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# Orbital Debris Assessment for The CubeSats on the (LV) /ELaNa-19 Mission per NASA-STD 8719.14A

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Reply to Attn of: VA-H1 January 14, 2017

TO: Garrett Skrobot, LSP Mission Manager, NASA/KSC/VA-C

FROM: Justin Treptow, NASA/KSC/VA-H1

SUBJECT: Orbital Debris Assessment Report (ODAR) for the ELaNa-19 Mission (FCC)

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. Armstrong, Jason; TriSept Corp. "ODAR info" email, Oct 20, 2016.
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

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the ELaNa-19 primary mission 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-19 auxiliary payload mission flown on ELaNa XIX. The fourteen CubeSats comprising the ELaNa-19 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 6.6 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 | ELaNa-19 includes the CubeSail mission, containing a 250m solar sail / tether |

## Section 1: Program Management and Mission Overview

The ELaNa-19 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:

ANDESITE: Walsh Brian, Principle Investigator

CeREs: Summerlin Errol, Principle Investigator

CHOMPTT: Conklin John, Principle Investigator

CubeSail: Carroll David, Principle Investigator

DaVinci: Finman Lorna, Principle Investigator

ISX: Bellardo John, Principle Investigator

NMTSat: Jorgensen Anders, Principle Investigator

RSat: Kang Jin, Principle Investigator

Shields-1: Thomsen Laurence, Principle Investigator

STF-1: Grubb Matthew, Principle Investigator

TOMSat EAGLESCOUT: Hattersley Bonnie, Principle Investigator

TOMSat R3: Hattersley Bonnie, Principle Investigator

GEOStare: de Vries Wim, Principle Investigator

SHFT-1: Lux Jim, Principle Investigator

| Program Milestone Schedule | |
|---|---|
| **Task** | **Date** |
| CubeSat Selection | CSLI award February 2016 |
| CubeSat Mission Readiness review: | February 28th 2017 |
| CubeSat delivery to TriSept | May 8th 2017 |
| CubeSat integration with LV | May 18th 2017 |
| Launch date | June 23rd 2017 |

**Figure 1: Program Milestone Schedule**

The ELaNa-19 mission will be launched as the Primary payload on the VCLS RocketLabs ELaNa XIX mission on an Electron launch vehicle from CCAFS, FL. The ELaNa-19 compliment, will deploy 14 pico-satellites (or CubeSats). The CubeSat slotted position is identified in Table 2: ELaNa-19 CubeSats. The ELaNa-19 manifest includes: ANDESITE, CeREs, CHOMPTT , CubeSail, DaVinci, ISX, NMTSat, RSat, Shields-1, STF-1, TOMSat EAGLESCOUT, TOMSat R3, GEOStare, and SHFT-1. The current launch date is in June 23, 2017. The 14 CubeSats are to be ejected from the Electron shortly after the launch, placing the CubeSats in an orbit approximately 500 X 500 km at inclination of 85 deg (ref. (h)).

Each CubeSat ranges in sizes from a 10 cm x 10cm x 30 cm to 10 cm x 20 cm x 30 cm, with masses from about 1.81 kg to ~9.19 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 14 CubeSats flying on the ELaNa-19 Mission. Table 2: ELaNa-19 CubeSats outlines their generic attributes.

**Table 2: ELaNa-19 CubeSats**

| CubeSat Quantity | CubeSat size | CubeSat Names | CubeSat Masses (kg) |
|---|---|---|---|
| 1 | 6U (24 cm x 36.3 cm x 11 cm) | ANDESITE | 9.19 |
| 1 | 3U (10 cm x 10 cm x 34 cm) | CeREs | 4.56 |
| 1 | 3U (10 cm x 10 cm x 34 cm) | CHOMPTT | 1.56 |
| 1 | 3U (10 cm x 10 cm x 31 cm) | CubeSail | 3.74 |
| 1 | 3U (11.7 cm x 11.3 cm x 34.05 cm) | DaVinci | 2.60 |
| 1 | 3U (11.2 cm x 11.1 cm x 34.05 cm) | ISX | 3.70 |
| 1 | 3U (10 cm x 10 cm x 34 cm) | NMTSat | 1.58 |
| 1 | 3U (11.3 cm x 11.3 cm x 34.05 cm) | Rsat | 4.15 |
| 1 | 3U (10.6 cm x 10.6 cm x 34.05 cm) | Shields-1 | 6.94 |
| 1 | 3U (11.5 cm x 11.5 cm x 34.05 cm) | STF-1 | 1.81 |
| 1 | 3U (10.3 cm x 10.3 cm x 34.05 cm) | TOMSat EAGLESCOUT | 4.09 |
| 1 | 3U (10.3 cm x 10.3 cm x 34.05 cm) | TOMSat R3 | 4.09 |
| 1 | 3U (11.2 cm x 11.1 cm x 34.05 cm) | GEOStare | 7.15 |
| 1 | 3U (11.3 cm x 11.2 cm x 36.6 cm) | SHFT-1 | 5.10 |

The following subsections contain descriptions of these 14 CubeSats.

## ISX (Ionospheric Scintillation eXplorer) – Cal Poly, SLO – 3U

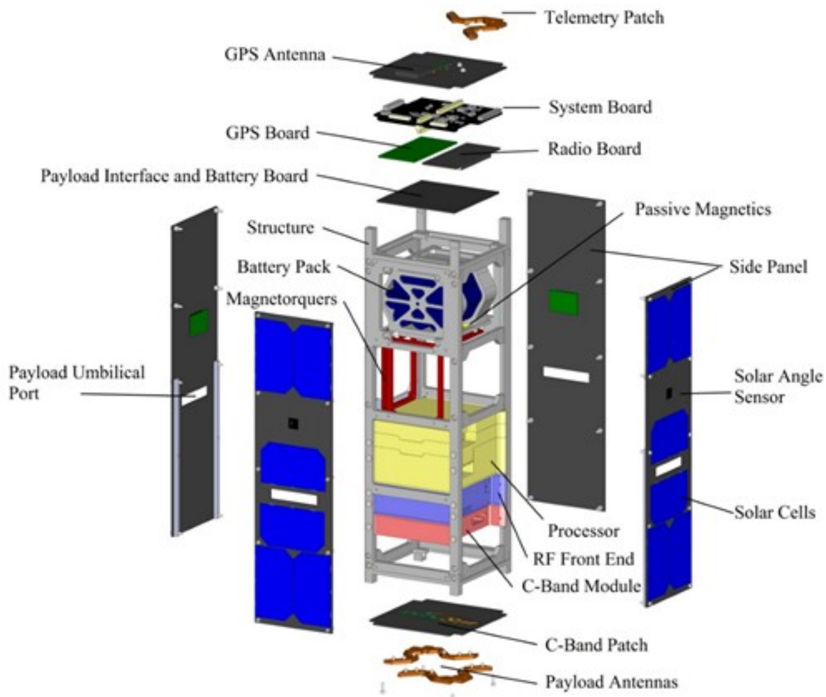


**Figure 11: *ISX* Expanded View**

**Overview**

The Ionospheric Scintillation eXplorer (ISX) is a satellite developed by undergraduate and graduate students as part of the PolySat research group in collaboration with SRI. The satellite is sponsored by NSF. ISX will measure the scintillation of disrupts in ionospheric plasma tubules using DTV signals. ISX will study the multi-frequency radio wave propagation properties of intermediate-to-large scale ionospheric structures of Equatorial Spread F that cause rapid phase and amplitude fluctuation of transionospheric signals.

**CONOPS**

Upon deployment from the PPOD, ISX will power on. Approximately 15 minutes later, the antenna will deploy. 115 minutes after antenna deployment, the beacon will be activated and the satellite will be available to acquire with the ground station. Acquisition and verification of the correct orientation and rates of the satellite will take place one week into the mission. The payload will then start taking data for one year.

**Materials**

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

**Hazards**

There are no pressure vessels, hazardous or exotic materials.

**Batteries**
The electrical power storage system consists of nine 3.7V 2600mAh Lithium-Ion 18650 batteries, model LR1865SK, with over-charge/current protection circuitry. There are three strings in parallel, with each string consisting of three batteries in series. UL Listing information is as follows BB*CV2.MH48285*.

## 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-19 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-19 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))

ELaNa-19 manifest one, 6U CubeSats which are not included in the 3U or smaller mentioned in ref. (h). However, this CubeSat has protective circuitry in their designs and COTS components.

ANDESITE's EPS and battery system has over-current poly switch protection, over-current bus protection, and battery under-voltage protection built into the EPS system. The ANDESITE CubeSat use UL listed battery cells.

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.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum cubesat lifetime of 6.6 years maximum the ELaNa-19 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 fourteen CubeSats is that of the CubeSail CubeSat with solar sail / tether deployed (250m X 0.08m solar sail):

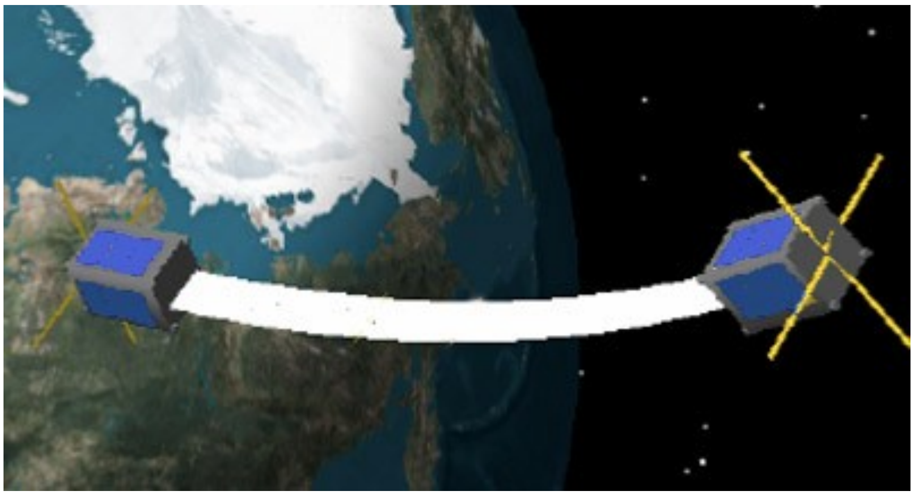

**Figure 21: CubeSail Deployed Config**

%&'( *+, = Σ +./0'1&,/&' / 2 = [3 ∗ (5 ∗ 6) + 2 ∗ (5 ∗ 8)] / 2

**Equation 1: Mean Cross Sectional Area for Convex Objects**

%&'( *+, = (,9': + ,; + ,;) / 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 component dimensions used in these calculations

The CubeSail (3.74 kg) orbit at deployment is 500km apogee altitude by 500 km perigee altitude, with an inclination of 85 degrees. With an area to mass ratio of 2.684 $m^2$/kg, DAS yields 0.1 years for orbit lifetime for its deployed state, which in turn is used to obtain the collision probability. Even with the variation in CubeSat design and orbital lifetime ELaNa-19 CubeSats see an average of 0.00000 probability of collision. All CubeSats on ELaNa-19 were calculated to have a 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 4: CubeSat Orbital Lifetime & Collision Probability**

| CubeSat | Mass (kg) | Stowed | | | | Deployed | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean C/S Area (m^2) | Area-to Mass (m^2/kg) | Orbital Lifetime (yrs) | Probability of collision (10^X) | Mean C/S Area (m^2) | Area-to Mass (m^2/kg) | Orbital Lifetime (yrs) | Probability of collision (10^X) |
| ANDESITE | 9.19 | 0.0763 | 0.0083 | 5.8 | 0.00000 | 0.1083 | 0.012 | 5.2 | 0.00000 |
| CeREs | 4.56 | 0.0390 | 0.0086 | 5.7 | 0.00000 | 0.0735 | 0.016 | 4.8 | 0.00000 |
| CHOMPTT | 1.56 | 0.0390 | 0.0250 | 4.4 | 0.00000 | 0.0415 | 0.027 | 4.3 | 0.00000 |
| CubeSail | 3.74 | 0.0362 | 0.0097 | 5.5 | 0.00000 | 10.0364 | 2.684 | 0.1 | 0.00000 |
| DaVinci | 2.60 | 0.0459 | 0.0177 | 4.7 | 0.00000 | 0.1006 | 0.039 | 4 | 0.00000 |
| ISX | 3.70 | 0.0442 | 0.0120 | 5.2 | 0.00000 | 0.0445 | 0.012 | 5.2 | 0.00000 |
| NMTSat | 1.58 | 0.0417 | 0.0264 | 4.3 | 0.00000 | 0.0493 | 0.031 | 4.2 | 0.00000 |
| Rsat | 4.15 | 0.0449 | 0.0108 | 5.3 | 0.00000 | 0.0629 | 0.015 | 4.9 | 0.00000 |
| Shields-1 | 6.94 | 0.0417 | 0.0060 | 6.6 | 0.00000 | 0.0494 | 0.007 | 6.2 | 0.00000 |
| STF-1 | 1.81 | 0.0467 | 0.0259 | 4.3 | 0.00000 | 0.0490 | 0.027 | 4.3 | 0.00000 |
| TOMSat EAGLESCOUT | 4.09 | 0.0406 | 0.0099 | 5.5 | 0.00000 | 0.0635 | 0.016 | 4.8 | 0.00000 |
| TOMSat R3 | 4.09 | 0.0406 | 0.0099 | 5.5 | 0.00000 | 0.0635 | 0.016 | 4.8 | 0.00000 |
| GEOStare | 7.15 | 0.0443 | 0.0062 | 6.4 | 0.00000 | 0.0880 | 0.012 | 5.2 | 0.00000 |
| SHFT-1 | 5.10 | 0.0476 | 0.0093 | 5.6 | 0.00000 | 0.1855 | 0.036 | 4.1 | 0.00000 |

**Solar Flux Table Dated 11/07/2016**

The probability of any ELaNa-19 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-19 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-19 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 Shields-1 in its stowed configuration as the worst case. The area-to-mass is calculated for is as follows:

$$\frac{\text{!"\#\$ \&/ ()"\# (+')}}{\text{!\#..(/0)}} = \text{()"\#} - 34 - \text{!\#..} \frac{\text{(+')}}{\text{/0}}$$

**Equation 3: Area to Mass**

$$\frac{0.0417\text{:;}}{6.94\text{>?}} = 0.0060 \frac{\text{=;}}{\text{>?}}$$

Shields-1 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: 500 km maximum apogee 500 km maximum perigee altitudes with an inclination of 85 degrees at deployment no earlier than June 23rd 2017. An area to mass ratio of 0.0060 $m^2$/kg for the Shields-1 CubeSat was imputed. DAS 2.0.2 yields a 6.6 years orbit lifetime for Shields-1 in its stowed state.

This meets requirement 4.6-1. For the complete list of CubeSat orbital lifetimes reference **Table 4: 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-19 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 possess the same negligible risk as stainless steel components. See Table 5 through Table 7.

**Table 5: ELaNa-19 High Melting Temperature Material Analysis (1/3)**

| CubeSat | High Temp Component | Material | Demise Alt (km) | KE (J) |
|---|---|---|---|---|
| ANDESITE | Node Deployment Springs | Steel AISI 304 | 76.4 | 0 |
| ANDESITE | Antennae | Steel AISI 410 | 0 | 0 |
| ANDESITE | 6-32 Screws | Stainless Steel (generic) | 77.5 | 0 |
| ANDESITE | 2-56 Screws | Stainless Steel (generic) | 77.4 | 0 |
| ANDESITE | Hinges | Stainless Steel (generic) | 0 | 1 |
| CeREs | Tungsten Tube | Tungsten | 0 | 150 |
| CeREs | Detector | Silicon | 0 | 0 |
| CeREs | Closeout Plate 1 | Tungsten | 0 | 8 |
| CHOMPTT | StenSat UHF Antennae | Stainless Steel (generic) | 0 | 0 |
| CHOMPTT | Lithium UHF Antennae | Stainless Steel (generic) | 0 | 0 |
| CHOMPTT | Backplane Holder - 11 mm | Steel AISI 304 | 0 | 0 |
| CHOMPTT | Backplane Holder - 13 mm | Steel AISI 304 | 0 | 0 |
| CHOMPTT | Reaction Wheel Assembly | Stainless Steel (generic) | 68.6 | 0 |

**Table 6: ELaNa-19 High Melting Temperature Material Analysis (2/3)**

| CubeSat | High Temp Component | Material | Demise Alt (km) | KE (J) |
|---|---|---|---|---|
| CHOMPTT | Batteries | Stainless Steel (generic) | 69 | 0 |
| CHOMPTT | Battery Holder Plates 2a&2b | Steel AISI 304 | 0 | 25 |
| CHOMPTT | Lithium Radio | Stainless Steel (generic) | 0 | 6 |
| CHOMPTT | Retoreflector Array | Stainless Steel (generic) | 0 | 4 |
| CubeSail | New Component | Stainless Steel (generic) | 0 | 1 |
| CubeSail | Fasteners* | Stainless Steel (generic) | 77.9 | 0 |
| CubeSail | SRU Nut Plate | Stainless Steel (generic) | 74.4 | 0 |
| CubeSail | Motor | Steel AISI 304 | 70 | 0 |
| CubeSail | Drive Pin | Steel AISI 304 | 77.1 | 0 |
| CubeSail | Reaction Wheel Daughter Board | Stainless Steel (generic) | 0 | 14 |
| ISX | Historesis Material | Stainless Steel (generic) | 77 | 0 |
| ISX | Screw - Representative | Stainless Steel (generic) | 76.9 | 0 |
| ISX | Structural Rods | Stainless Steel (generic) | 77.4 | 0 |
| ISX | ISIS screws | Stainless Steel (generic) | 77.1 | 0 |
| ISX | ISIS washers | Stainless Steel (generic) | 0 | 0 |
| ISX | GAMMA Antenna washers | Stainless Steel (generic) | 0 | 0 |
| ISX | GAMMA Antenna screws | Stainless Steel (generic) | 76.2 | 0 |
| ISX | GAMMA Antenna nuts | Stainless Steel (generic) | 0 | 0 |
| ISX | solar panel screw | Stainless Steel (generic) | 76.6 | 0 |
| ISX | solar panel nut | Stainless Steel (generic) | 0 | 0 |
| ISX | Solar panel clip | Stainless Steel (generic) | 0 | 0 |
| ISX | 15mm spacers | Stainless Steel (generic) | 75 | 0 |
| ISX | 25mm spacers | Stainless Steel (generic) | 73.5 | 0 |
| Rsat | Motors | Stainless Steel (generic) | 73.3 | 0 |
| Rsat | ADCS | Stainless Steel (generic) | 0 | 3 |
| Rsat | Fasteners | Stainless Steel (generic) | 77.6 | 0 |
| Shields-1 | Shield0 | Titanium (6 Al-4 V) | 0 | 16 |
| Shields-1 | Shield1 | Tantalum | 0 | 69 |
| Shields-1 | Shield2 | Titanium (6 Al-4 V) | 0 | 14 |
| Shields-1 | Shield3 | Tantalum | 0 | 27 |
| Shields-1 | Shield4 | Titanium (6 Al-4 V) | 0 | 0 |
| Shields-1 | Shield5 | Tantalum | 0 | 0 |
| Shields-1 | Shield6 | Titanium (6 Al-4 V) | 0 | 0 |
| Shields-1 | Shield7 | Titanium (6 Al-4 V) | 0 | 0 |
| Shields-1 | Shield8 | Titanium (6 Al-4 V) | 0 | 0 |
| Shields-1 | Charge Dissipation Film electrodes | Steel AISI 304 | 73.8 | 0 |
| Shields-1 | Charge Dissipation Film spring | Stainless Steel (generic) | 76.1 | 0 |
| Shields-1 | RTDs (Est Dims) | Stainless Steel (generic) | 77.5 | 0 |
| Shields-1 | Fasterners2 | Stainless Steel (generic) | 77.7 | 0 |
| Shields-1 | Fasteners3 | Stainless Steel (generic) | 77.7 | 0 |

**Table 7: ELaNa-19 Summary of Surviving High Temperature Material Components (3/3)**

| CubeSat | High Temp Component | Material | Demise Alt (km) | KE (J) |
|---|---|---|---|---|
| Shields-1 | Fasteners4 | Stainless Steel (generic) | 0 | 0 |
| Shields-1 | Solar Panel Screws | Steel AISI 410 | 77.6 | 0 |
| Shields-1 | Solar Panel Washers | Steel AISI 410 | 0 | 0 |
| Shields-1 | Remove Before Flight Pin | Stainless Steel (generic) | 73.7 | 0 |
| Shields-1 | Sep Switch | Stainless Steel (generic) | 73.7 | 0 |
| Shields-1 | ADCS Components (Hysteresis Rods) | Stainless Steel (generic) | 77.5 | 0 |
| STF-1 | Ferrite Bead | Stainless Steel (generic) | 77.3 | 0 |
| STF-1 | Geiger Tube | Stainless Steel (generic) | 67 | 0 |
| STF-1 | Fasteners5 | Stainless Steel (generic) | 77.9 | 0 |
| TOMSat | Reaction Wheels | Stainless Steel (generic) | 63.9 | 0 |
| TOMSat | Single Torque Rod | Stainless Steel (generic) | 74.8 | 0 |
| TOMSat | 18267 | Titanium (generic) | 0 | 2 |
| TOMSat | 18265 | Titanium (generic) | 0 | 1 |
| TOMSat | 18264 | Titanium (generic) | 0 | 1 |
| TOMSat | 18268 | Titanium (generic) | 0 | 0 |
| TOMSat | 18266 | Titanium (generic) | 0 | 2 |
| TOMSat | 18263 | Titanium (generic) | 0 | 0 |
| TOMSat | 18270 | Titanium (generic) | 0 | 0 |
| TOMSat | Laser | Aluminum 6061-T6 | 72.8 | 0 |
| GEOstare | Batteries-GEOStae | Stainless Steel (generic) | 0 | 1 |
| GEOstare | Telescope baffle | Titanium (generic) | 0 | 22 |
| GEOstare | Telescope | Stainless Steel (generic) | 65.4 | 0 |
| GEOstare | Fasteners7 | Steel A-286 | 78 | 0 |
| SHFT-1 | Internal Fasteners | Stainless Steel (generic) | 77 | 0 |
| SHFT-1 | External Fasteners | Stainless Steel (generic) | 77 | 0 |

The majority of high temperature 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 on Table 8.

**Table 8: Requirement 4.7-1 Compliance by CubeSat**

| CubeSat | Risk | Risk < 1:10,000 |
|---|---|---|
| ANDESITE | 1:0 | Compliant |
| CeREs | 1:210,600 | Compliant |
| CHOMPTT | 1:93,400 | Compliant |
| CubeSail | 1:0 | Compliant |
| DaVinci | 1:0 | Compliant |
| ISX | 1:0 | Compliant |
| NMTsat | 1:0 | Compliant |
| Rsat | 1:0 | Compliant |
| Shields-1 | 1:32,400 | Compliant |
| STF-1 | 1:0 | Compliant |
| TOMSat | 1:0 | Compliant |
| GEOstare | 1:200,000 | Compliant |
| SHFT-1 | 1:0 | Compliant |

*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. Which is why CubeSats that have surviving components like ANDESITE, CubeSail, DaVinci, ISX, NMTsat Rsat, STF-1 TOMSat EAGLESCOUT, TOMSat R3, and SHFT-1 have a 1:0 probability as none of their components have more than 15J of energy. The breakdown of CubeSat's with greater than 15J of energy components is as follows: CeREs has 1, CHOMPTT has1, Shields-1 has 3, and GEOStare has 1.

All CubeSats launching under the ELaNa-19 mission are 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**

In the ELaNa-19 mission, CubeSail's deployable sail made of a mylar film qualifies as a momentum tether although a ribbon would be a more accurate description of its dimensions (0.0004 cm x 7.9cm x 25,317 cm).

The tether mission plan can be referenced in the CubeSail specific mission plan located in Section 2.

Following the Methods to Assess Compliance for Tethered Systems (section 4.8.4), the DAS analysis determined the CubeSail design to be COMPLIANT with both Requirement 4.5-1 and 4.5-2 dealing with meeting the requirements limiting the generation or orbital debris from on-orbit collisions. The probability of collision on orbit for the un-deployed system, fully deployed system, and ½ the system in the event of a tether severing event was calculated to be << 0.001.

CubeSail is also compliant with Requirements 4.6-1 to 4.6-4 (Postmission Disposal), given the low 500km x 500km, this orbit will have CubeSail passively deorbit in 5.5 years if the system does not deploy, <<0.1 years if the system does deploy, and <<0.1 year if the tether breaks into two equal parts as calculated via DAS 2.0.2. All three scenarios are compliant with the Requirement 4.6-1 to 4.6-4.

| Row | Tether State | Requirement 4.5-1 Compliance Status | Requirement 4.5-2 Compliance Status | Requirement 4.6 Compliance Status | Orbital Decay (days) |
|---|---|---|---|---|---|
| 1 | momentum | Compliant | Compliant | Compliant | 12.0 |

**Figure 22: Tether Assessment of CubeSail**

ELaNa-19 CubeSat, CubeSail satisfies Section 8's requirement 4.8-1.

**Section 9-14**

ODAR sections 9 through 14 for the launch vehicle are not covered here.

If you have any questions, please contact the undersigned at 321-867-2958.

/original signed by/

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cc: VA-H/Mr. Carney
VA-H1/Mr. Beaver
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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-19 Component List by CubeSat: ANDESITE |
| **Appendix B.** | ELaNa-19 Component List by CubeSat: CeREs |
| **Appendix C.** | ELaNa-19 Component List by CubeSat: CHOMPTT |
| **Appendix D.** | ELaNa-19 Component List by CubeSat: CubeSail |
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| **Appendix N.** | ELaNa-19 Component List by CubeSat: SHFT-1 |

## Appendix F. ELaNa-19 Component List by CubeSat: ISX (1/2)

| CUBESAT | Row Number | Name | Qty | Material | Body Type | Individual Mass (g) | Diameter/ Width (mm) | Length (mm) | Height (mm) | High Temp | Melting Temp | Survivability |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ISX | 1 | ISX 3U CubeSat | 1 | Various | Box | 3699.3 | 100 | 100 | 340.5 | No | - | Demise |
| ISX | 2 | CubeSat Structure | 1 | Aluminum 6061 | Box | 456 | 100 | 100 | 340.5 | No | - | Demise |
| ISX | 3 | +Z Panel | 1 | PCB | Box | 30 | 100 | 100 | 2.5 | No | - | Demise |
| ISX | 4 | -Z Panel | 1 | PCB | Box | 30 | 100 | 100 | 2.5 | No | - | Demise |
| ISX | 5 | Radio Daughter Board | 1 | PCB | Box | 15 | 36 | 83 | 2.5 | No | - | Demise |
| ISX | 6 | GPS Daughter Board | 1 | PCB | Box | 15 | 39 | 83 | 2.5 | No | - | Demise |
| ISX | 7 | GPS Patch | 1 | Ceramic | Box | 11.4 | 25.1 | 25.1 | 5.2 | No | - | Demise |
| ISX | 8 | C-Band Patch | 1 | Ceramic | Box | 2.1 | 12 | 12 | 4.3 | No | - | Demise |
| ISX | 9 | Antenna Routes | 3 | Delrin | Box | 5 | 65 | 65 | 3.4 | No | - | Demise |
| ISX | 10 | Antenna | 6 | Nitonol Wire | Box | 2 | 0.31 | 165 | 0.51 | No | - | Demise |
| ISX | 11 | System Board | 1 | PCB | Box | 60 | 100 | 83 | 3 | No | - | Demise |
| ISX | 12 | Payload Interface and Battery Board | 1 | PCB | Box | 50 | 83 | 83 | 3 | No | - | Demise |
| ISX | 13 | Side Panel | 4 | PCB | Box | 120 | 83 | 320 | 2.5 | No | - | Demise |
| ISX | 14 | Solar Cell | 20 | Eglass | Box | 2.3 | 70 | 40 | 0.5 | No | - | Demise |
| ISX | 15 | Solar Angle Sensor Board | 5 | PCB | Box | 5 | 20 | 30 | 2.5 | No | - | Demise |
| ISX | 16 | Solar Angle Sensor Apperture | 5 | Aluminum | Box | 3 | 19 | 21 | 5 | No | - | Demise |
| ISX | 17 | Battery Bracket | 1 | Aluminum 6061 | Box | 168 | 76 | 82 | 67 | No | - | Demise |
| ISX | 18 | Heat Shrink | 2 | RNF-100 Polyolefin Heat Shrink | Tube | 2 | 63.5 | 25.4 | 0.5 | No | - | Demise |
| ISX | 19 | Batteries | 9 | Lithion Ion | Cylinder | 45 | 18.4 | 65.1 | N/A | No | - | Demise |
| ISX | 20 | Dummy Cell | 1 | Delrin | Cylinder | 10 | 19 | 66 | N/A | No | - | Demise |