

ELVL-2015-0044079 (DRAFT)
July 13, 2015

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

DRAFT

Signature Page

Justin Treptow, Analyst, NASA KSC VA-H1

Scott Higginbotham, Mission Manager, NASA KSC VA-C

Jason Crusan, Program Executive, NASA HQ SOMD

Suzanne Aleman, NASA HQ OSMA MMOD Program Executive

Signatures Required for Final Version of ODAR

Terrence W. Wilcutt, NASA Chief, Safety and Mission Assurance

William Gerstenmaier, NASA AA,
Human Exploration and Operations Mission Directorate.

National Aeronautics and
Space Administration

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



ELVL-2015-0044079

Reply to Attn of: **VA-H1**

July 13, 2015

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 (DRAFT)

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

Version: DRAFT – Technical information in this DRAFT is subject to change. Please see official release for finalized components and analysis.

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 4.0 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 Space 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; Cody Colley, Project Manager

LEO: Jordi Puig-Suari, Principal Investigator, Alex Wargo, Project Manager

StangSat: Tracey Beatovich Principal Investigator, Brian Robusto, Project Manager

DRAFT

Program Milestone Schedule	
Task	Date
CubeSat Selection	October 2014
MRR	May 2016
Pre-Ship Review	June 2016
CubeSat Delivery to KAFB	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 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, StangSat. 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)).

Each CubeSat 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	3	3U (10 cm X 10 cm X 30 cm)	ARMADILLO	[4.15]
B		2U (10 cm X 10 cm X 20 cm)	LEO	[1.9]
C		1U (10 cm X 10 cm X 10 cm)	StangSat	[0.77]

The following subsections contain descriptions of these 3 CubeSats.

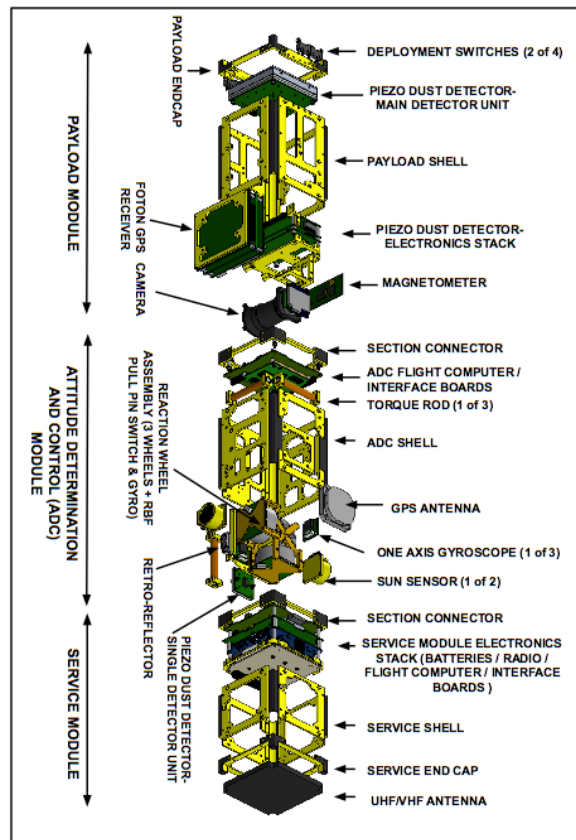


Figure 2: ARMADILLO Expanded View (Not Showing Solar Panels)

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 [TBD] 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 [TBD] 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.

DRAFT

LEO – Cal Poly – 2U

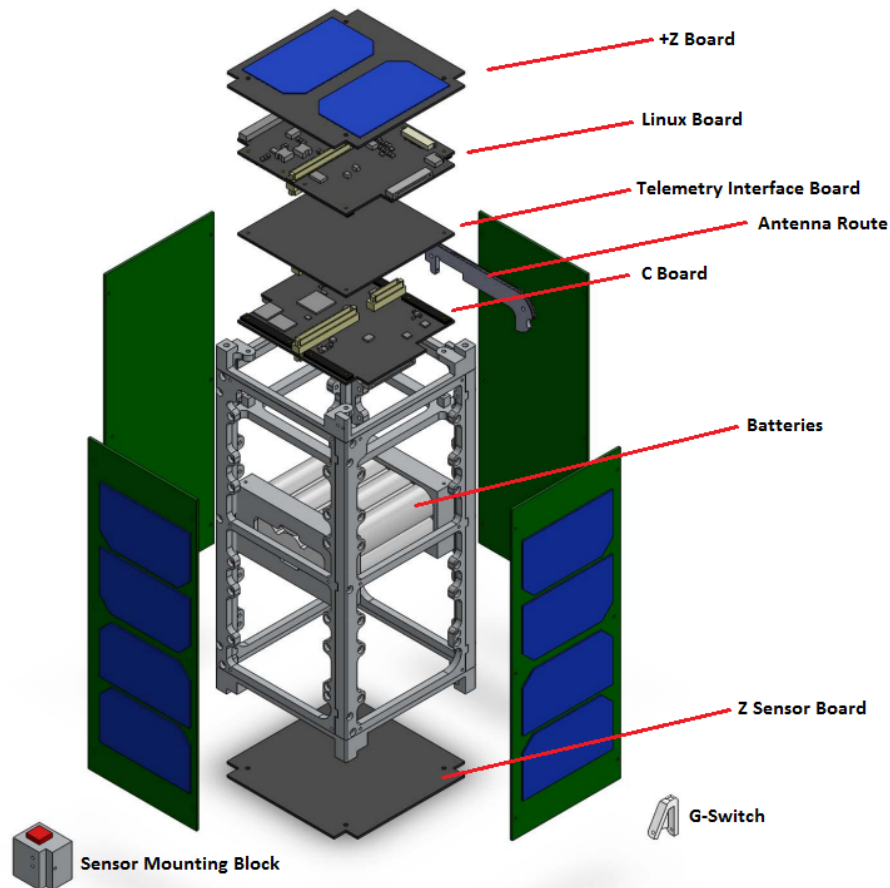


Figure 3: LEO Expanded View

LEO will record vibrational and thermal measurements with two accelerometers and a thermocouple and also record vibrational data taken by a second CubeSat that will be transferred through WiFi during launch.

Upon deployment from the P-POD, LEO will turn off its WiFi module and take pictures of the StangSat CubeSat as they separate. 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 from the requested EOI (events of interest) will then be able to be downlinked.

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

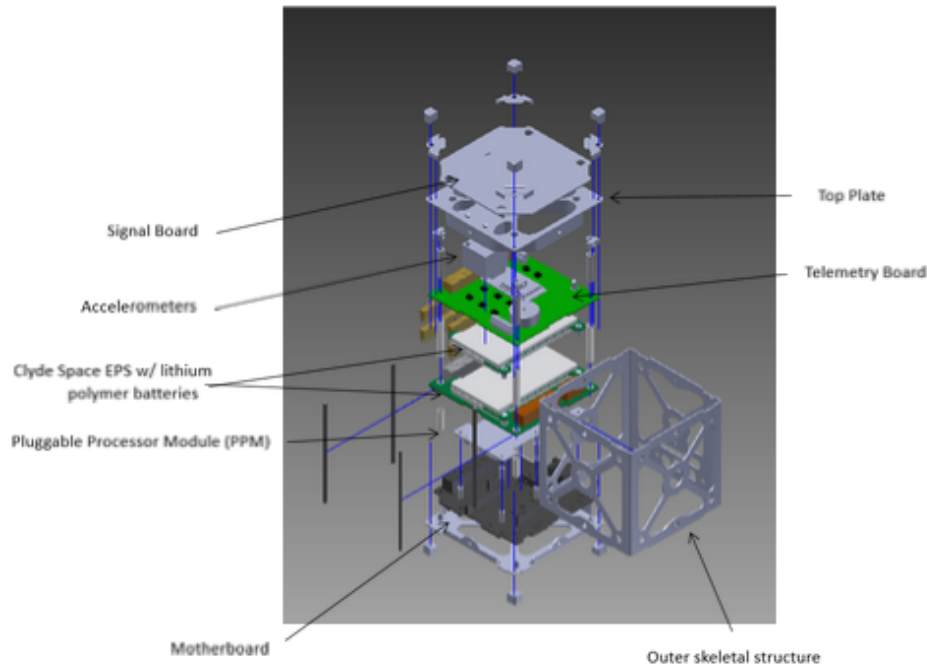


Figure 4: StangSat Expanded View

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 while also bleeding down batteries to an acceptable level for reentry. StangSat has no capability to and will not transmit to the ground with our low power WiFi transmission. No additional transmission capability exists on StangSat.

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.

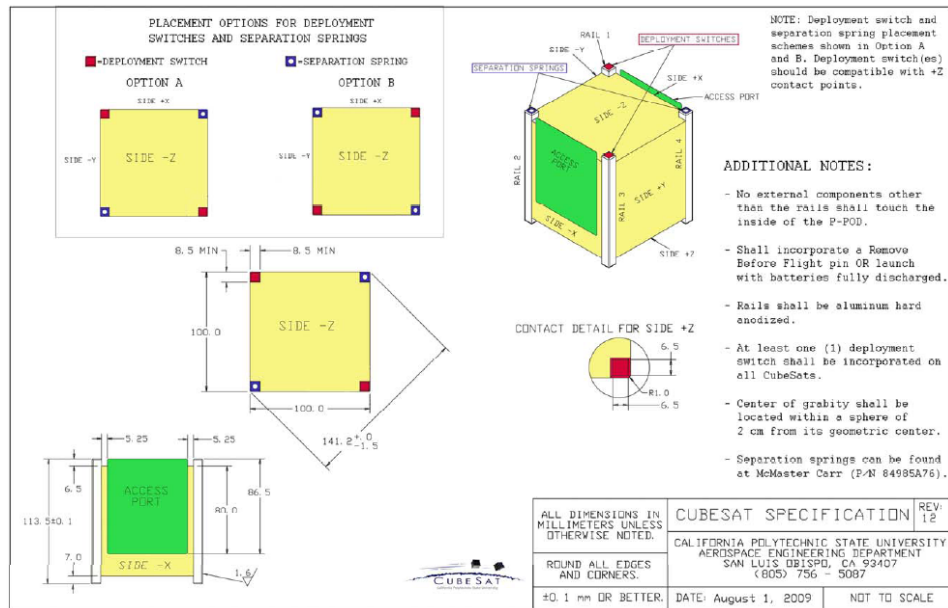


Figure 5: 1U CubeSat Specification

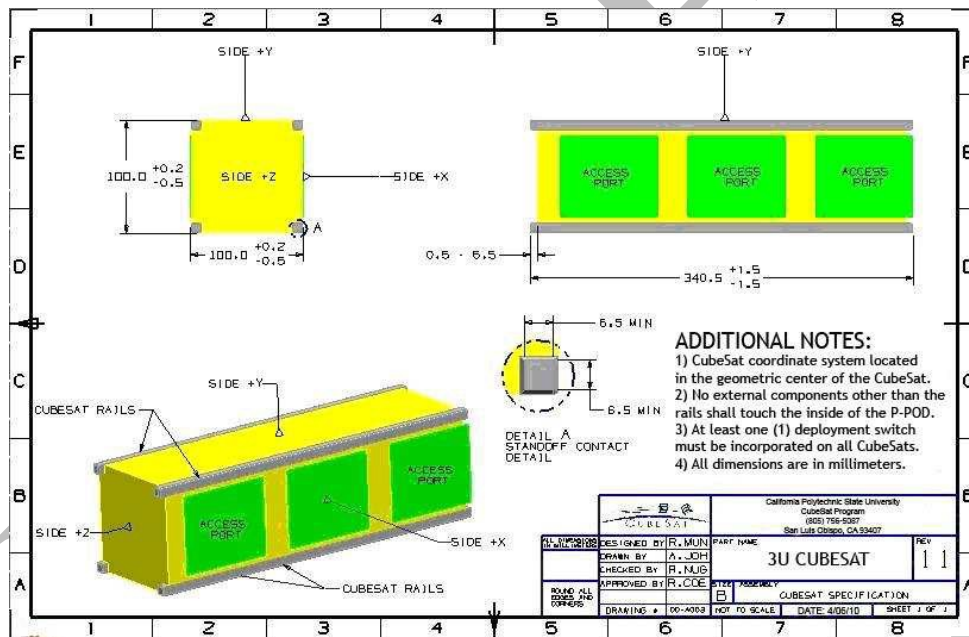


Figure 6: 3U CubeSat Specification

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.

DRAFT

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 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))

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a lifetime of 1.3 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 (10 X 10 X 30 cm):

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

Equation 1: Mean Cross Sectional Area for Convex Objects

$$\text{Mean CSA} = \frac{(A_{\max} + A_1 + A_2)}{3}$$

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 0.009 m²/kg, DAS yields 4.0 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]	[0.762]	[0.77]
Stowed	Mean C/S Area (m^2)	0.039	0.025	0.017
	Area-to Mass (m^2/kg)	0.009	0.033	0.023
	Orbital Lifetime (yrs)	4.0	2.8	1.3
	Probability of collision (10^X)	0.00000	0.00000	0.00000
Deployed	Mean C/S Area (m^2)	0.039	0.025	0.017
	Area-to Mass (m^2/kg)	0.009	0.033	0.023
	Orbital Lifetime (yrs)	4.0	2.8	1.3
	Probability of collision (10^X)	0.00000	0.00000	0.00000

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 Postmission 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 postmission disposal is not applicable. Disposal is achieved via passive atmospheric reentry.

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

$$\frac{\text{Mean } C/S \text{ Area } (m^2)}{\text{Mass } (kg)} = \text{Area} - \text{to} - \text{Mass } \left(\frac{m^2}{kg}\right)$$

Equation 3: Area to Mass

$$\frac{0.0174 m^2}{0.77kg} = 0.023 \frac{m^2}{kg}$$

Equation 4: Area to Mass Calculation of StangSat (Deployed)

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

DAS 2.0.2 Orbital Lifetime Calculations:

DAS inputs are: 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 0.009 m²/kg for the ARMADILLO CubeSat was imputed. DAS 2.0.2 yields a 4.0 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 – Wheel	Stainless Steel	200	50	15	-	63.4	-
LEO	Antennae	Steel 410	[20]	163	0.24	0.48	0	0.0
StangSat	Spacers	Steel	3	7	3	-	74.8	-

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.

DRAFT

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. Poffenberger
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
- Appendix B.** ELaNa-XV Component List by CubeSat: StangSat
- Appendix C.** ELaNa-XV Component List by CubeSat: LEO

*Note for this DRAFT version of the ODAR a number of component items dimensions and materials have been left empty [TBD] and will be updated upon final release of this document

DRAFT

Appendix A. ELaN-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	shelled 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

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
Gyroscopes	Internal - Major	3	FR4 PCB, copper, various electronic components	box	7.5	25	25	6.5	No	-	Demise
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		[TDB]	[TDB]	[TDB]	[TDB]	[TDB]	No	-	Demise
Fasteners	Internal - Minor	Many	Stainless steel	[TDB]	150	[TDB]	[TDB]	[TDB]	Yes	1500	Demise at 71.1km Altitude
Cabling	Internal - Minor	Many	Copper alloy	[TDB]	150	[TDB]	[TDB]	[TDB]	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		rectangular prism	158.4	38	38	74	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
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
Retroreflector	Exterior - Minor	1	-	[TDB]	[TDB]	[TDB]	[TDB]	[TDB]	No	-	Demise
Retroreflector bracket	Exterior - Minor	1	-	[TDB]	[TDB]	[TDB]	[TDB]	[TDB]	No	-	Demise

Appendix B. ELaNaxV 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 (C)	Survivability
LEO	-	1	-	-	1900	-	-	-	-	-	-
CubeSat Structure	External - Major	1	Aluminum 6061	Box	500	100.2	100.2	200	No	-	Demise
Antennae	External - Major	1	Steel 410	[TBD]	[TBD]	163	0.24	0.48	Yes		Survives to ground with < 1 J of energy
Solar Panels	External - Major	18	Fiberglass	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	No	-	Demise
Sep Switches	External - Minor	1	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	-	-	Demise
Batteries	Internal - Major	2	[TBD]	[TBD]	91.6	[TBD]	[TBD]	[TBD]	-	-	Demise
Battery Mount	Internal - Major	1	Aluminum 6061	[TBD]	28.22	[TBD]	[TBD]	[TBD]	No	-	Demise
Telemetry Interface Board	[TBD]	[TBD]	[TBD]	[TBD]	50	[TBD]	[TBD]	[TBD]	-	-	Demise
Comm Board	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	-	-	Demise
Linux Board	[TBD]	[TBD]	[TBD]	[TBD]	22.5	[TBD]	[TBD]	[TBD]	-	-	Demise
C Board	[TBD]	[TBD]	[TBD]	[TBD]	22.5	[TBD]	[TBD]	[TBD]	-	-	Demise
Z Sensor Board	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	-	-	Demise
Sensor Mounting Block	Internal - Major	1	Aluminum 6061	[TBD]	47.75	[TBD]	[TBD]	[TBD]	No	-	Demise
Fasteners	Internal - Minor	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	-	-	Demise
Cabling	Internal - Minor	[TBD]	Copper alloy	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	No	-	Demise

Appendix C. ELaNax-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	-	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	-	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	-	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	-	84	96	90.4	35	No	-	Demise
Signal Board	Internal - Major	1	FR4, Aluminum, Silicon, Nylon, Gold-Plated Brass	-	40	99.14	99.15	1.61	No	-	Demise
Wi-Fi Transmitter	Internal - Minor	1	FR4, Steel	-	15	[TDB]	[TDB]	[TDB]	No	-	Demise
Mounting Rod / Spacers	Internal - Minor	4	Steel, Aluminum	-	31	7	-	3	Yes	1500	Demise at 74.8 km Altitude
Accelerometer (100G)	Internal - Minor	1	Aluminum, Epoxy, Steel, Copper	-	22	25.4	21.6	10.8	No	-	Demise
Accelerometer 2 (25G)	Internal - Minor	1	Aluminum, Epoxy, Steel, Copper	-	22	25.4	21.6	10.8	No	-	Demise
Cabling	Internal - Minor	1	Copper, Vinyl, Beryllium Copper, Gold-Plating	-	5	[TDB]	[TDB]	[TDB]	No	-	Demise