ELVL-2015-0044079 (Rev1)
February 18, 2016

Orbital Debris Assessment for The CubeSats on the STP-2 /ELaNa-XV Mission per NASA-STD 8719.14A Rev. 1

Signature Page

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ELVL-2015-0044079

Reply to Attn of: VA-H1 February 19, 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-XV Mission (Rev 1)

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. "RE: Please confirm the mission launching ELaNa-15" 6 July 2015. E-mail.
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

Rev 1: Corrects the dimensions identified in Table 2 to reflect the component list dimensions. Updates the orbital lifetime of CubeSats using the Solar Flux DAS 2.0.0 input file dated 10/14/2015. Adjusts ARMADILLO cross sectional area calculation to reflect its component listed 11.35x11.35x34.5cm dimensions. Additional appendices have been added for clarification. All requirements continue to be satisfied.

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the ELaNa-XV auxiliary mission launching in conjunction with the STP-2 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-XV auxiliary payload mission flown on STP-2. The 3 CubeSats comprising the ELaNa-XV 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	Minimal risk to orbital environment, mitigated by orbital lifetime.
4.4-2	Compliant	Minimal risk to orbital environment, mitigated by orbital lifetime.
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 3.7 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-XV mission

Section 1: Program Management and Mission Overview

The ELaNa-XV 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:

ARMADILLO: Dr. E. Glenn Lightsey, Principle Investigator; Sean Horton, Project Manager

LEO: Dr. Jordi Puig-Suari, Principal Investigator, Andrew Blocher, Project Manager

StangSat: Tracey Beatovich Principal Investigator, Margaret Jennings, Project Manager

Program Milestone Schedule	
Task	Date
CubeSat Selection	October 2014
MRR	May 2016
Pre-Ship Review	June 2016
CubeSat Delivery to Cal Poly	July 2016
Launch	September 2016

Figure 1: Program Milestone Schedule

The ELaNa-XV mission will be launched as an auxiliary payload on the STP-2 mission on a Falcon 9 Heavy launch vehicle from Pad 39A at KSC, FL. The ELaNa-XV, will deploy 3 pico-satellites (or CubeSats). The CubeSat slotted position is identified in Table 2: ELaNa-XV CubeSats. The ELaNa-XV manifest includes: ARMADILLO, LEO, andStangSat. The current launch date is in (Sept 15, 2016**)**. The (3) CubeSats will be ejected from a PPOD carrier attached to the launch vehicle, placing the CubeSats in an orbit approximately 300 X 860 km at inclination of 28.5 deg (ref. (c)).

The CubeSat standard form ranges in sizes from a 10 cm cube to 10 cm x 10cm x 30 cm, with masses from about 1 kg to 4 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 three CubeSats flying on the ELaNa-XV. The CubeSats will be deployed out of 2 PPODs, as shown in Table 2: ELaNa-XV CubeSats below.

Table 2: ELaNa-XV CubeSats

PPOD Slot	CubeSat Quantity	CubeSat size	CubeSat Names	CubeSat Masses (kg)
A B C	3	3U (11.35 cm X 11.35 cm X 34 cm)* 2U (10 cm X 10 cm X 20 cm) 1U (10.5 cm X 10.5 cm X 11.36 cm)	ARMADILLO LEO StangSat	4.15 1.9 0.77

* Reference engineering drawings have been added to appendix for illustrational purposes

The following subsections contain descriptions of these 3 CubeSats.

ARMADILLO – UNIVERSITY OF TEXAS – 3U

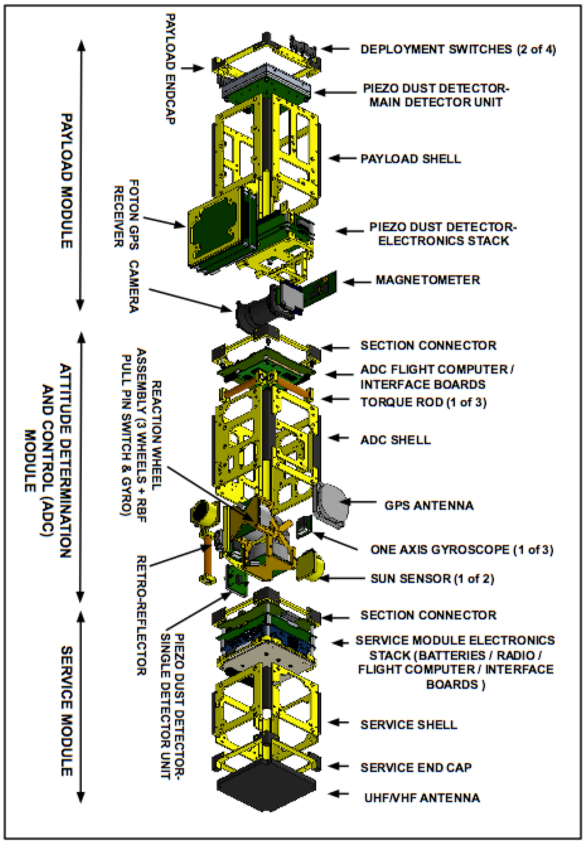

Figure 2: ARMADILLO Expanded View (Not Showing Solar Panels)

ARMADILLO will demonstrate the GPS Radio Occultation technique using a custom dual frequency GPS receiver and characterize the sub-millimeter space debris environment within the deployment orbit using a dedicated debris detector.

For this mission, the Texas Spacecraft Laboratory will utilize a software defined ground station to communicate with the spacecraft and downlink science data. The spacecraft uses the He-100 radio manufactured by Astronautical Development, LLC at uplink and downlink baud rates of 9600 and 19200 bps respectively.

Upon deployment, the spacecraft will wait for a period specified by the Launch Provider, then deploy its antennas and begin start up activities. These include detumble and transmission of the spacecraft's health beacon. After an initial checkout the spacecraft operators will schedule a daily occultation observation—in which the spacecraft's GPS antenna is pointed in the anti-velocity vector—and extended periods of observation with a debris detector pointed into the velocity vector. In conjunction with AMES Research Center, the spacecraft will also be occasionally pointed to a ground station for laser ranging experiments using a corner cube reflector. The primary mission will last at least 6 months, with extended operations continuing as long as the spacecraft is capable of doing so.

The primary CubeSat structure is made of 6061-T6 aluminum. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells.

There are no pressure vessels, hazardous or exotic materials.

The electrical power storage system consists of common lithium-ion 18650 cell batteries with over-charge/current protection circuitry. They are the GOMSpace, ApS NanoPower BP4 battery pack.

LEO – Cal Poly – 2U

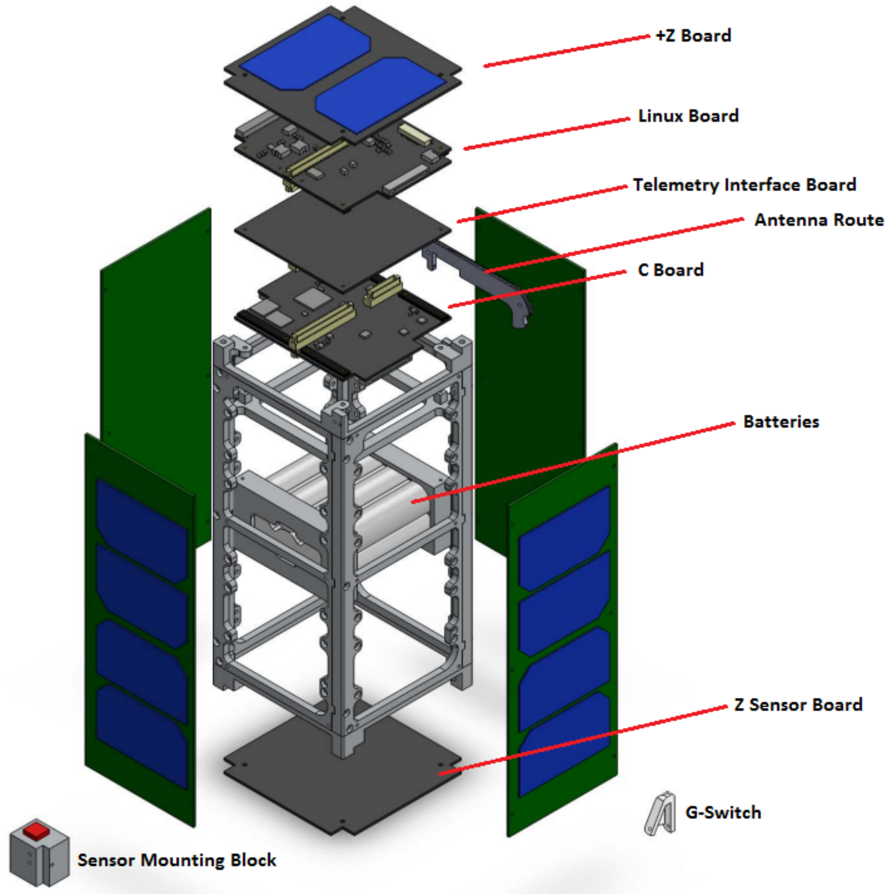

Figure 3: LEO Expanded View

LEO will record launch vehicle ascent vibrational and thermal environments with two accelerometers and a thermocouple and also record vibrational data taken by a second CubeSat (StangSat) that will be transferred through WiFi during ascent.

Immediately prior to deployment from the P-POD, LEO will turn off its WiFi module and upon deployment will take pictures of the StangSat CubeSat as they separate from the dispenser. 45 minutes after deployment the antenna will be deployed and the UHF beacon will be activated. For the first few passes the ground station operators will attempt communications to perform checkouts of the spacecraft. Data collected by the CubeSat will then be downlinked to the ground.

The CubeSat structure is made of Aluminum 6061-T6. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells.

There are no pressure vessels, hazardous or exotic materials.

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

StangSat – Merritt Island High School - 1U

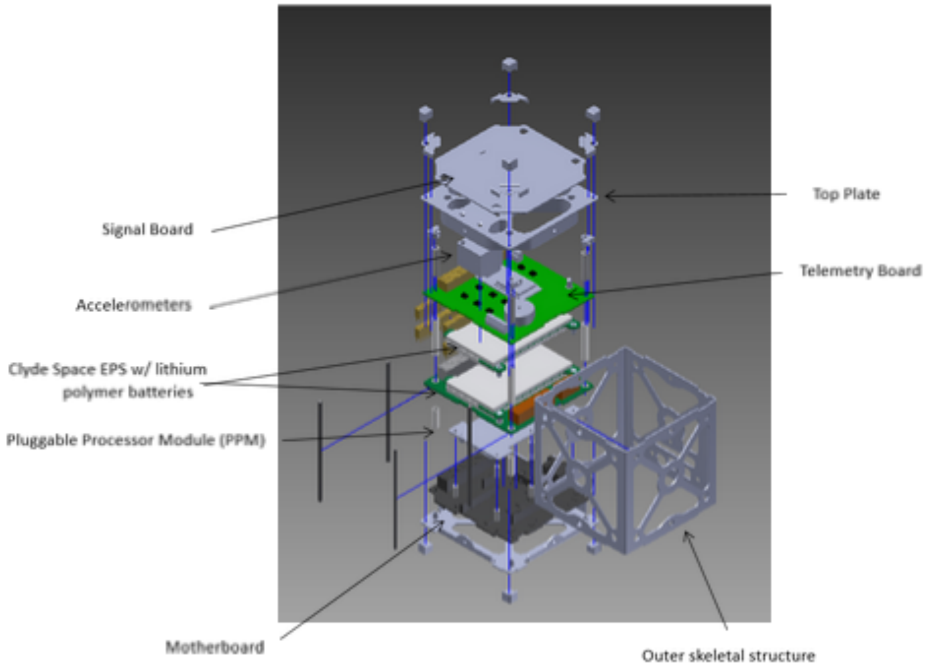

Figure 4: StangSat Expanded View

StangSat will record vibrational and shock measurements with two accelerometers located on the top plate shown above. This dynamic data will also be transmitted to our sister satellite LEO inside the PPOD over WiFi during launch.

Upon deployment from the P-POD, StangSat will be utilized as a ground reflective object. StangSat has no capability to and will not transmit to the ground after deployment

The CubeSat structure is made of Aluminum 6061-T6. The side and bottom plate contains all standard commercial off the shelf (COTS) materials, electrical components and "PCB clips" provided by Pumpkin (www.cubesatkit.com). The top plate which houses the accelerometers and signal board was custom machined and also made of Aluminum 6061-T6.

StangSat contains no pressure vessels, hazardous or exotic materials.

The electrical power storage system consists of Clyde Space procured lithium polymer batteries with over-charge/current protection circuitry included on the EPS module.

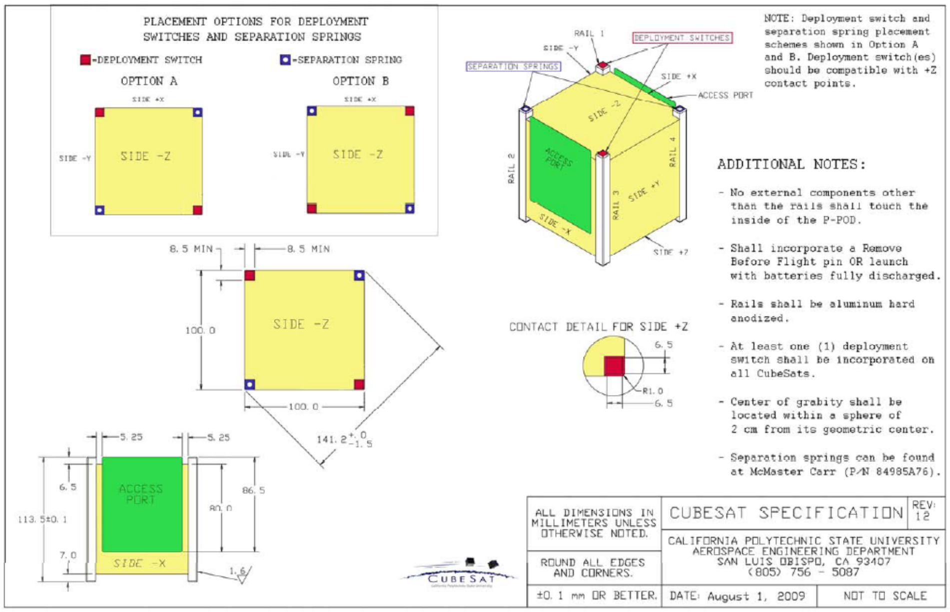

Figure 5: 1U CubeSat Specification

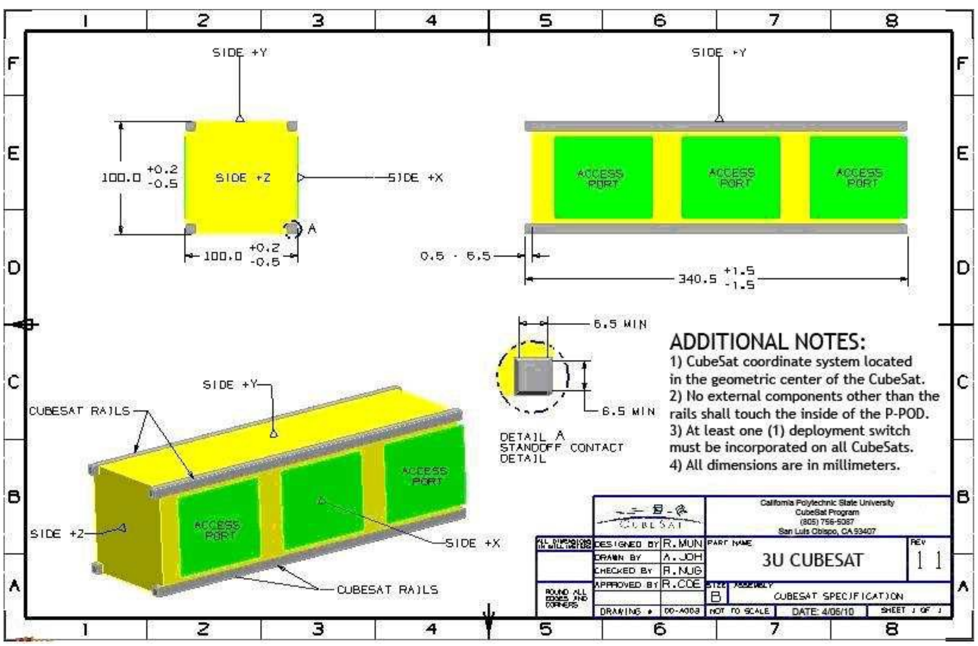

Figure 6: 3U CubeSat Specification

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-XV 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-XV 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 low earth orbit 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))

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a lifetime of 3.7 years maximum the ELaNa-XV 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 three CubeSats is that of the ARMADILLO CubeSat (11.35 X 11.35 X 34 cm):

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

Equation 1: Mean Cross Sectional Area for Convex Objects

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

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

Once a CubeSat has been ejected from the P-POD 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 dimensions used in these calculations

The ARMADILLO CubeSat has an orbit at deployment of 300 km perigee altitude by 860 km apogee altitude, with an inclination of 28.5 degrees. With an area to mass (4.15 kg) ratio of 0.0109 m^2/kg, DAS yields 3.7 years for orbit lifetime for its stowed state. Even with the variation in CubeSat design and orbital lifetime ELaNa-XV CubeSats see an average of 0.00000 probability of collision. ARMADILLO, with the largest cross sectional area will see the highest 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	ARMADILLO	LEO	StangSat
	Mass (kg)	4.15	1.9	0.77
Stowed	**Mean C/S Area (m^2)**	0.045	0.025	0.0174
	Area-to Mass (m^2/kg)	0.0109	0.013	0.023
	Orbital Lifetime (yrs)	3.7	2.9	1.3
	Probability of collision (10^X)	0.00000	0.00000	0.00000
Deployed	**Mean C/S Area (m^2)**	0.045	0.025	0.0174
	Area-to Mass (m^2/kg)	0.0109	0.013	0.023
	Orbital Lifetime (yrs)	3.7	2.9	1.3
	Probability of collision (10^X)	0.00000	0.00000	0.00000

DAS analysis updated and performed with Solar Flux file dated 10/14/2015

The probability of any ELaNa-XV 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-XV 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-XV 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 ARMADILLO 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

$$\frac{0.045\ m^2}{4.15 kg} = 0.0109 \frac{m^2}{kg}$$

Equation 4: Area to Mass Calculation of ARMADILLO (Stowed)

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

<u>DAS 2.0.2 Orbital Lifetime Calculations:</u>

DAS inputs are: 300 km maximum perigee 860 km maximum apogee altitudes with an inclination of 28.5 degrees at deployment in September of 2016. An area to mass ratio of 0.0109 m^2/kg for the ARMADILLO CubeSat was imputed. DAS 2.0.2 yields a 3.7-year orbit lifetime for ARMADILLO in its stowed state.

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

Assessment results show compliance.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on ELaNa-XV 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.

Table 4: ELaNa-VX Stainless Steel DAS Analysis

CubeSat	High Temp Components	Material	Mass (g)	Length / Diameter (mm)	Width (mm)	Height (mm)	Demise Alt (km)	KE (J)
ARMADILLO	Fasteners	Stainless Steel	15	3.05	2.54	1.67	71.1	-
ARMADILLO	Reaction Wheel	Stainless Steel	122	50	-	15	67.5	-
StangSat	Spacers	Steel	1	7	3	-	74.8	-
LEO	Fasteners	Stainless Steel	1	2.2	7.62	-	77.2	-
LEO	Antenna	Nickel Titanium	1	0.24	0.48	163	0	<1
LEO	G-Switch Mass	Stainless Steel	0.49	3.19	9.6	3.19	75.9	-
LEO	G-Switch Spring	Stainless Steel	0.02	2.26	11.23	2.26	77.9	-

The majority of stainless steel components demise upon reentry. The components that DAS conservatively identifies as reaching the ground have 1 or less joules of kinetic energy, far below the requirement of 15 joules. No stainless steel component will pose a risk to human casualty as defined by the Range Commander's Council. In fact, any injury incurred or inflicted by an object with such low energy would be negligible and wouldn't require the individual to seek medical attention.

Through the method described above, Table 4: ELaNa-VX Stainless Steel DAS Analysis, and the full component lists in the Appendix all CubeSats launching under the ELaNa-XV mission are conservatively shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

ELaNa-XV CubeSats will not be deploying any tethers.

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

Section 9-14

ODAR sections 9 through 14 for the launch vehicle are addressed in ref. (g), and 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-XV Component List by CubeSat: ARMADILLO

Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp	Survivability
ARMADILLO 3U CubeSat		1									
CubeSat Structure	External - Major	1	Aluminum 6061-T6511	box (2.5 mm thick)	1170	113.5	113.5	340.5	No	-	Demise
Antennae System	External - Major	4	Aluminum, FR4 PCB, flex PCB	box	86	98	98	5.8	No	-	Demise
Solar Panels (long)	External - Major	4	Germanium, glass, FR4 PCB, copper	sheet	512	83	340.5	2.4	No	-	Demise
Solar Panels (short)	External - Major	5	Germanium, glass, FR4 PCB, copper	sheet	63	98	98	1.6	No	-	Demise
Separation Switches	External - Minor	5	Thermoplastic acetal, copper, steel, silver plated bronze	box	42.5	20	12	6.5	No	-	Demise
Sun Sensors	External - Major	2	Aluminum, copper	box	66.5	32	34	20	No	-	Demise
Batteries	Internal - Major	4	Lithium-ion, FR4 PCB, aluminum	box	240	94	88	20	No	-	Demise
EPS Board	Internal - Major	1	FR4 PCB, copper, various electronic components	box	90	94	88	15	No	-	Demise
Magnetic Torque Rods	Internal - Major	3	Copper wire, magnetic alloy rod	cylinder	81.5	10	70	-	No	-	Demise
Reaction Wheels	Internal - Major	3	Aluminum, Nitronic, Acetal, Samarium Cobalt, Stainless Steel	box	369	50	50	29.5	No	-	Demise
Reaction Wheel - Wheel	Internal - Major	3	Stainless Steel	cylinder	300	50	15	-	Yes	1500	Demise at 63.4 km Altitude
Magnetometer	Internal - Major	1	FR4 PCB, copper, various electronic components	box	23.5	75	30.5	13	No	-	Demise
Gyroscopes	Internal - Major	3	FR4 PCB, copper, various electronic components	box	7.5	25	25	6.5	No	-	Demise

Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp	Survivability
UHF/VHF Radio	Internal - Major	1	FR4 PCB, copper, aluminum, various electronic components	box	68	94	88	13	No	-	Demise
phyCORE-LPC3250	Internal - Major	2	FR4 PCB, copper, various electronic components	box	30	70	58	8.5	No	-	Demise
Kesler Interface Board	Internal - Major	1	FR4 PCB, copper, various electronic components	box	60	94	88	15	No	-	Demise
Horton Interface Board	Internal - Major		FR4 PCB, copper, various electronic components	box	10	65	57	12	No	-	Demise
Kraken Interface Board	Internal - Major	1	FR4 PCB, copper, various electronic components	box	60	94	88	15	No	-	Demise
Hudson Interface Board	Internal - Minor	1	FR4 PCB, copper, various electronic components	box	10	65	57	12	No	-	Demise
Piezo Dust Detector - Single Detector	Internal - Major	1	See items 21-25	-	-	-	-	-	No	-	Demise
Fasteners	Internal - Minor	30	Stainless steel	box	150	2.54	3.05	1.67	Yes	1500	Demise at 71.1km Altitude
Cabling	Internal - Minor	Many	Copper alloy	-	150	-	-	-	No	-	Demise
PDD SDU	Internal - Major	1	FR4 PCB, copper, aluminum	box	21.35	30	30	21	No	-	Demise
PDD MDU	Internal - Major	1	FR4 PCB, copper, aluminum	box	170.6	100	100	21	No	-	Demise
PDD DCU	Internal - Major	1	FR4 PCB, copper	box	86.4	81.3	50.8	36	No	-	Demise
Camera	Both-Major	1	-	Rect. prism	158.4	38	38	74	No	-	Demise
FOTON	Internal - Major	1	FR4 PCB, copper, various electronic components	box	350	96	82.67	35.56	No	-	Demise
GPS Antenna	External - Major	1	6061-T6 ALUMINUM ALLOY BASE, COMPOSITE RADOME, IMPACT, ABRASION, UV, SOLVENT, SKYDROL RESISTANCE, AND FIRE RETARDANT	box	74	50.8	50.8	13.54	No	-	Demise
Retro reflector	Exterior - Minor	1	N-BK7 Optical Glass	cylinder	3	7.16	6.1	-	No	-	Demise
Retro reflector bracket	Exterior - Minor	1	Aluminum 6061	-	-	-	-	-	No	-	Demise

Appendix B. ELaNa-XV Component List by CubeSat: LEO

Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Mass (g)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp	Survivability
LEO		1									
CubeSat Structure	External - Major	1	Aluminum 6061	Box	310	100.2	100.2	200	No	-	Demise
Antennae	External - Major	1	Nickel Titanium	Rectangular Prism	1	0.24	0.48	163	Yes		Survives to ground with < 1J of energy
Solar Panels	External - Major	16	Germanium	Sheet	35.78	40	69	0.45	No	-	Demise
SidePanels	External - Major	5	Fiberglass	Box	66.72	82.7	219.1	1.55	No	-	Demise
Antennae Route	External - Minor	1	Delrin	Rectangular Prism	3.82	2.64	81.8	25.88	No	-	Demise
Sep Switches	External - Minor	1	PBT	Box	0.28	2.35	8	8.1	No	-	Demise
Batteries	Internal - Major	2	Lithium Cobalt Oxide	Box	383.4	73.53	65.75	38.66	No	-	Demise
Battery Mount	Internal - Major	1	Aluminum 6061	Box	28.22	82.05	82.2	52.5	No	-	Demise
Telemetry Interface Board	Internal - Major	1	Fiberglass	Rectangular Prism	50	85.57	87.82	1.67	No	-	Demise
Comm Board	Internal - Major	1	Fiberglass	Rectangular Prism	19.56	36	82.9	5.1	No	-	Demise
Linux Board	Internal - Major	1	Fiberglass	Rectangular Prism	22.5	82.7	93.9	1.2	No	-	Demise
C Board	Internal - Major	1	Fiberglass	Rectangular Prism	22.5	82.7	93.9	1.2	No	-	Demise
Z Sensor Board	Internal - Major	1	Fiberglass	Rectangular Prism	42.03	100	100	1.55	No	-	Demise
G-Switch Mass	Internal - Major	1	Stainless Steel 18-8	Cylinder	0.49	3.19	9.6	3.19	Yes	-	Demise at 75.9 km Altitude
G-Switch Spring	Internal - Major	1	Stainless Steel 302	Cylinder	0.02	2.26	11.23	2.26	Yes	-	Demise at 77.9 km Altitude
G-Switch Jaw	Internal - Major	1	Delrin	Box	1.3	5.5	21.83	19.5	No	-	Demise
G-Switch Mounting Plate	Internal - Major	1	Delrin	Cylinder	2.74	31.41	31.41	6.35	No	-	Demise
G-Switch Mounting Bar	Internal - Major	1	Aluminum 6061	Rectangular Prism	8.37	3.32	80.21	11.87	No	-	Demise
Sensor Mounting Block	Internal - Major	1	Aluminum 6061	Box	47.75	22	25	25	No	-	Demise
Fasteners	Internal - Minor	Many	Stainless Steel 316L	Cylinder	40	2.2	7.62	-	Yes	-	Demise at 77.2 km Altitude
Cabling	Internal - Minor	Many	Copper alloy	Rectangular Prism	-	10.18	535	0.75	No	-	Demise

Appendix C. ELaNa-XV Component List by CubeSat: StangSat

Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp	Survivability
StangSat		1			770					-	Demise
Pumpkin External Structure	External - Major	1	Aluminum T6-6061	Skeleton	218	105.15	105.3	113.6	No	-	Demise
Motherboard	Internal - Major	1	FR4, Steel, Nylon, Copper, Glass-Filled Polyester, Phosphor Bronze, Gold Plating	Box	79	96.12	92.21	13.16	No	-	Demise
PPM w/ Fasteners	Internal - Major	1	FR4, Aluminum, Silicon, Glass-Filled Polyester, Phosphor Bronze, Gold Plating	Box	21	54.6	89.5	1.6	No	-	Demise
Battery w/EPS board	Internal - Major	1	FR4, Aluminum, Silicon, Li-Polymer, Glass-Filled Polyester, Phosphor Bronze, Gold Plating	Box	233	90	95	22	No	-	Demise
Telemetry Board	Internal - Major	1	FR4, Aluminum, Silicon, Nylon, Gold-Plated Brass, Glass-Filled Polyester, Phosphor Bronze, Gold Plating	Box	84	96	90.4	35	No	-	Demise
Signal Board	Internal - Major	1	FR4, Aluminum, Silicon, Nylon, Gold-Plated Brass	Box	40	99.14	99.15	1.61	No	-	Demise
Wi-Fi Transmitter	Internal - Minor	1	FR4, Steel	Box	15				No	-	Demise
Mounting Rod / Spacers	Internal - Minor	4	Steel, Aluminum	Cylinder	31	7	-	3	Yes	1500	Demise at 74.8 km Altitude
Accelerometer (100G)	Internal - Minor	1	Aluminum, Epoxy, Steel, Copper	Box	22	25.4	21.6	10.8	No	-	Demise
Accelerometer 2 (25G)	Internal - Minor	1	Aluminum, Epoxy, Steel, Copper	Box	22	25.4	21.6	10.8	No	-	Demise
Cabling	Internal - Minor	1	Copper, Vinyl, Beryllium Copper, Gold-Plating	-	5	-	-	-	No	-	Demise

Appendix D. ARMADILLO Engineering Drawing

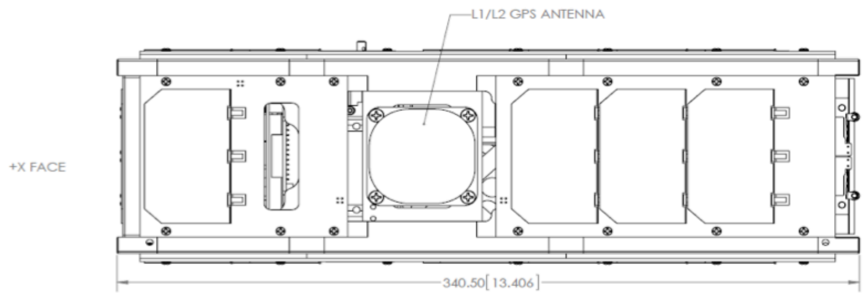

Figure 7: ARMADILLO Length Dimension (mm)

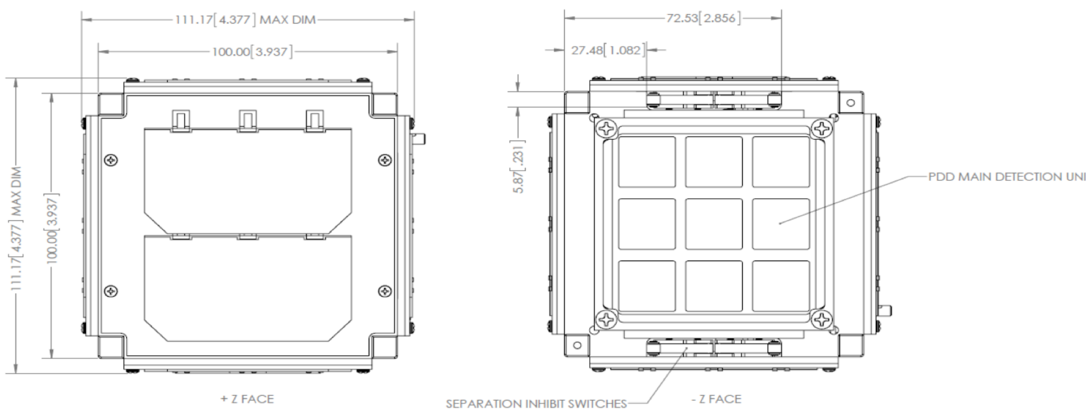

Figure 8: ARMADILLO Width Dimension (mm)

Appendix E. DAS 2.0.2 Lifetime Analysis Output

(Requirement 4.3-1) Debris Passing through LEO

Mission-Related Debris in LEO

	Debris	Released	Quantity of	Area-To-Mass	Perigee	Apogee	Inclination	RAAN	Argument of	Mean Anomaly
Row	Name	Year	Each Element	(m^2/kg)	Alt (km)	Alt (km)	(deg)	(deg)	Perigee (deg)	(deg)
1	Armadillo	2016.75	1	0.0109	300	860	28.5			
2	Leo	2016.75	1	0.013	300	860	28.5			
3	StangSat	2016.75	1	0.023	300	860	28.5			

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Output

	Debris	Compliance	Lifetime	Object Time
Row	Name	Status	(yrs)	(obj-yrs)
1	Armadillo	Compliant	3.7	3.7
2	Leo	Compliant	2.9	2.8
3	StangSat	Compliant	1.3	1.2

TOTAL OBJECT TIME:
7.8 obj yrs

Messages

Requirement 4.3-1
Compliant