ELVL-2018-0045207
March 1, 2018

Orbital Debris Assessment for The CubeSats on the CRS OA-10/ELaNa-21 Mission per NASA-STD 8719.14A

Signature Page

Yusef Johnson, Analyst, a.i. solutions, AIS2

Scott Higginbotham, Mission Manager, NASA KSC VA-C

National Aeronautics and
Space Administration

John F. Kennedy Space Center, Florida
Kennedy Space Center, FL 32899

ELVL-XXX-XXXX

Reply to Attn of: VA-H1

March 1, 2018

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

FROM: Yusef Johnson, a.i. solutions/KSC/AIS2

SUBJECT: Orbital Debris Assessment Report (ODAR) for the ELaNa-21 Mission

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. International Space Station Reference Trajectory, delivered May 2017
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
I. HQ OSMA Email:6U CubeSat Battery Non Passivation Suzanne Aleman to Justin Treptow, 8 August 2017

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the ELaNa-21 auxiliary mission launching on the CRS OA-10 vehicle. 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 4 payloads which are part of the ELaNa-21 mission to be flown to the ISS on the CRS OA-10 using a to be determined CRS vehicle. These 4 CubeSats which are part of the ELaNa-21 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 2.3 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-21 mission

Section 1: Program Management and Mission Overview

The ELaNa-21 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 for the CubeSats discussed in this document are as follows:

TJREVERB: Michael Piccione, Project Manager, Thomas Jefferson High School

Virginia CC: Mary Sandy, Principal Investigator, Virginia Space Grant Consortium

Program Milestone Schedule	
Task	**Date**
CubeSat Selection	September 15, 2017
CubeSat Delivery to NanoRacks	July 1, 2018
Launch	November 8,~~Q3/Q4~~ 2018

Figure 1: Program Milestone Schedule

The ELaNa-21 CubeSat complement will be launched as payloads on an upcoming CRS launch vehicle to the International Space Station. The ELaNa-21 mission will deploy 4 pico-satellites (or CubeSats) from the International Space Station, using the NanoRacks CubeSat dispenser. Each CubeSat is identified in Table 2: ELaNa-21 CubeSats~~Table 2: ELaNa-21 CubeSats~~. The ELaNa-21 manifest includes: TJREVERB, Aeternitas, Ceres, and Libertas

The CubeSats on this mission range in size from a 10 cm cube to 23 cm x 10 cm x 10 cm, with masses from about 1.1 kg to 2.6 kg, with a total mass of roughly 6 kg being manifested on this mission. The CubeSats have been designed and universities and government agencies and each have their own mission goals.

Section 2: Spacecraft Description

There are 4 CubeSats in total flying on the ELaNa-21 Mission.

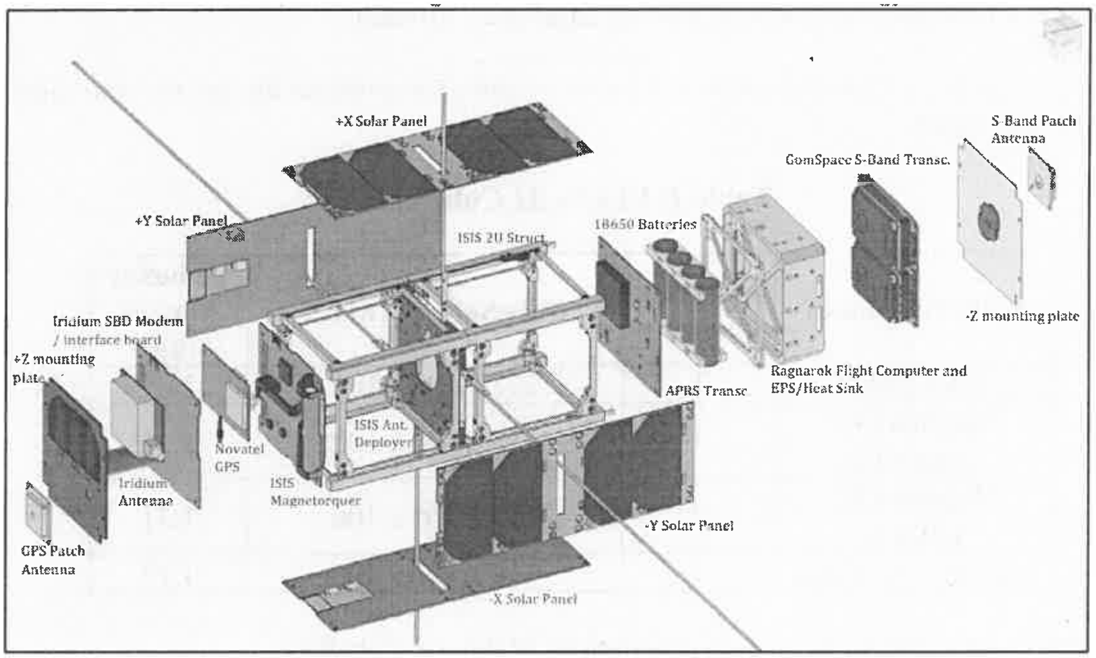
Table 2: ELaNa-21 CubeSats~~Table 2: ELaNa-21 CubeSats~~ outlines the generic attributes of these spacecraft.

Table 2: ELaNa-21 CubeSats

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Masses (kg)
TJREVERB	1	227 x 100 x 100	2.61
Virginia CC: Aeternitas	1	113 x 100 x 100	1.20
Virginia CC: Libertas	1	118 x 105 x 106	1.31
Virginia CC: Ceres	1	113 x 106 x 106	1.13

The following subsections contain descriptions of these 4 CubeSats.

TJREVERB – Thomas Jefferson High School for Science and Technology 2U



Overview

TJREVERB will be a 2U CubeSat with magnetic torque control. It will be using a VHF APRS transceiver on 145.825MHz for command and control. It will also have a 2.2-2.3 GHz transceiver and a 1.616-1.6265 GHz short burst data (SBD) modem to test the ability to send and receive data packets and compare the usage of the Near Earth Network and the Iridium satellite network. The SBD modem will also provide secondary command and control.

CONOPS

TJREVERB will be integrated into a NanoRacks CubeSat Deployer (NRCSD) prior to delivery to NASA, launched to the ISS on one of the Commercial Resupply System (CRS) missions (launch TBD), and then stored internally on the ISS and deployed by NanoRacks using the Japanese module Kibo's robotic arm. Deployment at clock 0-96 hours: Deployment and activation; power-on; self-check, after 30 mins, deploy antenna, start detumble. After 45 mins establishes communications link, establish GPS link, clock synch, orbit determination daily, transmit AMSAT APRS signals, and perform operations modes (Charging, Comms check, and update) and science modes. Science modes consist of running various transmission activities while orbiting in various attitude orientations modes such as spin-stabilized and 3-axis regulation. Clock 180+ days: disposal, continue testing as long as communications remains operational, and gracefully burn up in atmosphere.

Materials

TJREVERB's chassis is made of Aluminum 606. It contains standard commercial off-the-shelf (COTS) materials, electrical components, PCBs and solar cells.

Hazards

TJREVERB does not include any hazardous systems or pressure vessels. The only deployable mechanism is the ISIS model VHF antenna array, which will deploy four whip antennas, one each out of the center of the X and Y faces of the CubeSat. There are no articulating sections, and the spacecraft will not separate into smaller parts at any time during deployment, operation, or prior to breakup due to atmospheric re-entry. No outgassing or sublimation will take place at any time during the mission.

Batteries

The Orbtronics 18650B cell is a modified standard Panasonic 18650B NCR cell with UL listing MH12210 with flight heritage aboard past CubeSats such as GeneSat, SporeSaat, OREOS, and Pharmasat. Each cell is 65 mm in length and 18.6 mm in diameter. The Graphite/LiNiCoAlO2 (NCA) chemistry provides for maximum caoacity of 3400 mAhr at a full charge. Total of 40 Whr battery capacity is provided via 2 packs of 2 battery cells in series, @S2P, each at 20Whr.

Each cell contains a Positive Temperature Coefficient (PTC) device, Current Interrupt Device (CID), and an exhaust gas hole built into each battery cell to prevent cell rupture. The cell builds on the safety features of the 18650 cell by including a Seiko Protection Integrated Circuit (IC) that provides over voltage protections (OVP) at 4.35V, over-discharge (UVLO) protection (OCD) at 10-12A, and over-heating protection.

Aeternitas – Old Dominion University (Virginia CubeSat Constellation)

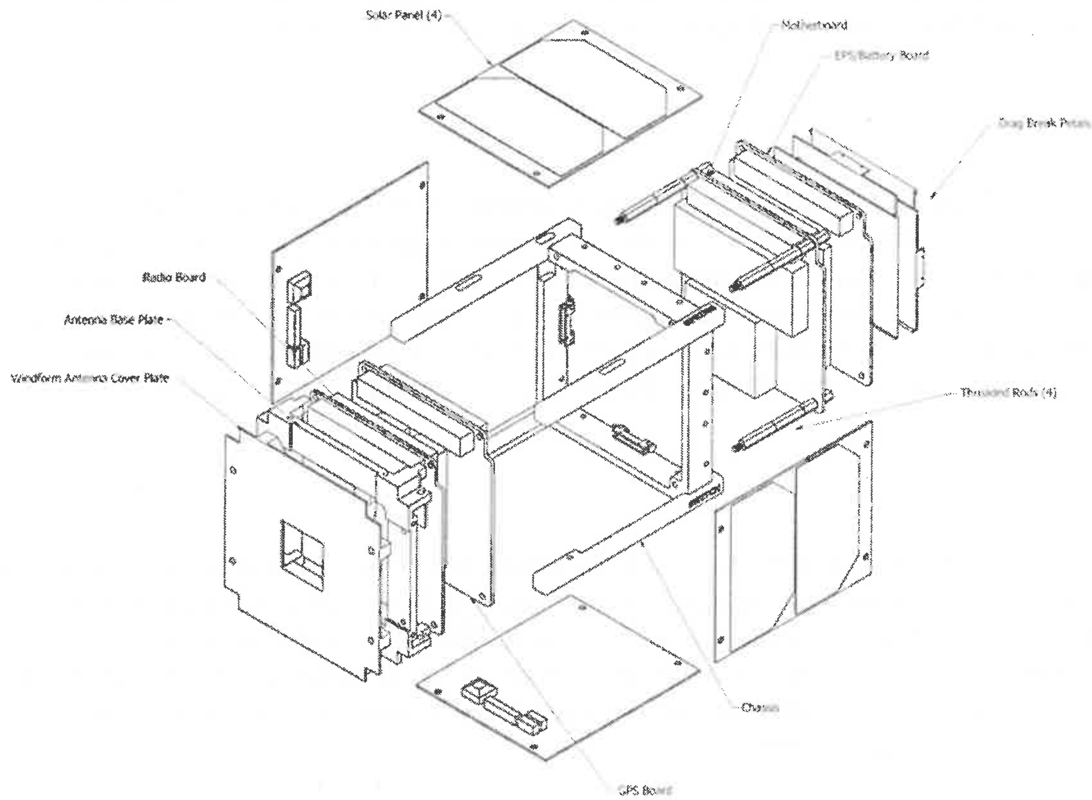


Figure 4: Aeternitas Expanded View

Overview

The Virginia CubeSat Constellation (VCC) mission is a joint operation between teams at Old Dominion University, University of Virginia, Virginia Tech, and Hampton University. ODU, UVA, and VT are each building 1U CubeSats (Aeternitas, Libertas, and Ceres, respectively) that will fly as a constellation in low earth orbit. The mission objectives are to provide undergraduate students with a hands-on flight project experience, to obtain data on atmospheric density and variability in LEO, and to test communication and relative ranging across a constellation of CubeSats. A Hampton University student team will perform analysis of spacecraft attitude, location, and orbital data to measure variations in atmospheric density in low earth orbit. Differing from Libertas and Ceres, Aeternitas will deploy a petal-like drag brake (similar to a deployable solar panel array) and will deorbit at an accelerated rate for the purposes of providing additional atmospheric drag data.

CONOPS

After deployment from the NanoRacks deployer and remaining off for the required 30min, the antenna will deploy. Once enough power has been stored and the attitude has been determined, detumbling via magnetorquers will commence in short bursts. Once the desired attitude stabilization is reached, Aeternitas will proceed with normal operations in which attitude and GPS data is recorded and inter-satellite ranging experiments are conducted with the other constellation CubeSats once per orbit. The results of these experiments, the scientific data, and health updates will be downlinked to the VT, ODU, and UVA ground stations during overflights. After initial data has been collected and downlinked, Aeternitas will deploy four drag brake petals that will remain connected to the satellite during de-orbit.

Materials

Aeternitas' chassis is made of Aluminum 6061-T6. It contains standard commercial off-the-shelf (COTS) materials, electrical components, PCBs and solar cells. The Aeternitas' payload includes a ceramic patch antenna and the cover plate for the antenna assembly will be printed from Windform.

Hazards

Aeternitas does not contain any pressure vessels, hazardous, or exotic materials.

Batteries

Aeternitas is using the GOMspace NanoPower P31u EPS which controls the charging and discharging of two 1-cell lithium-ion batteries. The EPS features under-voltage and over-voltage protection as well as over-current protection via power distribution switches.

Libertas –University of Virginia (Virginia CubeSat Constellation) – 1U

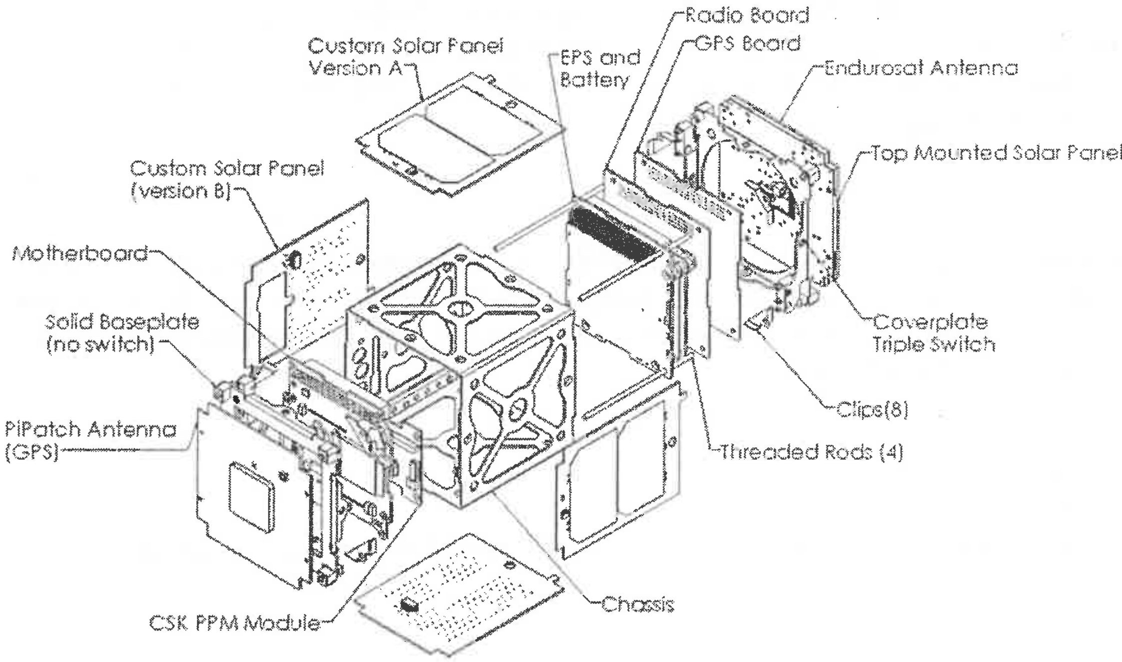


Figure 24: Libertas Expanded View

Overview

The Virginia CubeSat Constellation (VCC) mission is a joint operation between teams at Old Dominion University, University of Virginia, Virginia Tech, and Hampton University. ODU, UVA, and VT are each building 1U CubeSats (Aeternitas, Libertas, and Ceres, respectively) that will fly as a constellation in low earth orbit. The mission objectives are to provide undergraduate students with a hands-on flight project experience, to obtain data on atmospheric density and variability in LEO, and to test communication and relative ranging across a constellation of CubeSats. A Hampton University student team will perform analysis of spacecraft attitude, location, and orbital data to measure variations in atmospheric density in low earth orbit.

CONOPS

Once MemSat has been deployed and the mandated 45 minute radio silence period has passed, the antenna will be deployed and begin to run satellite diagnostics. Once the satellite is operational, it will attempt to communicate with its ground station. After a preliminary status update about the satellite has been sent, the MemSat will begin the Minimum Viable Experiment. The primary experiment will run for 30 days, with upkeep and diagnostics running in the background. After these 30 days, the mission operations team will begin to upload new experimental profiles to the MemSat to be performed.

Material

The Pumpkin CubeSat Kit 1U chassis is constructed primarily from Aluminum 5052. Internal components are either commercial-off-the-shelf or fabricated from common materials such as custom PCBs and aluminum brackets inside the spacecraft for securing magnets used for PMAC and separation switches.

Hazards

The University of Virginia's satellite will not contain any pressure vessels or materials that present Chemical, Biological, Radiological, or Nuclear (CBRN) concerns. There will be no hazardous or exotic materials on board.

Power Systems/Hazards

The electrical power storage system will consist of a Clyde Space 3rd Generation EPS and battery system that uses lithium-ion polymer cells with over-charge/current protection circuitry.

Ceres – Virginia Tech (Virginia CubeSat Constellation) – 3U

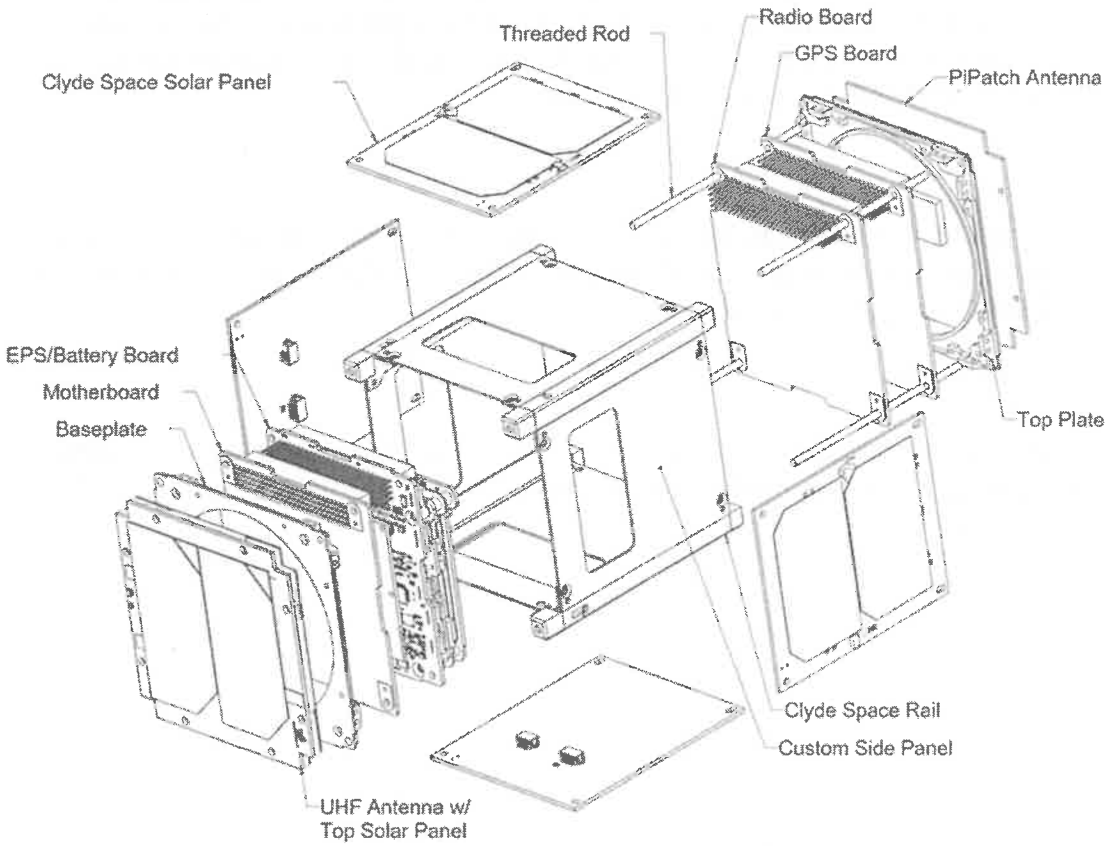


Figure 35: Ceres Expanded View

Overview

The Virginia CubeSat Constellation (VCC) mission is a joint operation between teams at Old Dominion University, University of Virginia, Virginia Tech, and Hampton University. ODU, UVA, and VT are each building 1U CubeSats (Aeternitas, Libertas, and Ceres, respectively) that will fly as a constellation in low earth orbit. The mission objectives are to provide undergraduate students with a hands-on flight project experience, to obtain data on atmospheric density and variability in LEO, and to test communication and relative ranging across a constellation of CubeSats. A Hampton University student team will perform analysis of spacecraft attitude, location, and orbital data to measure variations in atmospheric density in low earth orbit.

CONOPS

Following deployment, Ceres will power up and start a countdown timer. After 30 minutes have passed, a UHF turnstile antenna will be deployed. For the first few passes the ground station operators will attempt communications to perform checkouts of the spacecraft. Following successful checkout, the primary science mission will begin and continue for at least 3 months. This includes recording attitude and GPS data and performing inter-satellite ranging experiments with the other constellation CubeSats once per orbit. The results of these experiments, the scientific data, and health updates will be downlinked to the VT, ODU, and UVA ground stations during overflights.

Materials

The CubeSat rail structure and skeleton is made of Aluminum 5052-H32. Non-critical parts of the chassis are made of a 3D printed Ultem 1010 derivative with added carbon nanotubes, similar to GSC31264. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells.

Hazards

There are no pressure vessels, hazardous or exotic materials.

Batteries

The electrical power storage system consists of a Clyde Space 3rd Generation EPS and battery system that uses lithium-ion polymer cells with over-charge/current protection circuitry.

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-21 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-21 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))

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.

The CubeSats in this complement satisfy Requirements 4.4-1 and 4.4-2 if their batteries at equipped with protection circuitry, and they meet International Space Station (ISS) safety requirements for secondary payloads. Additionally, these CubeSats are being deployed from a very low altitude (ISS orbits at approximately 400 km), meaning any accidental explosions during mission operations or post-mission will have negligible long-term effects to the space environment.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum CubeSat lifetime of 2.3 years maximum, these ELaNa-21 CubeSats are 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 4 CubeSats discussed in this document is that of the Aeternitas CubeSat.

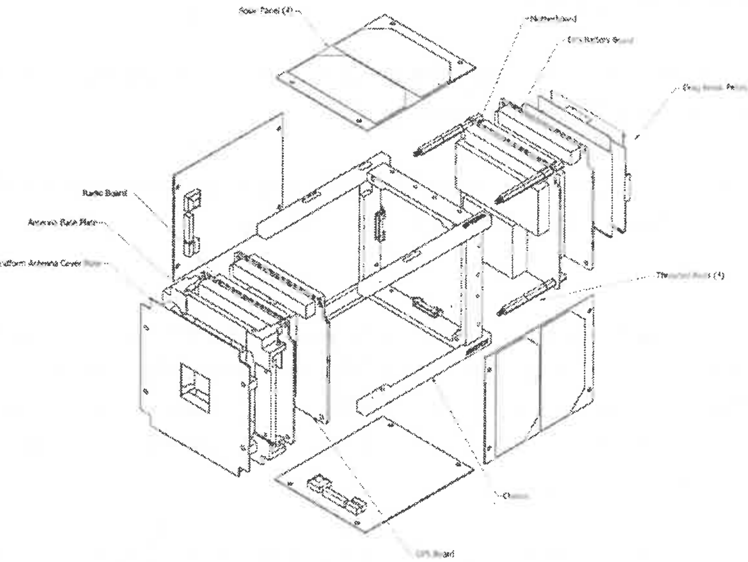


Figure 46:Aeternitas Expanded View

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

Equation 1: Mean Cross Sectional Area for Convex Objects

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

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 1Equation 1. This configuration renders the longest orbital life times for all CubeSats.

Once a CubeSat has been ejected from the NanoRacks dispenser and deployables have been extended, Equation 2Equation 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 Aeternitas (1.2 kg) orbit at deployment is 408 km apogee altitude by 400 km perigee altitude, with an inclination of 51.6 degrees. With an area to mass ratio of 0.0135 m^2/kg, DAS yields 2.32 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-21 CubeSats see an average of 0.0 probability of collision. These CubeSats CubeSats on ELaNa-21 were calculated to have a probability of collision of 0.0. Table 3 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.

	TJREVERB	Aeternitas	Ceres	Libertas
Mass (kg)	2.61	1.21	1.13	1.31
Mean C/S Area (m^2)	0.0712	0.0163	0.0176	0.01817
Area-to Mass (m^2/kg)	0.0273	0.0135	0.0156	0.0139
Orbital Lifetime (yrs)	**1.0**	**2.3**	**1.9**	**2.3**
Probability of collision (10^X)	**0.00000**	**0.00000**	**0.00000**	**0.00000**

Solar Flux Table Dated 8/14/2017

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of any ELaNa-21 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-23 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-21 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 post-mission 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 Aeternitas in its stowed configuration as the worst case. The area-to-mass is calculated for is as follows:

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

Equation 3: Area to Mass

$$\frac{0.0163\ m^2}{1.209\ kg} = 0.013482\frac{m^2}{kg}$$

Aeternitas 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 2.1.1 Orbital Lifetime Calculations:

DAS inputs are: 408 km maximum apogee 400 km maximum perigee altitudes with an inclination of 51.6° at deployment no earlier than April 2018. An area to mass ratio of .013482 m^2/kg for the Aeternitas CubeSat was used. DAS 2.1.1 yields a 2.32 years orbit lifetime for Aeternitas in its deployed state.

This meets requirement 4.6-1. For the complete list of CubeSat orbital lifetimes reference Table 3: CubeSat Orbital Lifetime & Collision ProbabilityTable 3: CubeSat Orbital Lifetime & Collision Probability.

Assessment results show compliance.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on ELaNa-23 was performed. The assessment used DAS 2.1.1, 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 possess the same negligible risk as stainless steel components.

Table 4: ELaNa-21 High Melting Temperature Material Analysis

CubeSat	Name	Material	Mass (kg)	Demise Alt (km)	Kenetic Energy (J)
TJREVERB	Standoff screws	Stainless Steel (generic)	.001	77.7	0
TJREVERB	6 mm screws	Stainless Steel (generic)	.001	77.5	0
Aeternitas	Antenna blades	Steel AISI 304	.0005	0.0	0
Aeternitas	Drag brake springs	Steel AISI 304	.0005	76.2	0
Aeternitas	Threaded rods	Stainless Steel (generic)	.02	73.5	0
Aeternitas	Fasteners	Steel AISI 304	.006	77.8	0
Ceres	Separation switches	Berylium element	.003	0.0	0
Ceres	Solar panel retaining clips	Stainless Steel (generic)	.001	0.0	0
Ceres	Mounting hardware	Stainless Steel (generic)	.002	77.1	0
Libertas	Magnets	Aluminum/Nickel	.001	77.5	0
Libertas	Separation switches	Beryllium	.003	0	0
Libertas	Mounting nuts	Stainless Steel (generic)	.002	77.2	0
Libertas	Threaded rods	Stainless Steel (generic)	.02	73.8	0

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 breakdown of the determined probabilities follows:

Table 5: Requirement 4.7-1 Compliance by CubeSat

Name	Status	Risk of Human Casualty
TJREVERB	Compliant	1:0
Aeternitas	Compliant	1:0
Ceres	Compliant	1:0
Libertas	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. This is why CubeSats that have surviving components like Aeternitas, Ceres, and Libertas have a 1:0 probability as none of their components have more than 15J of energy.

All CubeSats launching under the ELaNa-21 mission are shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

ELaNa-21 CubeSats will not be deploying any tethers.

ELaNa-21 CubeSats satisfy Section 8's requirement 4.8-1.

Section 9-14

ODAR sections 9 through 14 pertain to the launch vehicle, and are not covered here. Launch vehicle sections of the ODAR are the responsibility of the CRS provider.

If you have any questions, please contact the undersigned at 321-867-2098.

/original signed by/

Yusef A. Johnson
Flight Design Analyst
a.i. solutions/KSC/AIS2

cc: VA-H/Mr. Carney
VA-H1/Mr. Beaver
VA-H1/Mr. Haddox
VA-C/Mr. Higginbotham
VA-G2/Mr. Treptow
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-21 Component List by CubeSat: TJREVERB
Appendix B.	ELaNa-21 Component List by CubeSat: Aeternitas
Appendix C.	ELaNa-21 Component List by CubeSat: Ceres
Appendix D.	ELaNa-21 Component List by CubeSat: Libertas

* High temperature components are highlighted. Refer to Table 4 for further data.

Appendix A. ELaNa-21 Component List by CubeSat: TJREVERB

CUBESAT	Item Number	Name	Qty	Material	Body Type	Mass (g)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
TJREVERB	1	2U CubeSat Structural Chasis	1	Aluminum 5052-H32	Box	206	100	100	227	-	-	-
TJREVERB	2	SIDE Solar Panel	4	GaAs, G10 Fiberglass	Panel	100	100	226*	2.5	No	-	Demise
TJREVERB	3	pos Z Mounting Plate	1	Aluminum 5052	Sheer Panel	14.935	100	100	1	No	-	Demise
TJREVERB	4	-Z Mounting Plate	1	Aluminum 5052	Sheer Panel	14.935	100	100	1	No	-	Demise
TJREVERB	5	EPS Block, Ragnarok Flight Computer, Aluminum Heat Sink	1	Circuit Boards (FR-4 Fiberglass), Aluminum Heat Sink	Plate-like block	250	96	90	45	No	-	Demise
TJREVERB	6	18650 Li-Ion Battery Dual Cell	2	Lithium polymer	cylinder	256	96	91	21	No	-	Demise
TJREVERB	7	ISIS 3-axis Magnetorquer Board	1	PCB FR-4 Fiberglass, Aluminum, Copper	Board	196	90.1	95.9	17	No	-	Demise
TJREVERB	8	Iridium Radio (Iridium 9603-I daughterboard on motherboard from NAL Research)	1	FR-4 Fiberglass, Aluminum Heat Sink	box	150	47	80	10	No	-	Demise
TJREVERB	9	GomSpace S-band Radio (TR600)	1	FR-4 Fiberglass, Aluminum	box	200	92.682	88.875	19.531	No	-	Demise
TJREVERB	10	APRS Radio (SATT4)	1	FR-4 Fiberglass, Aluminum, Stainless Steel	box	150	95.885	86.17	9.087	No	-	Demise
TJREVERB	11	S-Band Patch Antenna	1	Aluminum 8062	box	50	76	-	4	No	-	Demise
TJREVERB	12	Patch Antenna(GPS)	1	Aluminum, Ceramic	Box	50	25	25	8	No	-	Demise
TJREVERB	13	Patch Antenna Near Earth Network	1	Aluminum, Ceramic	Box	10	17	17	9	No	-	Demise
TJREVERB	14	S-Band Heat Sink Block	2	Aluminum	Box	60	97*	97*	10	No	-	Demise
TJREVERB	15	ISIS Antenna Depolyer System (Turnstile)	1	Aluminum 6061*	Square plate	100	98 (stowed)	98 (stowed)	7 (stowed)	No	-	Demise
TJREVERB	16	Interface Board GPS/Iridium	1	FR-4 Fiberglass, Aluminum	Square	50	96	92	11.7	No	-	Demise
TJREVERB	17	Circuit board standoffs	20	Aluminum 5052*	cylinder	1	3	-	various	No	-	Demise
TJREVERB	18	Molex PicoBlade 4 Pin Connector Female 51021 Series	8	Stainless Steel	connector	0.3376		-	variable	No	-	Demise

TJREVERB	19	Molex PicoBlade 12 Pin Connector Female 51021 Series	4	Stainless Steel	connector	0.4256		-	variable	No	-	Demise
TJREVERB	20	2 Pin Shunt (used as an RBF pin)*	2	Stainless Steel	pin	10	5.08	6.5	2.54	No	-	Demise
TJREVERB	21	M3, 8mm Screw A(standoff screws)	20	Stainless Steel	Screws	1	3*	-	8	Yes	2500°	Demise
TJREVERB	22	Molex PicoBlade 4 Pin Connector Male 53047-0210	8	Stainless Steel	Pin connectors	1	11*	6.5*	2.45*	No	-	Demise
TJREVERB	23	M2.5, 6mm screw	64	Stainless Steel	Screws	1	2.5*	-	6	Yes	2500°	Demise
TJREVERB	24	Kapton Tape	-	Tape	Acrylic Adhesive (Coating)	22.5	-	-	-	No	-	Demise

Appendix B. ELaNa-21 Component List by CubeSat: Aeternitas

CUBESAT	Item Number	Name	Qty	Material	Body Type	Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
Aeternitas	1	Aeternitas ODU 1U Chassis	1	-	Box	-	-	-	-	-	-	-
Aeternitas	2	CubeSat Structure - Rails // +x-Axis	1	Aluminum 6061	Rectangular Sheet	57.07 9	100	113.5	6.9	No	-	Demise
Aeternitas	3	CubeSat Structure - Rails // -x-Axis	1	Aluminum 6061	Rectangular Sheet	57.20 5	100	113.5	6.9	No	-	Demise
Aeternitas	4	CubeSat Structure - Span // +y-Axis	1	Aluminum 6061	Rectangular Box	15.26 9	19	78.35	4.15	No	-	Demise
Aeternitas	5	CubeSat Structure - Span // -y-Axis	1	Aluminum 6061	Rectangular Box	13.90 1	15	78.35	4.15	No	-	Demise
Aeternitas	6	CubeSat Structure - Bolts and Fasteners	30	Steel Alloy	Cylindrical Rods	0.627 9	2.625	11.375	2.625	No	2500°	Demise
Aeternitas	7	Antenna - Cover Plate	1	Windform	Box	12.44 3	98	98	1	No	-	Demise
Aeternitas	8	Antenna - Base Plate	1	Aluminum 6061	Box	66.18	96.8	96.8	19.9	No	-	Demise
Aeternitas	9	Antenna - Antenna Swing Arms	2	Windform	L-shaped	1.944	25	50	7.3	No	-	Demise
Aeternitas	10	Antenna - Antenna Blades	4	Steel/copper plate	Sheet	0.5	6	187.4	0.4	Yes	2500°	0.0
Aeternitas	11	Antenna - GPS/Iridium Patch Antenna - Toaglas	1	Ceramic	Box	64	25	25	4	No	-	Demise
Aeternitas	12	Drag Brake - Hinge - Top	4	Aluminum 6061	Box/Cylindr ical	1	6.921	30	6	No	-	Demise
Aeternitas	13	Drag Brake - Hinge - Bottom	4	Aluminum 6061	Box/Cylindr ical	1	30	5	1	No	-	Demise
Aeternitas	14	Drag Brake - Petals - petal 1	1	Lexan	Box	8	65.4	70.8	1.6	No	-	Demise
Aeternitas	15	Drag Brake - Petals - petal 2-4	3	Lexan	Box	9	65.4	70.8	1.6	No	-	Demise
Aeternitas	16	Drag Brake - Springs	4	Alloy Steel	Cylindrical	0.578	4.7244	4.7244	0.5334	Yes	2500°	Demise
Aeternitas	17	Solar Panels with Maganetorquers/CSS - GOMSpace	4	Germanium	Rectangular Sheet	57				No	-	Demise

Aeternitas	18	piNAV GPS-L1 - SkyFox Labs	1	FR4, Metal Alloy	Rectangular Box	47	84	35	12	No	-	Demise
Aeternitas	19	Lithium Radio - Astro Dev	1	FR4, Aluminum	Rectangular Box	48	62	32	11.12	No	-	Demise
Aeternitas	20	EPS/Battery - GOMSpace	1	Lithium Ion, FR4	Rectangular Box	220	96	90		No	-	Demise
Aeternitas	21	Radio Board	1	FR4	Square Plate	40	96	90	2	No	-	Demise
Aeternitas	22	GPS Board	1	FR4	Square Plate	45	96	90	2	No	-	Demise
Aeternitas	23	Processor Board	1	FR4	Square Plate	40	96	90	2	No	-	Demise
Aeternitas	24	Mounting Hardware (4 Threaded Rods,12 Spacers, 12 Nuts)	1	Stainless Steel, Aluminum	Cylindrical Rod, Toroid	20	-	-	-	Yes	2500°	Demise
Aeternitas	25	Z-axis magnetorquer	1	Pre-evacuated enamel copper wire,Space grade epoxy 3M	Rectangular Box	7.5	50	50	4.3	No	-	Demise
Aeternitas	26	Iridium Radio	1	--	Rectangular Box	11.4	29.6	31.5	8.1	No	-	Demise
Aeternitas	27	Cables/Connectors	--	Copper alloy, Insulator	--	--	--	--	--	No	-	Demise
Aeternitas	28	IMU - MPU-9250	1	Ceramic, X7R	Square	1	3	3	1	No	-	Demise
Aeternitas	29	Intersat Radio - HopeRF RFM69HCW	1	Ceramic, FR4	Square	1	16	16	1.8	No	-	Demise

Appendix C. ELaNa-21 Component List by CubeSat: Ceres

CUBESAT	Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
Ceres	1	Ceres 1U CubeSat	1	..	Box	-	106.7	106.7	113.5	-	-	-
Ceres	2	CubeSat Structure (Side Walls)	4	Ultem 1010 Substrate with Carbon Nano Tube Matrix	Plate	8	1	83	95	No	-	Demise
Ceres	3	CubeSat Structure (Top Plate)	1	Aluminum 5052-H32	Plate	35	100	100	11.58	No	-	Demise
Ceres	4	CubeSat Structure (Bottom Plate)	1	Aluminum 5052-H32	Plate	35	100	100	38.3	No	-	Demise
Ceres	5	CubeSat Structure (Rails and Feet)	4	Aluminum 5052-H32	Plate	5	8.5	8.5	113.5	No	-	Demise
Ceres	6	Mother Board; TI MSP430FR5994	1	FR4	Plate	88	96	90	1.6	No	-	Demise
Ceres	7	Clyde Space 3rd Gen. EPS	1	FR4	Plate	86	95.89	90.17	23.24	No	-	Demise
Ceres	8	Processing Module; TI MSP430F5438A	1	FR4	Plate	11	54.6	53.4	1.6	No	-	Demise
Ceres	9	Batteries; ClydeSpace 20WHr	1	Lithium Ion Polymer, FR4	Plate	246	95.89	90.17	21.4	No	-	Demise
Ceres	10	ClydeSpace Solar Panels	3	FR4	Plate	46	83	97	1.6	No	-	Demise
Ceres	11	EnduroSat Solar Panel	1	FR4-Tg170	Plate	48	98	98	3.1	No	-	Demise
Ceres	12	piNAV GPS	1	FR4, Metal Alloy	Box	47	84	35	12	No	-	Demise
Ceres	13	Skyfox Labs PiPatch GPS Antenna	1	FR4, GPS L1 Patch	Plate	50	98	98	5.5	No	-	Demise
Ceres	14	EnduroSat UHF Antenna Assembly	1	Hard Annodized Aluminum, FR4	Plate	85	98	98	5.6	No	-	Demise
Ceres	15	Radio Board	1	FR4	Plate	24	96	90	1.6	No		Demise
Ceres	16	GPS and IMU Board	1	FR4	Plate	25	96	90	1.6	No	-	Demise
Ceres	17	Astro Dev Radio Li-1	1	FR4, Aluminum	Box	30	62	32	11.12	No	-	Demise
Ceres	18	Separation Switches	3	Thermoplastic, Beryllium Copper	Box	3	12.3	20	3.38	Yes	2349°	0 km
Ceres	19	Separation Spring	1	ASTM A228	Cylinder	1	3	-	10	No	-	Demise
Ceres	20	Bondable Terminals	2		Plate	<1	2.7	1.65	0.6	No	-	Demise
Ceres	21	Strain Gauge	2	encapsulated K-alloy	Plate	<1	3.18	6.35	0.6	No	-	Demise

Ceres	22	Mounting Hardware (Solar Panel Retaining Clips)	8	Stainless Steel	Plate	1	20	20	0.5	Yes	2500°	0 km
Ceres	23	IMU; Invensense MPU9250	1	Ceramic, X7R	Box	1	3	3	1	No	-	Demise
Ceres	24	Intersatellite Radio; HopeRF RFM69HCW	1	Ceramic, FR4	Box	1	16	16	1.8	No	-	Demise
Ceres	25	Mounting Hardware (4 Threaded Rods,12 Spacers, 12 Nuts)	1	Stainless Steel, Aluminum	Cylindrical Rod, Toroid	20	-	-	-	Yes	2500°	0 km
Ceres	26	Separating Switch Mounts	4	Aluminum	Plate	4	12.3	20	20	No	-	Demise
Ceres	27	Mounting Hardware (Nuts and Bolts Pairs)	30	Stainless Steel	Toroid, Cylindrical	2	3	-	7	Yes	2750°	Demise
Ceres	28	Cabling (Electrical)	1	Copper alloy, Insulator	Flexible Cable	15	2	300	-	No	-	Demise
Ceres	29	Cabling (Co-ax)	1	Copper alloy, Insulator	Flexible Cable	15	3	400	-	No	-	Demise

Appendix D. ELaNa-21 Component List by CubeSat: Libertas

CUBESAT	Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
Libertas	1	Libertas UVA 1U CubeSat	1	-	Box	-	106.75	105.66	118.6	No	-	Demise
Libertas	2	Pumpkin CubeSat Kit Structure (Side Walls and Feet)	1	Aluminum 5052-H32	Box	104	100	100	113.5	No	-	Demise
Libertas	3	Pumpkin CubeSat Kit Structure (Top Plate)	1	Aluminum 5052-H32	Square Plate	45	100	100	11.58	No	-	Demise
Libertas	4	Pumpkin CubeSat Kit Structure (Bottom Plate)	1	Aluminum 5052-H32	Square Plate	58	100	100	38.3	No	-	Demise
Libertas	5	Pumpkin CubeSat Kit (CSK)Motherboard	1	FR4	Square Plate	88	96	90	1.6	No	-	Demise
Libertas	6	Clyde Space EPS	1	FR4	Square Plate	86	95.89	90.17	23.24	No	-	Demise
Libertas	7	Pumpkin CSK Pluggable Processing Module	1	FR4	Rectangular Plate	11	54.6	53.4	1.6	No	-	Demise
Libertas	8	Clyde Space 20 WHr Battery Pack (integrated with EPS)	1	Lithium Ion Polymer, FR4	Square Plate	246	95.89	90.17	21.4	No	-	Demise
Libertas	9	Clyde Space Solar Panels	3	FR4	Rectangular Plate	46	83	97	1.6	No	-	Demise
Libertas	10	Clyde Space Solar Panel (RBF Cutout)	1	FR4	Rectangular Plate	46	81.74	111	3.58	No	-	Demise
Libertas	11	EnduroSat Solar Panel	1	FR4-Tg170	Rectangular Plate	48	98	98	3.1	No	-	Demise
Libertas	12	Skyfox Labs piNAV GPS	1	FR4, Metal Alloy	Rectangular Box	47	84	35	12	No	-	Demise
Libertas	13	Skyfox Labs PiPatch GPS Antenna	1	FR4, GPS L1 Patch	Square Plate	50	98	98	5.5	No	-	Demise
Libertas	14	EnduroSat UHF Antenna Assembly	1	Hard Anodized Aluminum, FR4	Square Plate	85	98	98	5.6	No	-	Demise
Libertas	15	Radio Board	1	FR4	Square Plate	24	96	90	1.6	No	-	Demise
Libertas	16	GPS and IMU Board	1	FR4	Square Plate	25	96	90	1.6	No	-	Demise
Libertas	17	Astro Dev Lithium Radio	1	FR4, Aluminum	Rectangular Box	30	62	32	11.12	No	-	Demise
Libertas	18	Magnets for PMAC	20	Al Ni Co	Cylindrical	1	3.175		4.953	Yes	2651°	Demise

Libertas	19	Separation Switches	3	Thermoplastic, Beryllium Copper	Rectangular Box	3	12.3	20	3.38	Yes	2349°	0 km
Libertas	20	Separation/deployment Springs (in CSK cover plate)	1	ASTM A228	Spring Coil	1	3	-	10	No	-	Demise
Libertas	21	Mounting Hardware (Solar Panel Retaining Clips)	8	Stainless Steel	Bent Plate	1	20	20	0.5	Yes	2500°	Demise
Libertas	22	Invensense MPU9250 IMU	1	Ceramic X7R	Box	1	3	3	1	No	-	Demise
Libertas	23	HopeRF RFM69HCW Intersatellite radio	1	Cermaic/FR4	Box	1	16	16	1.8	No	-	Demise
Libertas	24	Separation Switch Mounts	4	Aluminum	Bent Plate	4	12.3	20	20	No	-	Demise
Libertas	25	Magnet Mounting Hardware	4	Aluminum	Cylindrical	4	4.175	-	25	No	-	Demise
Libertas	26	Mounting Hardware (Nuts and Bolts Pairs)	45	Stainless Steel	Toroid, Cylindrical	2	3	-	7	Yes	-	Demise
Libertas	27	Mounting Hardware (4 Threaded Rods,12 Spacers, 12 Nuts)	1	Stainless Steel, Aluminum	Cylindrical Rod, Toroid	20	-	-	-	Yes	2500°	Demise
Libertas	28	Cabling (Electrical)	1	Copper alloy, Insulator	Flexible Cable	15	2	600	-	No	-	Demise
Libertas	29	Cabling (RG178 Coax)	1	Copper alloy, Insulator	Flexible Cable	15	3	400	-	No	-	Demise