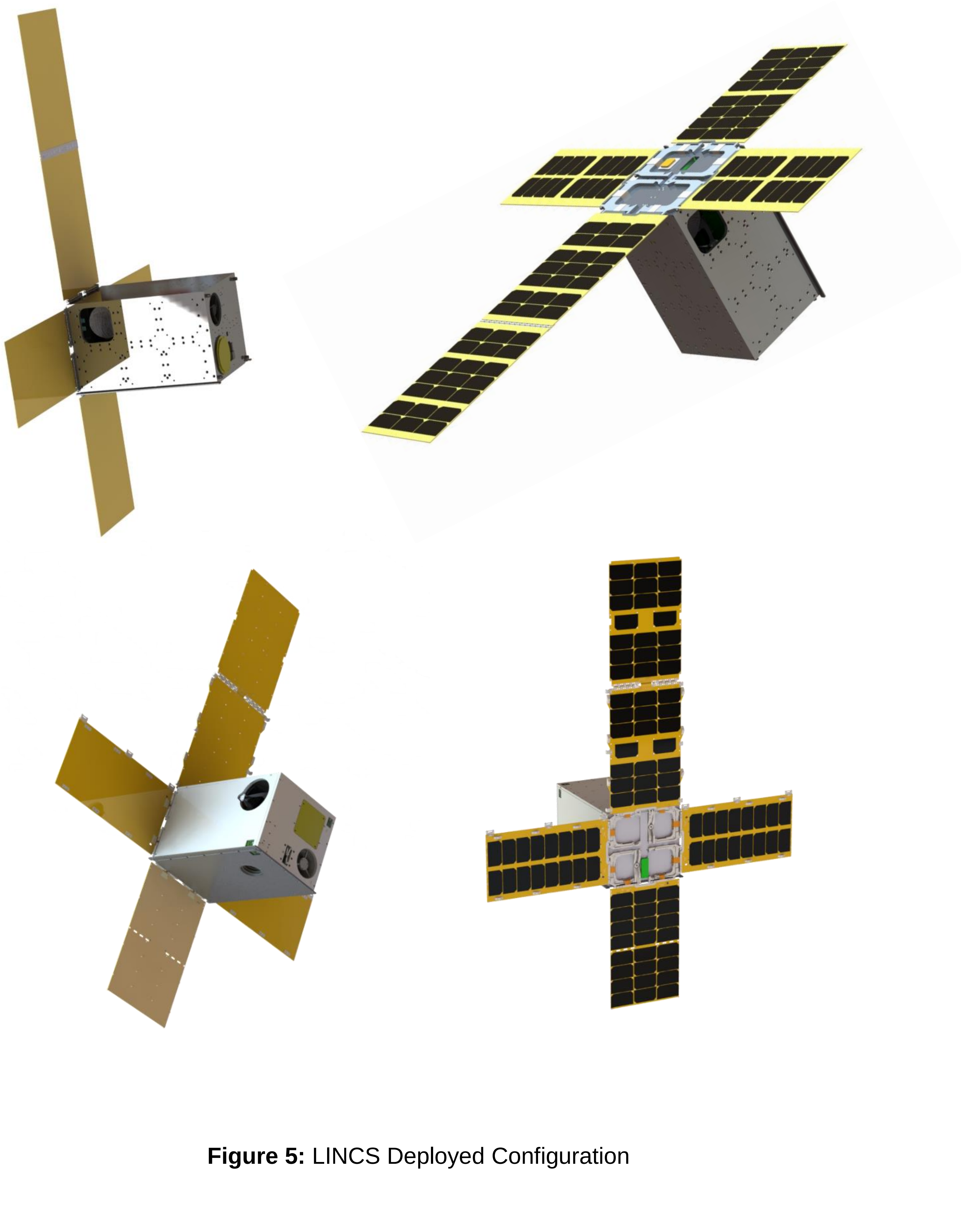


Figure 5: LINCS Deployed Configuration

Interaction or potential physical interference with other operational spacecraft:

- At this time, we know of no potential interaction or physical interference between LINCS and any other operational spacecraft.

LINCS Project Management:

- Program Manager: Dr. David Robie
- Project Engineer: Luis Aguilera

Bus Key engineering personnel:

- Program Manager: Erin Shelton
- Systems IPT Lead: James Lambert
- Avionics IPT Lead: Jason Xerri
- Flight Software IPT Lead: Kevin Welsh
- ACS Lead: Rusty Anderson
- COMM Lead: Tony Correa
- Mechanical/Thermal Lead: Matt Jones
- Thermal Analysis: Ming Dan
- EPS Lead: Randy Rice

Payload Key engineering personnel

- IRPL IPT Lead: Dr. Aaron Freeman
- Laser Comm IPT Lead: Dr. Aaron Freeman

Foreign government or space agency participation:

- No foreign agency is participating in this mission.
- All GA-EMS personnel working on LINCS are United States citizens.

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

- Not applicable.

Schedule of mission design and development milestones from mission selection through proposed launch date, including spacecraft PDR and CDR (or equivalent) dates*:

Table 2: Mission Milestones

DATE	MILESTONE
June 2020	Design and Fabrication
July 2020	Integration
September 2020	Testing
September 2020	Shipment
December 2020	Launch
January 2020	Deployment and Operations

SECTION 2: SPACECRAFT DESCRIPTION

Physical description of the spacecraft:
The LINCS satellites consist of two identical 12U satellites and payloads each stowed in a 12U canisterized deployment mechanism. Approximate mass of each satellite is 21.3 Kg.

Each LINCS satellite is equipped with the following:

- S/S-Band Patch Antenna
- GPS Patch Antenna
- Innoflight SCR-104 S-Band transceiver
- Innoflight CFC-400 flight computer with I/O expansion board
- MAI ADACS-500 with one star tracker
- Sinclair Interplanetary Reaction Wheels (qty 3)
- Adcole MAI Sun Tracker (qty 1)
- Adcole MAI Sun sensor (qty 6)
- Novatel OEM719 GPS receiver
- Adcole MAI Torque Rods (qty 3)
- Pumpkin solar panels (Spectrolab XJT cells) 5 panels
- Eagle Pitcher LP-33081 battery (qty 4)
- Electrical Power System (EPS) Controller-GA-EMS design
- DuraNet 20-11 Gigabit Ethernet Switch
- Laser Communications payload - GA-EMS design
- Infrared remote sensor payload - GA-EMS design

Total satellite mass at launch, including all propellants and fluids:

- 21.3 kg

Dry mass of satellite at launch, excluding solid rocket motor propellants:

- 21.3 kg

Description of all propulsion systems (cold gas, mono-propellant, bi-propellant, electric, nuclear):

- There is no propulsion system on the LINCS Space Vehicles (SVs).

Identification, including mass and pressure, of all fluids (liquids and gases) planned to be on board and a description of the fluid loading plan or strategies, excluding fluids in sealed heat pipes:

- Not applicable as there will be no fluids or gasses on board.

Fluids in Pressurized Batteries:

- No pressurized liquids. LINCS uses flight qualified EaglePicher LP-33081, 30Ah Space Cell Lithium-Ion battery equipped with over-pressure burst disk. Battery information, including the Article Information Sheet (AIS), is provided in **Appendix A** of this document.i

Description of Attitude Control System:

- Each LINCS CubeSat is equipped with a three-axis Active Control System consisting of three (3) reaction wheels and three (3) Magnetorquer rods. Attitude determination is accomplished by a single Star Tracker with a backup system utilizing sun and magnetic vectors. No propulsion system exists, thus NOT used as means of pointing control.

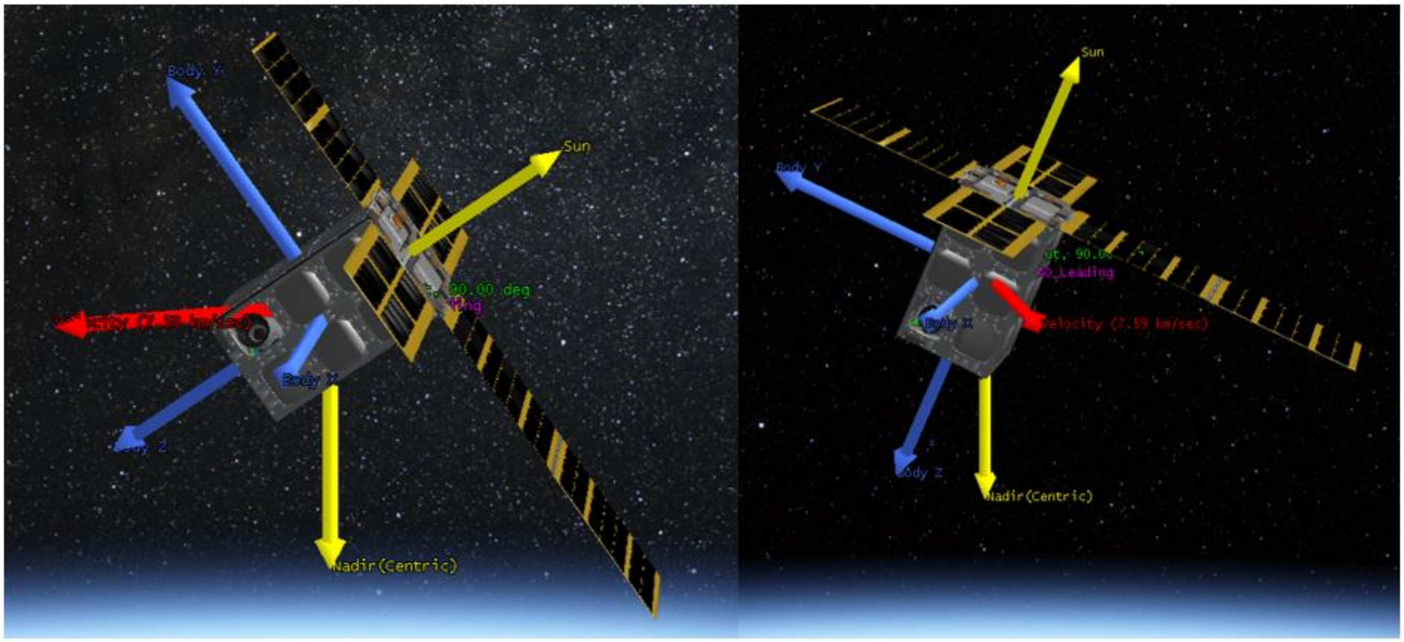


Figure 6: LINCS SV Attitude w.r.t. velocity vector

Normal attitude of the spacecraft with respect to the velocity vector:

- During normal operations, the LINCS SV will be in sun-pointing mode as can be seen on **Figure 6**. The images show the flight configuration at different Sun positions. We use an alignment vector and a constraining vector method to point at all times. For this sun pointing mode, the negative (-)Z_{body} is pointed to the sun, and positive (+)Y_{body} is constrained to Zenith.

Description of any range safety or other pyrotechnic devices:

- There are no Range Safety or other Pyrotechnic devices on the LINCS experiment SVs.

Description of the electrical generation and storage system:

- The SV power is generated using five (5) solar panels provided by Pumpkin Inc. There are 96 solar cells over these 5 panels. The cells are Spectrolab XJT Prime Triple Junction Space Grade Solar cells. The solar cells generate 111 Watts of power used to charge four (4) EaglePicher LP-33081, 30Ah batteries configured in parallel. An Electrical Power System (EPS), of GA-EMS design, provides regulated 3.3VDC, 5VDC, 12VDC and unregulated outputs to the different on-board systems.

Identification of any other sources of stored energy not noted above:

- None.

Identification of any radioactive materials on board:

- None.

Section 3:
Assessment of Spacecraft Debris Released during Normal Operations

Identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material:

- There are no planned or intentional debris releases at any time during the mission lifetime.

Rationale/necessity for release of each object:

- Not applicable.

Time of release of each object, relative to launch time:

- Not applicable.

Release velocity of each object with respect to spacecraft:

- Not applicable.

Expected orbital parameters (apogee, perigee, and inclination) of each object after release:

- Not applicable.

Calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO):

- Not applicable.

Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2 (per DAS v2.1.1):

- 4.3-1, Mission Related Debris Passing Through LEO: **COMPLIANT**
- 4.3-2, Mission Related Debris Passing Near GEO: **COMPLIANT**

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

There are no intentional breakups scheduled during on orbit operation. We are aware of no known potential causes of spacecraft breakup during deployment and mission operations.

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.

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

- The battery safety systems discussed in the FMEA (see requirement 4.4-1 below) describe the combined faults that must occur for any of nine independent, mutually exclusive failure modes that could lead to a battery venting. The EaglePicher batteries are equipped with a safety vent feature that prevents the batteries from exploding by venting excessive built-up pressure. These batteries are space qualified and flown on many space missions including a NASA Mars Rover.

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

- There are no planned intentional breakups by explosion, collision, nor by any other means.

List of components which shall be passivated at End of Mission (EOM) including method of passivation and amount which cannot be passivated:

- Solar Panels will be disconnected from the EPS at EOM via electronic switch as indicated in **Figure 7** below.
- Batteries will be passivated at EOM. The calculated energy left in the battery pack after the EPS cut-off limit is approximately 14.4 Watts.
- Reaction wheels will be switched-off and power removed at EOM allowing all kinetic energy to be dissipated before reentry.

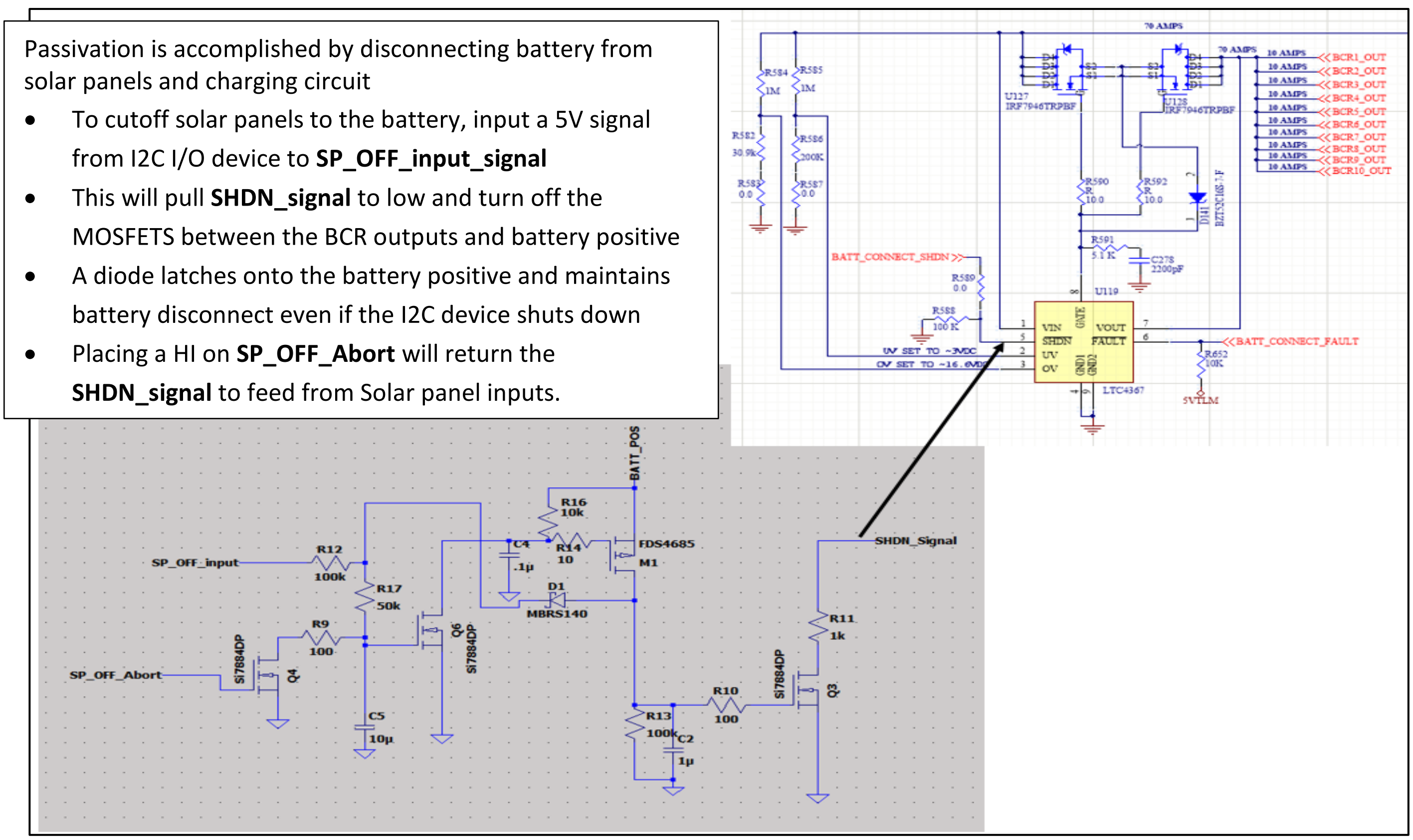


Figure 7: Passivation Circuitry

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

- All components identified above will be passivated upon EOM.

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).*

Supporting Rationale:
Required Probability: **0.001**
Expected probability**: 0.000**

FMEA details:
Battery explosion:
Effect:

- All failure modes below might result in battery explosion with the possibility of orbital debris generation. However, in the unlikely event that a battery cell does explosively rupture, the cell 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 should be contained within the vessel due to the lack of penetration energy.

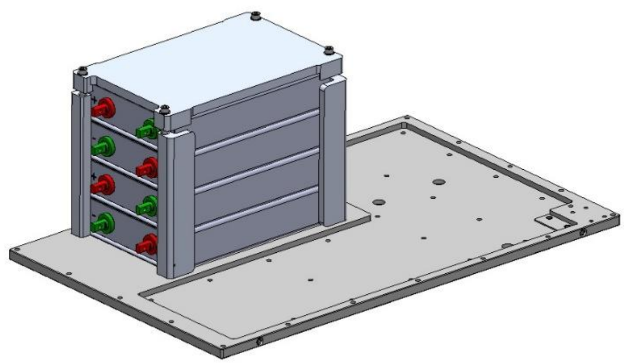


Figure 8: Battery configuration

Probability:

- Very Low. It is believed to be less than 0.1% given that multiple independent (not common mode) faults must occur for each failure mode to cause the ultimate effect (explosion). This family of cells has a long history in space applications. They are also hermetically sealed in a stainless steel case, constrained by compression plates, with an integrated over-pressure burst disc that prevents explosions by venting any over-pressure conditions. The battery configuration as it exists in the cubesatellite is shown in **Figure 8**.

Failure mode 1: Internal short circuit.
Mitigation 1:
Prior to battery assembly, individual cells are monitored during storage and any cell that exhibits a higher than expected leakage is not included within a satellite battery assembly.
The satellite acceptance tests include shock, vibration, thermal cycling, vacuum and numerous electrical and software checks. In many cases, a hard internal short is preceded by increased leakage current within a cell. Individual cell voltages are available within the satellite telemetry. The cells are checked for out-of-balance condition periodically and a resistive load is placed across cells for balancing. Any unbalanced cell voltage caused by an abnormal internal leakage will likely be

discovered during the balancing process. Also the cell voltages can be checked at any time prior to installation onboard a launch vehicle. Post launch, if telemetry indicates an impending internal short condition, a decision can be made to curtail the mission and enter a low energy state.

Combined faults required for realized failure:
Environmental testing AND Electrical/Software testing AND pre-assembly cell monitoring AND post assembly monitoring all must provide no indication of cell failure or combined preliminary cell problems AND the Burst Disc within the outer steel case must fail.

Failure Mode 2: Internal thermal rise due to high load discharge rate.
Mitigation 2:
The internal resistance per cell is 2mΩ at 20°C (from spec sheet in appendix A).
Each subsystem output power switch from the Electrical Power System (EPS) has an overcurrent protection feature. If all EPS subsystem power outputs were turned on and were drawing maximum current at the over-current trip threshold, the total power output would be ~920W. (Note this condition is extremely unlikely) At a 14.4V battery voltage, the output current would be ~64A. (Note: The specification indicates the cell is capable of 150A continuous output.) The resultant heating per cell would be 8.2 Watts or 32.8W for the battery. The battery mass excluding the compression fixture is 3.8 Kg.

A fully charged battery could theoretically maintain a 64 Amp load for ~28 min (neglecting any power input from the solar panels).

<u>Temperature Rise Calculation - Assumptions:</u>

Cell Heat capacity = c = **950J/Kg°K**
(Note this is for an 18650 cell and since our cell is encased by stainless steel it will likely be higher)

m = **3.8 Kg** (total mass of battery stack, not including the compression fixture)

32.8W for 28 minutes equals approximately **55104 Joules** = Q

$Q = mc\Delta T$

Solving for ΔT

$\Delta T = Q/mc$

ΔT = 55104J/(3.8 Kg*950J/Kg°K)

ΔT = **15.3°C**, This is the calculated temperature rise

Given the specified 150A continuous output, the limited temperature rise at absolute worst case output and the installation of an over-pressure burst disc on each cell, the probability for catastrophic failure due to overt temperature conditions is very low

Combined faults required for realized failure:
The EPS subsystem power outputs must fail in a condition that allows greater than 64 Amps

continuous current AND the battery would need to contain significantly more energy than is theoretically possible to allow for longer heating of the battery assembly AND the cell case Burst Discs must fail.

Failure Mode 3: Overcharging and excessive charge rate.

Mitigation 3:

For overcharging: There are 8 independent BCR channels. Each channel has a set point for the upper battery charge voltage. There is also a window pass circuit at the BCR summing point that also limits the upper battery charge voltage to safe levels. Also the battery charge voltage is available in system telemetry for monitoring by the flight computer. Bench testing has been performed and continuing combined subsystem testing is ongoing. At no time has there been any incident of an overcharge condition.

Combined faults required for realized failure:

For overcharging: At least one of the BCR channels must fail AND the window pass circuit at the BCR summing point must fail AND telemetry monitoring must fail AND the cell case Burst Discs must fail.

For excessive charge rate: There are 96 total solar cells on the combined panels. At the lowest possible battery voltage of 12V, the total current into the battery would be 8 Amps. The cell is rated at C = 35 and is specified by the operators manual for a 1C recharge rate. An 8 Amp rate is calculate as C/(35/8) = C/4.375 which is well below the 1C specification. Simply put, even neglecting all losses, it is not possible to exceed the specified charge rate of the cell. Also the battery charge current is monitored by telemetry.

Failure Mode 4: 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 4:

- Each subsystem's power circuit contains a short circuit protection that is tested at a board level.
- The battery terminals are protected by coating with an insulating epoxy after the harness is installed.
- There are no points in the battery harness where the conductive metal is exposed.
- All surfaces where the harness might be abraded will be covered with a layer of Kapton tape.
- The highest battery voltage is 16V, Arcing at these voltage levels is at a low probability.
- All Circuit Card Assemblies (CCAs) within the EPS will be conformal coated to add another layer of protection against accidental shorting and arcing.
- The satellite acceptance tests include shock, vibration, thermal cycling, vacuum and numerous electrical and software checks. Any propensity towards external device failure or abrasion of insulated conductors or inadequate separation should become evident during these tests.
- This scenario is also similar to a hard external short. Previous short circuit testing for a 6 Amp-Hour cell with the same type design showed no occurrence of case damage and the case Burst Disc was still intact post-test (no venting).

Combined faults required for realized failure:

The EPS subsystem power circuit short protection circuit must fail OR at least one point on the battery harness insulation must fail OR an area on one of the CCAs must lose its conformal coating and become shorted in some fashion AND all of these potential failures must remain undetected during Environmental/Electrical/Software testing AND the cell case Burst Discs must fail.

Failure Mode 5: Inoperable vents.

Mitigation 5:

- This family of cells has a long history in space applications. Burst discs are lot sample tested for burst at specified pressure. Burst disk details can be seen on **Figure 9**. Note the case design is also tested to ensure failure at a pressure above that of the burst disc threshold. Previous records of burst disc testing have shown that defective burst discs tend to fail at lower design pressures rather than higher.

Figure 9: Battery Burst Disk

- The cell manufacturer provides a Certificate of Conformity indicating "We hereby certify that all items in the above shipment have been produced at the above listed facility, inspected and found to be in compliance with applicable drawings, customer and military specifications, and standards and purchase requirements."
- All cells are visually inspected prior to battery assembly.
- The cell burst disc are not obstructed within the satellite.
- The satellite acceptance tests include shock, vibration, thermal cycling, vacuum and numerous electrical and software checks. Any defective burst disc should become evident during these tests.

Combined effects required for realized failure:

The manufacturer fails to properly install a burst disc OR the burst disc is defective AND inspection fails to detect any defects or improper installation AND remains undetected during Environmental/Electrical/Software testing

Failure Mode 6: Crushing.

Mitigation 6:

This mode is negated by space vehicle design. There are no moving parts in the proximity of the batteries.

Combined faults required for realized failure:

A catastrophic failure must occur in an external system AND the failure must cause a collision sufficient to crush the cells leading to a hard internal short circuit AND the cell case must be crushed in a manner that allows the case to still retain internal pressure, otherwise the cell will vent AND the cell case Burst Discs must fail.

Failure Mode 7: Low level current leakage or short-circuit through battery pack case or due to moisture-based degradation of insulators.

Mitigation 7:

- There is no point within the combined battery cable harness design and CCA design that is not covered by an insulator material. The wire insulation within the battery harness is PTFE and has low moisture absorption (<0.01%).
- The stainless steel cell case is completely insensitive to moisture and as manufactured has a high resistance (MΩ range) to internal cell voltages.
- These satellites will be assembled in a controlled environment limiting exposure to high humidity conditions.

- Individual cell voltages are available within satellite telemetry. The cells are checked for out of balance condition periodically and a resistive load is placed across cells for balancing. Any unbalanced cell voltage caused by an abnormal low level leakage will likely be discovered during the balancing process. Also the cell voltages can be checked at any time prior to installation onboard a launch vehicle.
- The satellite acceptance tests include shock, vibration, thermal cycling, vacuum and numerous electrical and software checks. Any unexpected leakage should become evident during these tests.

Combined faults required for realized failure:
Abrasion or piercing of circuit board coating or battery wire harness insulator due to excess moisture-based degradation AND failure to detect anomalies during environmental tests AND failure to detect cell out of balance conditions during periodic cell balance checks AND any resulting explosion would also require Burst Disc failure.

Failure Mode 8: Excess temperatures due to orbital environment and high discharge combined.
Mitigation 8:
Preliminary thermal analysis indicates a maximum internal bus temperature of 30°C. The specified cell maximum operating temperature is 60°C. Refer to discussion and temperature rise calculation in Failure Mode 2. The worst case expected battery temperature rise due to High discharge is 15.3°C. Therefore the theoretical worst case temperature for the battery would be 45.3°C which is well below the battery's upper operating range.

Combined faults required for realized failure:
Satellite thermal analysis must be incorrect AND Temperature rise calculation from Failure Mode 2 must be incorrect AND Battery upper operation temperature specification must be incorrect AND the EPS subsystem power outputs must fail in a condition that allows greater than 150 Amps continuous current AND the battery would need to contain significantly more energy than is theoretically possible to allow for longer heating of the battery assembly AND the cell case Burst Discs must fail

Failure Mode 9: Polarity reversal due to over-discharge caused by continuous load during periods of negative power generation vs. consumption.
Mitigation 9:
- At a battery voltage lower that 12.6 V, the power output from the battery is turned off for the entire space vehicle.
- At battery voltages of ~14.5 to13.5 V, the flight processor monitors the battery energy level and determines if satellite mission operations need to be curtailed in order to prevent low voltage cutoff. If the mission operations are curtailed, the satellite would immediately enter the Sun Pointing mode to provide a recharge. The dedicated recharge will not be stopped until the battery is charged to a state that can support the expected mission power requirements.
- The Battery Charge Regulators (BCRs) cannot support reverse battery charging and the window pass circuit design at the point where all BCRs are summed also prevents the possibility of reverse charge.

Combined faults required for realized failure: The low battery voltage cutoff circuit must fail AND the BCRs must fail AND the window pass circuit must fail AND the flight processor hardware/software must fail.

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 cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft.*

Compliance statement:

Circuits are in place to allow disconnect of all solar panel power as indicated in **Figure 7**. Once this EOM mode is entered, the battery will discharge to the low voltage cutoff within few days. At the low battery cutoff, the total battery energy remaining is ~14.4Watt-Hours. After the "End-of-Mission" mode is entered and the low battery cutoff point is reached, the satellite cannot be recovered.

Amount of Energy left at Low Battery Cutoff:
Energy Density at Low Battery Cutoff = 9.61 Watt-Hours/Liter (Worst Case)
Total energy remaining in the Battery Pack = 14.4 Watt-Hours (Worst Case)
Explanation:

The low battery cutoff voltage is 12.6V or 3.15V per cell (4 cells per each CubeSat).
From the enclosed cell spec sheet, the energy remaining at cutoff is ~1 Amp-Hour or ~2.7% of the total energy.

For a fully charged cell, the amount of energy in each cell is 37 Amp-Hours (at C/2 discharge) for a nominal voltage of 3.6V this calculates to 37*3.6 = 133.2 Watt-Hours (or 532.8Wh for all 4 cells)
The cell volume is 22.8 cubic Inches or 0.374 Liters.
So the energy density is ~**356 Watt-Hours/Liter** worst case (note the spec sheet indicates 335Wh/L).
At a low battery cutoff of 2.7% energy remaining, the energy density would be ~9.61Watt-Hours/Liter worst case. Note the energy density is the same for all four cells as it is for one.

The total worst case energy remaining for four cells at low battery cutoff is:
(532.8Wh*0.027) ~ 14.4Watt-Hours

Requirement 4.4-3: Requirement 4.4-3. Limiting the long-term risk to other space systems from planned breakups for Earth and lunar missions: Planned explosions or intentional collisions shall:

a. be conducted at an altitude such that for orbital debris fragments larger than 10 cm the object-time product does not exceed 100 object-years. For example, if the debris fragments greater than 10cm decay in the maximum allowed 1 year, a maximum of 100 such fragments can be generated by the breakup.

b. Not generate debris larger than 1 mm that remains in Earth orbit longer than one year.

Compliance statement:

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

Requirement 4.4-4: Requirement 4.4-4: Limiting the short-term risk to other space systems from planned breakups for Earth orbital missions: *Immediately before a planned explosion or intentional collision, the probability of debris, orbital or ballistic, larger than 1 mm colliding with any operating spacecraft within 24 hours of the breakup shall be verified to not exceed 10^{-6}.*

Compliance statement:

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

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

Assessment of spacecraft compliance with Requirements 4.5-1 and 4.5-2 (per DAS2.1.1, and calculation methods provided in NASA-STD-8719.14, section 4.5.4):

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.*

Large Object Impact and Debris Generation Probability: Compliant per DAS2.1 Output

```
Processing Requirement 4.5-1:
Return Status:  Passed
Collision Probability = 0.000003
Returned Error Message: Normal Processing
Date Range Error Message: Normal Date Range
Status = Pass.
```

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.*

Small Object Impact and Debris Generation Probability: Compliant per DAS2.1 Output

```
Requirement 4.5-2:  Compliant
Return Status:  Passed
```

SECTION 6: ASSESSMENT OF SPACECRAFT POSTMISSION DISPOSAL PLANS AND PROCEDURES

6.1 Description of spacecraft disposal option selected:

- The satellite will de-orbit naturally by atmospheric reentry. There is no propulsion unit or any de-orbiting devices onboard.

6.2 Plan for any spacecraft maneuvers required to accomplish post mission disposal:

- None.

6.3 Calculation of area-to-mass ratio after post mission disposal, if the controlled reentry option is not selected:

- Spacecraft Mass: **21.33 kg**
- Cross-sectional Area: **0.3810 m^2** for the deployed configuration in **Figure 5.**
- Area to mass ratio: **0.3810 m^2 /21.33 Kg**= **0.0178 m^2/Kg**

6.4 Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-4 (per DAS2.1 and NASA-STD-8719.14B section):

- ***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:*

  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.*

Analysis: The LINCS satellite is **COMPLIANT** using Method "**a**" **Atmospheric Reentry Option**. LINCS will re-enter approximately **4** years after launch as can be seen from orbit history plot in **Figure 10** (analysis assumes a nadir pointing configuration).

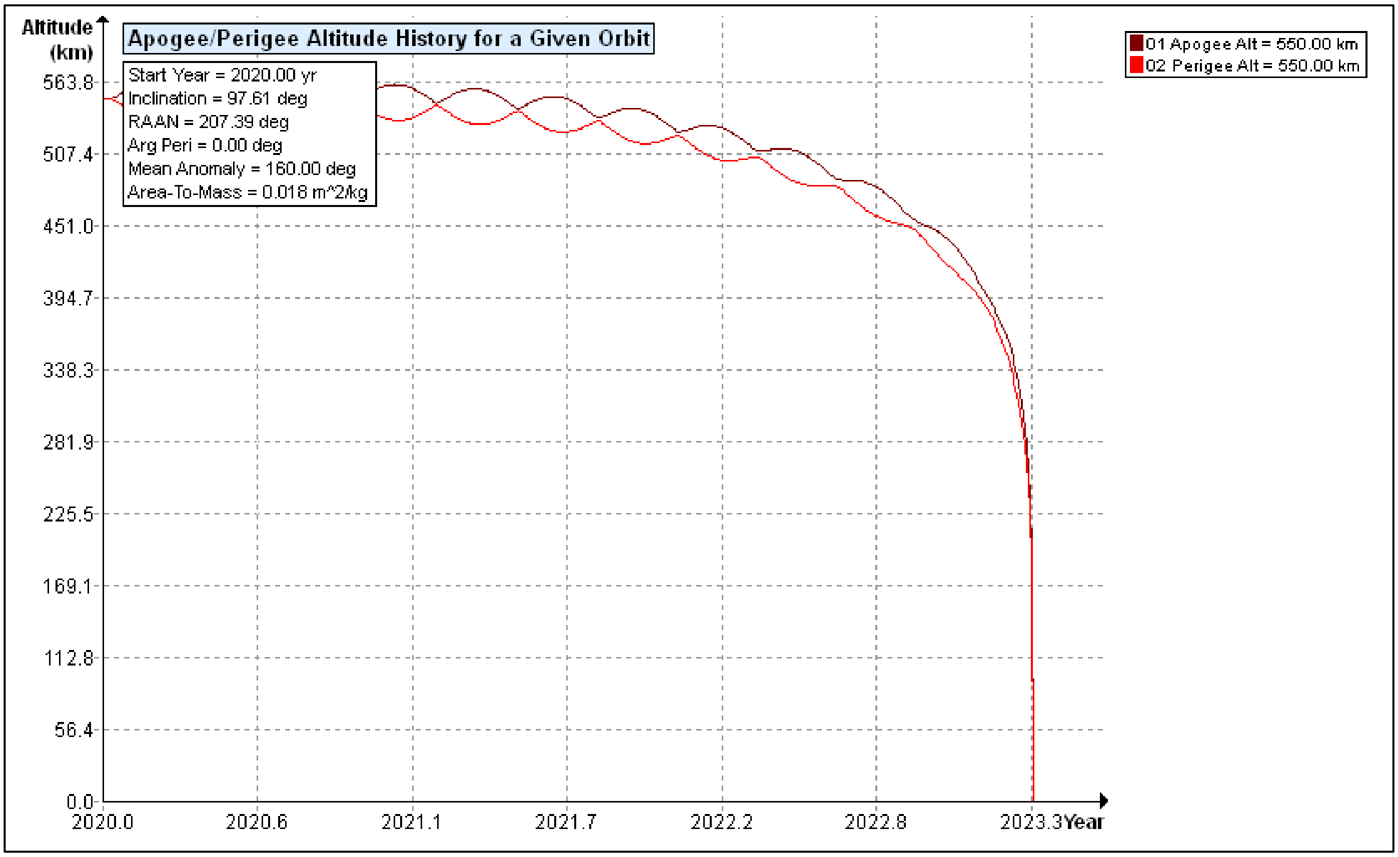


Figure 10: LINCS orbit history (fully deployed configuration)

In contrast, an undeployed configuration (0.003 m^2/kg drag coefficient-see **Figure 3**) was selected as the worst-case scenario to estimate longest on-orbit reentry. It was estimated that in this **worst-case scenario** the CubeSats **will reenter in approximately 19 years after launch as indicated in Figure 11. These results are COMPLAINT with the maximum 25 year reentry requirement.**

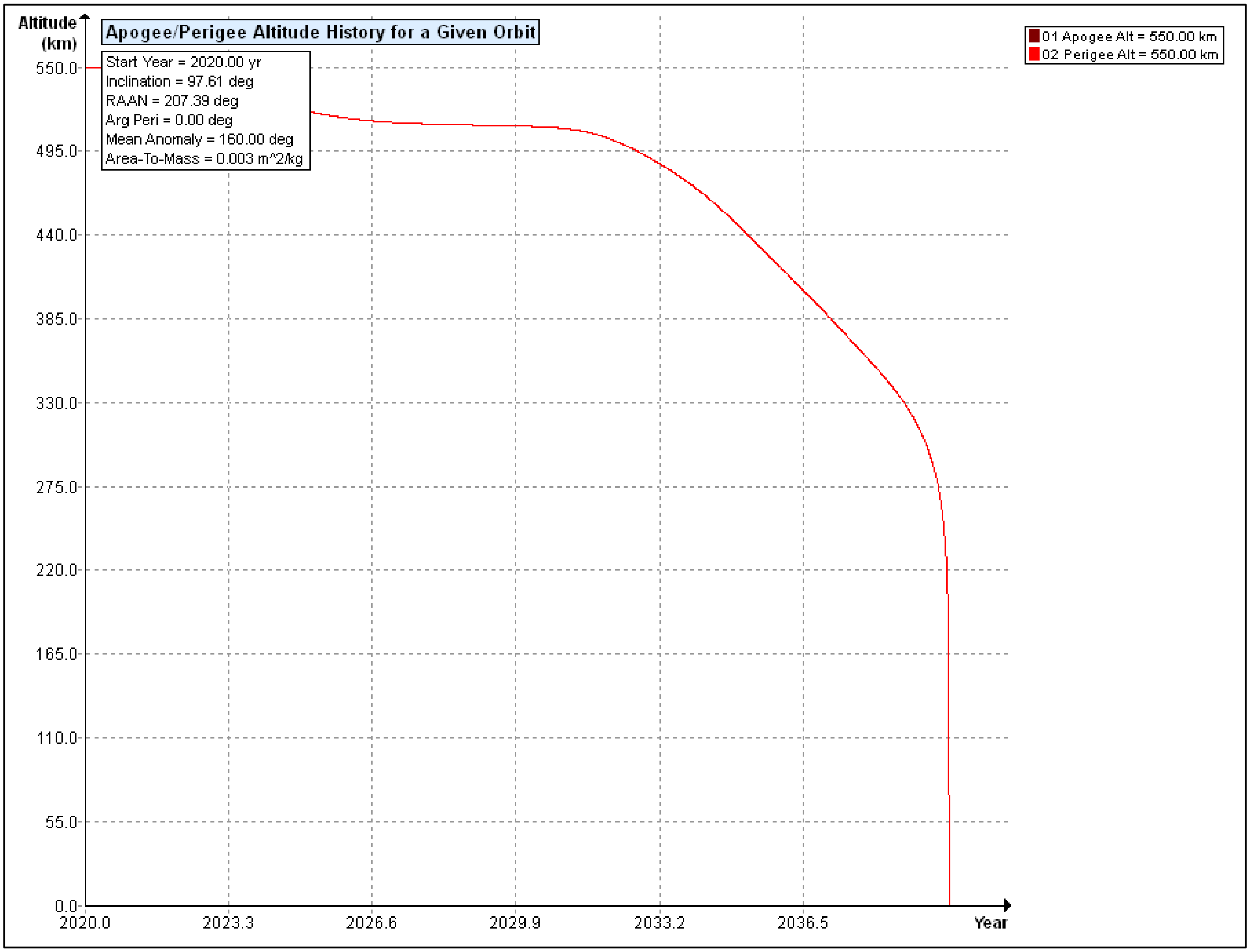


Figure 11: LINCS orbit history (Worst-case Scenario)

Requirement 4.6-2. Disposal for space structures near GEO.
Analysis: Not applicable. LINCS orbit is LEO.

***Requirement 4.6-3. Disposal for space structures between LEO and GEO*.**
Analysis: Not applicable. LINCS orbit is LEO.

Requirement 4.6-4. Reliability of Post-mission Disposal Operations
Analysis: LINCS de-orbiting does not rely on de-orbiting devices. Deployment from launch vehicle will result in de-orbiting in approximately 4 years with no disposal or de-orbiting actions required.

Section 7: Assessment of Spacecraft Reentry Hazards

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.*

Atmospheric reentry option*: For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000).*

Summary Analysis Results: DAS v2.1 reports that the highest human casualty rate for all components/subcomponents is **1:100,000,000** and a total debris casualty area of **0.0 m^2**. This reported risk is **compliant** with the stipulated 1:10,000 (0.0001) for human casualty risk.

Activity log file follows:

```
02 11 2020; 07:27:41AM   Activity Log Started
02 11 2020; 07:27:41AM   Opened Project
C:\Users\corrja\Desktop\DAS211\LINCS\LINCS-ODAR\

02 11 2020; 07:28:22AM   Processing Requirement 4.3-1:
Return Status :  Not Run

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

=============== End of Requirement 4.3-1 ===============
02 11 2020; 07:28:26AM   Processing Requirement 4.3-2:
Return Status : Passed

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

=============== End of Requirement 4.3-2 ===============
02 11 2020; 07:28:29AM   Requirement 4.4-3:  Compliant

=============== End of Requirement 4.4-3 ===============
02 11 2020; 07:33:42AM   Processing Requirement 4.5-1:
Return Status:  Passed

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

**INPUT**

   Space Structure Name = CTB-14/15
   Space Structure Type = Payload
   Perigee Altitude = 550.000000 (km)
   Apogee Altitude = 550.000000 (km)
   Inclination = 97.610000 (deg)
   RAAN = 0.000000 (deg)
```

```
    Argument of Perigee = 0.000000 (deg)
    Mean Anomaly = 0.000000 (deg)
    Final Area-To-Mass Ratio = 0.017800 (m^2/kg)
    Start Year = 2020.000000 (yr)
    Initial Mass = 21.330000 (kg)
    Final Mass = 21.330000 (kg)
    Duration = 2.000000 (yr)
    Station-Kept = False
    Abandoned = True
    PMD Perigee Altitude = -1.000000 (km)
    PMD Apogee Altitude = -1.000000 (km)
    PMD Inclination = 0.000000 (deg)
    PMD RAAN = 0.000000 (deg)
    PMD Argument of Perigee = 0.000000 (deg)
    PMD Mean Anomaly = 0.000000 (deg)
```

****OUTPUT****

```
    Collision Probability = 0.000003
    Returned Error Message: Normal Processing
    Date Range Error Message: Normal Date Range
    Status = Pass

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

=============== End of Requirement 4.5-1 ===============
02 11 2020; 07:33:52AM   Requirement 4.5-2:  Compliant
02 11 2020; 07:33:54AM   Processing Requirement 4.6
Return Status :  Passed

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

**INPUT**

    Space Structure Name = CTB-14/15
    Space Structure Type = Payload

    Perigee Altitude = 550.000000 (km)
    Apogee Altitude = 550.000000 (km)
    Inclination = 97.610000 (deg)
    RAAN = 0.000000 (deg)
    Argument of Perigee = 0.000000 (deg)
    Mean Anomaly = 0.000000 (deg)
    Area-To-Mass Ratio = 0.017800 (m^2/kg)
    Start Year = 2020.000000 (yr)
    Initial Mass = 21.330000 (kg)
    Final Mass = 21.330000 (kg)
    Duration = 2.000000 (yr)
    Station Kept = False
    Abandoned = True
    PMD Perigee Altitude = 511.059291 (km)
    PMD Apogee Altitude = 539.068241 (km)
```

PMD Inclination = 97.634474 (deg)
PMD RAAN = 2.388498 (deg)
PMD Argument of Perigee = 97.436315 (deg)
PMD Mean Anomaly = 0.000000 (deg)

****OUTPUT****

Suggested Perigee Altitude = 511.059291 (km)
Suggested Apogee Altitude = 539.068241 (km)
Returned Error Message = **Passes LEO reentry orbit criteria.**

Released Year = 2023 (yr)
Requirement = 61
Compliance Status = Pass

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

=============== **End of Requirement 4.6** ===============
02 11 2020; 07:34:09AM
*********__Processing Requirement 4.7-1__
Return Status : Passed

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

name = CTB-14/15
quantity = 1
parent = 0
materialID = 5
type = Box
Aero Mass = 21.330000
Thermal Mass = 21.330000
Diameter/Width = 0.220000
Length = 0.330000
Height = 0.190000

name = Battery case
quantity = 4
parent = 1
materialID = 54
type = Box
Aero Mass = 1.150000
Thermal Mass = 0.950000
Diameter/Width = 0.095700
Length = 0.152000
Height = 0.028100

name = Battery Li-ion
quantity = 4
parent = 2
materialID = 39
type = Box
Aero Mass = 0.200000
Thermal Mass = 0.200000

```
Diameter/Width = 0.093000
Length = 0.150000
Height = 0.026000

name = Battery Plate
quantity = 1
parent = 1
materialID = 9
type = Flat Plate
Aero Mass = 0.040200
Thermal Mass = 0.040200
Diameter/Width = 0.099800
Length = 0.157900

name = Radio
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 0.500000
Thermal Mass = 0.500000
Diameter/Width = 0.082000
Length = 0.082000
Height = 0.049000

name = Computer
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 0.250000
Thermal Mass = 0.250000
Diameter/Width = 0.082000
Length = 0.082000
Height = 0.043000

name = Switch
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 0.022700
Thermal Mass = 0.022700
Diameter/Width = 0.076500
Length = 0.084800
Height = 0.030500

name = EPS-PIM enclosure
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.795700
Thermal Mass = 0.795700
```

```
Diameter/Width = 0.095200
Length = 0.146800
Height = 0.081300

name = ADACS card
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.150000
Thermal Mass = 0.150000
Diameter/Width = 0.086400
Length = 0.088100
Height = 0.020000

name = Wheels
quantity = 3
parent = 1
materialID = 54
type = Box
Aero Mass = 0.240000
Thermal Mass = 0.240000
Diameter/Width = 0.057200
Length = 0.057200
Height = 0.020300

name = Torque Rods
quantity = 3
parent = 1
materialID = 5
type = Box
Aero Mass = 0.070000
Thermal Mass = 0.070000
Diameter/Width = 0.025500
Length = 0.062900
Height = 0.017100

name = Star Tracker
quantity = 1
parent = 1
materialID = 5
type = Cylinder
Aero Mass = 0.170000
Thermal Mass = 0.170000
Diameter/Width = 0.061000
Length = 0.092800

name = Sun Sensor
quantity = 6
parent = 1
materialID = 23
type = Box
Aero Mass = 0.003500
Thermal Mass = 0.003500
```

```
Diameter/Width = 0.019700
Length = 0.031800
Height = 0.003400

name = Antenna TT&C
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 0.123000
Thermal Mass = 0.123000
Diameter/Width = 0.079800
Length = 0.079800
Height = 0.028000

name = Antenna GPS
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.009000
Thermal Mass = 0.009000
Diameter/Width = 0.036000
Length = 0.036000
Height = 0.007400

name = Pin Puller
quantity = 2
parent = 1
materialID = 65
type = Cylinder
Aero Mass = 0.049100
Thermal Mass = 0.030000
Diameter/Width = 0.023500
Length = 0.034900

name = screws
quantity = 54
parent = 16
materialID = 59
type = Cylinder
Aero Mass = 0.000500
Thermal Mass = 0.000500
Diameter/Width = 0.002500
Length = 0.014000

name = springs
quantity = 8
parent = 16
materialID = 56
type = Cylinder
Aero Mass = 0.001400
Thermal Mass = 0.001400
Diameter/Width = 0.005500
```

```
Length = 0.007700

name = Sol Pan Hinge Assy
quantity = 2
parent = 1
materialID = 9
type = Box
Aero Mass = 0.090100
Thermal Mass = 0.071000
Diameter/Width = 0.102100
Length = 0.102700
Height = 0.022200

name = Screws
quantity = 54
parent = 19
materialID = 59
type = Cylinder
Aero Mass = 0.000500
Thermal Mass = 0.000500
Diameter/Width = 0.002500
Length = 0.014000

name = Springs
quantity = 8
parent = 19
materialID = 56
type = Cylinder
Aero Mass = 0.001400
Thermal Mass = 0.001400
Diameter/Width = 0.005500
Length = 0.007700

name = Sol Pan Hinge Assy & rel mch
quantity = 2
parent = 1
materialID = 9
type = Box
Aero Mass = 0.115100
Thermal Mass = 0.115100
Diameter/Width = 0.102100
Length = 0.108800
Height = 0.022200

name = Batt comprss Link
quantity = 2
parent = 1
materialID = 9
type = Box
Aero Mass = 0.051300
Thermal Mass = 0.051300
Diameter/Width = 0.020900
Length = 0.103200
Height = 0.014800
```

```
name = Separation Swtch Assy
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 0.026500
Thermal Mass = 0.026500
Diameter/Width = 0.024600
Length = 0.061500
Height = 0.024500

name = DCE Mount Bracket
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.122000
Thermal Mass = 0.122000
Diameter/Width = 0.103200
Length = 0.103800
Height = 0.020900

name = Wheel Mount Bracket
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.150100
Thermal Mass = 0.150100
Diameter/Width = 0.057200
Length = 0.065200
Height = 0.057200

name = Torque Bracket
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.018100
Thermal Mass = 0.018100
Diameter/Width = 0.026700
Length = 0.027200
Height = 0.025400

name = Switch Bracket
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.073700
Thermal Mass = 0.073700
Diameter/Width = 0.066300
Length = 0.085000
```

```
Height = 0.029200

name = SDR & FC Bracket
quantity = 2
parent = 1
materialID = 8
type = Box
Aero Mass = 0.022500
Thermal Mass = 0.022500
Diameter/Width = 0.052000
Length = 0.083000
Height = 0.010200

name = StarTracker Bracket
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.129800
Thermal Mass = 0.129800
Diameter/Width = 0.059500
Length = 0.085100
Height = 0.019000

name = Chassis +X side
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.893900
Thermal Mass = 0.893900
Diameter/Width = 0.199600
Length = 0.346600

name = Chassis -X side
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 1.146200
Thermal Mass = 1.146200
Diameter/Width = 0.199600
Length = 0.346600

name = Chassis +Y side
quantity = 1
parent = 1
materialID = 9
type = Flat Plate
Aero Mass = 1.169200
Thermal Mass = 1.169200
Diameter/Width = 0.239200
Length = 0.365000
```

```
name = Chassis -Y side
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.997600
Thermal Mass = 0.997600
Diameter/Width = 0.221700
Length = 0.354200

name = Chassis +Z side
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.530100
Thermal Mass = 0.530100
Diameter/Width = 0.199600
Length = 0.221700

name = Chassis -Z side
quantity = 1
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.340500
Thermal Mass = 0.340500
Diameter/Width = 0.197500
Length = 0.206400

name = Port Covers -Z side
quantity = 4
parent = 1
materialID = 8
type = Flat Plate
Aero Mass = 0.099100
Thermal Mass = 0.099100
Diameter/Width = 0.085000
Length = 0.085000

name = Solar Panels X sides
quantity = 2
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.245000
Thermal Mass = 0.245000
Diameter/Width = 0.188100
Length = 0.360200

name = Solar Panel +Y
quantity = 1
parent = 1
materialID = 23
```

```
type = Flat Plate
Aero Mass = 0.311000
Thermal Mass = 0.311000
Diameter/Width = 0.213900
Length = 0.360200

name = Solar Panel -Y dble panel
quantity = 1
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.452800
Thermal Mass = 0.452800
Diameter/Width = 0.230400
Length = 0.695900

name = IRPL Lens Assy
quantity = 1
parent = 1
materialID = 8
type = Cylinder
Aero Mass = 0.747000
Thermal Mass = 0.747000
Diameter/Width = 0.095200
Length = 0.141900

name = IRPL Camera w/ mount
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.326700
Thermal Mass = 0.326700
Diameter/Width = 0.059800
Length = 0.069000
Height = 0.054100

name = LCT Baseplate
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.662000
Thermal Mass = 0.662000
Diameter/Width = 0.205400
Length = 0.327000
Height = 0.006000

name = Electronics Assy
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 2.420000
```

Thermal Mass = 2.420000
Diameter/Width = 0.099100
Length = 0.175000
Height = 0.096500

name = LCT Assy
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.313000
Thermal Mass = 1.313000
Diameter/Width = 0.124000
Length = 0.208600
Height = 0.105600

name = LCT Rad Shield
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.394700
Thermal Mass = 0.394700
Diameter/Width = 0.102000
Length = 0.117600
Height = 0.073700

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

name = CTB-14/15
Demise Altitude = 77.997475
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Battery case
Demise Altitude = 61.544075
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Battery Li-ion
Demise Altitude = 61.383602
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Battery Plate
Demise Altitude = 77.664497
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****

```
name = Radio
Demise Altitude = 72.363998
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Computer
Demise Altitude = 74.931129
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Switch
Demise Altitude = 77.685532
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = EPS-PIM enclosure
Demise Altitude = 74.253822
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = ADACS card
Demise Altitude = 76.637283
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Wheels
Demise Altitude = 65.928619
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Torque Rods
Demise Altitude = 75.658951
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Star Tracker
Demise Altitude = 75.742714
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Sun Sensor
Demise Altitude = 77.741936
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
```

```
name = Antenna TT&C
Demise Altitude = 76.157509
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Antenna GPS
Demise Altitude = 77.638794
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Pin Puller
Demise Altitude = 73.347839
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = screws
Demise Altitude = 72.801117
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = springs
Demise Altitude = 71.399345
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Sol Pan Hinge Assy
Demise Altitude = 77.320602
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Screws
Demise Altitude = 76.699409
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Springs
Demise Altitude = 75.175430
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Sol Pan Hinge Assy & rel mch
Demise Altitude = 76.918243
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
```

```
name = Batt comprss Link
Demise Altitude = 76.759262
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Separation Swtch Assy
Demise Altitude = 77.220856
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = DCE Mount Bracket
Demise Altitude = 76.690948
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Wheel Mount Bracket
Demise Altitude = 76.042526
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Torque Bracket
Demise Altitude = 77.011650
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Switch Bracket
Demise Altitude = 77.003128
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = SDR & FC Bracket
Demise Altitude = 77.538727
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = StarTracker Bracket
Demise Altitude = 75.923714
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Chassis +X side
Demise Altitude = 75.195808
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
```

```
name = Chassis -X side
Demise Altitude = 74.371620
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Chassis +Y side
Demise Altitude = 75.091560
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Chassis -Y side
Demise Altitude = 75.089539
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Chassis +Z side
Demise Altitude = 75.466080
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Chassis -Z side
Demise Altitude = 76.263596
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Port Covers -Z side
Demise Altitude = 76.180397
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Solar Panels X sides
Demise Altitude = 77.498825
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Solar Panel +Y
Demise Altitude = 77.405365
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Solar Panel -Y dble panel
Demise Altitude = 77.493195
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
```

```
name = IRPL Lens Assy
Demise Altitude = 73.577393
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = IRPL Camera w/ mount
Demise Altitude = 73.970406
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = LCT Baseplate
Demise Altitude = 75.891388
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Electronics Assy
Demise Altitude = 69.613159
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = LCT Assy
Demise Altitude = 74.125359
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = LCT Rad Shield
Demise Altitude = 75.583389
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

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

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

A summary of these results is provided in **Table 3:** reentry data, located at the end of document.

Requirements **4.7-1b** and **4.7-1c** below are **non-applicable** requirements because LINCS does not use controlled reentry.

4.7-1, b) NOT APPLICABLE.

4.7-1 c) NOT APPLICABLE.

Section 7A:
Assessment of Spacecraft Hazardous Materials

Not Applicable. There are no hazardous materials contained on the space vehicle.

Section 8:
Assessment for Tether Missions

Not applicable. There are no tethers in the LINCS mission.

END of ODAR for LINCS.

APPENDIX A
DATA SHEETS
Battery

EAGLEPICHER TECHNOLOGIES

30Ah Space Cell

High energy, long-cycle life and low maintenance lithium-ion cell for demanding applications

Lithiated Nickel Cobalt Aluminum Oxide

Features and Benefits

- Case neutral
- Safety vent feature
- True prismatic design
- Hermetically sealed
- Stainless steel case
- Long life: over 40,000 low-earth orbit cycles at 40% depth of discharge (DOD) over 10 years of operation
- Qualified for operation from -20 to 60°C (-4 to 140°F)

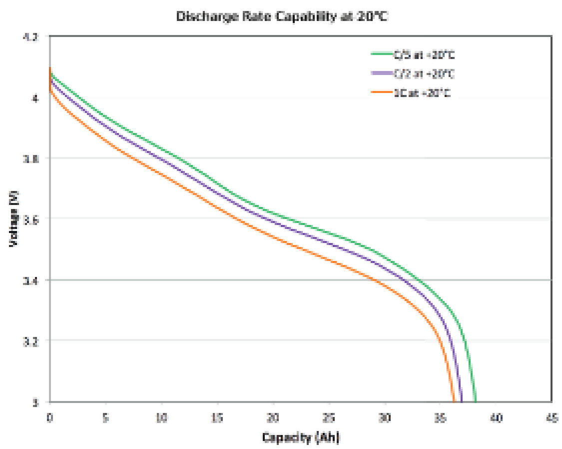
Applications

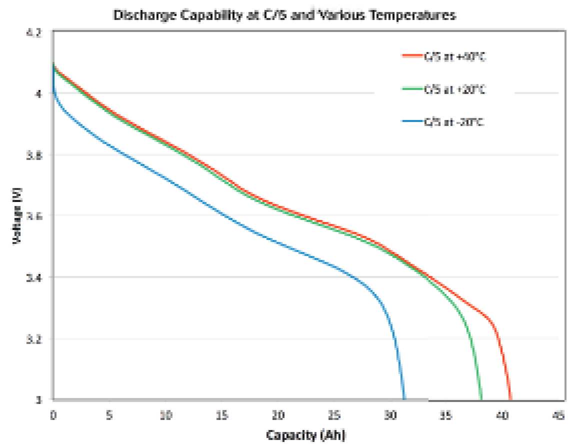
- Aerospace
- Mars landers
- Low-earth orbit satellite missions
- Mid-earth orbit satellite missions
- Geosynchronous-earth orbit satellite missions
- Scientific and exploratory satellite missions

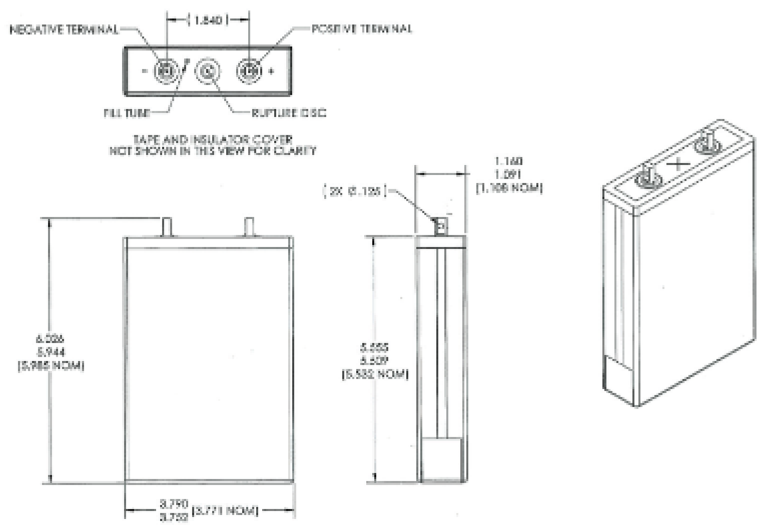
Specifications	
Part Number	LP 33081
Nominal Cell Weight	950 g (2.1 lbs)
Dimensions	See details on back
Voltage Range	3.0 to 4.1V
Nominal Voltage	3.6V
Nominal Capacity	30Ah at C/5 at 20°C (68°F)
Energy Density	335 Wh/L
Specific Energy	141 Wh/kg
Discharge Rates	Max constant current 150A
	Max pulse current (<1 sec.) 300A
Nominal Cell Impedance	2mΩ at 20°C (68°F)
Cycle Life (80% capacity measured at 0.5C discharge current at 20°C (68°F))	>2000 at 100% DOD
Standard Charging Method	Constant current at 6A (C/5) to 4.1V
	Constant voltage at 4.1V to 0.6A (C/50)
Operating Temperature	-20 to 60°C (-4 to 140°F)
Storage Temperature	-40°C to 20°C (-40 to 68°F)

417.623.8000 | inquiry.technologies@eaglepicher.com | www.eaglepicher.com

30Ah Space Cell







Product: Lithium-ion battery
NCP and LIBG families

Applicable Product Numbers: **Batteries:** LP30794; LP31768; LP32094; LP32095; LP32100; LP33081; LP33333; LP33732; LP33925; LP33940;
Cells: NCP 12-4, 25-5, 43-4, 55-4, 55-6;
LiBG18EV-1;
LiBH18GP

Date: 2/06/2020
Revision: F

Document Number: EHS-AIS-1011

ARTICLE INFORMATION SHEET (AIS)

This Article Information Sheet (AIS) is provided as a courtesy or in response to a customer request. A Safety Data Sheet (SDS) has not been prepared for this product because it is an Article. This AIS provides relevant battery information to consumers, OEMs and other users requesting a GHS-compliant SDS. Articles, such as batteries and electrodes, are exempt from GHS SDS classification criteria. The GHS criteria is not designed or intended to be used to classify the physical, health and environmental hazards of an article.

SECTION 1: COMPANY INFORMATION

Manufacturer:

EaglePicher Technologies, LLC
PO Box 47
Joplin, MO 64802
417-623-8000

www.eaglepicher.com
Emergency Telephone Number: CHEMTREC 1-800-424-9300

SECTION 2: ARTICLE INFORMATION

This product is exempt from hazard classification according to OSHA Hazard Communication Standard, 29 CFR 1910.1200.

Description	Lithium Ion Battery
Recommended Use	Portable power source
Article Construction	
Can	Stainless Steel
Anode	Graphite, CAS 7782-42-5; Carbon, CAS 1333-86-4; Polyvinylidene Fluoride, CAS 24937-79-9, Ketamine, CAS 25707-70-4; Ethyl alcohol, CAS 64-17-5; Methyl alcohol, CAS 67-56-1
Cathode	Lithium aluminum boron* cobalt nickel oxide, CAS 12057-24-8, CAS 1344- 28-1, CAS 1303-86-2, CAS 1308-04-9, CAS 1314-0603; Carbon, CAS 1333-86-4; Polyvinylidene Fluoride, CAS 24937-79-9; Graphite, CAS 7782-42-5 *- some product variations do not contain boron

Electrolyte	Lithium hexafluorophosphate in ethylene carbonate/dimethyl carbonate/diethyl carbonate/ethylmethyl carbonate with ethyl acetate*, CAS 213244-40-3, CAS 96-49-1, CAS 141-78-6; with lithium bis- (oxalato)*, CAS 244761-29-3; vinylene carbonate*, CAS 872-36-6 * - some product variations do not contain these ingredients

SECTION 3: HEALTH AND SAFETY

Normal conditions of Use	Exposure to contents inside the sealed battery will not occur unless the battery leaks, is exposed to high temperatures, or is mechanically or electrically abused.
First Aid – Eye Contact	If exposed to internal components of the battery, flush with running water for at least 15 minutes and then seek medical attention.
First Aid – Skin Contact	If exposed to internal components of the battery, flush with running water for at least 15 minutes and then seek medical attention.
First Aid – Inhalation	Contents of leaking battery may be irritating to respiratory passages. Move to fresh air and seek medical attention if irritation persists.
First Aid – Ingestion	Do not induce vomiting. Seek immediate medical attention. If mouth irritation or burning has occurred, rinse mouth and surrounding area with tepid water for at least 15 minutes. Call the National Battery Ingestion Hotline (202) 625-3333 collect, day or night.
Precautionary Statements	Battery can leak or explode if heated, disassembled, shorted, recharged, exposed to fire or high temperature or inserted incorrectly. Do not pierce or burn, even after use. Store in a well ventilated place. Keep cool. Store in original container.

SECTION 4: FIRE HAZARDS AND FIREFIGHTING MEASURES

Fire Hazard	Batteries may rupture or leak if involved in a fire.
Extinguishing Media	Use any extinguishing media appropriate for the surrounding area. For incipient (beginning) fires, carbon dioxide extinguishers or copious amounts of water are effective in cooling burning lithium batteries. Do not use Halon, dry powder or soda ash extinguishers.
Advice for Fire Fighters	Firefighters should wear Self-Contained Breathing Apparatus and turnout gear.

SECTION 5: HANDLING AND STORAGE

Handling	Avoid mechanical and electrical abuse. Do not short circuit or install incorrectly. Batteries may rupture or vent if disassembled, crushed, recharged or exposed to high temperatures. Do not directly heat or solder. Install batteries in accordance with equipment instructions.
Storage	Store batteries in a dry place. Do not store at a temperature greater than 60° C. To maximize product life, refer to product-specific documentation for recommend storage conditions. Do not place near heating equipment or leave in direct sunlight for a long time.

SECTION 6: DISPOSAL CONSIDERATIONS

Collection and Proper Disposal	Dispose of used (or excess) batteries in compliance with federal, state/provincial and local regulations. Do not accumulate large quantities of used batteries for disposal as accumulations could cause batteries to short-circuit. Do not incinerate. In countries, such as Canada and the EU, where there are regulations for the collection and recycling of batteries, consumers should dispose of their used batteries into the collection network at municipal depots and retailers. They should not dispose of batteries with household trash.
USA DOT (49 CFR 173.185 (d))	Lithium cells or batteries shipped for disposal or recycling. A lithium cell or battery, including a lithium cell or battery contained in equipment, that is transported by motor vehicle to a permitted storage facility or disposal site, or for purposes of recycling, is excepted from the testing and record keeping requirements of paragraph (a) and the specification packaging requirements of paragraph (b)(3) of this section, when packed in a strong outer packaging conforming to the requirements of §§173.24 and 173.24a. A lithium cell or battery that meets the size, packaging, and hazard communication conditions in paragraph (c)(1)-(3) of this section is excepted from subparts C through H of part 172 of this subchapter.
California Universal Waste Rule (Cal. Code Regs.	California prohibits disposal of batteries as trash (including household trash).

SECTION 7: TRANSPORTATION INFORMATION

Regulatory Status	EaglePicher Technologies, LLC lithium batteries are delivered in accordance with current DOT and/or IATA/ICAO regulations. Persons who prepare or offer lithium batteries for transport are required by regulation to be trained to the extent of their responsibility. The information in this section is provided for informational purposes only. The transportation of lithium batteries is regulated by ICAO, IATA, IMO, ADR and US DOT.		
Total Lithium Content	**See below for each product number:**		
	Part No.	**Total Lithium Content (grams)**	**Total Cell/Battery Weight**
	LP32094	127.0	38 lbs.
	LP32095	230.0	110 lbs.
	LP33333	126.0	39 lbs.
	NCP55-4 (LP32772)	16.5	1680 grams
	NCP55-6 (LP33101)	18.0	1600 grams
	NCP12-4 (LP32977)	3.72	465 grams
	LIBG 18EV-1 (LP34102)	1.55	290 grams

DOT (US)	UN Number	Shipping Name	Hazard Class
	UN3480	Lithium ion batteries	9
	UN3481	Lithium ion batteries contained in equipment	9
	UN3481	Lithium ion batteries packed with equipment	9

USA DOT Special Provisions: 49 CFR 172.102 A51, A54

USA DOT Exceptions for Lithium Cells or Batteries Shipped for Disposal or Recycling: 40 CFR 173.185(d)

Air Transport (IATA/ICAO) Packing Instructions (61st edition):
PI 965 – Lithium ion batteries
Marine/Water Transport (IMDG 38th Amendment) Special Provision: SP188, PI903
ADR.RID Special Provision: 188

SECTION 8: REGULATORY DEFINITIONS AND REQUIREMENTS - ARTICLES USA

OSHA	29 CFR 1910.1200(b)(6)(v)
USA TSCA	40 CFR 704.3; 710.2(3)(c); and [19 CFR 12.1209a)]
EU REACH	Title 1 - Chapter 2 - Article 3(3)
GHS	Section 1.3.2.1

Globally Harmonized System (GHS)	GHS SDS requirements and classification criteria do not apply to articles or products (such as batteries) that have a fixed shape, which are not intended to release a chemical. The article exemption is found in Section 1.3.2.1.1 of the GHS and reads: ***The GHS applies to pure substances and their dilute solutions and to mixtures. "Articles" as defined by the Hazard Communication Standard (29 CFR 1900.1200) of the OSHA of the USA, or by similar definition, are outside the scope of the system."***
Joint Article Management Promotion Consortium JAMP	An international standard that came into effect in March 2012 concerning declaration for electrical and electronic products. IEC 6274 replaces the defunct Joint Industry Guide – Material Declaration for Electro-technical Products (JIG-101-Ed 4.1 (May 21, 2012)
IEC 62474 Ed. 1.0 B:2012 Material Declaration for Products of and for the Electro-technical Industry	An international standard that came into effect in March 2012 concerning declaration for electrical and electronic products. IEC 6274 replaces the defunct Joint Industry Guide – Material Declaration for Electro-technical Products (JIG-101-Ed 4.1 (May 21, 2012)

Table 3: Reentry Data

Reentry Data														
Row Num	Name	Parent	Qty	Material	Body Type	Thermal Mass	Diameter/ Width	Length	Height	Status	Risk	Demise Alt	Total DCA	KE
1	CTB-14	0	1	Aluminum (generic)	Box	21.33	0.22	0.33	0.19	**Compliant**	**1:100000000**		0	
2	Battery case	1	4	Stainless Steel (generic)	Box	0.95	0.0957	0.152	0.0281			61.5	0	0
3	Battery Li-ion	2	4	Lead Element	Box	0.2	0.093	0.15	0.026			61.4	0	0
4	Battery Plate	1	1	Aluminum 7075-T6	Flat Plate	0.0402	0.0998	0.1579				77.7	0	0
5	Radio	1	1	Aluminum (generic)	Box	0.5	0.082	0.082	0.049			72.4	0	0
6	Computer	1	1	Aluminum (generic)	Box	0.25	0.082	0.082	0.043			74.9	0	0
7	Switch	1	1	Aluminum (generic)	Box	0.0227	0.0765	0.0848	0.0305			77.7	0	0
8	EPS-PIM enclosure	1	1	Aluminum 6061-T6	Box	0.7957	0.0952	0.1468	0.0813			74.3	0	0
9	ADACS card	1	1	Fiberglass	Box	0.15	0.0864	0.0881	0.02			76.6	0	0
10	Wheels	1	3	Stainless Steel (generic)	Box	0.24	0.0572	0.0572	0.0203			65.9	0	0
11	Torque Rods	1	3	Aluminum (generic)	Box	0.07	0.0255	0.0629	0.0171			75.7	0	0
12	Star Tracker	1	1	Aluminum (generic)	Cylinder	0.17	0.061	0.0928				75.7	0	0
13	Sun Sensor	1	6	Fiberglass	Box	0.0035	0.0197	0.0318	0.0034			77.7	0	0
14	Antenna TT&C	1	1	Aluminum (generic)	Box	0.123	0.0798	0.0798	0.028			76.2	0	0
15	Antenna GPS	1	1	Fiberglass	Box	0.009	0.036	0.036	0.0074			77.6	0	0
16	Pin Puller	1	2	Titanium (6 Al-4 V)	Cylinder	0.03	0.0235	0.0349				73.3	0	0
17	screws	16	54	Steel AISI 316	Cylinder	0.0005	0.0025	0.014				72.8	0	0
18	springs	16	8	Stainless Steel 17-4 ph	Cylinder	0.0014	0.0055	0.0077				71.4	0	0
19	Sol Pan Hinge Assy	1	2	Aluminum 7075-T6	Box	0.071	0.1021	0.1027	0.0222			77.3	0	0
20	Screws	19	54	Steel AISI 316	Cylinder	0.0005	0.0025	0.014				76.7	0	0
21	Springs	19	8	Stainless Steel 17-4 ph	Cylinder	0.0014	0.0055	0.0077				75.2	0	0
22	Sol Pan Hinge Assy & rel mch	1	2	Aluminum 7075-T6	Box	0.1151	0.1021	0.1088	0.0222			76.9	0	0
23	Batt comprss Link	1	2	Aluminum 7075-T6	Box	0.0513	0.0209	0.1032	0.0148			76.8	0	0
24	Separation Swtch Assy	1	1	Aluminum (generic)	Box	0.0265	0.0246	0.0615	0.0245			77.2	0	0
25	DCE Mount Bracket	1	1	Aluminum 6061-T6	Box	0.122	0.1032	0.1038	0.0209			76.7	0	0
26	Wheel Mount Bracket	1	1	Aluminum 6061-T6	Box	0.1501	0.0572	0.0652	0.0572			76	0	0
27	Torque Bracket	1	1	Aluminum 6061-T6	Box	0.0181	0.0267	0.0272	0.0254			77	0	0
28	Switch Bracket	1	1	Aluminum 6061-T6	Box	0.0737	0.0663	0.085	0.0292			77	0	0
29	SDR & FC Bracket	1	2	Aluminum 6061-T6	Box	0.0225	0.052	0.083	0.0102			77.5	0	0
30	StarTracker Bracket	1	1	Aluminum 6061-T6	Box	0.1298	0.0595	0.0851	0.019			75.9	0	0
31	Chassis +X side	1	1	Aluminum 6061-T6	Flat Plate	0.8939	0.1996	0.3466				75.2	0	0
32	Chassis -X side	1	1	Aluminum 6061-T6	Flat Plate	1.1462	0.1996	0.3466				74.4	0	0
33	Chassis +Y side	1	1	Aluminum 7075-T6	Flat Plate	1.1692	0.2392	0.365				75.1	0	0
34	Chassis -Y side	1	1	Aluminum 6061-T6	Flat Plate	0.9976	0.2217	0.3542				75.1	0	0
35	Chassis +Z side	1	1	Aluminum 6061-T6	Flat Plate	0.5301	0.1996	0.2217				75.5	0	0
36	Chassis -Z side	1	1	Aluminum 6061-T6	Flat Plate	0.3405	0.1975	0.2064				76.3	0	0
37	Port Covers -Z side	1	4	Aluminum 6061-T6	Flat Plate	0.0991	0.085	0.085				76.2	0	0

38	Solar Panels X sides	1	2	Fiberglass	Flat Plate	0.245	0.1881	0.3602				77.5	0	0
39	Solar Panel +Y	1	1	Fiberglass	Flat Plate	0.311	0.2139	0.3602				77.4	0	0
40	Solar Panel -Y dble panel	1	1	Fiberglass	Flat Plate	0.4528	0.2304	0.6959				77.5	0	0
41	IRPL Lens Assy	1	1	Aluminum 6061-T6	Cylinder	0.747	0.0952	0.1419				73.6	0	0
42	IRPL Camera w/ mount	1	1	Aluminum 6061-T6	Box	0.3267	0.0598	0.069	0.0541			74	0	0
43	LCT Baseplate	1	1	Aluminum 6061-T6	Box	0.662	0.2054	0.327	0.006			75.9	0	0
44	Electronics Assy	1	1	Aluminum 6061-T6	Box	2.42	0.0991	0.175	0.0965			69.6	0	0
45	LCT Assy	1	1	Aluminum 6061-T6	Box	1.313	0.124	0.2086	0.1056			74.1	0	0
46	LCT Rad Shield	1	1	Aluminum 6061-T6	Box	0.3947	0.102	0.1176	0.0737			75.6	0	0