ELVL-2018-0045207 Rev A
May 4, 2018

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

Signature Page

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ELVL-2018-0045207 Rev A

Reply to Attn of: VA-H1

May 4, 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
J. *TechEdSat-8 Orbital Debris Assessment Report (ODAR),* T8MP-06-XS001 Rev 0, NASA Ames Research Center

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.

RECORD OF REVISIONS		
REV	**DESCRIPTION**	**DATE**
0	ODAR Submission for TJREVERB and VCC CubeSats	March 2018
A	Combined original submission with full ELaNa-21 complement	May 2018

The following table summarizes the compliance status of the ELaNa-21 payload mission to be flown on the OA-10 vehicle. The 13 CubeSats comprising 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 3.9 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 are as follows:

CapSat: McKale Berg, Project Manager, University of Illinois

CySat 1: Rami Shoukih, Project Manager, Iowa State University

KickSat-2: BJ Jaroux, Project Manager, NASA Ames Research Center

HARP: Dr. J. Vanderlei Martins, Principal Investigator

OPAL: Dr. Charles Swenson, Principal Investigator, Utah State

Phoenix: Sarah Rogers, Project Manager, Arizona State University

SPACE HAUC: Supriya Chakrabarti, Principal Investigator, University of Massachusetts-Lowell

TechEdSat 8: Marcus Murbach, Project Manager, Ames Research Center

TJREVERB: Michael Piccione, Principal Investigator, Thomas Jefferson High School

UNITE: Glen Kissel, Principal Investigator, University of Southern Indiana

Virginia CubeSat Consortium (Aeternitas, Ceres, Libertas): Mary Sandy, Principal Investigator, Virginia Space Grant Consortium

Program Milestone Schedule	
Task	Date
CubeSat Selection	September 15, 2017
CubeSat Delivery to NanoRacks	August 20th, 2018
Launch	November 17st, 2018

Figure 1: Program Milestone Schedule

The ELaNa-21 CubeSat complement will be launched as payloads on the OA-10 Antares launch vehicle to the International Space Station. The ELaNa-21 mission will deploy 13 pico-satellites (or CubeSats) from the International Space Station, using the NanoRacks CubeSat dispenser. Each CubeSat is identified in Table 2: ELaNa-21 CubeSats. The ELaNa-21 manifest includes: CapSat, CySat, HARP, KickSat-2, OPAL, Phoenix, SPACE HAUC, TechEdSat 8, TJREVERB, UNITE, and the three Virginia CubeSat Consortium CubeSats (Aeternitas, Ceres, and Libertas). The current launch date is projected to be November 17th, 2018.

The CubeSats on this mission range in size from a 10 cm cube to 60 cm x 10 cm x 10 cm, with masses from about 1.2 kg to 3.5 kg, with a total mass of roughly 20 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 13 CubeSats flying on the ELaNa-21 Mission. Table 2: ELaNa-21 CubeSats outlines their generic attributes.

Table 2: ELaNa-21 CubeSats

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Masses (kg)
CapSat	1	300 x 100 x 100	2.8
CySat	1	340 x 100 x 100	1.6
* HARP	1	368 x 100 x 100	4.1
* KickSat-2	1	300 x 100 x 100	2.3
* OPAL	1	368 x 100 x 100	5.0
Phoenix	1	325 x 100 x 100	3.2
SPACE HAUC	1	340 x 100 x 100	2.9
*TechEdSat 8	1	600 x 100 x 100	7.9
TJREVERB	1	227 x 100 x 100	2.6
UNITE	1	340 x 108 x 108	3.5
Virginia CC - Aeternitas	1	113 x 100 x 78	1.2
Virginia CC - Ceres	1	113 x 106 x 106	1.2
Virginia CC - Libertas	1	118 x 105 x 106	1.4

*The following pages describe the CubeSats flying on the ELaNa-21 mission, with the omissions noted below. ODARs for these CubeSats were previously submitted to the Agency as follows:

HARP: ELaNa-22 Rev A ODAR 5/2017
KickSat-2: KickSat-2 9/2015
OPAL: ELaNA-22 ODAR 10/16
TechEdSat-8's ODAR was drafted by NASA Ames (Document No. T8MP-06-XS001 Rev 0)

SPACE HAUC – University of Massachusetts, Lowell – 3U

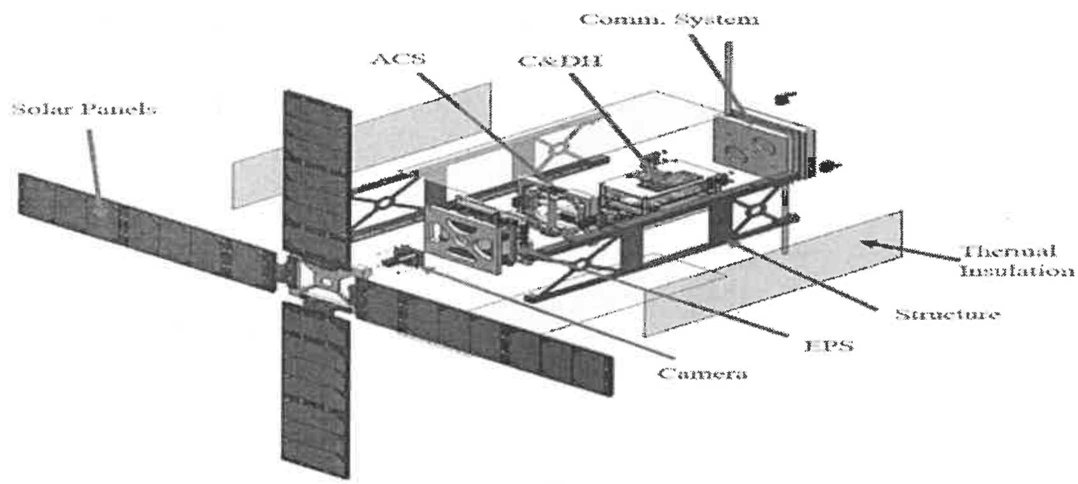

Figure 5: SPACE HAUC Expanded View

Overview

SPACE HAUC will demonstrate that high data transmission rates can be achieved by using a X-Band Phased-Array antenna with an electronically steered beam on a CubeSat.

CONOPS

Immediately upon deployment, SPACE HAUC will power up and determine if it is spin stabilized. If not, the Attitude Determination and Control System will stabilize the spin. It will then determine if it is sun pointed, if not the Attitude Determination and Control System will point SPACE HAUC at the sun. SPACE HAUC will then wait for a beacon signal from the ground, upon receipt of the beacon, SPACE HAUC will take pictures of the sun and transmit them down. The process of waiting for the beacon signal will be repeated whenever the beacon signal is lost.

Materials

The CubeSat structure is made of Aluminum 7075-T6. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells except for the RF front end board and patch antennas which are custom designed. The high-speed radio uses a ceramic patch antenna.

Hazards

There are no pressure vessels, hazardous, or exotic materials.

Batteries

The lithium-ion battery is charged with all the available power from the photo-voltaic inputs that is not drained by the loads on the external power busses. The battery is protected against voltage being too high or too low.

The software high voltage protection implements a constant voltage charge scheme that will keep the battery at its maximum voltage. The full mode regulation works by lowering voltage on the solar panel inputs, thereby only taking in the power needed.

The software low voltage protection is a four state system. Should the battery voltage drop below 7.2 V, the battery hardware will switch to a 'safe mode' configuration, which allows for the switching off of all essential systems and leaves only a simple power beacon running. Should the battery drop below 6.5 V, the software will switch off all user outputs.

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 6U CubeSat 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 3.9 years maximum, the 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 13 CubeSats is that of the SPACE HAUC CubeSat with solar arrays deployed.

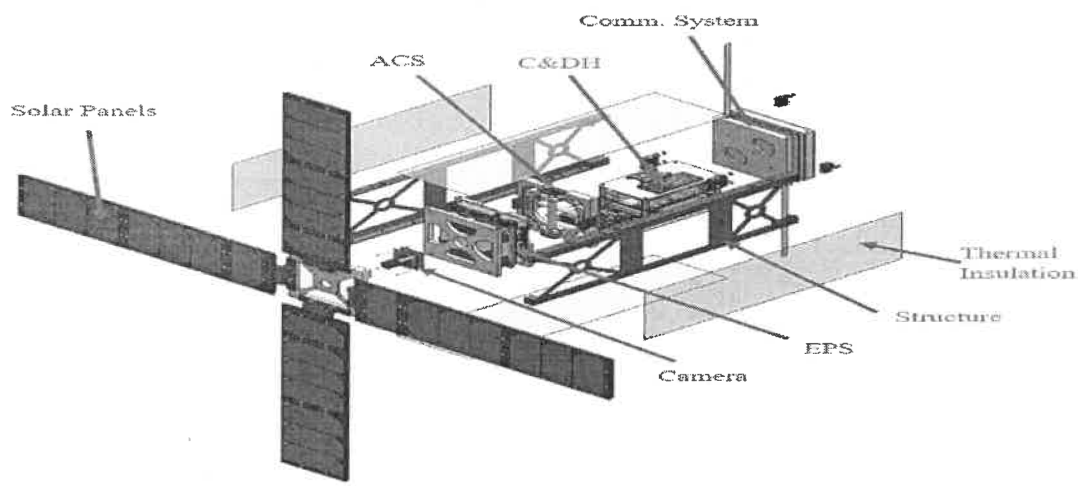

Figure 10: SPACE HAUC Expanded View (with solar panels deployed)

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

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, the 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 NanoRacks dispenser 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 SPACE HAUC (2.9 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 0.00398 m^2/kg, DAS yields 3.9 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. All 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.

CubeSat

	CubeSat	CapSat	CySat	Phoenix	SPACE HAUC	TechEdSat 8
	Mass (kg)	2.8	2.7	3.2	2.9	7.9
Stowed	Mean C/S Area (m^2)	0.282	0.018	0.015	0.0116	0.104
Stowed	Area-to Mass (m^2/kg)	0.102	0.014	0.012	0.004	0.0132
Stowed	Orbital Lifetime (yrs)	**0.23**	**3.4**	**3.7**	**3.9**	**2.2**
Stowed	Probability of collision (10^X)	**0.00000**	**0.00000**	**0.00000**	**0.00000**	**0.00000**
Deployed **	Mean C/S Area (m^2)				0.0709	0.564
Deployed **	Area-to Mass (m^2/kg)				0.0243	0.0714
Deployed **	Orbital Lifetime (yrs)				**1.09**	**0.482**
Deployed **	Probability of collision (10^X)				**0.00000**	**0.00000**

Solar Flux Table Dated 8/14/2017

****Note: Blacked out areas represent CubeSats which do not have deployables or have deployable antennae with negligible areas with respect to on-orbit dwell time calculation. Data for TechEdSat-8 taken from Ames-submitted ODAR report.**

Table 3: CubeSat Orbital Lifetime & Collision Probability

	CubeSat	TJREVERB	UNITE	Aeternitas	Ceres	Libertas
	Mass (kg)	2.6	3.5	1.2	1.2	1.4
Stowed	Mean C/S Area (m^2)	0.085	0.020	0.0163	0.0176	0.0182
Stowed	Area-to Mass (m^2/kg)	0.0327	0.006	0.0136	0.0147	0.0130
Stowed	Orbital Lifetime (yrs)	**0.77**	**3.4**	**2.3**	**2.0**	**2.4**
Stowed	Probability of collision (10^X)	**0.00000**	**0.00000**	**0.00000**	**0.00000**	**0.00000**
Deployed **	Mean C/S Area (m^2)			0.0398		
Deployed **	Area-to Mass (m^2/kg)			0.0333		
Deployed **	Orbital Lifetime (yrs)			**0.75**		
Deployed **	Probability of collision (10^X)			**0.0000**		

Table 3: CubeSat Orbital Lifetime & Collision Probability (cont.)

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.

The VCC CubeSat Aeternitas will deploy a petal-like drag brake, for the purpose of providing data regarding drag effects upon its orbit. This feature does not increase the probability of on-orbit collision. The ELaNa-21 CubeSats have no capability or plan for end-of-mission disposal, therefore requirement 4.5-2 is not applicable.

In summary, assessment of spacecraft compliance with Requirements 4.5-1 shows ELaNa-21 to be compliant. Requirement 4.5-2 is not applicable to this mission.

Section 6: Assessment of Spacecraft Post Mission 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 SPACE HAUC 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

$$\frac{0.0116\, m^2}{2.9\, kg} = 0.004\frac{m^2}{kg}$$

SPACE HAUC 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 ~0.004 m^2/kg for the SPACE HAUC CubeSat was used. DAS 2.1.1 yields a 3.9 years orbit lifetime for SPACE HAUC in its stowed state.

This meets requirement 4.6-1. For the complete list of CubeSat orbital lifetimes reference **Table 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-21 was performed. (Data provided for TechEdSat-8 in their submitted ODAR report was reviewed as well). 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.

An assessment of the components flown on TechEdSat-8 is contained in Reference J.

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	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
CAPSat	Antennae	Stainless Steel	.0176	0	0
CAPSat	Pointing Panel	301 Stainless Steel	.0382	0	10
CAPSat	Face Seal Edge Connector	316 Stainless Steel	.0093	77.5	0
CAPSat	Gear Pump	316 Stainless Steel	.110	68.6	0
CAPSat	Bellows Accumulator	316 Stainless Steel	.218	63.8	0
CAPSat	Pressure Sensors	316 Stainless Steel	.079	70.3	0
CAPSat	Radiator Panel Hinge	Unfinished Steel	.0068	76.5	0
CAPSat	Radiator Board Standoffs	18-8 Stainless Steel	.0055	73.8	0
CAPSat	Pipe Fittings	Stainless Steel (generic)	various	75.2	0
CySat	Rods	Stainless Steel (generic)	.080	0	0
CySat	Standoffs	Stainless Steel (generic)	.084	72.8	0

CySat	Fasteners	Stainless Steel (generic)	.040	77.0	0
CySat	Separation Switches	Stainless Steel (generic)	.028	0	0
CySat	RBF Pin	Stainless Steel (generic)	.017	74.7	0
CySat	Separation Springs	Stainless Steel (generic)	.0002	77.3	0
CySat	Reaction Wheel	Brass	.060	73.1	0
CySat	Magnetometer	Stainless Steel (generic)	.005	77.3	0
CySat	Deployable Magnetometer	Stainless Steel (generic)	.002	77.8	0
Phoenix	Screws	Stainless Steel (generic)	6.94	77.7	0
Phoenix	Nuts	Stainless Steel (generic)	3.92	77.6	0
Phoenix	Electronics Stack Rod	Stainless Steel (generic)	4.29	76.8	0
Phoenix	Separation Springs	Stainless Steel (generic)	0.072	77.9	0
SPACE HAUC	Torsion Spring	Steel (AISI 304)	.00015	77.9	0
SPACE HAUC	4-40 Screws	Steel (AISI304)	.004	76.2	0
SPACE HAUC	Spacer RF Boards	Steel (AISI 304)	.004	76.5	0
TJREVERB	Standoff screws	Stainless Steel (generic)	.020	77.7	0
TJREVERB	6 mm screws	Stainless Steel (generic)	.064	77.5	0
UNITE	External Fasteners	Stainless Steel (generic)	.020	77.6	0
UNITE	Magnet Holder	Lexan	.010	78.0	0
UNITE	Mu-Metal Rod	HyMu80 (nickel alloy)	.047	71.4	0
UNITE	Internal Fasteners	Stainless Steel (generic)	.0002	77.9	0
Virginia CC: Aeternitas	Antenna Blades	Steel/copper plate	.0005	0	0
Virginia CC: Ceres	Separation Switches	Beryllium Copper	.003	0	0
Virginia CC: Ceres	Solar Panel Retaining Clips	Stainless Steel	.001	0	0
Virginia CC: Ceres	Magnet Mounting Plates	Aluminum	.050	0	0
Virginia CC: Libertas	Separation Switches	Beryllium Copper	.003	0	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
CapSat	Compliant	1:0
CySat	Compliant	1:0
SPACE HAUC	Compliant	1:0
TechEdSat-8	Compliant	1:0
TJREVERB	Compliant	1:0
UNITE	Compliant	1:0
Virginia CC:Aeternitas	Compliant	1:0
Virginia CC: Ceres	Compliant	1:0
Virginia CC: 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 all of the ELaNa-21 CubeSats 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-C/Mrs. Nufer
VA-G2/Mr. Treptow
SA-D2/Mr. Frattin
SA-D2/Mr. Hale
SA-D2/Mr. Henry
Analex-3/Mr. Davis
Analex-22/Ms. Ramos

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Appendix J.	ELaNa-21 TechEdSat-8 ODAR (produced by NASA-Ames)

Appendix D. ELaNa-21 Component List by CubeSat: SPACE HAUC

Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
1	SpaceHAUC 3U CubeSat	1	N/A	Box	2.92	100	340	12	-	-	-
2	Spacecraft Bus Side	2	Aluminum 7075-T6	Box	266.62	82.2	337	2.83	No	-	Demise
3	Solar Panel Frame	4	Aluminum 7075-T6	Panel	308.72	95	96	9.75	No	-	Demise
4	Camera Plate	1	Aluminum 7075-T6	Plate	71.69	10	64	10	No	-	Demise
5	Hinge Base	4	Aluminum 7075-T6	Box	25.08	20	34	5	No	-	Demise
6	Hinge Rotor	4	Aluminum 7075-T6	Plate	18.12	2.02	37.5	N/A	No	-	Demise
7	Hinge Pin	4	Aluminum 7075-T6	Pin	1.68	0.305	19.34	N/A	No	-	Demise
8	180o Torsion Spring	4	AISI 304 Stainless Steel	Spring	0.1528	0.0382	0.1528	0.305	No	2550°	Demise
9	4-40 Screws		AISI 304 Stainless Steel	Bolt	0	6.35	25	8.5	No	2550°	Demise
10	Dowel Holster	4	Aluminum 7075-T6	Box	9.72	3.175	27.94	N/A	No	-	Demise
11	Dowel	4	Aluminum 7075-T6	Pin	2.192	4.76	1.59	N/A	No	-	Demise
12	Dowel Hex Nut	8	AISI 304 Stainless Steel	Nut	1.4712	1.44	12.7	4.57	No	-	Demise
13	Compression Spring	4	AISI 304 Stainless Steel	Spring	0.4684	82.6	326	2.3	No	-	Demise
14	Solar Panels	4	Commercial FR4	Panel	624	95	96	5	No	-	Demise
15	EPS Front Mount	1	Aluminum 7075-T6	Plate	81.53	95	96	5	No		Demise
16	EPS Back Mount	1	Aluminum 7075-T6	Plate	78.24	92.92	93.39	36.75	No	-	Demise
17	Electronic Power Supply (EPS)	1	Commercial FR4	Box	100	93.34	87.44	28.71	No	-	Demise
18	Battery Pack	1	Glass/Polymide	Box	270	6.35	16.26	12.45	No	-	Demise
19	Deployment Switch	2		Box	4				No	-	Demise
20	Wires	1	Copper	Wires	20	14	27.4	5.9	No	-	Demise
21	NanoSSOC-A60 Fine Sun Sensor	1		Box	4	16.51	19.05	1.63	No	-	Demise
22	TSL2561 Coarse Sun Sensor	8		Chip	24	95	96	10	No	-	Demise

23	Magnetorquer Board	1	Aluminum 7075-T6	Plate	98.22	8.5	70	N/A	No	-	Demise
24	Magnetorquer Rods	3	Copper	Cylinder	90	6	20	6.5	No	-	Demise
25	Magnetorquer Rod Collar	4	Aluminum 7075-T6	Box	5.2	22.86	33.02	2.36	No	-	Demise
26	9 DOF Adafruit Magnetometer	1	Commercial FR4	Chip	2.8	62	100	11.73	No	-	Demise
27	ADRV9361	1		Board	60	76.2	152.4	6.65	No	-	Demise
28	ADRV9361 Breakout Board	1		Board	80	54	92	1.57	No	-	Demise
29	Auxilary Mounting Board	1	Aluminum 7075-T6	Plate	26.94	88	144	1.57	No	-	Demise
30	Base Board	1	Aluminum 7075-T6	Plate	64.09	30	30	41.2	No		Demise
31	Camera	1		Cylinder	21	2.5	22	N/A	No	-	Demise
32	Standoff_Camera	4	Aluminum 7075-T6	Cylinder	0.448	6	6.93	20	No	-	Demise
33	Standoff_ADRV	8		Cylinder	8.4	95	96	8	No	-	Demise
34	Tape Antenna Base	1	Aluminum 7075-T6	Plate	114.54	95	96	10	No	-	Demise
35	Antenna Mounting Brace	1	Aluminum 7075-T6	Plate	123.67	95	96	1.57	No	-	Demise
36	Back End Board	1	RO4000	Board	35	95	96	1.57	No	-	Demise
37	Daughter Board	1	RO4000	Board	35	95	96	1.57	No	-	Demise
38	Patch Antenna	1	RO4000	Board	14	16	23.6	4.74	No	-	Demise
39	Tape Cage_Monopole Antenna	2	Aluminum 7075-T6	Plate	1.5	22	9	N/A	No	-	Demise
40	Pulley_Monopole Antenna	2	Aluminum 7075-T6	Cylinder	10.76	4.5	5	4.5	No	-	Demise
41	Spacer_RF Boards	8	AISI 304 Stainless Steel	Cylinder	4.312				Yes	2550°	Demise
42	Wires	1	Copper	Wires	20	100	340	0.2	No	-	Demise
43	Multi-Layer Insulation	1	Insulation	Panel	40				No	-	Demise
44	Radiators	2	Aluminum 7075-T6	Panel	150	N/A	N/A	N/A	No	-	Demise
45	Paints	1	AZ-93 White Paint	Paint	5	100	340	12	No	-	Demise