ELVL-2016-0044542 (FCC)
October 3, 2016

Orbital Debris Assessment for
The CubeSats on the
(LV) /ELaNa-22 Mission
per NASA-STD 8719.14A

Signature Page

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ELVL-2016-0044542

Reply to Attn of: VA-H1 October 3, 2016

TO: Scott Higginbotham, LSP Mission Manager, NASA/KSC/VA-C

FROM: Justin Treptow, NASA/KSC/VA-H1

SUBJECT: Orbital Debris Assessment Report (ODAR) for the ELaNa-22 Mission (FCC)

REFERENCES:

A. *NASA Procedural Requirements for Limiting Orbital Debris Generation*, NPR 8715.6A, 5 February 2008
B. *Process for Limiting Orbital Debris*, NASA-STD-8719.14A, 25 May 2012
C. Higginbotham, Scott. 2016_June_CSLI_Monthly_Status, June 2016. PDF.
D. McKissock, Barbara, Patricia Loyselle, and Elisa Vogel. *Guidelines on Lithium-ion Battery Use in Space Applications*. Tech. no. RP-08-75. NASA Glenn Research Center Cleveland, Ohio
E. *UL Standard for Safety for Lithium Batteries, UL 1642*. UL Standard. 4th ed. Northbrook, IL, Underwriters Laboratories, 2007
F. Kwas, Robert. Thermal Analysis of ELaNa-4 CubeSat Batteries, ELVL-2012-0043254; Nov 2012
G. Range Safety User Requirements Manual Volume 3- Launch Vehicles, Payloads, and Ground Support Systems Requirements, AFSCM 91-710 V3.
H. HQ OSMA Policy Memo/Email to 8719.14: CubeSat Battery Non-Passivation, Suzanne Aleman to Justin Treptow, 10, March 2014

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the ELaNa-22 auxiliary mission launching in conjunction with the CRS-12 primary payload. It serves as the final submittal in support of the spacecraft Safety and Mission Success Review (SMSR). Sections 1 through 8 of ref. (b) are addressed in this document; sections 9 through 14 fall under the requirements levied on the primary mission and are not presented here.

The following table summarizes the compliance status of the ELaNa-22 auxiliary payload mission flown on CRS-12. The five CubeSats comprising the ELaNa-22 mission are fully compliant with all applicable requirements.

Table 1: Orbital Debris Requirement Compliance Matrix

Requirement	Compliance Assessment	Comments
4.3-1a	Not applicable	No planned debris release
4.3-1b	Not applicable	No planned debris release
4.3-2	Not applicable	No planned debris release
4.4-1	Compliant	On board energy source (batteries) incapable of debris-producing failure
4.4-2	Compliant	On board energy source (batteries) incapable of debris-producing failure
4.4-3	Not applicable	No planned breakups
4.4-4	Not applicable	No planned breakups
4.5-1	Compliant	
4.5-2	Not applicable	
4.6-1(a)	Compliant	Worst case lifetime 3.6 yrs
4.6-1(b)	Not applicable	
4.6-1(c)	Not applicable	
4.6-2	Not applicable	
4.6-3	Not applicable	
4.6-4	Not applicable	Passive disposal
4.6-5	Compliant	
4.7-1	Compliant	Non-credible risk of human casualty
4.8-1	Compliant	No planned tether release under ELaNa-22 mission

Section 1: Program Management and Mission Overview

The ELaNa-22 mission is sponsored by the Human Exploration and Operations Mission Directorate at NASA Headquarters. The Program Executive is Jason Crusan. Responsible program/project manager and senior scientific and management personnel are as follows:

ASTERIA: Dr. Sara Seager (MIT), Principle Investigator; Mary White (JPL), Project Manager

RBLE: Dr. Jones and Dr. Kepko (NASA GSFC), Principle Investigator; Luis Santos (NASA GSFC), Project Manager

LAICE: Dr. G. Swenson (University of Illinois), Principle Investigator; Dr. Ghosh (University of Illinois), Project Manager

OPAL: Dr. C. Swenson, Dr. Taylor (Utah State), Principle Investigator; Mr. Fish (Space Dynamics Laboratory), Project Manager

OSIRIS-3U: Dr. Bilén (Penn. State), Principle Investigator; Mr. O’Neil (Penn. State), Project Manager

Program Milestone Schedule	
Task	**Date**
CubeSat Selection	April 18, 2016
CubeSat Delivery to NanoRacks	March 16, 2017
Launch	June 1, 2017

Figure 1: Program Milestone Schedule

The ELaNa-22 mission will be launched as an auxiliary payload on the SpaceX CRS-12 mission on a Falcon 9 FT launch vehicle from CCAFS, FL. The ELaNa-22 compliment, will deploy 5 pico-satellites (or CubeSats). The CubeSat slotted position is identified in Table 2: ELaNa-22 CubeSats. The ELaNa-22 manifest includes: ASTERIA, RBLE, LAICE, OSIRIS-3U, and OPAL. The current launch date is in June 1, 2017. The 5 CubeSats are to be ejected from a NanoRack's ISS deployer sometime after the launch date, placing the CubeSats in an orbit approximately 412 X 400 km at inclination of 51.6 deg (ref. (h)).

Each CubeSat ranges in sizes from a 10 cm cube to 10 cm x 10cm x 30 cm, with masses from about 2 kg to ~11.7 kg total. The CubeSats have been designed and universities and government agencies and each have their own mission goals.

Section 2: Spacecraft Description

There are 5 CubeSats flying on the ELaNa-22 Mission. Table 2: ELaNa-22 CubeSats outlines their generic attributes.

Table 2: ELaNa-22 CubeSats

CubeSat Quantity	CubeSat size	CubeSat Names	CubeSat Masses (kg)
1	6U (23.9cm X 36.6cm X 11.6cm)	ASTERIA	11.67
1	6U (23.9cm X 36.9cm X 10.1cm)	RBLE	9.31
1	6U (22.63cm X 36.6cm X 10cm)	LAICE	6.08
1	3U (10cm X 10 cm X 34.05cm)	OSIRIS-3U	2.0
1	3U (10cm X 10cm X 36.8cm)	OPAL	5.00

The following subsections contain descriptions of these 5 CubeSats.

ASTERIA – Jet Propulsion Laboratory – 6U

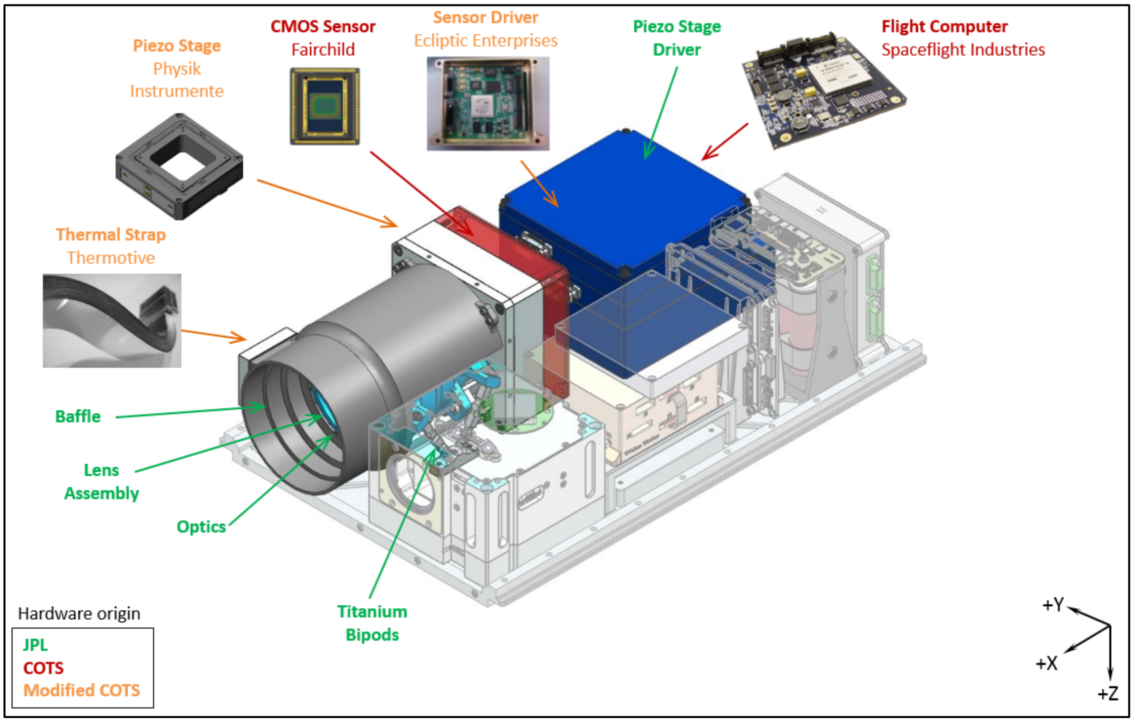

Figure 2. ASTERIA Payload Components.

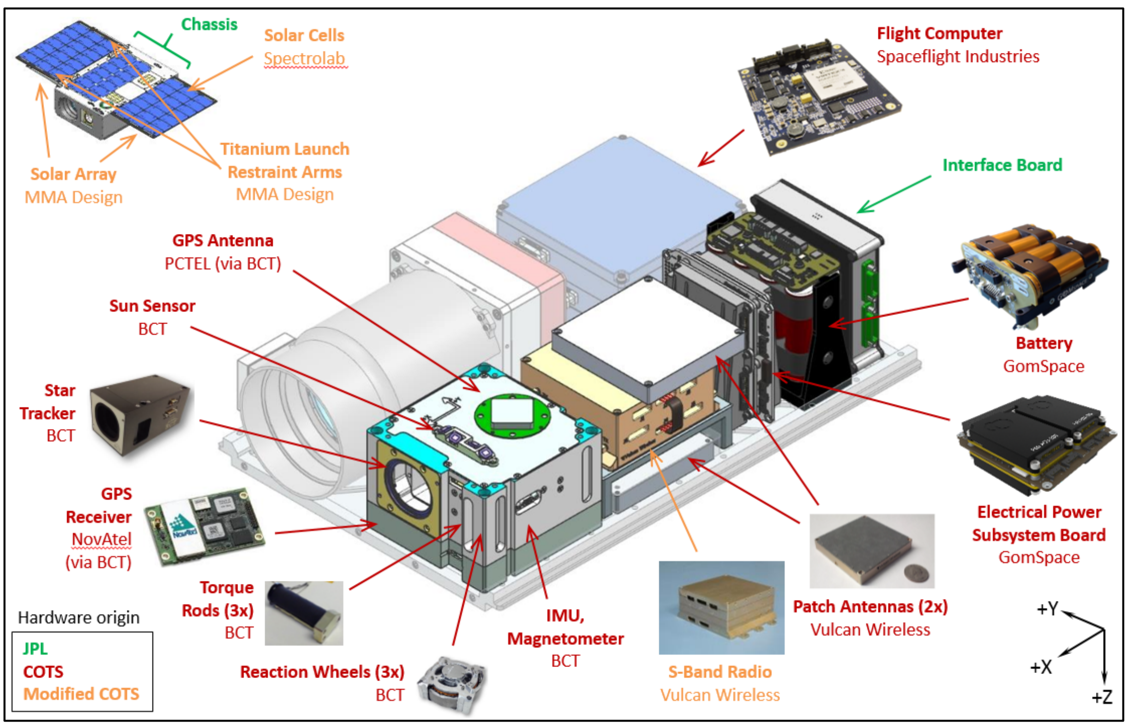

Figure 3. ASTERIA Bus Components.

Overview

ASTERIA is a technology demonstration mission to advance capabilities in areas that enable photometric studies of astrophysical phenomena using CubeSats. The mission objectives are to 1) demonstrate high precision optical line-of-sight pointing, 2) demonstrate high precision focal plane temperature control, 3) conduct proof-of-concept photometric measurements and deliver data to MIT.

The ASTERIA flight system is a 6U CubeSat (roughly 10 x 20 x 30 cm, 12 kg) that will operate in low-Earth orbit. The payload consists of a lens and baffle assembly, a CMOS imager, and a two-axis piezoelectric positioning stage on which the focal plane is mounted. A set of commercial reaction wheels provides coarse attitude control (Blue Canyon Technologies XACT). Fine pointing control is achieved by tracking a set of guide stars on the CMOS sensor and moving the piezoelectric stage to compensate for residual pointing errors. Precision thermal control is achieved by isolating the payload from the spacecraft bus, passively cooling the detector, and using trim heaters to perform small temperature corrections over the course of an observation.

CONOPS

Once deployed from the P-POD, a 30 minute timer will start. The solar panels are held down by two launch restraint arms with a nichrome melt wire over a Delrin pin at the end of each launch restraint arm. After the timer expires, current passes through the melt wires, heating them up and cutting through the Delrin pins. This releases the restraint arms and deploys the solar panels.

The XACT attitude determination and control unit will then begin detumbling the spacecraft. Once detumble and sun acquisition is complete, the radio beacon will be activated. For the first few passes the ground station operators will attempt communications to perform checkouts of the spacecraft.

Following checkout, payload tests and technology demonstration activities will begin and continue for approximately 60 days. The baseline mission duration is 90 days.

Materials

The CubeSat external structure is made of aluminum 7075-T7351. Internal structural components are made of aluminum 7075-T7351 and aluminum 6061-T6. The spacecraft primarily contains standard commercial off the shelf (COTS) materials, electrical components, and PCBs. The solar cells are Spectrolab UTJ cells. The launch restraint arms are titanium and the mass of each is currently estimated to be 21 g.

The optical payload contains five glass lens elements mounted in an aluminum barrel (both 7075-T7351 and 6061-T6 are used for the lens barrel). The lens barrel is attached to the spacecraft chassis with three bipods, each made from Ti-6Al-4V. Two of the bipods weigh 13 and one of the bipods weighs 17 g. The piezo stage is aluminum 5083.

Hazards

ASTERIA contains no pressure vessels, hazardous or exotic materials.

Batteries

The power system (EPS card and batteries) are from GomSpace. The batteries are Lithium Ion 18650 cells (4.1V), specifically LG Chem ICR18650 2600mAh. There are 8 of these cells total in the spacecraft. The UL listing number is considered by GomSpace to be proprietary information and is therefore not available to JPL. The number has been provided to NanoRacks via a non-disclosure agreement with GomSpace.

RBLE – NASA Goddard Space Flight Center – 6U CubeSat

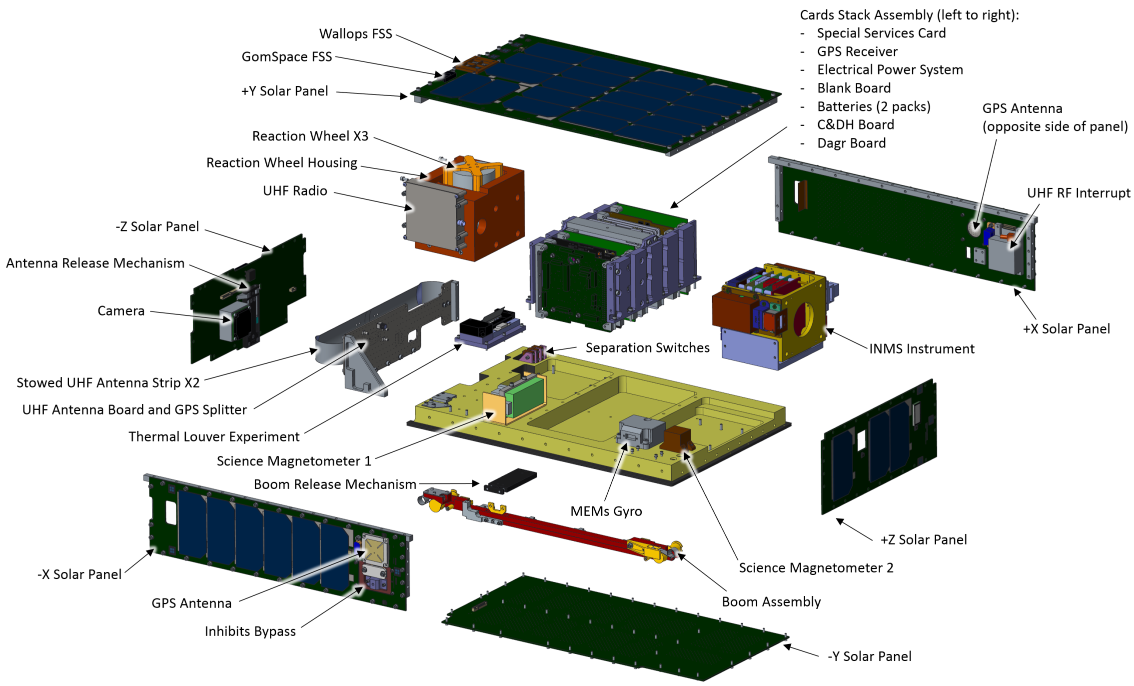

Figure 4: RBLE Expanded View

Overview

RBLE's science objectives are focused on understanding the role of solar wind energy deposition on composition changes in Earth's upper atmosphere. RBLE carries two science-grade magnetometer systems that will measure energy coupling between the ionosphere and magnetosphere as detected by field aligned current magnetic perturbations. RBLE also carries an ion/neutral mass spectrometer that will measure both neutral and ion relative composition changes, in particular the O/N2 ratio, in relation to the FACs and other measures of space weather, such as Dst. This science will complement science from the 6U LAICE cubesat and the ICON and GOLD Heliophysics Explorer missions to provide a comprehensive suite of in situ and remote measurements of mid and low latitude electrodynamics.

CONOPS

RBLE will immediately turn on after deployment from NanoRacks deployer. This will enable the power system, computer and radio. The software will boot up and identify it as the first boot of the mission and will initiate a 30-minute timer for deployments. Other components such as sun sensors and reaction wheels will be checked and the spacecraft will move into a Sun pointing mode while waiting for the timer to expire. The software will initiate deployments after timer expiration. The radio turns on immediately after deployment and stays in receiving/standby mode. The only way to initiate communication with the satellite is through a ground command to ensure no transmission will happen during the first 30 minutes after deployment. Commissioning period starts and should last about 1 week. RBLE will operate for a minimum of 3 months. No deorbit maneuver is planned since analysis has shown the satellite will easily comply with the 25-year orbit lifetime requirement.

Materials

Structural components are mainly Aluminum 7075 and 6061. Fasteners include stainless steel, A286 steel, titanium and brass. Other constructions include PCBs, COTS electrical systems and solar cells with coverglass.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Batteries

The electrical power storage system consists of lithium-polymer batteries with over-voltage, low-voltage and over-current protection circuitry. In addition the electrical power system includes a second layer of these 3 critical protections. The batteries contain 3 independent inhibits to disable the batteries while inside the deployer per NanoRacks ICD. The lithium-polymer battery cells Underwriters Laboratories number is UL1642.

LAICE – UIUC/VT – 6U

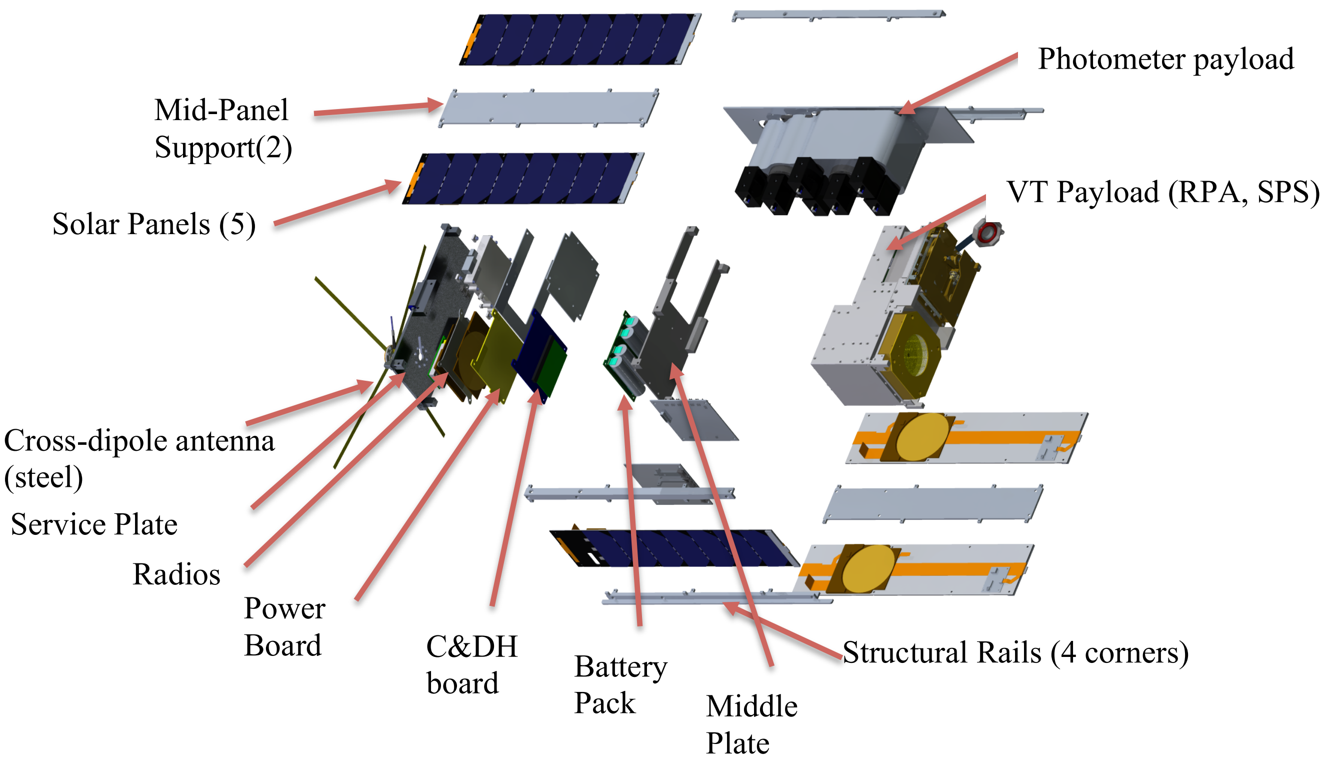

Figure 5: LAICE Expanded View

Overview

LAICE will investigate the energy and momentum transfer of waves produced by low-atmosphere weather systems to the mesosphere, lower thermosphere and ionosphere. It will observe gravity waves with large vertical wavelengths in the lower F-regions and correlate on a global scale to airglow perturbations in the upper mesosphere.

CONOPS

Thirty minutes after all three separations switches register deployment, the power board will set a flag to initiate full boot. The C&DH will be brought online, and attempt to fire the thermal knives to release the antenna. After three attempts, it will begin a Bdot detumbling algorithm to attempt to reduce all angular motion. Beaconing will begin after the antenna has attempted deployment. Once we are able to uplink its TLE and a datestamp update, the ADCS algorithm will switch to controlling the satellite such that the VT payload is the ram, and the photometer payload is nadir. After a few weeks of commissioning and testing the payloads, science operations will begin. This primarily encompasses taking simultaneous data on all three payloads (SPS, RPA, Photometers) and looking for correlations. This can only be done during eclipse. Data will be transmitted down on the CadetU radio to Wallops, while commands will be transmitted on UHF from VT or UIUC on a Lithium-2 radio. Science will continue until the satellite re-enters.

Materials

Satellite structure is made from AL60601T6, while the solar panels are Carbon fiber with an aluminum backing. The VT payload contains significant portions of stainless steel. PCBs are made from FR-4 and using automotive grade or worse components.

Hazards

There are no hazardous systems on board. There are no pressure vessels nor thrusters nor any chemical reactants.

Batteries

The electrical power storage system consists of common lithium-ion batteries with over-charge/current protection circuitry. The charging system incorporates an MPPT logic. The lithium batteries carry the UL-listing number MH12210.

OSIRIS-3U –Pennsylvania State University Student Space Programs Laboratory – 3U

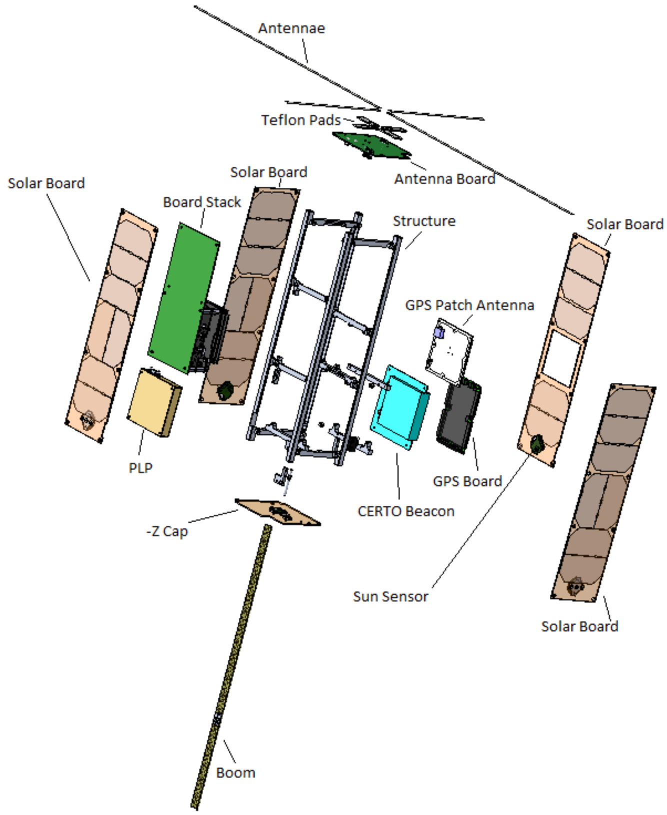

Figure 6: OSIRUS-3U Expanded View

Overview

OSIRIS-3U will provide *in situ* and remote sensing measurements of the spatial characteristics of the stimulated ionosphere. These measurements will be correlated with ground-based measurements to better understand variable space weather. Measurements will be taken using three scientific instruments. Scientific instruments include a Pulsed Langmuir Probe (PLP), the Coherent Electromagnetic Radio Tomography (CERTO) beacon, and the Compact Total Electron Content Sensor (CTECS). The Pennsylvania State Student Space Programs Laboratory will be coordinating with Arecibo Observatory in Puerto Rico. At predefined times the Arecibo Observatory will activate their atmospheric heaters. The OSIRIS-3U satellite will pass through the heated region and take measurements using devices described above.

CONOPS

Upon deployment from the ISS, OSIRIS-3U will begin charging its batteries and a timer will begin. After 45 minutes, the antennas and boom will be deployed and the GPS receiver will be activated. The satellite will begin beaconing once 3 GPS points have been collected and the battery has sufficient charge. After contact with ground has been made the satellite will continue to beacon less frequently, and will enter an idle state. At predetermined times the satellite will pass through a synthetically heated region of the ionosphere and take measurements with the suite of instruments described above.

Scientific data will be collected and periodically downlinked to the State College, Pennsylvania earth station. The mission will last approximately one year.

Material

The satellite frame will be 3D printed in AlSi10Mg or constructed from 6061 aluminum. The power and communications subsystem are built upon COTS modules. The communications subsystem makes use of the Astronautical Development Lithium-1 radio, and the power subsystem uses the Clyde Space Third Generation EPS and the 10Whr Lithium Polymer battery. The boom required for the PLP is built from LoadPath P/N 1106-03TS-0050-180-041-005 polymer. Solar cells will be secured to the cover glass using Dow Corning 93-500 epoxy. The solar cells to be used are SolAero Technologies' ZTJ space solar cell. In order to have large enough conducting body for the PLP's measurements the cover glass for the solar panels will be coated with a thin layer of indium tin oxide (ITO). All bolts will use Loctite 242 or 247 to ensure thread all threads remain locked. Both the communications and science antennas will be constructed from steel measuring tape. Teflon will be used on the antenna mount to provide isolation from the body of the craft. All electrical components are standard and commercially available.

Hazards

There are no pressure vessels or hazardous materials on the satellite. The solar panel cover glass will be coated with ITO. A boom constructed from LoadPath P/N 1106-03TS-0050-180-041-005 polymer will be used. The communications and science antennas will be constructed from steel measuring tape.

Batteries

The electrical power storage system consists of the Clyde Space Third Generation 10Whr Lithium Polymer battery. The battery has over-charge, over-current, over-voltage, and under-voltage protection circuitry. The battery is qualified to NASA standards EP-Wi-032

OPAL – University of Maryland, Baltimore County (UMBC) – 3U

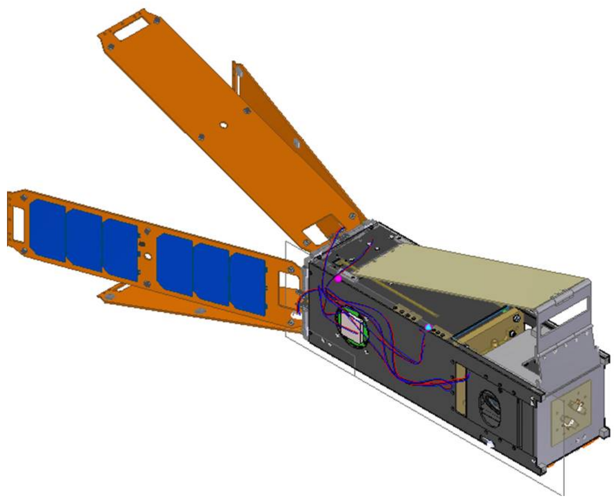

Figure 7: OPAL 3D Rendering

Overview

The Optical Profiling of the Atmospheric Limb (OPAL) experiment is designed to measure temperature-altitude profiles of molecular oxygen in the middle atmosphere from 90-140 km. These profiles are also sampled across the limb, effectively sampling three-dimensional temperature. OPAL plans to observe the temperature response of the atmosphere during geomagnetic storms and as gravity waves propagate upware. The OPAL payload is a hyperspectral imager that focuses incoming light onto a slit array, re-collimates the light, disperses it through a transmissive grating, then re-images onto the a focal plane array. This technique allows for high-resolution vertical sampling, low-resolution horizontal sampling, and sufficient spectral resolution to determine oxygen temperatures, all with no moving parts. The spacecraft is a 3-axis stabilized 3U CubeSat, pointing continuously at the atmospheric limb.

CONOPS

Upon deployment from the ISS NanoRacks Deployer, OPAL will power up and start counting down timers. At 30 minutes, the antennas and solar array will be deployed, then at 45 minutes the UHF Radio will be activated and able to transmit but still only upon command from the ground. For the first few passes the ground station operators will attempt communications to perform checkouts of the spacecraft. Approximately 4 days from launch, payload tests will begin and continue for 4-6 months until the spacecraft burns up in the atmosphere.

Materials

The CubeSat structure is made of Aluminum 7075. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells designed for use in CubeSats.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Batteries

The electrical power storage system consists of common lithium-ion batteries with over-charge/current protection circuitry. They are provided by ClydeSpace.

Section 3: Assessment of Spacecraft Debris Released during Normal Operations

The assessment of spacecraft debris requires the identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material.

The section 3 requires rationale/necessity for release of each object, time of release of each object, relative to launch time, release velocity of each object with respect to spacecraft, expected orbital parameters (apogee, perigee, and inclination) of each object after release, calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO), and an assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2.

No releases are planned on the ELaNa-22 CubeSat mission therefore this section is not applicable.

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

There are NO plans for designed spacecraft breakups, explosions, or intentional collisions on the ELaNa-22 mission.

The probability of battery explosion is very low, and, due to the very small mass of the satellites and their short orbital lifetimes the effect of an explosion on the far-term LEO environment is negligible (ref (h)).

The CubeSats batteries still meet Req. 56450 (4.4-2) by virtue of the HQ OSMA policy regarding CubeSat battery disconnect stating;

> “CubeSats as a satellite class need not disconnect their batteries if flown in LEO with orbital lifetimes less than 25 years.” (ref. (h))

ELaNa-22 manifest three, 6U CubeSats which are not included in the 3U or smaller mentioned in ref. (h). However, all three of these CubeSats have protective circuitry in their designs and COTS components.

ASTERIA’s EPS and battery system has thermal regulation circuitry. LAICE has over-charge / current protection circuitry and MPPT charging logic. RBLE has two levels of over voltage, low-voltage, and over current protection circuitry as well as 3 independent inhibits while stowed in it’s deployer. All three 6U CubeSats are using UL listed battery cells.

Limitations in space and mass prevent the inclusion of the necessary resources to disconnect the battery or the solar arrays at EOM. However, the low charges and small battery cells on the CubeSat’s power system prevents a catastrophic failure, so that passivation at EOM is not necessary to prevent an explosion or deflagration large enough to release orbital debris.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum cubesat lifetime of 3.6 years maximum the ELaNa-22 CubeSat is compliant.

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

Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft takes into account both the mean cross sectional area and orbital lifetime.

The largest mean cross sectional area (CSA) among the five CubeSats is that of the ASTERIA CubeSat with solar arrays deployed (23.9 X 36.6 X 11.6 cm with two deployed arrays each 23.9cm X 36.6cm):

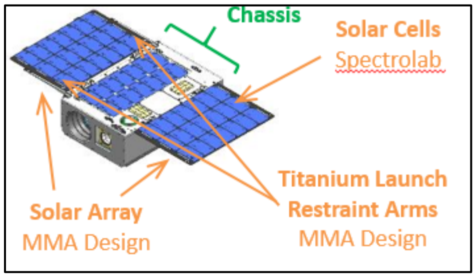

Figure 8: ASTERIA Deployed Config

$$\boldsymbol{Mean\ CSA} = \frac{\sum \boldsymbol{Surface\ Area}}{\mathbf{4}} = \frac{[\mathbf{2} * (\boldsymbol{w} * \boldsymbol{l}) + \mathbf{4} * (\boldsymbol{w} * \boldsymbol{h})]}{\mathbf{4}}$$

Equation 1: Mean Cross Sectional Area for Convex Objects

$$\boldsymbol{Mean\ CSA} = \frac{(\boldsymbol{A_{max}} + \boldsymbol{A_1} + \boldsymbol{A_1})}{\mathbf{2}}$$

Equation 2: Mean Cross Sectional Area for Complex Objects

All CubeSats evaluated for this ODAR are stowed in a convex configuration, indicating there are no elements of the CubeSats obscuring another element of the same CubeSats from view. Thus, mean CSA for all stowed CubeSats was calculated using Equation 1. This configuration renders the longest orbital life times for all CubeSats.

Once a CubeSat has been ejected from the ISS and deployables have been extended Equation 2 is utilized to determine the mean CSA. A_{max} is identified as the view that yields the maximum cross-sectional area. A_1 and A_2 are the two cross-sectional areas orthogonal to A_{max}. Refer to Appendix A for component dimensions used in these calculations

The ASTERIA (11.67 kg) orbit at deployment is 412km apogee altitude by 400 km perigee altitude, with an inclination of 51.6 degrees. With an area to mass ratio of 0.07 m^2/kg, DAS yields 3.6 years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability. Even with the variation in CubeSat design and orbital lifetime ELaNa-22 CubeSats see an average of 0.00000 probability of collision. All CubeSats on ELaNa-22 were calculated to have a probability of collision of 0.00000. Table 4 below provides complete results.

There will be no post-mission disposal operation. As such the identification of all systems and components required to accomplish post-mission disposal operation, including passivation and maneuvering, is not applicable.

Table 3: CubeSat Orbital Lifetime & Collision Probability

	CubeSat	ASTERIA	RBLE	LAICE	OSIRIS-3U	OPAL
	Mass (kg)	11.67	9.31	6.085	2.0	5.00
Stowed	Mean C/S Area (m^2)	0.086	0.0813645	0.0710279	0.03905	0.0418
	Area-to Mass (m^2/kg)	0.007	0.009	0.0117	0.020	0.008
	Orbital Lifetime (yrs)	**3.6**	**3.2**	**2.3**	**1**	**3.4**
	Probability of collision (10^X)	**0.00000**	**0.00000**	**0.00000**	**0.00000**	**0.00000**
Deployed	Mean C/S Area (m^2)	0.189	0.1224255	0.072377275	0.057272	0.092685182
	Area-to Mass (m^2/kg)	0.016	0.013	0.0119	0.029	0.019
	Orbital Lifetime (yrs)	**1.4**	**2**	**2.2**	**0.6**	**1.1**
	Probability of collision (10^X)	**0.00000**	**0.00000**	**0.00000**	**0.00000**	**0**

Solar Flux Table Dated 1/26/2016

The probability of any ELaNa-22 spacecraft collision with debris and meteoroids greater than 10 cm in diameter and capable of preventing post-mission disposal is less than 0.00000, for any configuration. This satisfies the 0.001 maximum probability requirement 4.5-1.

Since the CubeSats have no capability or plan for end-of-mission disposal, requirement 4.5-2 is not applicable.

Assessment of spacecraft compliance with Requirements 4.5-1 shows ELaNa-22 to be compliant. Requirement 4.5-2 is not applicable to this mission.

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

All ELaNa-22 spacecraft will naturally decay from orbit within 25 years after end of the mission, satisfying requirement 4.6-1a detailing the spacecraft disposal option.

Planning for spacecraft maneuvers to accomplish postmission disposal is not applicable. Disposal is achieved via passive atmospheric reentry.

Calculating the area-to-mass ratio for the worst-case (smallest Area-to-Mass) post-mission disposal among the CubeSats finds ASTERIA in its stowed configuration as the worst case. The area-to-mass is calculated for is as follows:

$$\frac{\boldsymbol{Mean}\ {}^{\boldsymbol{C}}/_{\boldsymbol{S}}\,\boldsymbol{Area}\ (\boldsymbol{m^2})}{\boldsymbol{Mass}\ (\boldsymbol{kg})} = \boldsymbol{Area-to-Mass}\ (\frac{\boldsymbol{m^2}}{\boldsymbol{kg}})$$

Equation 3: Area to Mass

$$\frac{0.086\, m^2}{11.67 kg} = 0.007 \frac{m^2}{kg}$$

ASTERIA has the smallest Area-to-Mass ratio and as a result will have the longest orbital lifetime. The assessment of the spacecraft illustrates they are compliant with Requirements 4.6-1 through 4.6-5.

DAS 2.0.2 Orbital Lifetime Calculations:

DAS inputs are: 412 km maximum apogee 400 km maximum perigee altitudes with an inclination of 52 degrees at deployment no earlier than June 2017. An area to mass ratio of 0.007 m^2/kg for the ASTERIA CubeSat was imputed. DAS 2.0.2 yields a 3.6 years orbit lifetime for ASTERIA in its stowed state.

This meets requirement 4.6-1. For the complete list of CubeSat orbital lifetimes reference **Table 3**.

Assessment results show compliance.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on ELaNa-22 was performed. The assessment used DAS 2.0, a conservative tool used by the NASA Orbital Debris Office to verify Requirement 4.7-1. The analysis is intended to provide a bounding analysis for characterizing the survivability of a CubeSat's component during re-entry. For example, when DAS shows a component surviving reentry it is not taking into account the material ablating away or charring due to oxidative heating. Both physical effects are experienced upon reentry and will decrease the mass and size of the real-life components as the reenter the atmosphere, reducing the risk they pose still further.

The following steps are used to identify and evaluate a components potential reentry risk relative to the 4.7-1 requirement of having less than 15 J of kinetic energy and a 1:10,000 probability of a human casualty in the event the survive reentry.

1. Low melting temperature (less than 1000 °C) components are identified as materials that would never survive reentry and pose no risk to human casualty. This is confirmed through DAS analysis that showed materials with melting temperatures equal to or below that of copper (1080 °C) will always demise upon reentry for any size component up to the dimensions of a 1U CubeSat.

2. The remaining high temperature materials are shown to pose negligible risk to human casualty through a bounding DAS analysis of the highest temperature components, stainless steel (1500°C). If a component is of similar dimensions and has a melting temperature between 1000 °C and 1500°C, it can be expected to posses the same negligible risk as stainless steel components. See Table 4 and Table 4.

Table 4: ELaNa-4 High Melting Temperature Material Analysis (1/2)

CubeSat	Name	Material	Mass (g)	Demise Alt (km)	Kenetic Energy (J)
ASTERIA	Solar Panel Restraint Arms	Titanium (generic)	21	0	9
ASTERIA	Lens Bipod "L"	Titanium (generic)	13	0	1
ASTERIA	Lense Bipod "V"	Titanium (generic)	17	0	2
ASTERIA	ASTERIA FASTENERS	Stainless Steel (generic)	1	77	0
RBLE	linear spring	Stainless Steel (generic)	0.0004	78	0
RBLE	Constant Torque Spring	Stainless Steel (generic)	0.0029	78	0
RBLE	Boom Rel Pin	Titanium (generic)	0.0008	78	0
RBLE	Switch slider	Stainless Steel (generic)	0.0069	78	0
RBLE	Spring Roller Shaft	Titanium (generic)	0.0009	78	0
RBLE	Hinge Shaft	Titanium (generic)	0.0004	78	0
RBLE	Rel Mech Pins	Stainless Steel (generic)	0.0058	78	0
RBLE	UHF Antenna	Stainless Steel (generic)	0.0228	78	0
RBLE	Misc 1	Stainless Steel (generic)	0.0017	78	0

Table 5: ELaNa-22 High Melting Temperature Material Analysis (2/2)

CubeSat	Name	Material	Mass (g)	Demise Alt (km)	Kenetic Energy (J)
RBLE	Misc 2	Stainless Steel (generic)	0.0009	78	0
RBLE	Misc 3	Stainless Steel (generic)	0.0011	78	0
RBLE	Misc 4	Stainless Steel (generic)	0.002	78	0
RBLE	Misc 5	Stainless Steel (generic)	0.0024	78	0
RBLE	Misc 6	Stainless Steel (generic)	0.0047	78	0
RBLE	Misc 7	Stainless Steel (generic)	0.0044	78	0
RBLE	Misc 13	Titanium (generic)	0.0003	78	0
RBLE	Misc 14	Titanium (generic)	0.0007	78	0
RBLE	Misc 15	Titanium (generic)	0.001	78	0
RBLE	Spring	Stainless Steel (generic)	0.0017	78	0
RBLE	Misc 16	Stainless Steel (generic)	0.0005	78	0
RBLE	Misc 17	Stainless Steel (generic)	0.0003	78	0
RBLE	Misc 18	Stainless Steel (generic)	0.001	78	0
RBLE	Misc 19	Stainless Steel (generic)	0.0005	78	0
RBLE	Misc 20	Stainless Steel (generic)	0.0014	78	0
RBLE	Misc 21	Stainless Steel (generic)	0.0005	78	0
RBLE	Misc 22	Stainless Steel (generic)	0.0006	78	0
RBLE	Misc 23	Stainless Steel (generic)	0.0011	78	0
RBLE	Misc 24	Stainless Steel (generic)	0.0006	78	0
RBLE	Misc 25	Stainless Steel (generic)	0.0007	78	0
RBLE	Misc 26	Stainless Steel (generic)	0.0008	78	0
RBLE	Misc 27	Stainless Steel (generic)	0.0025	78	0
RBLE	Misc 28	Stainless Steel (generic)	0.0028	78	0
RBLE	Misc 29	Stainless Steel (generic)	0.0014	78	0
RBLE	Misc 30	Stainless Steel (generic)	0.0018	78	0
RBLE	Misc 31	Stainless Steel (generic)	0.0021	78	0
RBLE	Misc 34	Stainless Steel (generic)	0.0001	78	0
RBLE	Misc 35	Stainless Steel (generic)	0.0001	78	0
RBLE	Reaction Wheel*	Stainless Steel (generic)	0.2689	0	0
LAICE	Antennae	Stainless Steel (generic)	1.0844	0	0
LAICE	Radio Support Board	Stainless Steel (generic)	0.1	0	0
LAICE	Fasteners	Stainless Steel (generic)	1	76.6	0
LAICE	Accommodation Chamber	Steel AISI 304	507	0	270
LAICE	T-Baffle	Steel AISI 304	39.92	0	11
LAICE	MCP Mount Bottom	Steel AISI 304	50	0	17
LAICE	MCP Top Bracket	Steel AISI 304	11.793402	72.8	0
LAICE	Release Mechanism Base	Steel AISI 304	360.605934	0	213
LAICE	Release Mech Cover Plate	Steel AISI 304	66.224486	0	7
LAICE	SPS Release Cap	Steel AISI 304	55	70.3	0
LAICE	Latch Arm	Steel AISI 304	20	0	5
LAICE	Aperture Plate	Steel AISI 316	59.776	0	6
LAICE	Collector Plate	Steel AISI 304	90.408	0	24
LAICE	RPA and LINAS Lok-tainer Rail	Stainless Steel (generic)	17.7	74.2	0
LAICE	LIIB Lok-tainer Rail	Stainless Steel (generic)	23	74.5	0
LAICE	SNeuPI Lok-tainer Rail	Stainless Steel (generic)	15.42	73.9	0
LAICE	VT Payload Fasteners	Stainless Steel (generic)	0.01	77.6	0
OSIRIS-3U	Communications Antennae	Stainless Steel (generic)	15	0	1
OSIRIS-3U	Science Antennae	Stainless Steel (generic)	20	0	1
OSIRIS-3U	Ejection Pins	Stainless Steel (generic)	2	75.7	0
OSIRIS-3U	Assorted Fasteners	Stainless Steel (generic)	0.01	77.9	0
OPAL	Separation Switch	Steel AISI 316	2	0	0
OPAL	RBF Switch	Steel AISI 316	2	0	0
OPAL	Standoffs	Stainless Steel (generic)	0.5	77.6	0
OPAL	OPAL Fasteners	Stainless Steel (generic)	0.25	77.1	0

Table 6: E-22 Summary of Surviving High Temperature Material Components

CubeSat	Name	Material	Mass (g)	Demise Alt (km)	Kinetic Energy (J)
ASTERIA	Solar Panel Restraint Arms	Titanium (generic)	21	0	9
ASTERIA	Lens Bipod "L"	Titanium (generic)	13	0	1
ASTERIA	Lense Bipod "V"	Titanium (generic)	17	0	2
LAICE	Accommodation Chamber	Steel AISI 304	507	0	270
LAICE	T-Baffle	Steel AISI 304	39.92	0	11
LAICE	MCP Mount Bottom	Steel AISI 304	50	0	17
LAICE	Release Mechanism Base	Steel AISI 304	360.6	0	213
LAICE	Release Mech Cover Plate	Steel AISI 304	66.2	0	7
LAICE	Latch Arm	Steel AISI 304	20	0	5
LAICE	Aperture Plate	Steel AISI 316	59.8	0	6
LAICE	Collector Plate	Steel AISI 304	90.4	0	24
OSIRIS-3U	Communications Antennae	Stainless Steel (generic)	15	0	1
OSIRIS-3U	Science Antennae	Stainless Steel (generic)	20	0	1

The majority of stainless steel components demise upon reentry. And all CubeSats comply with the 1:10,000 probability of Human Casualty Requirement 4.7-1. A break down of the determined probabilities follows:

Table 7: Requirement 4.7-1 Compliance by CubeSat

Name	Status	Risk of Human Casualty
ASTERIA	Compliant	1:0
RBLE	Compliant	1:0
LAICE	Compliant	1:32400
OSIRIS-3U	Compliant	1:0
OPAL	Compliant	1:0

*Requirement 4.7-1 Probability of Human Casualty > 1:10,000

If a component survives to the ground but has less than 15 Joules of kinetic energy it is not included in the Debris Casualty Area that inputs into the Probability of Human Casualty calculation. Which is why CubeSats that have surviving components like ASTERIA, RBLE, OSIRIS-3U, and OPAL have a 1:0 probability as none of their components have more than 15J of energy. LAICE has 4 components with greater than 15J of energy but because of their small size, the CubeSat's probability exceeds the NASA requirement by 3x.

All CubeSats launching under the ELaNa-22 mission are shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

See the Appendix for a complete accounting of the survivability of all CubeSat components.

Section 8: Assessment for Tether Missions

ELaNa-22 CubeSats will not be deploying any tethers.

ELaNa-22 CubeSats satisfy Section 8’s requirement 4.8-1.

Section 9-14

ODAR sections 9 through 14 for the launch vehicle are not covered here.

If you have any questions, please contact the undersigned at 321-867-2958.

/original signed by/

Justin Treptow
Flight Design Analyst
NASA/KSC/VA-H1

cc: VA-H/Mr. Carney
VA-H1/Mr. Beaver
VA-H1/Mr. Haddox
VA-G2/Mr. Atkinson
VA-G2/Mr. Marin
SA-D2/Mr. Frattin
SA-D2/Mr. Hale
SA-D2/Mr. Henry
Analex-3/Mr. Davis
Analex-22/Ms. Ramos

Appendix Index:

Appendix A. ELaNa-22 Component List by CubeSat: ASTERIA

CUBESAT	Row Number	Name	Qty	Material	Body Type	Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp	Survivability
ASTRIA	1	ASTERIA	-	-	-	-	-	-	-	-	-	-
ASTRIA	2	CubeSat Structure	1	Aluminum 6061	Box	3742	239	366	116	No	-	Demise
ASTRIA	3	Antennae	2	Aluminum 6061	Box	76	82	82	13	No	-	Demise
ASTRIA	4	Solar Panels	2	Graphite composite	Box	370	239	366	4	No	-	Demise
ASTRIA	5	Solar Panel Restraint Arms	2	Titanium	Box	21	220	5	5	Yes	1660	Survives with 9J. See Table 4 & 5
ASTRIA	6	Sep Switches	4	Phenolic	Box	2	12.7	6.35	20.3	No	-	Demise
ASTRIA	7	GPS Antenna	1	Ceramic	Box	16	30	30	7	No	-	Demise
ASTRIA	8	Battery Assembly	8	Various	Box	470	78	40	85	No	-	Demise
ASTRIA	9	Blue Canyon Technologies XACT (ADCS Assembly)	1	Aluminum 6061	Box	1050	100	100	69	No	-	Demise
ASTRIA	10	Sensor Driver Board	1	FR4	Box	70	90	90	5	No	-	Demise
ASTRIA	11	Piezo Driver Board	1	FR4	Box	95	90	90	5	No	-	Demise
ASTRIA	12	Radio	1	Aluminum 6061	Box	370	82	82	38	No	-	Demise
ASTRIA	13	Power Board	1	FR4	Box	215	92	88.9	30.4	No	-	Demise
ASTRIA	14	C&DH Board	1	FR4	Box	94	90	90	10	No	-	Demise
ASTRIA	15	Piezo Stage	1	Aluminum 5083	Box	462	95	95	25	No	-	Demise
ASTRIA	16	Lens 1	1	Optical glass	Cylinder	109	72	10	-	No	-	Demise
ASTRIA	17	Lens 2	1	Optical glass	Cylinder	95	65	10	-	No	-	Demise
ASTRIA	18	Lens 3	1	Optical glass	Cylinder	77	60	10	-	No	-	Demise
ASTRIA	19	Lens 4	1	Optical glass	Cylinder	13	50	5	-	No	-	Demise
ASTRIA	20	Lens 5	1	Optical glass	Cylinder	17	50	5	-	No	-	Demise
ASTRIA	21	Lens Housing	1	Aluminum 7075-T7351	Tube	230	73	106	-	No	1660	Survives with 1J. See Table 4 & 5
ASTRIA	22	Lens Baffle	1	Aluminum 7075-T7351	Tube	73	85	130	-	No	1660	Survives with 2J. See Table 4 & 5

Appendix B. ELaNa-22 Component List by CubeSat: RBLE

(RBLE 1/6)

CUBESAT	Row Number	Name	Qty	Material	Body Type	Mass (lbm)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp	Survivability
RBLE	2193376	INMS Instrument	1	-	-	1.3227001	-	-	-	No	-	Demise
RBLE	219840	SSC	1	Board	-	0.1653	-	-	-	No	-	Demise
RBLE	2198811	Base plate	1	Al 7075	-	5.3132735	-	-	-	No	-	Demise
RBLE	2198812	Elbow retainer	1	Al 6061	-	0.012892649	-	-	-	No	-	Demise
RBLE	2198813	Billingsley Mag	1	-	-	0.16837987	-	-	-	No	-	Demise
RBLE	2198816	Sep Switch Bracket	1	Al 6061	-	0.03252431	-	-	-	No	-	Demise
RBLE	2198818	Thermal Louvers	1	-	-	0.2	-	-	-	No	-	Demise
RBLE	2198819	Mag harness clamp	1	Al 6061	-	0.005809722	-	-	-	No	-	Demise
RBLE	2198822	Spring drum 1	1	Al 6061	-	0.008726251	-	-	-	No	-	Demise
RBLE	2198823	Lower shoulder hinge	1	Al 6061	-	0.019455457	-	-	-	No	-	Demise
RBLE	2198824	Spring drum 2	1	Al 6061	-	0.008157211	-	-	-	No	-	Demise
RBLE	2198825	Clamp 1	1	Al 6061	-	0.0006855	-	-	-	No	-	Demise
RBLE	2198826	Clamp 2	1	Al 6061	-	0.004070887	-	-	-	No	-	Demise
RBLE	2198827	Clamp 3	2	Al 6061	-	0.001707475	-	-	-	No	-	Demise
RBLE	2198828	Clamp 4	2	Al 6061	-	0.001352711	-	-	-	No	-	Demise
RBLE	2198829	Elbow spring bracket	1	Al 6061	-	0.012261019	-	-	-	No	-	Demise
RBLE	2198831	Ecard bracket 1	7	Al 6061	-	0.01597484	-	-	-	No	-	Demise
RBLE	2198832	Ecard bracket 2	7	Al 6061	-	0.015066553	-	-	-	No	-	Demise
RBLE	2198833	Ecard side plate 1	1	Al 6061	-	0.48213241	-	-	-	No	-	Demise
RBLE	2198834	Ecard side plate 2	1	Al 6061	-	0.50608739	-	-	-	No	-	Demise
RBLE	2198835	Ecard G10 Bar	1	G10	-	0.040222839	-	-	-	No	-	Demise
RBLE	2198836	GPS spacer	4	Al 6061	-	0.000554207	-	-	-	No	-	Demise
RBLE	2198837	Harness drum	2	Al 6061	-	0.007259192	-	-	-	No	-	Demise
RBLE	2198838	Harness rail	7	Al 6061	-	0.000829466	-	-	-	No	-	Demise

(RBLE 2/6)

CUBESAT	Row Number	Name	Qty	Material	Body Type	Mass (lbm)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp	Survivability
RBLE	2198839	Magnetometer Head	1	G10	-	0.019455729	-	-	-	No	-	Demise
RBLE	2198842	Blank PC Board	1	FR4-Cu	-	0.054148706	-	-	-	No	-	Demise
RBLE	2198843	Lower Boom	1	Al 6061	-	0.10789424	10	200	10	No	-	Demise
RBLE	2198844	Upper Boom	1	Al 6061	-	0.074459882	10	200	10	No	-	Demise
RBLE	2198846	RW+Radio Housing	1	Al 6061	-	1.4896197	-	-	-	No	-	Demise
RBLE	2198849	Boom Rel Plate	1	Al 6061	-	0.003409847	-	-	-	No	-	Demise
RBLE	2198851	Camera Bracket	1	Al 6061	-	0.023331271	-	-	-	No	-	Demise
RBLE	2198854	Switch plate	3	Al 6061	-	0.00077105	-	-	-	No	-	Demise
RBLE	2198855	-Z Solar Panel	1	-	-	0.2657	-	-	-	No	-	Demise
RBLE	2198858	Spring Roller	2	Al 6061	-	0.000659274	-	-	-	No	-	Demise
RBLE	2198861	Backing Con Plate	1	Al 6061	-	0.003739812	-	-	-	No	-	Demise
RBLE	2198865	+X Solar Panel	1	-	-	0.386	-	-	-	No	-	Demise
RBLE	2198869	Boom Spacer 1	1	G10	-	0.001130361	-	-	-	No	-	Demise
RBLE	2198871	FSS Housing	1	Al 6061	-	0.020214415	-	-	-	No	-	Demise
RBLE	2198872	Boom Spacer 2	1	G10	-	0.001061337	-	-	-	No	-	Demise
RBLE	2198873	Internal Mag	1	G10	-	0.04492078	-	-	-	No	-	Demise
RBLE	2198874	RF Interrupt Bracket	1	Al 6061	-	0.04649856	-	-	-	No	-	Demise
RBLE	2198875	FSS Populated PCB	1	-	-	0.005165878	-	-	-	No	-	Demise
RBLE	2198878	Inhibit Bypass Bracket	1	Al 6061	-	0.060237277	-	-	-	No	-	Demise
RBLE	2198879	Inhibit Bypass Conn	1	Al 6061	-	0.010397538	-	-	-	No	-	Demise
RBLE	2198880	+Z Solar Panel	1	-	-	0.2826	-	-	-	No	-	Demise
RBLE	2198885	+Y Solar Panel	1	-	-	1.0692	-	-	-	No	-	Demise
RBLE	2198891	Bar 1	1	Al 6061	-	0.013257192	-	-	-	No	-	Demise
RBLE	2198892	Bar 2	1	Al 6061	-	0.080446371	-	-	-	No	-	Demise

(RBLE 3/6)

CubeSat	Part Number	Name	Qty	Material	Body Type	Mass (lbm)	Diameter / Width (mm)	Length (mm)	Height (mm)	Low Melting Temperature	Melting Temperature	Survivability
RBLE	2198893	Bar 3	1	Al 6061	-	0.012318356	-	-	-	No	-	Demise
RBLE	2198894	Bar 4	1	Al 6061	-	0.012318356	-	-	-	No	-	Demise
RBLE	2198895	-X Solar Panel	1	-	-	0.3979	-	-	-	No	-	Demise
RBLE	2198898	Bar 5	1	Al 6061	-	0.013597276	-	-	-	No	-	Demise
RBLE	2198899	Bar 6	1	Al 6061	-	0.080446371	-	-	-	No	-	Demise
RBLE	2198901	Bar 7	1	Al 6061	-	0.016267673	-	-	-	No	-	Demise
RBLE	2198902	Bar 8	1	Al 6061	-	0.033904001	-	-	-	No	-	Demise
RBLE	2198903	Bar 9	1	Al 6061	-	0.045410915	-	-	-	No	-	Demise
RBLE	2198905	-Y Solar Panel	1	-	-	0.8907	-	-	-	No	-	Demise
RBLE	2198915	Mag Card	1	-	-	0.1293	-	-	-	No	-	Demise
RBLE	2198921	Rel mech Housing	2	Al 6061	-	0.025566891	-	-	-	No	-	Demise
RBLE	2198923	Rel Mech Slider	2	Al 6061	-	0.002406386	-	-	-	No	-	Demise
RBLE	2198924	Rel Mech Holder	2	ABS Plus	-	0.000240977	-	-	-	No	-	Demise
RBLE	2198925	Rel Mech Populated PCB	2	PCB	-	0.007160192	-	-	-	No	-	Demise
RBLE	2198928	UHF Ground Bar	1	Al 6061	-	0.010363978	-	-	-	No	-	Demise
RBLE	2198929	UHF Ground Strip	2	Cu	-	0.001307695	-	-	-	No	-	Demise
RBLE	2198932	Bar 10	1	Al 6061	-	0.042948538	-	-	-	No	-	Demise
RBLE	2198933	UHF Bracket	1	Al 6061	-	0.03275073	-	-	-	No	-	Demise
RBLE	2198935	UHF Populated PCB	1	PCB	-	0.098	-	-	-	No	-	Demise
RBLE	2198938	UHF Antenna Tip	2	Al 6061	-	0.004838377	-	-	-	No	-	Demise
RBLE	2198941	GPS Antenna PCB	2	PCB	-	0.003755456	-	-	-	No	-	Demise
RBLE	2198944	GPS Antenna Patch	2	FR4-Cu	-	0.009650481	-	-	-	No	-	Demise
RBLE	2198946	GPS Antenna Bracket	2	Al 6061	-	0.005130977	-	-	-	No	-	Demise
RBLE	2274564	UHF Interrupt Cover	1	Al 6061	-	0.015216344	-	-	-	No	-	Demise

(RBLE 4/6)

CubeSat	Part Number	Name	Qty	Material	Body Type	Mass (lbm)	Diameter / Width (mm)	Length (mm)	Height (mm)	Low Melting Temperature	Melting Temperature	Survivability
RBLE	2274565	Connector Cover	1	Al 6061	-	0.004993466	-	-	-	No	-	Demise
RBLE	2274570-	INMS Screen Base	1	Al 6061	-	0.001693049	-	-	-	No	-	Demise
RBLE	3D-01-02373	Battery Pack	2	-	-	0.73193503	-	-	-	No	-	Demise
RBLE	41SM1-T	Separation Switch	3	-	-	0.006317878	-	-	-	No	-	Demise
RBLE	60089435	Radio Transciever	1	-	-	0.2205	-	-	-	No	-	Demise
RBLE	92451A074	Misc 8	8	Brass	-	0.000258098	-	-	-	No	-	Demise
RBLE	92451A076	Misc 9	18	Brass	-	0.000350505	-	-	-	No	-	Demise
RBLE	92725A510	Misc 10	6	Be Cu	-	6.81612E-05	-	-	-	No	-	Demise
RBLE	92916A310	Misc 11	10	Brass	-	6.56616E-05	-	-	-	No	-	Demise
RBLE	95395A104	Misc 12	4	Brass	-	0.000568794	-	-	-	No	-	Demise
RBLE	A712D	Computer	1	-	-	0.1274	-	-	-	No	-	Demise
RBLE	CS-XUEPS3-60	Power System	1	-	-	0.4	-	-	-	No	-	Demise
RBLE	NANOFSS	GomSpace FSS	2	-	-	0.00661387	-	-	-	No	-	Demise
RBLE	NAS1352N04-6	Misc 32	6	A286	-	0.00175911	-	-	-	No	-	Demise
RBLE	NAS1352N04-8	Misc 33	20	A286	-	0.00211132	-	-	-	No	-	Demise
RBLE	OEMV1	GPS Receiver	1	-	-	0.05119999	-	-	-	No	-	Demise
RBLE	SEN-12804	Camera	1	-	-	0.030999	-	-	-	No	-	Demise
RBLE	STIM210	MEMs Gyro	1	-	-	0.11023098	-	-	-	No	-	Demise
RBLE	_5V_MESH	INMS Mesh	1	Al 6061	-	0.000054417	-	-	-	No	-	Demise
RBLE	Others	Harness, Connectors, etc.	1	See below	-	2	-	-	-	No	-	Demise

(RBLE 5/6)

CubeSat	Part Number	Name	Qty	Material	Body Type	Mass (lbm)	Diameter / Width (mm)	Length (mm)	Height (mm)	Low Melting Temperature	Melting Temperature	Survivability
RBLE	1986K77	linear spring	3	CRES	Cylinder	0.00037962	7.62	2.54	-	Yes	1500	Demise
RBLE	2198821	Constant Torque Spring	2	CRES	Box	0.002912143	7.9502	57.15	0.381	Yes	1500	Demise
RBLE	2198848	Boom Rel Pin	1	Ti-6AL-4V	Cylinder	0.000818364	2.3876	19.304	-	Yes	1650	Demise
RBLE	2198853	Switch slider	3	CRES	Cylinder	0.006942506	7.7724	17.526	-	Yes	1500	Demise
RBLE	2198859	Spring Roller Shaft	2	Ti-6AL-4V	Cylinder	0.000933228	2.3876	21.9456	-	Yes	1650	Demise
RBLE	2198868	Hinge Shaft	2	Ti-6AL-4V	Cylinder	0.000446534	2.3876	10.414	-	Yes	1650	Demise
RBLE	2198922	Rel Mech Pins	4	CRES	Cylinder	0.005792887	3.175	40.64	-	Yes	1500	Demise
RBLE	2198931	UHF Antenna	2	CRES	Box	0.02281811	24.892	177.8	0.3302	Yes	1500	Demise
RBLE	91075A460	Misc 1	6	CRES	Cylinder	0.001660907	5.461	9.525	-	Yes	1500	Demise
RBLE	91801A154	Misc 2	12	CRES	Cylinder	0.000919556	2.9972	8.001	-	Yes	1500	Demise
RBLE	92196A105	Misc 3	2	CRES	Cylinder	0.001065325	4.6482	7.62	-	Yes	1500	Demise
RBLE	92196A140	Misc 4	1	CRES	Cylinder	0.001962846	2.1844	27.5844	-	Yes	1500	Demise
RBLE	92196A141	Misc 5	2	CRES	Cylinder	0.002378175	2.1844	33.9344	-	Yes	1500	Demise
RBLE	92196A215	Misc 6	2	CRES	Cylinder	0.004707557	2.8448	44.1198	-	Yes	1500	Demise
RBLE	92290A148	Misc 7	3	CRES	Cylinder	0.004400449	7.0104	16.002	-	Yes	1500	Demise
RBLE	95435A213	Misc 13	10	Ti-6AL-4V	Cylinder	0.000331403	3.556	8.5344	-	Yes	1650	Demise
RBLE	95435A344	Misc 14	2	Ti-6AL-4V	Cylinder	0.000737223	4.6482	10.4394	-	Yes	1650	Demise
RBLE	95435A356	Misc 15	2	Ti-6AL-4V	Cylinder	0.0009564	2.8448	15.5448	-	Yes	1650	Demise
RBLE	C0180-022-1750S	Spring	4	CRES	Cylinder	0.001733721	4.572	23.3172	-	Yes	1500	Demise
RBLE	MS21043-04	Misc 16	14	CRES	Cylinder	0.000454412	5.2324	2.8956	-	Yes	1500	Demise
RBLE	MS24693-17	Misc 17	18	CRES	Cylinder	0.000317243	4.3688	3.9624	-	Yes	1500	Demise
RBLE	MS24693-C3	Misc 18	26	CRES	Cylinder	0.001009422	2.8448	7.9248	-	Yes	1500	Demise
RBLE	MS35649-224	Misc 19	1	CRES	Cylinder	0.000454738	5.4864	1.6764	-	Yes	1500	Demise
RBLE	MS51957-13	Misc 20	28	CRES	Cylinder	0.001361899	2.8448	8.3058	-	Yes	1500	Demise

(RBLE 6/6)

CubeSat	Part Number	Name	Qty	Materia	Body Type	Mass (lbm)	Diameter / Width (mm)	Length (mm)	Height (mm)	Low Melting Temperature	Melting Temperature	Survivability
RBLE	MS51959-3	Misc 21	3	CRES	Cylinder	0.0005132	2.1844	6.35	-	Yes	1500	Demise
RBLE	MS51959-4	Misc 22	2	CRES	Cylinder	0.0006162	2.1844	7.9248	-	Yes	1500	Demise
RBLE	MS51959-8	Misc 23	1	CRES	Cylinder	0.001136182	2.1844	15.875	-	Yes	1500	Demise
RBLE	NAS1352C0 2-3	Misc 24	24	CRES	Cylinder	0.00061962	3.556	6.9596	-	Yes	1500	Demise
RBLE	NAS1352C0 2-4	Misc 25	46	CRES	Cylinder	0.000722622	3.556	8.5344	-	Yes	1500	Demise
RBLE	NAS1352C0 2-5	Misc 26	19	CRES	Cylinder	0.000825623	3.556	10.1092	-	Yes	1500	Demise
RBLE	NAS1352C0 4-10	Misc 27	4	CRES	Cylinder	0.00246353	2.8448	18.7198	-	Yes	1500	Demise
RBLE	NAS1352C0 4-12	Misc 28	4	CRES	Cylinder	0.002815741	2.8448	21.8948	-	Yes	1500	Demise
RBLE	NAS1352C0 4-4	Misc 29	167	CRES	Cylinder	0.0014069	2.8448	9.1948	-	Yes	1500	Demise
RBLE	NAS1352C0 4-6	Misc 30	23	CRES	Cylinder	0.00175911	2.8448	12.3698	-	Yes	1500	Demise
RBLE	NAS1352C0 4-8	Misc 31	9	CRES	Cylinder	0.00211132	2.8448	15.5448	-	Yes	1500	Demise
RBLE	NAS620C2	Misc 34	85	CRES	Cylinder	5.13221E-05	3.7846	0.4064	-	Yes	1500	Demise
RBLE	NAS620C4L	Misc 35	241	CRES	Cylinder	0.000109458	5.3086	0.4064	-	Yes	1500	Demise
RBLE	RW-0-01-4	Reaction Wheel*	3	CRES	Cylinder	0.26894828	50.8	25.4	-	Yes	1500	Survives to Ground with <1J

Appendix C. ELaNa-22 Component List by CubeSat: LAICE

CubeSat	Part Number	Name	Qty	Material	Body Type	Mass (g)	Diameter / Width (mm)	Length (mm)	Height (mm)	Low Melting Temperature	Melting Temperature	Survivability
LAICE	1	Right Rail	1	Aluminum 6061	Box	73.52	17.26	23.5	366.02	No	-	Demise
LAICE	2	Left Rail	1	Aluminum 6061	Box	73.52	17.26	23.5	366.02	No	-	Demise
LAICE	3	Flat Rail	1	Aluminum 6061	Box	138.03	3.176	60.296	329.52	No	-	Demise
LAICE	4	Corner Rail	2	Aluminum 6061	Box	54.532	17	17	329.52	No	-	Demise
LAICE	5	Top Service Plate	1	Aluminum 6061	Plate	293.7	99.005	226.3	25.5	No	-	Demise
LAICE	6	Side Plate	1	Aluminum 6061	Plate	147.6	2.5	80	352.4	No	-	Demise
LAICE	7	Mounting Plate	1	Aluminum 6061	Plate	215.556	100	224.7	38.977	No	-	Demise
LAICE	8	Middle Plate	1	Aluminum 6061	Plate	131.524	93.65	223.13	13.5	No	-	Demise
LAICE	9	Mounting Box	1	Aluminum 6061	Box	0.0011	20.47	68.58	12.015	No	-	Demise
LAICE	10	Antennae Assembly	1	Brass, CU, AL6061	-	-	13.902	-	6.84	No	-	Demise
LAICE	11	Antennae	4	Stainless Steel	Cylinder	1.0844	6.35	175	0.127	Yes	-	Survives with <1J. See Table 4 & 5
LAICE	12	Solar Panels	4	Carbon Fiber	Panel		80	352.4	0.97	No	-	Demise
LAICE	13	Solar Shielding	8	Aluminum 6061	Panel	77.502	80	352.4	1.016	No	-	Demise
LAICE	14	Torque Coil	10	FR-4	Plate	52.218	86	76.2	3.5	No	-	Demise
LAICE	15	Sep Switches		plastic	Box	-	2.7	8.2	11.09	No	-	Demise
LAICE	16	Other Ext comp		-	-	-	-	-	-	-	-	Demise
LAICE	17	PMT	7	Aluminum 6061	Box	85.833	36	22	45	No	-	Demise
LAICE	18	Big Lens	2	glass	Cylinder	154.857	56		114	No	-	Demise
LAICE	19	Small Lens	5	glass	Cylinder	-	30.48		66.294	No	-	Demise
LAICE	20	Batteries	4	Lithium-Ion battery chemistry	Cylinder	-	18.4	65		No	-	Demise
LAICE	21	ADCS Components (eg. Magnets)		Neodymium	Box	-	-	-	-	No	-	Demise
LAICE	22	Payload Board	1		Board		90	90	1.63	No	-	Demise
LAICE	23	CPU Board	1	Circuit Board	Board	26.106	90	90	5.6	No	-	Demise
LAICE	24	Battery Board	1	Circuit Board	Board	30.9	86	84	1.6	No	-	Demise

CubeSat	Part Number	Name	Qty	Material	Body Type	Mass (g)	Diameter / Width (mm)	Length (mm)	Height (mm)	Low Melting Temperature	Melting Temperature	Survivability
LAICE	25	Battery Tab	8	Copper	L- shaped	1.302	15.25	10.5	10	No	-	Demise
LAICE	26	Power Board	1	Circuit Board	Board	18.26	90	94	1.5	No	-	Demise
LAICE	27	FPGA Board	1	FR-4	Board	22	90	90	1.63	No	-	Demise
LAICE	28	Sensor Board	1	FR-4	Board	36	90	90	1.63	No	-	Demise
LAICE	29	Radio Support Board	1	18-8 Stainless Steel	Board	-	0.16	22.0126	9.38	Yes		Survives with <1J. See Table 4 & 5
LAICE	30	Fasteners		Stainless Steel (See items 33-73)	-	-	-	-	-	Yes		Demise
LAICE	31	Pin Fastener	4	Aluminum 6061	-	-	4.154	16.5257	-	No	-	Demise
LAICE	32	Cabling		Copper alloy, teflon insulation	-	-	-	-	-	No	-	Demise
LAICE	33	VT Mounting Plate	1	Aluminum 6061	Panel	214	100.002	224.712	38.977	No	-	Demise
LAICE	34	Accommodation Chamber	1	Stainless Steel 304	Box	507	98.425	100.025	59.512	Yes	1450	Survives with 270J. See Table 4 & 5
LAICE	35	Accommodation Chamber Gasket	1	Viton	Ring	3.51	85.8	85.8	2.36	No	-	Demise
LAICE	36	T-Baffle	1	Stainless Steel 304	Welded Plates	39.92	37.186	37.186	27.43	Yes	1450	Survives with 11J. See Table 4 & 5
LAICE	37	Emitter Mounting Bracket	1	PCTFE	Panel	4.572482536	39.497	7.696	16.51	No	-	Demise
LAICE	38	MCP Mount Bottom	1	Stainless Steel 304	Panel	118.8412	39.497	59.9694	14.5542	Yes	1450	Survives with 17J. See Table 4 & 5
LAICE	39	MCP Top Bracket	2	Stainless Steel 304	Block	11.7934016	13.1826	23.5966	11.43	Yes	1450	Demise
LAICE	40	Release Mechanism Base	1	Stainless Steel 304	Plate	360.605934	99.9998	99.9998	13.4112	Yes	1450	Survives with 213J. See Table 4 & 5
LAICE	41	Release Mech Cover Plate	1	Stainless Steel 304 (Gold Plated)	Plate	66.224486	99.9998	99.9998	9.3472	Yes	1450	Survives with 7J. See Table 4 & 5
LAICE	42	SPS Release Cap	1	Stainless Steel 304	Cylinder	56.6990463	41.46	41.46	14.3	Yes	1450	Demise
LAICE	43	Cubesat Standoff	2	Aluminum 6061	Block	4.955448154	6.5024	6.5024	8.2296	No	-	Demise
LAICE	44	SPS Cap O-ring	1	Viton	Ring	3.0086	17.7	17.7	4.7	No	-	Demise
LAICE	45	Latch Arm	4	Stainless Steel 304 (Gold Plated)	Plate	28.576319	23.291	55.779	11.43	Yes	1450	Survives with 5J. See Table 4 & 5
LAICE	46	Aperture Plate	1	Stainless Steel 304 (Gold Plated)	Plate	59.776	95.08	95.08	1.27	Yes	1450	Survives with 6J. See Table 4 & 5
LAICE	47	RPA Grids	5	Gold	Plate	1.228	75	75	0.241	No	-	Demise
LAICE	48	RPA Front Cup	1	Aluminum 6061 (Gold Plated)	Shell	85.0172	95.08	95.08	10.668	No	-	Demise

CubeSat	Part Number	Name	Qty	Material	Body Type	Mass (g)	Diameter / Width (mm)	Length (mm)	Height (mm)	Low Melting Temperature	Melting Temperature	Survivability
LAICE	49	RPA Back Cup	1	Aluminum 6061 (Gold Plated)	Shell	87.102	95.08	95.08	7.62	No	-	Demise
LAICE	50	Grid Spacer	4	PCTFE	Plate	13.58497	90	90	2.032	No	-	Demise
LAICE	51	Collector Holder	1	PCTFE	Plate	29.3099	90	90	5.08	No	-	Demise
LAICE	52	Collector Plate	1	Stainless Steel 304 (Gold Plated)	Plate	90.408	75	75	2.54	Yes	1450	Survives with 24J. See Table 4 & 5
LAICE	53	Mounting Plate Bushing	1	Aluminum 6061	Ring	4.989	31.623	31.623	11.66	No	-	Demise
LAICE	54	Machined Box Top Piece 1	1	Aluminum 6061	Panel	101	122.934	90.45	12.7	No	-	Demise
LAICE	55	Machined Right Side	2	Aluminum 6061	Panel	59	91.694	219.708	1.6	No	-	Demise
LAICE	56	End Cap SPS Side	1	Aluminum 6061	Panel	28	31.928	90.45	6.35	No	-	Demise
LAICE	57	Machined Box Bottom Piece 1	1	Aluminum 6061	Panel	53	90.45	103.65	5.41	No	-	Demise
LAICE	58	Machined Box Bottom Piece 2	1	Aluminum 6061	Panel	11	90.45	21.59	5.41	No	-	Demise
LAICE	59	Machined Box Bottom Piece 3	1	Aluminum 6061	Panel	61	90.45	121.468	5.41	No	-	Demise
LAICE	60	Tie-Rod	5	Aluminum 6061	Rod	6.8038856	6.35	6.35	90.449	No	-	Demise
LAICE	61	Machined Box Top Piece 2	1	Aluminum 6061	Panel	22	28.943	90.45	6.35	No	-	Demise
LAICE	62	RPA and LINAS Lok-tainer Rail	4	Stainless Steel 304	Box	17.690102	107.508	5.283	7.849	Yes	1500	Demise
LAICE	63	RPA Daughterboard PCB	1	FR-4	Board	4.12298	39.37	38.1	1.524	No	-	Demise
LAICE	64	RPA Motherboard PCB	1	FR-4	Board	24.6772795	101.6	86.64	1.524	No	-	Demise
LAICE	65	LINAS PCB	1	FR-4	Board	24.6772795	101.6	86.64	1.524	No	-	Demise
LAICE	66	LIIB PCB	1	FR-4	Board	38.89551555	152.4	86.64	1.524	No	-	Demise
LAICE	67	SNeuPI FPGA PCB	1	FR-4	Board	18.00774464	73.66	86.64	1.524	No	-	Demise
LAICE	68	SNeuPI Emitter Control PCB	1	FR-4	Board	18.00774464	73.66	86.64	1.524	No	-	Demise
LAICE	69	SNeuPI Daughterboard	1	FR-4	Board	4.517094199	46.99	46.99	1.524	No	-	Demise
LAICE	70	LIIB Lok-tainer Rail	2	Stainless Steel 304	Box	23	158.276	5.283	7.849	Yes	1500	Demise
LAICE	71	SNeuPI Lok-tainer Rail	4	Stainless Steel 304	Box	15.422141	82.118	5.283	7.849	Yes	1500	Demise
LAICE	72	Kapton Heater	1	Kapton and Copper	Sheet	4	50.8	50.8	0.076	No	-	Demise
LAICE	73	VT Payload Fasteners	150	Stainless Steel	Bolt	0.131096512				Yes	1500	Demise

Appendix D. ELaNa-22 Component List by CubeSat: OSIRIS-3U

CubeSat	Part Number	Name	Qty	Material	Body Type	Mass (g)	Diameter / Width (mm)	Length (mm)	Height (mm)	Low Melting Temperature	Melting Temperature	Survivability
OSIRIS	1	Communications Antennae	2	Steel Measuring Tape	Flat Plate	15	25.4	175	5	Yes	1500	Survives with 1J. See Table 4 & 5
OSIRIS	2	Science Antennae	2	Steel Measuring Tape	Flat Plate	20	25.4	425	5	Yes	1500	Survives with 1J. See Table 4 & 5
OSIRIS	3	Antenna Mounting Board	1	FR4 PCB	Flat Plate	32	92.4	97.2	13.6	No	-	Demise
OSIRIS	4	GPS Patch Antenna	1	Ceramic and copper	Box	54.575	76.2	76.2	10.3886	No	-	Demise
OSIRIS	5	PLP Boom	1	LoadPath P/N 1106-03TS-0050-180-041-005 polymer	Flat Plate	5	14.2	420	6.2	No	-	Demise
OSIRIS	6	Solar Panels, Long Face, Whole	3	ZTJ Space Solar Cell, ITO Cover Glass, FR4 PCB	Flat Plate	97	39.41	83.91	4	No	-	Demise
OSIRIS	7	Solar Panels, Long Face, Cutout	2	ZTJ Space Solar Cell, ITO Cover Glass, FR4 PCB	Flat Plate	70	39.41	83.91	4	No	-	Demise
OSIRIS	8	Solar Panels, Short Face	1	ZTJ Space Solar Cell, ITO Cover Glass, FR4 PCB	Flat Plate	44	92.4	97.2	4	No	-	Demise
OSIRIS	9	Deployment Switches	2	Multiple Compositions	Box	14.174	6.1976	15.678	19.8882	No	-	Demise
OSIRIS	10	Ejection Pins	2	18-8 Stainless Steel	Cylinder	3.7837	3.175	38.1	N/A	Yes	1500	Demise
OSIRIS	11	CubeSat Structure	1	Aluminum 6061	Box	248.14	100	100	340.5	No	-	Demise
OSIRIS	12	Clyde Space Third Gen.10Whr Li-Poly	1	Lithium Polymer Battery	Flat Plate	127	95.89	90.17	12.6	No	-	Demise
OSIRIS	13	Clyde Space Third Generation EPS	1	FR4 PCB, Standard Electronics Plastic Housing	Flat Plate	88	95.89	90.17	12.6	No	-	Demise
OSIRIS	14	COM Board - AstroDev Li-1	1	FR4 PCB, Standard Electronics Plastic Housing, Met. shield radio	Flat Plate	105	95.89	90.17	12.6	No	-	Demise
OSIRIS	15	GNC Board	1	FR4 PCB, Standard Electronics Plastic Housing	Flat Plate	49	95.89	90.17	12.6	No	-	Demise
OSIRIS	16	C&DH Board	1	FR4 PCB, Standard Electronics Plastic Housing	Flat Plate	67	95.89	90.17	12.6	No	-	Demise
OSIRIS	17	CERTO Beacon	1	Scientific instrument incased in metal housing	Flat Plate	152	95.885	90.17	16.51	No	-	Demise
OSIRIS	18	CTECS GPS Occultation Instrument	1	NovAtel OEM 6 GPS Module	Box	37	71.1	45.7	11.05	No	-	Demise
OSIRIS	19	Connector Board	1	FR4, Standard Electronics Plastic Housing	Flat Plate	98	191.78	90.17	1.57	No	-	Demise
OSIRIS	20	Sun Sensor	5	Aluminum housing, FR4 PCB	Cylinder	5	25.551	25.551	5.3	No	-	Demise
OSIRIS	21	Teflon standoffs	4	Teflon	Box	1.672	12.7	39	1.5875	No	-	Demise
OSIRIS	22	Internal Wiring Harness	1	Standard copper wire and plastic connectors	Cylinder	61	95.89	191.78	12.6	No	-	Demise
OSIRIS	23	Sun Sensor Cable	5	Flat Flex Copper/Plastic Ribbon cable	Cylinder	5	150	10	1	No	-	Demise
OSIRIS	24	RF Coaxial Cable	3	Rigid RF Coax Cable	Cylinder	12	7.9	490	7.9	No	-	Demise
OSIRIS	25	Assorted Nuts, Bolts, Washers	At least 60	18-8 Stainless Steel	Cylinder	0.8207	2.8448	2.8448	12.7	Yes	1500	Demise

Appendix E. ELaNa-22 Component List by CubeSat: OPAL

CubeSat	Part Number	Name	Qty	Material	Body Type	Mass (g)	Diameter / Width (mm)	Length (mm)	Height (mm)	Low Melting Temperature	Melting Temperature	Survivability
OPAL	1	OPAL 3U CubeSat	1	Aluminum 7075 External, Various internal	Box	5000.002	100	100	368	No	-	Demise
OPAL	2	3U Structure	1	Aluminum 7075 External, Various internal	Hollow box	475	100	100	267.2	No	-	Demise
OPAL	3	Earth Shade/Light Baffle	1	Aluminum/ G10 /Kapton B	Triangular Prism	120	76.2	279.4	82.3	No	-	Demise
OPAL	4	ADCS Structure	1	Aluminum	Box	694	100	100	62.28	No	-	Demise
OPAL	5	Deployable Solar Panels	4	FR4/GaAs/Glass	Rectangle	139.9	82	339.32	6.19	No	-	Demise
OPAL	6	Fixed Solar Panels	1	FR4/GaAs/Glass	Rectangle	115.9	82	327.51	1.52	No	-	Demise
OPAL	7	Bottom Cover (Anti-ram structure)	1	Aluminum	Square	44	96.95	96.95	14.12	No	-	Demise
OPAL	8	Top Cover (Ram structure)	1	Aluminum	Square	41	96.95	96.95	14.12	No	-	Demise
OPAL	9	UHF Antenna Assembly	1	Aluminum/FR4/	Square	60.8	3.18	139.19	0.51	No	-	Demise
OPAL	10	GPS Antenna	2	Ceramic/FR4	Circle + Square Patch	18	45.2	N/A	7.7	No	-	Demise
OPAL	11	Solar Panel Hinges	4	Aluminum/Stainless Steel	Barrel	6	5.84	82.88	8.06	No	-	Demise
OPAL	12	Separation Switch	3	Steel	Box	2	6.4	19.9	17.2	Yes	1510	Survives with <1J. See Table 4 & 5
OPAL	13	Thermal Knife Deployer	2	G10/Nichrome	Complex	1	10.88	24.32	5.08	No	-	Demise
OPAL	14	Instrument Interface Plate	2	Aluminum	Square	128	97.46	98.5	10.8	No	-	Demise
OPAL	15	ADCS Interface Plate	2	Aluminum	Square	64	97.46	100	8.32	No	-	Demise
OPAL	16	GPS Receiver	1	FR4	Rectangle	22	45.7	71.1	8.9	No	-	Demise
OPAL	17	Interface Board	1	FR4	Square	65	95.9	90.2	11	No	-	Demise
OPAL	18	Battery	1	FR4/Lithium Polymer	Box	273	95.9	90.2	20	No	-	Demise
OPAL	19	EPS Board	1	FR4	Square	56	95.9	90.2	14.5	No	-	Demise
OPAL	20	Flight Processor	1	FR4	Rectangle	17	54.61	89.535	1.6	No	-	Demise
OPAL	21	Motherboard	1		Rectangle	77	91.82	95.88	16	No	-	Demise
OPAL	22	Cadet Radio Board	1	FR4	Square	233	95.9	90.2	25.3	No	-	Demise
OPAL	23	Instrument	1	FR4/Aluminum	Complex	570	96.5	92	63.25	No	-	Demise
OPAL	24	Electronic Stack Mounts	2	Aluminum 6061-T6	Angle Bracket	44	96.95	96.95	4.7	No	-	Demise

CubeSat	Part Number	Name	Qty	Material	Body Type	Mass (g)	Diameter / Width (mm)	Length (mm)	Height (mm)	Low Melting Temperature	Melting Temperature	Survivability
OPAL	25	RBF Switch	1	Steel	Box	2	6.4	19.9	17.2	Yes	1510	Survives with <1J. See Table 4 & 5
OPAL	26	Standoffs	10	Stainless Steel	Cylinder	0.5	6.35		25.4	Yes	1500	Demise
OPAL	27	Fasteners	150	Stainless Steel	Cylinder	0.25	4.11	3.18	N/A	Yes	1500	Demise
OPAL	28	Thermal Straps	1	Copper	Complex	13.43	20	50	1.5	No	-	Demise
OPAL	29	Ballast weights	4	Lead	Rectangle	244.693	27.84	27.84	27.84	No	-	Demise