ELVL-2015-000440003 (Final v2)
May 5, 2015

Orbital Debris Assessment for The CubeSats on the (HTV-5 & Orb-4) /ELaNa-IX Mission per NASA-STD 8719.14A

Sensitive But Unclassified (SBU)

Signature Page

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ELVL-2015-000440003

Reply to Attn of: VA-H1 May 5, 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-IX Mission (Final v2)

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. "FW: ISS Orbital Parameters." 7 Mar. 2014. 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

Release
v1 – Initial release
v2 – Corrections to timetable and editorial changes

The intent of this report is to satisfy the orbital debris requirements listed in ref. (A) for the ELaNa-IX auxiliary mission launching in conjunction with the HTV-5 and Orb-4 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 missions and are not presented here.

The following table summarizes the compliance status of the ELaNa-IX auxiliary payload mission flown on HTV-5 and Orb-4 missions. The three CubeSats comprising the ELaNa-IX 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 1.1 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-IX mission

Section 1: Program Management and Mission Overview

The ELaNa-IX 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:

MinXSS: Rick Kohnert, Principle Investigator
STMSat-1: Joe Pellegrino, Principle Investigator; Melissa Pore, Project Manager
CADRE: Dr. Cutler and Dr. Ridley Principle Investigator; Casey Steuer, Project Manager

Program Milestone Schedule	
Task	Date
CubeSat Selection	April 2014
CubeSat Build, Test, and Integration	April 2014 to May 2015
CubeSat Delivery to NanoRacks	June 8 – (STMSat) Aug 10 – (MinXSS) Aug 11 – (CADRE)
CubeSat Integration into Deployers	June 9 – (STMSat) Aug 11 – (MinXSS) Aug 12 – (CADRE)
Launch to ISS Deployment from the ISS is TDB	8/16/15 (HTV-5 – STMSat) 11/19/15 (ORB-4 – MinXSS) 11/19/15 (ORB-4 – CADRE)

Figure 1: Program Milestone Schedule

The ELaNa-IX mission will be jointly launched as an auxiliary payload on the HTV-5 and Orb-4 missions. HTV-5 will be launched on a H-IIB from Tanegashima, Japan and Orb-4 will be launched on an Falcon 9 launch vehicle from CCAFS,. The ELaNa-IX, will deploy 3 pico-satellites (or CubeSats) from the ISS. The CubeSat slotted position is identified in Table 2: ELaNa-IX CubeSats. The ELaNa-IX manifest includes: MinXSS, STMSat-1, and CADRE. The current launch dates are in August and October 2015. The three CubeSats will be ejected from the ISS, placing the CubeSats in an orbit approximately 400 X 420 km at inclination of 51.6 deg (ref. (c)).

Each ELaNa 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-IX Mission. They will be deployed out of ISS via NanoRacks, as shown in Table 2: ELaNa-IX CubeSats below.

Table 2: ELaNa-IX CubeSats

CubeSat Quantity	CubeSat size	CubeSat Names	CubeSat Masses (kg)
1	3U (10 cm X 10 cm X 30 cm)	MinXSS	3.48
1	1U (10 cm X 10 cm X 10 cm)	STMSat-1	1.0
1	3U (10 cm X 10cm X 30 cm)	CADRE	4.4

The following subsections contain descriptions of these three CubeSats.

MinXSS – University of Colorado -3U

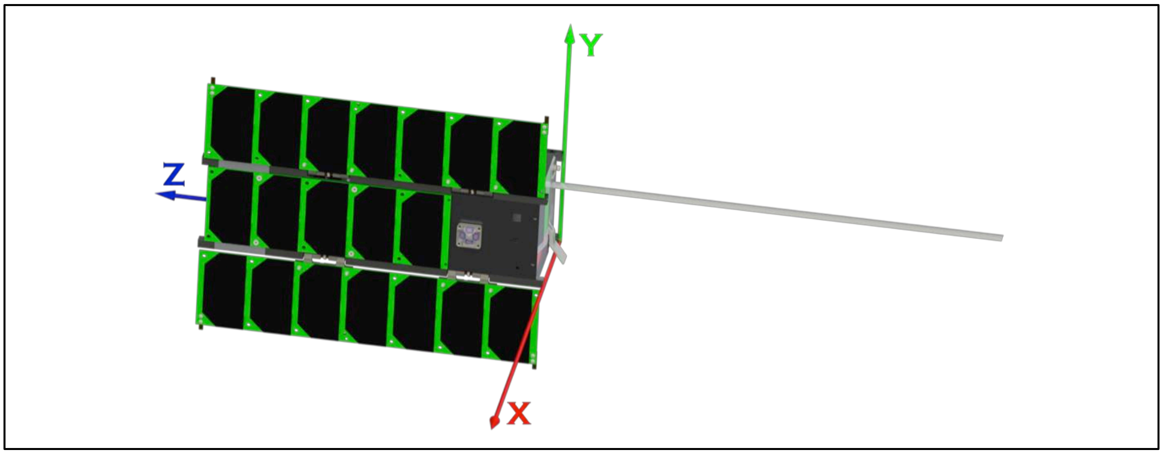

Figure 2: MinXSS with deployed components

The Miniature X-ray Solar Spectrometer (MinXSS) is a 3U CubeSat mission, developed by the Laboratory for Atmospheric and Space Physics (LASP). Its purpose is to better understand the solar flare energy distribution within the soft X-rays (SXR) and its impact on Earth's ionosphere, thermosphere, and mesosphere (ITM). Nominally designed for a NanoRack mission, MinXSS's is expected to have a 0.4 year mission, as limited by the orbit provided by deployment from the International Space Station (ISS). The nominal orbit for MinXSS is expected to be a 420 x 400 km circular orbit at a 51.6° inclination with a launch date in the second half of 2015 with deployment from the ISS approximately two months later. The primary science payload is Amptek's commercial X123 X-ray Spectrometer with repackaged electronics to mitigate thermal effects due to the space environment. From the 420 x 400 km orbit at a 51.6° inclination, MinXSS takes daily spectral measurements of the solar soft X-rays. LASP will process and distribute the data daily through the LASP Interactive Solar IRradiance Datacenter (LISIRD). The mission's ground segment that includes mission operations, the UHF ground station operating at 437 MHz, science and engineering data processing, and data distribution are located at the Laboratory for Atmospheric and Space Physics (LASP) in Boulder, Colorado.

MinXSS is a solar-pointing, 3-axis-controlled, 3U CubeSat that observes the solar soft X-ray spectrum (SXR) between 0.4 and 40 keV (0.03-3 nm) with 0.15 keV resolution (0.0001 nm at 0.03 nm to 1 nm at 3 nm). The spacecraft is designed for use in low earth orbit (LEO) with two deployable solar panels and a deployable UHF monopole antenna. There is a single, fixed solar array panel along the plus X axis. The total spacecraft mass is 3.48 kg with a volume of 10 cm x 34 cm x 10 cm in the stowed configuration. When fully deployed, the spacecraft's monopole antenna extends 47 cm along the minus Z axis and all three solar panels are sun facing. A miniaturized star tracker is mounted such that its boresight is perpendicular to the plus X axis of MinXSS and pointing 10° from the plus Y axis.

The 3 axis inertial pointing system (from Blue Canyon Technologies) contains 3 reaction wheel assemblies, 3 torque rods, a miniaturized star tracer, and a processor board all self-contained in a ½ U unit that is attached to plus Z side of the main body of the spacecraft.

The MinXSS battery pack is comprised of four 2 amp-hour lithium polymer batteries connected in series and parallel to make an 8.4 Volt battery pack with 4 amp-hour capacity.

All sensors on MinXSS are passive and there are no lasers, radiation sources, propellants, pressure vessels, or other hazardous materials on board the spacecraft.

STMSat-1 – St. Thomas More Cathedral School – 1U

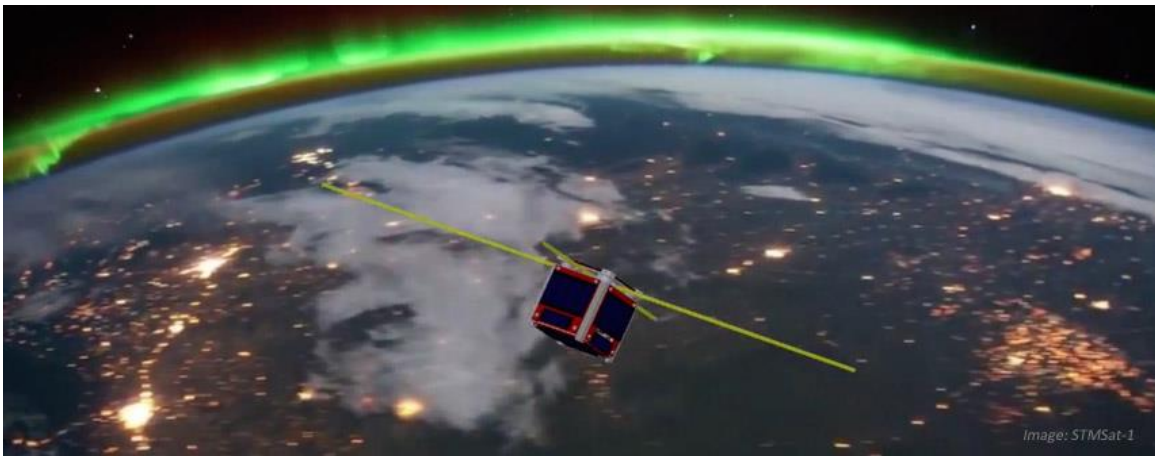

Figure 3: STMSat-1 Deployed

The STM Mission Possible CubeSat Project goals include (1) earth observation and (2) a network of Remote Mission Operation Centers (RMOC) made up of schools all over the world. By allowing other schools with a HAM radio to track our satellite and become an official RMOC school, we will be able to create a global learning opportunity for our mission. Participation requires having a working HAM radio and a licensed operator on campus so data can be downloaded when the CubeSat is overhead. With RMOCs all over the world, we will be able to collect and share data on a global level once our satellite is in orbit. The only deployable on the spacecraft is the antenna. A Pumpkin 1U cubesat kit was used for this mission. Since this spacecraft has been design, assembled and tested by grade school children, the design is very simple.

Thirty minutes after deployment the batteries will achieve a full state of charge. 46 minutes after deployment the antennas will be released. Ground link check will be performed at deploy plus 50 minutes and the first image will be downlinked at 60 minutes after deploy.

There are no pressure vessels, hazardous or exotic materials.

The electrical power storage system consists of a Clyde Space CS-1UEPS2-10. Relying on Lithium Ion technology with over-charge/current protection circuitry

CADRE – University of Michigan – 3U

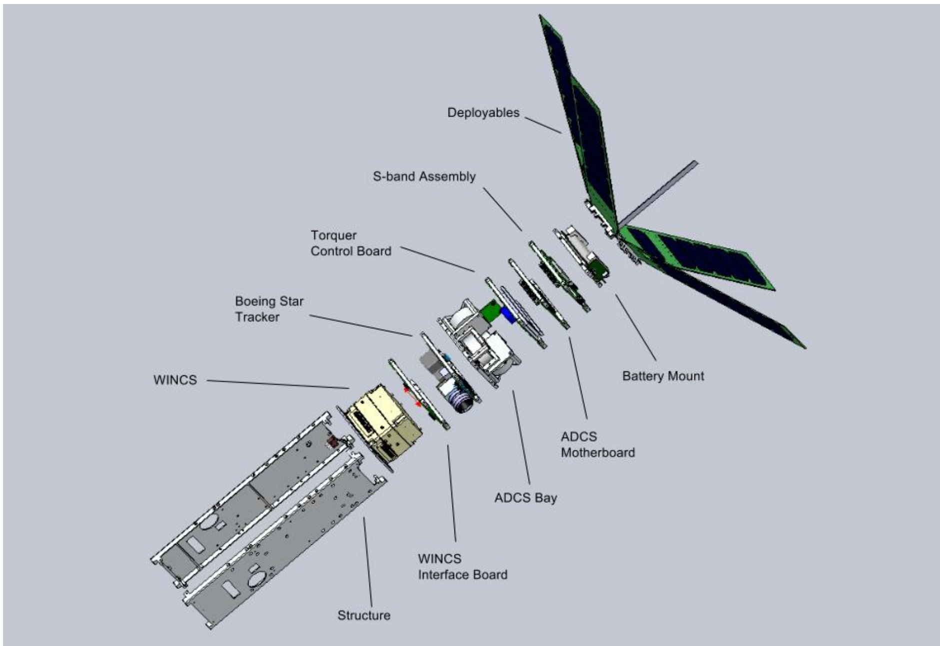

Figure 4: CADRE Expanded View

CADRE will test the Winds Ions Neutrals Composition suite (WINCS), developed by the Navy Research Laboratory. WINCS consists of four electrostatic analyzers and two mass spectrometers; it will measure the density, temperature and composition of the ionosphere. Four deployed solar panels and bus will fly in a dart configuration using a star tracker, IMUs, photodiodes and reaction wheels.

Upon deployment from the P-POD, CADRE will power up and start counting down timers. At 30 minutes, the antennas will be deployed and a UHF beacon will be activated shortly thereafter. After approximately 120 minutes antenna deployment will be confirmed. At about 200 minutes four solar panels will be deployed using a thermal resistive inhibit release. After about 300 minutes, solar panel deployment and autonomous activation of magnetorquers will be confirmed. For the first few passes the ground station operators will attempt communications to perform checkouts of the spacecraft. After core checkout CADRE will begin ADCS calibration and S-band checkout. After 15 days WINCS commissioning will begin followed by nominal operations.

The CubeSat structure is made of Aluminum 6061-T6. It contains mostly 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 two Panasonic lithium-ion batteries (18650) with over-charge/current protection circuitry.

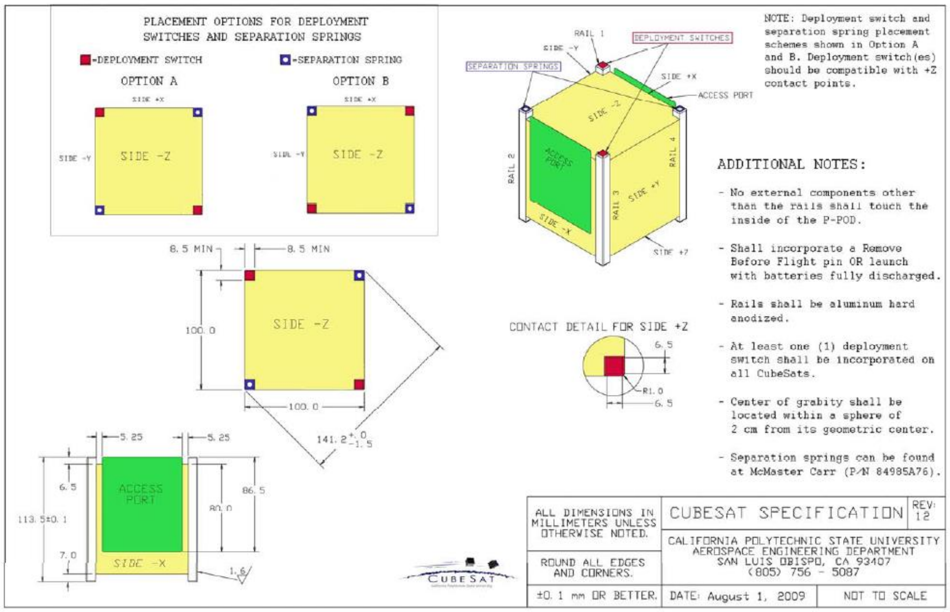

Figure 5: 1U CubeSat Specification

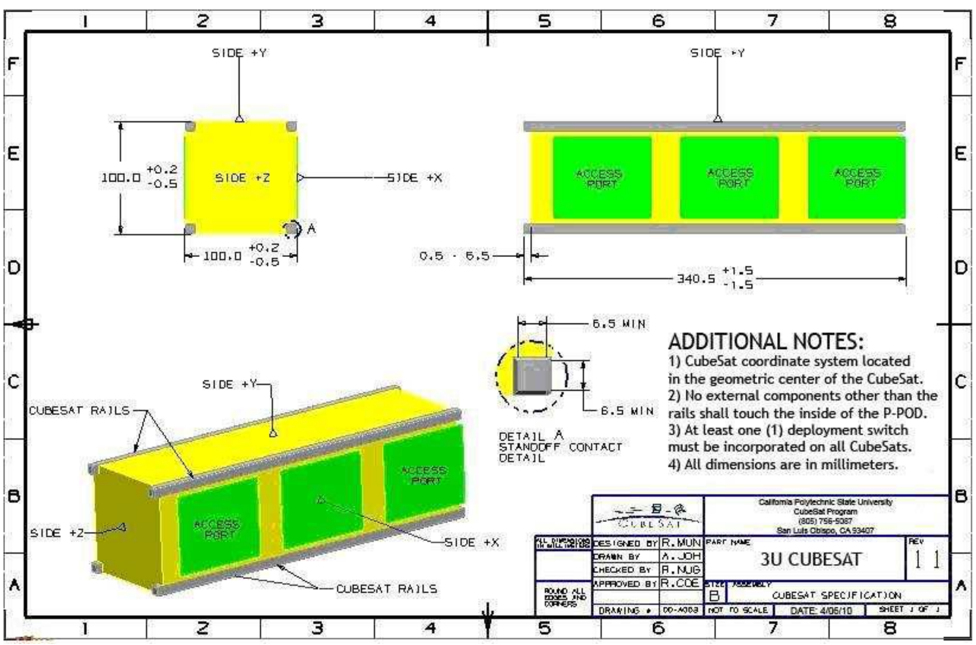

Figure 6: 3U CubeSat Specification

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-IX 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-IX mission. No passivation of components is planned at the End of Mission for ELaNa-IX.

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 (j)).

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 1.1 years maximum the ELaNa-IX 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 CADRE CubeSat with antennas and solar arrays deployed (10 X 10 X 30 cm with one deployable antenna 1.2 X 16.35 cm and four deployable solar arrays 8.3 X 32.6 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 CADRE (4.4kg) orbit at deployment is 420 km apogee altitude by 400 km perigee altitude, with an inclination of 51.6 degrees. With an area to mass ratio of 0.0214 m^2/kg, DAS yields 1.1 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-IX CubeSats see an average of 0.00000 probability of collision. SMTSat-1 also sees a probability of collision at 0.00000. Table 4 below provides complete results.

Table 3: CubeSat Orbital Lifetime & Collision Probability

CubeSat		MinXSS	SMTSast-1	CADRE
	Mass (kg)	3.48	0.999	4.4
Stowed	**Mean C/S Area (m^2)**	0.0390	0.0157	0.039
	Area-to Mass (m^2/kg)	0.0112	0.0157	0.009
	Orbital Lifetime (yrs)	0.9	0.6	1.1
	Probability of Collision*	0.00000	0.00000	0.00000
Deployed	**Mean C/S Area (m^2)**	0.0693	0.0175	0.0942
	Area-to Mass (m^2/kg)	0.0199	0.0175	0.0214
	Orbital Lifetime (yrs)	0.5	0.6	0.5
	Probability of Collision*	0.00000	0.00000	0.0000

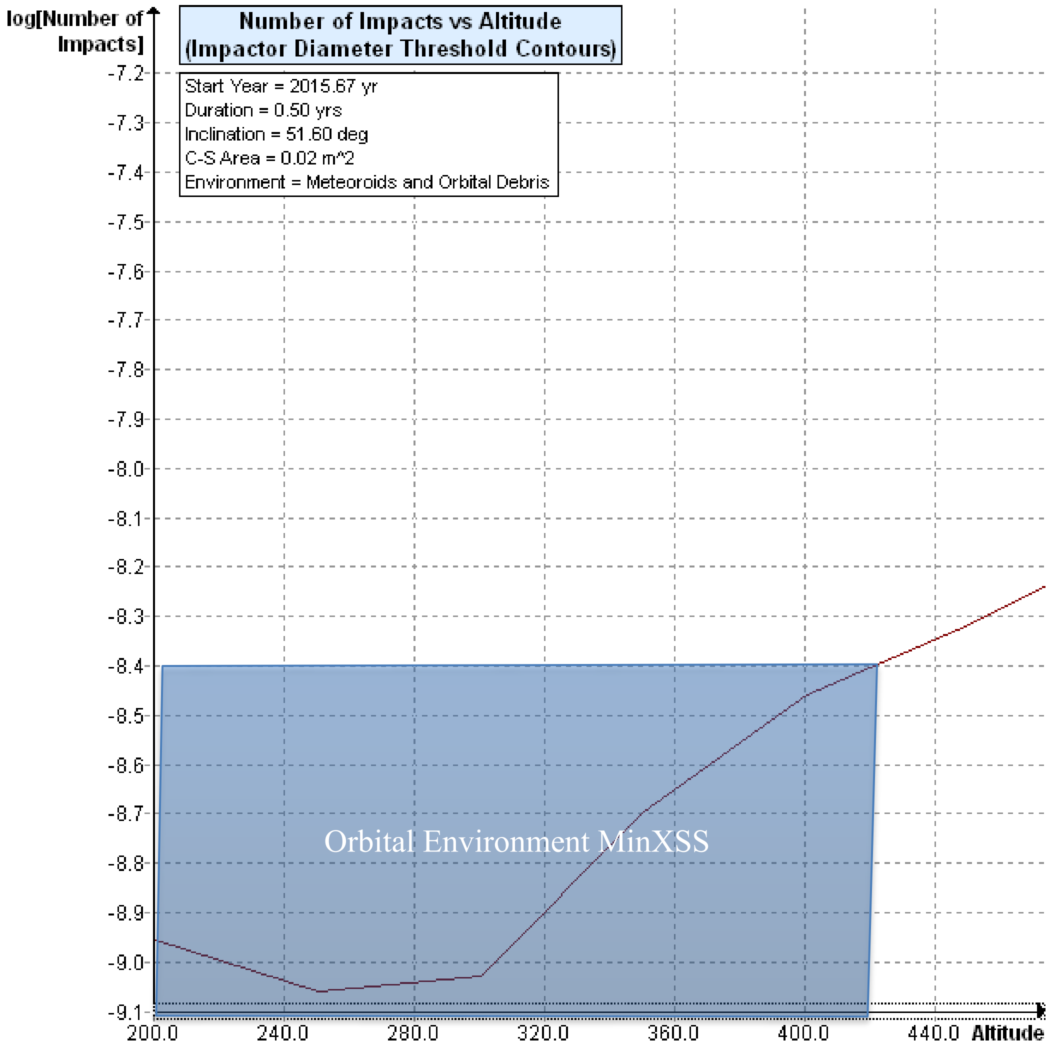

Figure 7: Orbit Collision (< 10 cm) vs. Altitude (MinXSS)

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.

The probability of any ELaNa-IX 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 returned DAS 2.0 value for probability shows a probability lower than its significant figures can report.

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-IX 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-IX 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.

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

$$\frac{0.0391\ m^2}{4.4\ kg} = \ 0.089\frac{m^2}{kg}$$

CADRE in the stowed configuration 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.

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

DAS inputs are: 400 km maximum perigee 420 km maximum apogee altitudes with an inclination of 51.6 degrees at deployment sometime after reaching ISS in August year 2015. An area to mass ratio of 0.009 m^2/kg for the CADRE CubeSat was imputed. DAS 2.0.2 yields a 1.1 years orbit lifetime for CADRE 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-IX 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-IX Survivability DAS Analysis

CubeSat	High Temp Component	Material	Mass (kg)	Length / Diameter(m)	Width (m)	Height (m)	Demise (Alt)	KE (J)
MinXSS	Solar Panel Hinge (Halves)	Stainless Steel (generic)	0.003	0.014	0.113	0.005	0	0
MinXSS	Antenna	Stainless Steel (generic)	0.005	0.012	0.467	0.001	0	0
MinXSS	ADCS Reaction Wheel	Stainless Steel (generic)	0.022	0.013	0.041	-	72	0
MinXSS	Payload1 Detector	Stainless Steel (generic)	0.011	0.021	0.014	-	74	0
MinXSS	Detector Aperture	Tungsten	0.005	0.019	0.0024	-	0	1
MinXSS	Fasteners	Steel A-286	0.001	0.003	0.02	-	-	0

CubeSat	High Temp Component	Material	Mass (kg)	Length / Diameter(m)	Width (m)	Height (m)	Demise (Alt)	KE (J)
CADRE	UHF Whip Antenna	Steel 410	10	0.1	0.013	0.164	0	1
CADRE	S Band Patch Antenna	Steel 410	10	0.028	0.028	0.004	0	2
CADRE	Sep Switch Plunger	Stainless Steel 18-8	2.35	0.0045	0.027	0.005	76	0
CADRE	Mounting Screw	316 Stainless Steel	0.1	0.004	0.007	-	77.7	0

SMTSat-1 does not have any high temperature components that have an effect on the DAS analysis. Various fasteners will be onboard constructed of a stainless steel material, however they will have negligible energy on reentry

The majority of high temperature components demise upon reentry. The components that DAS conservatively identifies as reaching the ground have less than or equal to 2 joules of kinetic energy, far below the requirement of 15 joules. No high temperature 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-IX Survivability DAS Analysis, and the full component lists in the Appendix all CubeSats launching under the ELaNa-IX mission are conservatively shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

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

Section 8: Assessment for Tether Missions

ELaNa-IX CubeSats will not be deploying any tethers.

ELaNa-IX 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-H1/Mr. Beaver
VA-H1/Mr. Haddox
VA-C/Mr. Higginbotham
VA-G2/Mr. Poffenberger
VA-G2/Mr. Atkinson
SA-D2/Mr. Homero
SA-D2/Mr. Hale
AIS-22/Ms. Griffin

Appendix Index:

Appendix A. ELaNa-IX Component List by CubeSat: MinXSS

Name	Quantity	Material	Body Type	Mass (kg)	Diameter/ Width (m)	Length (m)	Height (m)	Low Melting Temperature	Melting Temp (°C)	Comment
MinXSS	1	Aluminum 6061-T6	Box	3.48	0.1	0.341	0.1	Yes	-	Demise
Deployable Solar Arrays	1	Fiberglass	Box	0.26	0.081	0.34	0.006	Yes	-	Demise
Fixed Solar Array	1	Fiberglass	Box	0.092	0.081	0.34	0.006	Yes	-	Demise
Solar Panel Hinge (Halves)	8	Stainless Steel (generic)	Box	0.003	0.014	0.113	0.005	No	1510	See Table 4 Has 0J KE
Solar Panel Hinge Pins	4	Brass- Cartridge	Cylinder	0.002	0.003	0.045	-	Yes	-	Demise
Antenna	1	Stainless Steel (generic)	Box	0.005	0.012	0.467	0.001	No	1510	See Table 4 Has 0J KE
ADCS Housing	2	Aluminum 6061-T6	Box	0.253	0.100	0.1	0.05	Yes	-	Demise
ADCS - Reaction Wheel Case	3	Aluminum 6061-T6	Box	0.017	0.040	0.041	0.017	Yes	-	Demise
ADCS - Reaction Wheel Magnets	24	Iron	Box	0.0008	0.006	0.011	0.0019	Yes	-	Demise
ADCS Reaction Wheel	3	Stainless Steel (generic)	Cylinder	0.022	0.013	0.041	-	No	1510	See Table 4 Demise at 72km alt
ADCS Torque Rods	3	Iron	Cylinder	0.005	0.008	0.038	-	Yes	-	Demise
ADCS Star Tracker Housing	1	Aluminum 6061-T6	Box	0.052	0.052	0.053	0.048	Yes	-	Demise
ADCS Tracker Lens	1	Aluminum 6061-T6	Box	0.046	0.027	0.039	0.026	Yes	-	Demise
ADCS Electronics Board	1	Fiberglass	Box	0.045	0.091	0.097	1.57	Yes	-	Demise
MinXSS Structure	1	Aluminum 6061-T6	Box	0.69	0.1	0.291	0.1	Yes	-	Demise
Payload1 Case	1	Aluminum 6061-T6	Box	0.11	0.068	0.1	0.03	Yes	-	Demise
Payload1 Electronics board	2	Fiberglass	Box	0.036	0.068	0.1	0.03	Yes	-	Demise
Payload1 Detector	1	Stainless Steel (generic)	Cylinder	0.011	0.021	0.014	-	No	1510	See Table 4 Demise at 74 km alt
Detector Bracket	1	Aluminum 6061-T6	Box	0.27	0.029	0.047	0.021	Yes	-	Demise

Name	Quantity	Material	Body Type	Mass (kg)	Diameter/ Width (m)	Length (m)	Height (m)	Low Melting Temperature	Melting Temp (°C)	Comment
Detector Aperture	1	Tungsten	Cylinder	0.005	0.019	0.0024	-	No	1510	See Table 4, has 1 J of energy on reentry
Payload2 Case	1	Aluminum 6061-T6	Box	0.298	0.062	0.092	0.059	Yes	-	Demise
Payload2 Electronics Boards	2	Fiberglass	Box	0.026	0.062	0.092	0.059	Yes	-	Demise
Comm Board	1	Fiberglass	Box	0.03	0.079	0.083	0.006	Yes	-	Demise
Comm Radio	1	Aluminum 6061-T6	Box	0.052	0.039	0.064	0.008	Yes	-	Demise
Battery Board	1	Fiberglass	Box	0.046	0.079	0.083	0.006	Yes	-	Demise
Batteries	4	Polymide	Box	0.024	0.053	0.06	0.01	Yes	-	Demise
EPS Electronics Board	1	Fiberglass	Box	0.055	0.079	0.083	0.006	Yes	-	Demise
EPS Daugher Board	1	Fiberglass	Box	0.029	0.06	0.079	0.006	Yes	-	Demise
C&DH Electronics Board	1	Fiberglass	Box	0.046	0.079	0.083	0.006	Yes	-	Demise
Back Plane Board	1	Fiberglass	Box	0.155	0.064	0.156	0.012	Yes	-	Demise
Antenna Delplogment Module	1	Polymide	Box	0.08	0.039	0.066	0.03	Yes	-	Demise
Fasteners	120	Steel A-286	Cylinder	0.001	0.003	0.02	-	No	3422	Components have negligible energy
Wire Harnessing	40	Copper Alloy	Cylinder	0.001	0.0006	0.4	-	Yes	-	Demise
Connectors	10	Polymide	Box	0.003	0.009	0.014	0.006	Yes	-	Demise

Appendix B. ELaNa-IX Component List by CubeSat: SMTSat-1

Name	Quantity	Material	Body Type	Mass (kg)	Diameter/ Width (m)	Length (m)	Height (m)	Low Temperature	Melting Temp (°C)	Comment
E1P 1U CubeSat	1	Aluminum 6061	Cube (1U)	0.0881	0.096	0.09	0.031	Yes	-	Demise
CubeSat Structure	1	5052-H32	Cube (1U)	0.087	0.1	0.1	0.1065	Yes	-	Demise
Antennae	2	Nitinol	Wire	0.0237	0.004	0.457	0.004	Yes	-	Demise
Solar Panels	4	Fiberglass	Rectangle	0.1762	0.094	0.094	0.101	Yes	-	Demise
Sep Switches	3	EEE Parts	Small Electronic Part	0.0055	0.013	0.01	0.012	Yes	-	Demise
Batteries	1	Li-ion	Payload Slice (standalone board)	0.148	0.096	0.09	0.022	Yes	-	Demise
Comm Board	1	EEE Parts	Payload Slice (standalone board)	0.078	0.096	0.09	0.0016	Yes	-	Demise
Battery Board	1	EEE Parts	Payload Slice (standalone board)	0.078	0.096	0.09	0.014	Yes	-	Demise
Science Payload (Camera)	1	EEE Parts	Rectangle	0.02	0.04	0.033	0.036	Yes	-	Demise
Special Payloads	1	Aluminum 6061, human hair	Payload Slice (standalone board)	0.097	0.096	0.09	0.032	Yes	-	Demise
Fasteners	30	Stainless Steel	Nuts, bolts, washers	0.013	various	various	various	No	1510	Components have negligible energy
Cabling	6	Copper alloy	Harness	0.0188	various	various	various	Yes	-	Demise

Appendix C. ELaNa-11 Component List by CubeSat: CADRE

Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	Low Melting Temp	Melting Temp (°C)	Comment
CubeSat Structure	External - Major	1	Aluminum 6061-T6	Box - 3U	326	100	100	340.5	Yes	-	Demise
UHF Whip Antenna	External - Major	1	Steel 410	Rectangle	10	1	12.7	163.5	No	1530	See Table 4
S Band Patch Antenna	External - Major	1	Steel 410	Rectangle	10	28	28	4.1	No	1530	See Table 4
Solar Cells	External - Major	64	Gallium Arsenide Solar Cell	Flat Rectangle	2.2	0.5	39.6	68.96	Yes	-	Demise
Deployables	External - Major	4	FR-4	Rectangle	400	1.27	83	326	Yes	-	Demise
Sep Switch Plunger	External - Minor	2	Stainless Steel 18-8	Rectangle	2.35	4.5	26.5	4.5	No	1450	Demise, see Table 4
Sep Switches	External - Minor	2	Plastic	Cylinder	1.3	12.3	20	6.4	Yes	-	Demise
Solar Cell Mounting PCB	External - Minor	4	FR4 PCB	Rectangle	27.7	1.57	82.5	99.5	Yes	-	Demise
Solar Panel Coverglass	External - Minor	4	Glass	Rectangle	1	1	68.9	40	Yes	-	Demise
Batteries	Internal - Major	2	Li-ion	Cylinder	45	18	-	64.167	Yes	-	Demise
ADCS Coil	Internal - Major	1	Copper	Wrapped Wire	44	70.1	-	6.35	Yes	-	Demise
Rxn Wheels	Internal - Major	3	Alluminum 6061	Rectangle	120	28	44	50	Yes	-	Demise
ADCS Magnet	Internal - Major	1	AlNiCo-5	Cylinder	6.78	2.4	-	5.4	Yes	-	Demise
Payload Board	Internal - Major	1	FR4 PCB	Square with Components	35	3.25	90.2	95.885	Yes	-	Demise
S Band Indigo Board	Internal - Major (Part of C&DH)	1	Aluminium + PCB	Mounted on C&DH Board	35	-	-	-	Yes	-	Demise
Solar Board	Internal - Major	1	FR4 PCB	Square with Components	50	1.1	96	90	Yes	-	Demise
Battery Mount	Internal - Major	1	FR4 PCB	Square with Components		-	-	-	Yes	-	Demise
C&DH Board	Internal - Major	1	FR4 PCB	Square with Components	75	17.8	94.6	90	Yes	-	Demise

Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	Low Melting	Melting Temp (°C)	Comment
Boeing Star Tracker	Internal - Major		-	-	-	-	-	-	Yes	-	Demise
Minus Z Interface Board	Internal Major	1	FR4 PCB	Square with Components	71.8	1.1	96	90	Yes	-	Demise
Camera Interface Board	Internal - Major	1	FR4 PCB	Rectangular	2.6	57.4	24.3	5.11	Yes	-	Demise
WINCS	Internal Major	1	Aluminum 6061-T6	Square with Components		76	76	71	Yes	-	Demise
Active Coil Mount	Internal - Minor	4	Aluminum 6061-T6	Beam	20	74.9	74.9	11.17	Yes	-	Demise
HuMy80 Hysteresis Material	Internal - Minor	2	HyMu-80	Rectangle	2	7.6	24	1	Yes	-	Demise
Gyros	Internal - Minor	2	PCB + sensor	Rectangle	3	3	5	3	Yes	-	Demise
Battery Case	Internal - Minor	1	Alluminum 6061	Extruded Arbelos	9	15.8	43.2	10.15	Yes	-	Demise
SMA/SMA Coax Cable	Internal - Minor	1	RG316 Wire	Cable	12	-	-	-	Yes	-	Demise
Board Mounts	Internal - Minor	8	Alluminum 6061	Beam	5.56	5	97	17	Yes	-	Demise
Wiring and Harnesses	Internal - Minor	1	Teflon Coated Wire	Wire	20	-	-	-	Yes	-	Demise
Mounting Screw	Internal - Minor	56	316 Stainless Steel	Cylinder	0.1	4.11	6.35	-	No	1399	Demise, see Table 4