ELVL-2016-0044593
February 27, 2017

Orbital Debris Assessment for The CubeSats on the ICESat-2 /ELaNa-18 Mission per NASA-STD 8719.14A

Signature Page

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Reply to Attn of: VA-H1 February 27, 2017

TO: Rex Engelhardt, LSP Mission Manager, NASA/KSC/VA-C

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

SUBJECT: Orbital Debris Assessment Report (ODAR) for the ELaNa-18 Mission (HQ)

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. *Preliminary Mission Analysis for Delta II 7420-10 / ICESAT-2 Spacecraft Mission*, *PGAA No. 2*, ULA-TP-16-163, Sept 14 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-18 auxiliary mission launching in conjunction with the ICESat-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-18 auxiliary payload mission flown on ICESat-2. The three CubeSats comprising the ELaNa-18 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 4.6 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	No planned tether release under ELaNa-18 mission

Section 1: Program Management and Mission Overview

The ElaNa-18 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:

CHEFSat: Chen Yunghsin, Principle Investigator; Tim Duffey, Project Manager

ELFIN: Vassalis Angelopoulos, Principle Investigator; Lydia Bingley Project Manager

IT-SPINS: David Klumpar, Principle Investigator; Larry Springer, Project Manager

Program Milestone Schedule	
Task	Date
CubeSat Selection	1/19/16
MRR	6/30/17
CubeSat Integration into P-PODs	7/31/17
CubeSat Delivery to VAFB	10/26/17
Launch	11/10/17

Figure 1: Program Milestone Schedule

The ElaNa-18 mission will be launched as an auxiliary payload on the NASA ICESat-2 mission on a Delta II 7420-10 launch vehicle from VAFB, CA. The ElaNa-18 compliment, will deploy 3 pico-satellites (or CubeSats). The CubeSat slotted position is identified in Table 2: ElaNa-18 CubeSats. The ElaNa-18 manifest includes: CHEFSat, ELFIN, IT-SPINS. The current launch date is in August 19, 2017. The 3 CubeSats are to be ejected from PPOD deployers mounted on the Delta II second stage, placing the CubeSats in an orbit approximately 450 X 473 km at inclination of 93.0 deg (ref. (h)).

Each CubeSat conforms to the 3U configuration 10 cm x 10cm x 30-34 cm, with masses from about 3.2 kg to 3.7 kg total. The CubeSats have been designed by universities and government agencies and each has their own mission goals.

Section 2: Spacecraft Description

There are 3 CubeSats flying on the ElaNa-18 Mission. Table 2: ElaNa-18 CubeSats outlines their generic attributes.

Table 2: ElaNa-18 CubeSats

P-POD #	CubeSat size	CubeSat Names	CubeSat Masses (kg)
1	3U (10cm X 10cm X 34cm)	IT-SPINS	3.52
1	3U (10cm X 10cm X 32.2cm)	ELFIN	3.26
1	3U (10cm X 10cm X 31.8cm)	CHEFSat	3.70

The following subsections contain descriptions of these 3 CubeSats.

IT-SPINS – Montana State University – 3U

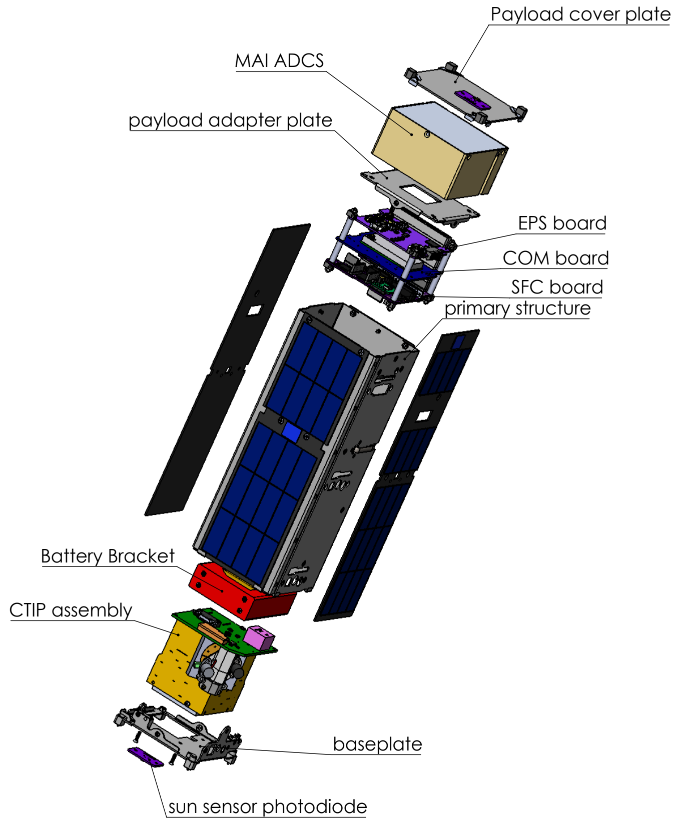

Figure 2: IT-SPINS Expanded View

Overview: The Ionospheric-Thermospheric Scanning Photometer for Ion-Neutral Studies (IT-SPINS) mission's aim is to provide the first two-dimensional (2D) tomographic imaging from a 3U research CubeSat, addressing the basic nature of the nocturnal ionosphere. This nominal 6-month mission (post-commissioning) aims to strengthen our fundamental understanding for development of ion gradient structures in two places:

1. In the topside of the Earth's ionosphere
2. Within regional phenomena such as equatorial plasma bubbles (EPBs) or polar patches.

The IT-SPINS spacecraft will rotate at 2 RPM about orbit normal while acquiring 135.6-nm nightglow (from O+/electron recombination) along multiple intersecting ray-paths, above and below the spacecraft, using the same high-sensitivity UV photometer currently in orbit on the USAF's first operational space weather CubeSat mission. Half-second integrations will yield sufficient photometric sensitivity and spatial resolution to enable unambiguous identification of topside and EPB/patch gradient structures. Closed-loop kinematic simulation of IT-SPINS attitude control indicates that the high-heritage axisymmetric spacecraft will have sufficient pointing authority and knowledge precision to meet all science requirements with generous system margins for mass, power, and telemetry.

This mission is managed and built at Montana State University with payload development by SRI International. John Hopkins University will provide the data processing and tomographic analysis.

CONOPS: Upon deployment from the P-POD, IT-SPINS will power up and start the mission elapsed timer to sequence the antenna deployment and activation of the tracking beacon at deployment plus 60 minutes. Following a one to two week commissioning phase to flush out the performance of the ADCS, the payload sun shade will be deployed prior to starting nominal payload operations.

Materials: The CubeSat structural components are made of the following aluminum alloys: 5052-H32, 7075-T6, and 6061-T6. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells. The UHF antenna is made of spring steel.

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

Batteries: Characteristics of the batteries are shown in Table 1. The Tenergy 18650P-5200 battery pack contains four 18650-2600 Li-Ion cells. The pack includes integrated overcharge/over current/undercurrent circuitry protection. They are Underwriters' Laboratories (UL) recognized, as shown in Table 1. There are no modifications to the cell cases as tested by UL and they are considered safe for travel.

ELFIN – UCLA – 3U+

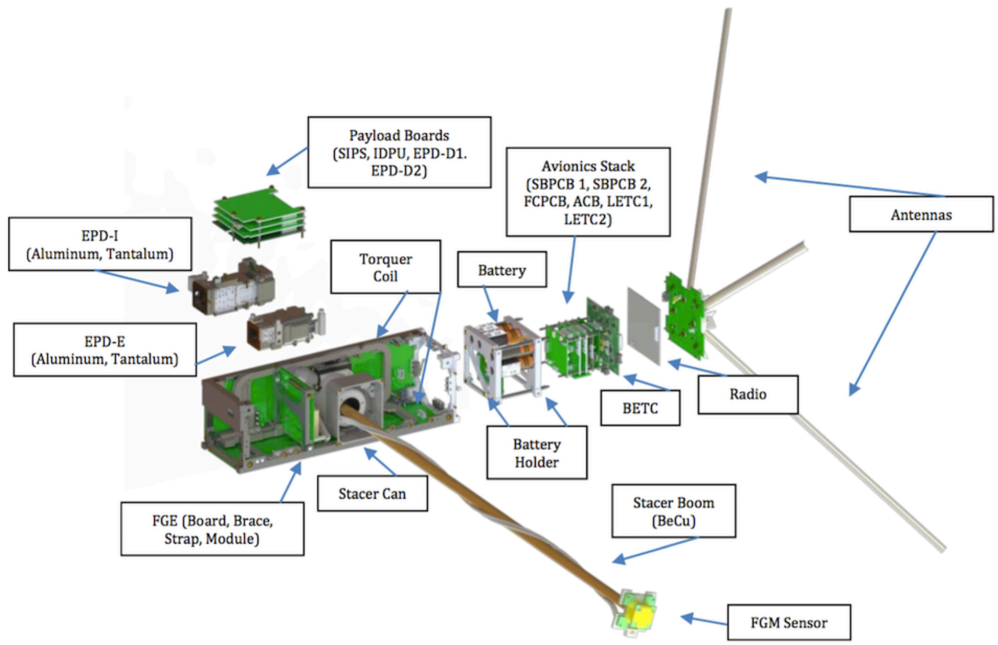

Figure 3: ELFIN Expanded View

Overview: The Electron Losses and Fields Investigation (ELFIN) Mission, is a space weather CubeSat that will investigate the loss of relativistic particles from the radiation belts into the Earth's atmosphere. ELFIN will accomplish this using two primary payload instruments; a fluxgate magnetometer and an energetic particle detector.

CONOPS: Upon deployment from the PPOD, ELFIN will power up and initiate a 45 minute timer counting down for antenna deployment. If tip off rates from the PPOD are large, ELFIN will execute an automatic detumble sequence in order to get the spacecraft in a stable attitude configuration. At 45 minutes, the UHF/VHF antennas will deploy, and the spacecraft will begin beaconing. After communication with the ground is established, spacecraft and instrument commissioning will begin. At a minimum of 2 weeks after deployment, the stacer boom will be commanded to deploy, the spacecraft will be spun up to ~20 rmp, and nominal operations will begin. Science will resume for a minimum of 3 months (nominally 6 months).

Materials: ELFIN's structure is primarily composed of Aluminum 6061-T6, with some peek components as additional structural components. Most materials are standard commercial off the shelf, as well as standard electrical components, printed circuit boards, and solar cells. The Energetic Particle Detector is built with a combination of Aluminum and Tantalum parts. All Tantalum parts are internal components, and are relatively small.

Hazards: There are no pressure vessels or hazardous materials on this satellite.

Batteries: The power system uses 4 Molicel ICR18650J Lithium-ion batteries that are screened by the Aerospace Corporation before delivery to ELFIN. The UL listing number is BBCV2.MH27672.

CHEFSat – NRL – 3U+

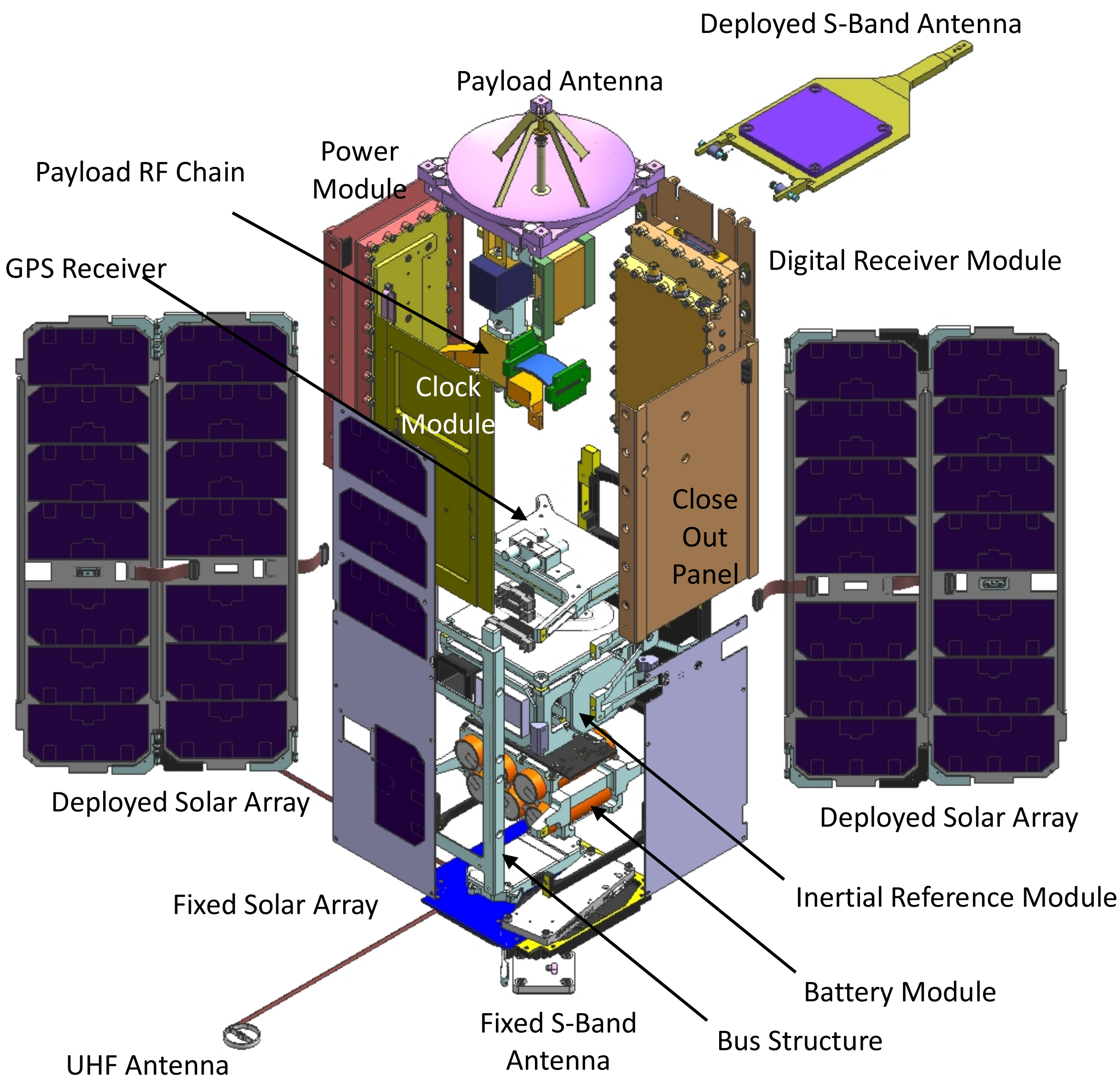

Figure 4: CHEFSat Expanded View

Overview: CHEFSat will test new, emerging millimeter wave components in space. Low cost, high performance, reliable IC devices that operate in E-band are now readily available. The main mission objective is to better understand the effects of weather and atmospheric conditions on E-band links.

CONOPS: After ejection from the dispenser, CHEFSat will be in low power mode for 45 minutes. At the 45 minute mark, CHEFSat will deploy the S-band telemetry flip-out patch antenna and the UHF folded dipole antennas. The bus will remain in low power tumble mode until first contact over the ground station. CHEFSat will be commanded to de-tumble. Once the tumble rate drops below an acceptable level (<1 deg / min), CHEFSat will be commanded to deploy solar panels during the next available ground station contact. Once deployed, CHEFSat will enter into coarse sun-pointing mode to increase power generation. Post deployment, spacecraft checkout activities will commence to verify the functionality of the remaining subsystems. Once the bus systems have been verified, the payload checkout activities will begin.

Materials: The CHEFSat structure is made of Aluminum 6061-T6, 6061-T651, and 7075-T651 alloys. It contains standard commercial off the shelf (COTS) and custom designed electronics, RF components, structures, coax, and wire harnesses made from aluminum alloys, brass, copper, electrical components, FR-4 PCBs, solar cells, and ceramic patch antennas.

Hazards: There are no pressure vessels, propulsion systems, hazardous or exotic materials on the CHEFSat 3U+ CubeSat.

Batteries: The electrical power storage system consists of common lithium-ion batteries with under and over voltage protection, and over current discharge protection. The batteries are LG Chem ICR18650C2 cells with UL Listing Number BBCV2.MH19896.

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-18 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-18 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 maximum CubeSat lifetime of 4.6 years maximum the ElaNa-18 CubeSat is compliant.

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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 ELFIN CubeSat with deployable extended (2x long antennas, 2x short antennas, Tuna Can, Stacer Boom and Sensor):

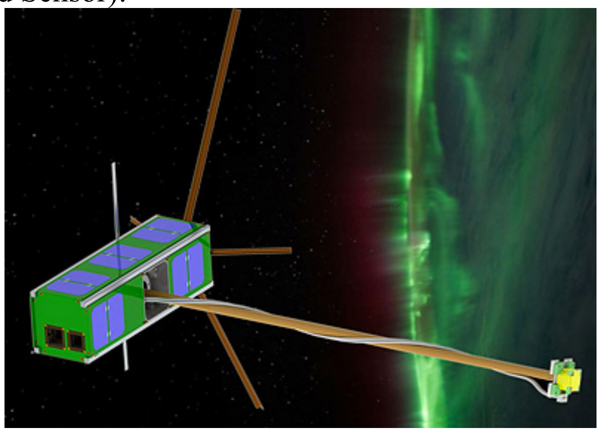

Figure 5: ELFIN Deployed Configuration

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

Equation 1: Mean Cross Sectional Area for Convex Objects

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

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 component dimensions used in these calculations

The ELFIN (3.26 kg) orbit at deployment is 476km apogee altitude by 450 km perigee altitude, with an inclination of 93 degrees. With an area to mass ratio of 0.019 m^2/kg, DAS yields 3.9 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-18 CubeSats see an average of 0.00000 probability of collision. All CubeSats on ElaNa-18 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.

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Table 3: CubeSat Orbital Lifetime & Collision Probability

	CubeSat	IT-SPINS	ELFIN	CHEFSat
	Mass (kg)	3.524	3.26	3.70
Stowed	Mean C/S Area (m^2)	0.039	0.035856858	0.037
Stowed	Area-to Mass (m^2/kg)	0.0111	0.011	0.010
Stowed	Orbital Lifetime (yrs)	**4.4**	**4.4**	**4.6**
Stowed	Probability of collision (10^X)	**0.00000**	**0.00000**	**0.00000**
Deployed	Mean C/S Area (m^2)	0.041381	0.06212388	0.107
Deployed	Area-to Mass (m^2/kg)	0.0117	0.019	0.029
Deployed	Orbital Lifetime (yrs)	**4.4**	**3.9**	**3.4**
Deployed	Probability of collision (10^X)	**0.00000**	**0.00000**	**0.00000**

Solar Flux Table Dated 1/26/2016

The probability of any ElaNa-18 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-18 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-18 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 CHEFSat 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

$$\frac{0.037\ m^2}{3.70kg} = 0.010\frac{m^2}{kg}$$

CHEFSat 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: 476 km maximum apogee 450 km maximum perigee altitudes with an inclination of 93 degrees at deployment no earlier than November 2017. An area to mass ratio of 0.010 m^2/kg for the CHEFSat CubeSat was imputed. DAS 2.0.2 yields a 4.6 years orbit lifetime for CHEFSat 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-18 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 and Table 4.

Table 4: ELaNa-18 High Melting Temperature Material Analysis

CubeSat	High Temp Component	Material	Mass (g)	Demise Alt (km)	KE (J)
CHEFSat	Hardware	A286, CRES, Al Alloys	72.7	77.7	0
CHEFSat	S-Band Radio*	FR-4 & Electronics, SS Housing	42.0	0	12
CHEFSat	Deployment Switch	Stainless Steel	5.0	77.5	0
CHEFSat	Bus Fasteners	316SS, A286	125.0	76.9	0
ELFIN	Back Wall	Tantalum	19.35	0	13
ELFIN	Side Wall (outer)	Tantalum	11.91	0	10
ELFIN	Side Wall (top&bot)	Tantalum	16	0	13
ELFIN	Side Wall (inner)	Tantalum	4.59	0	4
ELFIN	E Front	Tantalum	16.73	0	9
ELFIN	Auxiliary Shield T 1	Tantalum	7.93	0	6
ELFIN	Auxiliary Shield G 1	Tantalum	8.98	0	6
ELFIN	Auxiliary Shield T 2	Tantalum	6.44	0	4
ELFIN	Auxiliary Shield G 2	Tantalum	7.47	0	4
ELFIN	Auxiliary Shield T 3	Tantalum	5.69	0	3

* S-Band Radio assembly was modeled as all Stainless Steel, which is conservative. It is likely that less than ½ of the mass is actually stainless steel.

CubeSat	High Temp Component	Material	Mass (g)	Demise Alt (km)	KE (J)
ELFIN	Auxiliary Shield G 3	Tantalum	6.4	0	3
ELFIN	Auxiliary Shield T 4	Tantalum	5.04	0	2
ELFIN	Auxiliary Shield G 4	Tantalum	5.26	0	2
ELFIN	Back Wall	Tantalum	19.35	0	13
ELFIN	Side Wall	Tantalum	6.03	0	5
ELFIN	Side Wall (Outer)	Tantalum	4.21	0	3
ELFIN	Side Wall (Inner)	Tantalum	1.7	0	1
ELFIN	Mag Stage Front	Tantalum	10.98	0	5
ELFIN	Cone Wall	Tantalum	7.21	0	2
ELFIN	Auxiliary Shield M	Tantalum	0.57	0	0
ELFIN	Payload Rods	#4 Titanium Rod	1	0	0
IT-SPINS	Antennae	Spring Steel 410	3	77.2	0
IT-SPINS	ADCS Components (Magnets)	6061-T6 A, Copper, ferrite core	100	72	0
IT-SPINS	ADCS Components (Wheels)	6061-T6 A, Copper, ferrite core	90	70.8	0
IT-SPINS	Fasteners	CRES/SS/nylon	0.25	0	0

The majority of stainless steel components demise upon reentry. All components have less than 15J of energy upon reentry. As a result probability of Human Casualty is not calculated, resulting in automatic compliance with the 1:10,000 probability of Human Casualty Requirement 4.7-1.

All CubeSats launching under the ElaNa-18 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

ElaNa-18 CubeSats will not be deploying any tethers.

ElaNa-18 CubeSats satisfy Section 8's requirement 4.8-1.

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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/

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:

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Appendix A. ElaNa-18 Component List by CubeSat: IT-SPINS

CUBESAT	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (C)	Survivability
IT-SPINS	IT-SPINS	1	CubeSat	Box	4000	100	100	340.5	-	-	Demise
IT-SPINS	CubeSat Structure	1	5052-H32/7075-T6/6061-T6 Aluminum	Box	500	100	100	2944.1	No	-	Demise
IT-SPINS	Antennae	1	Spring Steel 410	Rectangle /Strip	3	5.58	170	<1	Yes	1510	Demise
IT-SPINS	Solar Panels	4	FR4 PCB Fiberglass	Rectangle	14.44	18.04	47.65	1.5	No	-	Demise
IT-SPINS	Sep Switches	2	Steel/Silver/Diallyl Phthalate	Rectangle	10	6.35	19.84	12.27	No	-	Demise
IT-SPINS	Sun Sensors	6	FR4 PCB/Si/ Copper wire	Square	25	25.4	25.4	1.5	No	-	Demise
IT-SPINS	Batteries	4	LiCoO2/Graphite/Steel/FR4 PCB/Copper	Cylindrica l	190	70	72	20	No	-	Demise
IT-SPINS	ADCS Whole	1	6061-T6 Al/Copper/FR4 PCB/Others	Box	700	100	100	55.9	No	-	Demise
IT-SPINS	ADCS Components (Magnets)	3	6061-T6 A, Copper, ferrite core	Box	100	14.5	33.5	11.4	Yes	1510	Survives - See Table 4
IT-SPINS	ADCS Components (Wheels)	3	6061-T6 A, Copper, ferrite core	Box	90	33	33	38.4	Yes	1430	Demise
IT-SPINS	CTIP	1	6061-T6 Al/Copper/FR4 PCB/Others	Box	482	91.765	91.295	95.853	No	-	Demise
IT-SPINS	Comm Board	1	FR4 PCB Fiberglass	Square	90	85.6	95.89	1.5	No	-	Demise
IT-SPINS	SFC Board	1	FR4 PCB Fiberglass	Square	75	85.6	95.89	20.18 (w/compnts)	No	-	Demise
IT-SPINS	EPS Board	1	FR4 PCB Fiberglass	Square	100	85.6	95.89	1.5	No	-	Demise
IT-SPINS	Fasteners	50	CRES/SS/nylon	Cyclinder	0.25	5.6	5	5	Yes	~1500	Demise
IT-SPINS	Cabling	~5ft	22/24 AWG copper	Cyclinder	0.882/ft	1.25	1524	N/A	No	-	Demise

Appendix B. ElaNa-18 Component List by CubeSat: ELFIN (1/4)

CUBESAT	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (C)	Survivability
ELFIN	ELFIN	1		Box						-	
ELFIN	Chassis Rail (+x,+y)	1	Aluminum 6061-T6	Bar	48.94	7	18.8	322.38	No	-	Demise
ELFIN	Chassis Rail (-x,+y)	1	Aluminum 6061-T6	Bar	50.79	7	18.74	322.38	No	-	Demise
ELFIN	Chassis Rail (+x,-y)	1	Aluminum 6061-T6	Bar	51.06	7	18.8	322.38	No	-	Demise
ELFIN	Chassis Rail (-x,-y)	1	Aluminum 6061-T6	Bar	53.52	7	18.8	322.38	No	-	Demise
ELFIN	Top Hat (-Z)	1	Aluminum 6061-T6	Block	55.79	100	100	24.3	No	-	Demise
ELFIN	Top Hat (+Z)	1	Aluminum 6061-T6	Block	100.97	100	100	24.3	No	-	Demise
ELFIN	Tuna Can (+ Unit)	1	Windform LX2.0	Cylinder	48	61.01	-	30	No	-	Demise
ELFIN	Stacer Boom	1	Wrought Copper	Rod	-	29	750	-	Yes	1085	Demise
ELFIN	Stacer Tip Piece	2	Peek	Block	4.6	5	20.08	49.82	No	-	Demise
ELFIN	Mag Sensor	1	6061-T6 A, Copper, ferrite, NdFeB	Box	-	-	-	-	No	-	Demise
ELFIN	Mag Cable	1	6061-T6 A, Copper	Cable	-	-	-	-	No	-	Demise
ELFIN	Antenna (long)	2	BeCu / Fiber Glass	Thin sheet	6.9	13.8	609.6	-	No	-	Demise
ELFIN	Antenna (short)	2	BeCu / Fiber Glass	Thin sheet	2.91	13.8	228.6	-	No	-	Demise
ELFIN	(+y - long) Solar Panel	1	FR4	PCB	48	1.65	82	146.33	No	-	Demise
ELFIN	(+y - short) Solar Panel	1	FR4	PCB	38	1.65	82	112.95	No	-	Demise
ELFIN	(+y) Solar Cell	4	GaInP2/GaAs/Ge	Sheet	2.54	39.3	69.5	-	No	-	Demise
ELFIN	(-y) Solar Panel	1	FR4	PCB	111	1.65	82	329.29	No	-	Demise
ELFIN	(-y) Solar Cell	6	GaInP2/GaAs/Ge	Sheet	2.54	39.3	69.5	-	No	-	Demise
ELFIN	(+x) Solar Panel	1	FR4	PCB	112	1.65	82	329.29	No	-	Demise
ELFIN	(+x) Solar Cell	6	GaInP2/GaAs/Ge	Sheet	2.54	39.3	69.5	-	No	-	Demise
ELFIN	(-x) Solar Panel	1	FR4	PCB	111	1.65	82	329.29	No	-	Demise
ELFIN	(-x) Solar Cell	4	GaInP2/GaAs/Ge	Sheet	2.54	39.3	69.5	-	No	-	Demise
ELFIN	(+z) Solar Panel	1	FR4	PCB	19	1.65	98.98	61.9	No	-	Demise
ELFIN	(-z) Solar Panel	1	FR4	PCB	32	1.65	97.97	97.97	No	-	Demise
ELFIN	Fasteners	48	Brass	Rod	0.25	-	-	-	No	-	Demise
ELFIN	Shield Insert	1	Aluminum 6061-T6	Block	6.29	23.3172	19.8628	12.5222	No	-	Demise
ELFIN	Aluminum Shield	1	Aluminum 6061-T6	Block	71.78	39.0144	33.8328	39.0144	No	-	Demise
ELFIN	Back Wall	1	Tantalum	Block	19.35	20.94992	4.59994	20.94992	Yes	2980	Survives - See Table 4
ELFIN	Side Wall (outer)	1	Tantalum	Block	11.91	16.74876	2.99974	14.65072	Yes	2980	Survives - See Table 4
ELFIN	Side Wall (top&bot)	2	Tantalum	Block	16	16.74876	2.99974	20.94992	Yes	2980	Survives - See Table 4
ELFIN	Side Wall (inner)	2	Tantalum	Block	4.59	16.74876	5.4991	2.99974	Yes	2980	Survives - See Table 4
ELFIN	Spacer	1	Aluminum 6061-T6	Block	0.4	12.90066	0.89408	12.90066	No	-	Demise
ELFIN	Insulator Side	1	PEEK	Block	0.19	17.74952	4.4704	6.55066	No	-	Demise
ELFIN	Wave Spring Washer	1	Beryllium Copper UNS C17200	Block	0.052	4.18846	0.127	-	No	-	Demise

(ELFIN 2/4)

CUBESAT	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (C)	Survivability
ELFIN	Insulator Back	1	PEEK	Block	0.19	12.90066	0.84328	12.90066	No	-	Demise
ELFIN	Spacer MSD	1	PEEK	Block	0.138	12.99972	1.80086	12.99972	No	-	Demise
ELFIN	Foil Frame Back	1	Aluminum 6061-T6	Block	0.19	14.69898	0.73406	14.69898	No	-	Demise
ELFIN	Lexan Foil	1	Aluminum 6061-T6	Sheet	0.01	14.50086	-	14.50086	No	-	Demise
ELFIN	Foil Frame Front	1	Aluminum 6061-T6	Block	0.11	14.69898	0.5588	14.69898	No	-	Demise
ELFIN	E Front	1	Tantalum	Block	16.73	20.94992	5.74802	20.94992	Yes	2980	Survives - See Table 4
ELFIN	E Aperture 1	1	Phosphor Bronze	Block	4.536	21.7932	1.61036	21.7932	No	-	Demise
ELFIN	Aperture Frame	1	Aluminum 6061-T6	Block	69.08	39.0144	48.895	39.0144	No	-	Demise
ELFIN	Auxiliary Shield T 1	2	Tantalum	Block	7.93	18.71726	2.49936	10.28954	Yes	2980	Survives - See Table 4
ELFIN	Auxiliary Shield G 1	2	Tantalum	Block	8.98	23.3553	3.18008	10.28954	Yes	2980	Survives - See Table 4
ELFIN	E Aperture 2	1	Phosphor Bronze	Block	5.8	25.8064	1.61036	25.8064	No	-	Demise
ELFIN	Auxiliary Shield T 2	2	Tantalum	Block	6.44	21.0058	1.80086	10.28954	Yes	2980	Survives - See Table 4
ELFIN	Auxiliary Shield G 2	2	Tantalum	Block	7.47	25.6032	2.99974	10.28954	Yes	2980	Survives - See Table 4
ELFIN	E Aperture 3	1	Phosphor Bronze	Block	5.06	26.1112	1.61036	26.1112	No	-	Demise
ELFIN	Auxiliary Shield T 3	2	Tantalum	Block	5.69	21.51126	1.45034	11.03884	Yes	2980	Survives - See Table 4
ELFIN	Auxiliary Shield G 3	2	Tantalum	Block	6.4	25.8572	2.90068	11.03884	Yes	2980	Survives - See Table 4
ELFIN	E Aperture 4	1	Phosphor Bronze	Block	4.07	21.7932	1.61036	21.7932	No	-	Demise
ELFIN	Auxiliary Shield T 4	2	Tantalum	Block	5.04	22.96668	1.19888	11.03884	Yes	2980	Survives - See Table 4
ELFIN	Auxiliary Shield G 4	2	Tantalum	Block	5.26	26.28646	2.3495	11.03884	Yes	2980	Survives - See Table 4
ELFIN	E Aperture 5	1	Phosphor Bronze	Block	7.46	32.766	1.5748	32.766	No	-	Demise
ELFIN	Sensor E	1	Polyimide/G-10/Silicon Dioxide/PEEK/Epoxy	Block	3.63	12.94892	9.70788	12.94892	No	-	Demise
ELFIN	Preamp Cover Top	1	Aluminum 6061-T6	Block	22.17	56.90	19.02	43.33	No	-	Demise
ELFIN	Preamp Cover Base	1	Aluminum 6061-T6	Block	15.15	56.90	7.62	43.33	No	-	Demise
ELFIN	Preamp Spacer	4	Aluminum 6061-T6	Cylinder	0.09	3.81	4.57	-	No	-	Demise
ELFIN	Aluminum Shell I	1	Aluminum 6061-T6	Block	44.39	45.42	19.46	39.01	No	-	Demise
ELFIN	Mag Stage Frame	1	Aluminum 6061-T6	Block	48.55	39.01	25.27	39.01	No	-	Demise
ELFIN	Back Wall	1	Tantalum	Block	19.35	20.95	4.60	20.95	Yes	2980	Survives - See Table 4
ELFIN	Side Wall	2	Tantalum	Block	6.03	20.95	6.20	3.00	Yes	2980	Survives - See Table 4
ELFIN	Side Wall (Outer)	1	Tantalum	Block	4.21	14.65	6.20	3.00	Yes	2980	Survives - See Table 4
ELFIN	Side Wall (Inner)	2	Tantalum	Block	1.7	5.50	6.20	3.00	Yes	2980	Survives - See Table 4
ELFIN	Insulator Side	2	PEEK	Block	0.19	17.75	6.10	7.27	No	-	Demise
ELFIN	Spacer	1	Aluminum 6061-T6	Block	0.4	12.90	0.89	12.90	No	-	Demise
ELFIN	Wave Spring Washer	1	Beryllium Copper UNS C17200	Block	0.052	4.19	0.13	-	No	-	Demise
ELFIN	Insulator Back	1	PEEK	Block	0.19	12.90	0.84	12.90	No	-	Demise
ELFIN	Spacer MSX	1	PEEK	Block	0.03	12.95	0.26	12.95	No	-	Demise

(ELFIN 3/4)

CUBESAT	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (C)	Survivability
ELFIN	Mag Stage Front	1	Tantalum	Block	10.98	20.95	2.70	20.95	Yes	2980	Survives - See Table 4
ELFIN	Insulator Front	1	PEEK	Block	0.08	12.95	0.85	12.95	No	-	Demise
ELFIN	Cone Wall	4	Tantalum	Block	7.21	18.45	14.84	7.22	Yes	2980	Survives - See Table 4
ELFIN	Small WSW	2	Beryllium Copper UNS C17200	Block	0.03	7.62	0.13	-	No	-	Demise
ELFIN	RF Shield EFE	1	Aluminum 6061-T6	Block	3.72	7.92	36.02	9.86	No	-	Demise
ELFIN	RF Shield EFE Cover	1	Aluminum 6061-T6	Block	1.18	1.27	36.02	9.86	No	-	Demise
ELFIN	I Aperture Frame	1	Aluminum 6061-T6	Block	27.66	36.58	30.02	36.58	No	-	Demise
ELFIN	EPDD2 Fastener Widget	1	Aluminum 6061-T6	Block	0.86	5.59	13.50	7.62	No	-	Demise
ELFIN	Yoke	4	Hi Perm 49 Annealed	Block	0.9325	10.30	8.30	2.24	No	-	Demise
ELFIN	Spring Retainer	1	Aluminum 6061-T6	Block	0.89	22.80	8.30	2.35	No	-	Demise
ELFIN	I Aperture 1	1	Phosphor Bronze	Block	0.6	8.80	1.61	6.33	No	-	Demise
ELFIN	Outside Magnet	4	SmCo 2:17	Block	0.92	4.15	8.30	3.20	No	-	Demise
ELFIN	Auxiliary Shield M	2	Tantalum	Block	0.57	6.55	3.50	1.70	Yes	2980	Survives - See Table 4
ELFIN	Inside Magnet	2	SmCo 2:17	Block	1.84	8.30	3.20	8.30	No	-	Demise
ELFIN	Magnet Retainer	1	Aluminum 6061-T6	Block	1.87	20.50	8.30	8.10	No	-	Demise
ELFIN	Strawman Bridge	1	Aluminum 6061-T6	Block	1.546	25.40	7.94	4.95	No	-	Demise
ELFIN	I to E Standoff	1	Aluminum 6061-T6	Block	0.49	38.86	8.59	1.22	No	-	Demise
ELFIN	I Aperture 2	1	Phosphor Bronze	Block	6.73	24.00	1.61	24.00	No	-	Demise
ELFIN	I Aperture 2 Spacer	1	6063-T6	Block	2.88	24.00	8.29	24.00	No	-	Demise
ELFIN	I Aperture 3	1	Phosphor Bronze	Block	6.01	26.00	1.61	26.00	No	-	Demise
ELFIN	I Aperture 3 Spacer	1	6063-T6	Block	3.15	26.00	8.29	26.00	No	-	Demise
ELFIN	I Aperture 4	1	Phosphor Bronze	Block	6.88	31.00	1.61	31.00	No	-	Demise
ELFIN	I Aperture 4 Spacer	1	6063-T6	Block	3.61	31.00	8.29	31.00	No	-	Demise
ELFIN	I Aperture 5	1	Phosphor Bronze	Block	7.61	36.60	1.60	36.60	No	-	Demise
ELFIN	Sensor I	1	Polyimide/G-10/Silicon Dioxide/PEEK/Epoxy	Block	1.03	13.00	2.70	13.00	No	-	Demise
ELFIN	Stacer Can	1	Aluminum 6061-T6	Box	560	76.00	83.00	101.35	No	-	Demise
ELFIN	Payload Rods	4	#4 Titanium Threaded Rod	Rod	1	2.85	3.5	-	Yes	1650	Demise
ELFIN	EPD Digital 1 Board	1	FR4	PCB	58	1.57	93.22	86.61	No	-	Demise
ELFIN	EPD Digital 2 Board	1	FR4	PCB	58	1.57	93.22	86.61	No	-	Demise
ELFIN	EPD Extended Front End	1	FR4	PCB	10.6	49.91	69.6	10.77	No	-	Demise
ELFIN	EPD preamp	1	FR4	PCB	24	1.58	46.025	50.06	No	-	Demise
ELFIN	IDPU	1	FR4	PCB	62	1.57	93.23	86.61	No	-	Demise
ELFIN	SIPS	1	FR4	PCB	31.15	1.57	90.68	86.61	No	-	Demise
ELFIN	FGE (FGM Electronics PCBA)	1	FR4, various	85.05		92.66	92.28	23.69	No	-	Demise
ELFIN	FGE brace	1	Aluminum 6061-T6	Box	46.97	10.16	87.02	87.17	No	-	Demise

(ELFIN 4/4)

CUBESAT	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (C)	Survivability
ELFIN	FGE strap	1	Peek	Box	4.27	5.84	78.26	10.16	No	-	Demise
ELFIN	Torquer Coil - Y Spool		Peek		30.9	95.15	241.3	7.49	No	-	Demise
ELFIN	Torquer Coil - Y Wire		HTCCA	Wire	43.7	-	-	-	No	-	Demise
ELFIN	Torquer Coil - X Spool		Peek		31.9	85.73	243.84	16.64	No	-	Demise
ELFIN	Torquer Coil - X Wire		HTCCA	Wire	49.2	-	-	-	No	-	Demise
ELFIN	Battery Holders	2	Peek	Block	26	82	83.83	8.53	No	-	Demise
ELFIN	Batteries	4	Molicel ICR18650J Lithium-ion	Cylinder	46.39	18.4	65.4	-	No	-	Demise
ELFIN	Battery Arcs	4	Aluminum 6061-T6	Block	3.61	16.71	5.74	28.35	No	-	Demise
ELFIN	SBPCB	2	FR4	PCB	28.78	55.88	55.88	16.16	No	-	Demise
ELFIN	FCPCB	1	FR4	PCB	19	55.88	55.88	16.16	No	-	Demise
ELFIN	LETC1	1	FR4	PCB	17.4	55.88	55.88	16.16	No	-	Demise
ELFIN	LETC2	1	FR4	PCB	15.63	55.88	55.88	16.16	No	-	Demise
ELFIN	ACB	1	FR4	PCB	17.8	55.88	55.88	16.16	No	-	Demise
ELFIN	BETC	1	FR4	PCB	40.44	55.88	55.88	16.16	No	-	Demise
ELFIN	Radio	1	FR4/Aluminum	PCB	48.5	15	82	82	No	-	Demise

Appendix C. ElaNa-18 Component List by CubeSat: CHEFSat (1/2)

CUBESAT	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (C)	Survivability
CHEFSat	Vehicle Name CHEFSat	-	-	-	-	-	-	-	-	-	-
CHEFSat	Integrated Reflector	1	Al 6061-T651	Parabolic Dish in Box	105.8	108.0	100.0	16.8	No	-	Demise
CHEFSat	Digital Receiver Housing	1	Al 6061-T651	Box	132.2	162.2	94.9	28.6	No	-	Demise
CHEFSat	Power Panel Housing	1	Al 6061-T651	Box	93.6	162.2	100.0	12.8	No	-	Demise
CHEFSat	Clock Panel	1	Al 6061-T651	Flat Pocketed Panel	77.7	162.2	94.9	5.3	No	-	Demise
CHEFSat	Close Out Panel	1	Al 6061-T651	Flanged Panel	75.1	162.2	100.0	13.7	No	-	Demise
CHEFSat	Axial Horn	1	Brass (ASTM B16)	Flanged Tube	38.6	38.1	0.0	45.1	No	-	Demise
CHEFSat	S-Band Panel	1	Al 6061-T651	Flat Pocketed Panel	40.9	188.0	76.2	6.2	No	-	Demise
CHEFSat	S-Band Antenna	1	RT/Duroid (Reinforced PTFE)	Flat Panel	31.6	63.5	63.5	3.6	No	-	Demise
CHEFSat	Subreflector	1	Al 6061-T651	Cylinder	0.7	10.8	0.0	8.5	No	-	Demise
CHEFSat	Subreflector Supports	2	Glass Epoxy Laminate	Flat Panel	0.9	76.4	53.3	0.8	No	-	Demise
CHEFSat	Retroreflector	4	Glass	Cylinder	0.34	7.2	0.0	6.1	No	-	Demise
CHEFSat	Dgtl Rcvr Main Cover	1	Al 6061-T651	Flat Panel	30.8	119.9	79.2	2.5	No	-	Demise
CHEFSat	Dgtl Rcvr Small Cover	1	Al 6061-T651	90 deg Angle	10.0	79.2	24.6	13.8	No	-	Demise
CHEFSat	Digital Receiver Closeout	1	Al 6061-T651	Flat Panel	2.9	62.6	11.0	1.8	No	-	Demise
CHEFSat	Micro-D Cover	1	Al 6061-T651	Flat Panel	1.6	43.7	10.8	5.2	No	-	Demise
CHEFSat	Nano-D Cover	1	Al 6061-T651	Flat Panel	1.9	45.7	12.4	3.8	No	-	Demise
CHEFSat	ROC Board	1	FR-4 & Electronics	Electronics Board	26.1	84.1	69.0	7.6	No	-	Demise
CHEFSat	Interface Board	1	FR-4 & Electronics	Electronics Board	86.7	126.7	69.0	22.1	No	-	Demise
CHEFSat	Digital Receiver Module	1	FR-4 & Electronics	Electronics Board	119.3	101.6	57.2	4.9	No	-	Demise
CHEFSat	Inteface Board Support	2	Al 6061-T651	90 deg Angle	1.7	16.0	16.0	6.9	No	-	Demise
CHEFSat	Power Panel Cover	1	Al 6061-T651	Flat Panel	30.7	133.1	67.1	5.5	No	-	Demise
CHEFSat	Heatsink	1	Al 6061-T651	Block	13.7	50.0	38.0	5.3	No	-	Demise
CHEFSat	Power Board	1	FR-4 & Electronics	Electronics Board	78.5	122.4	56.4	15.6	No	-	Demise
CHEFSat	Solar Array Hinge Fitting	2	Al 6061-T651	Block	1.3	18.2	13.3	7.3	No	-	Demise
CHEFSat	Polarizer	1	Brass	Flanged Cylinder	25.9	19.1	0.0	25.4	No	-	Demise
CHEFSat	Waveguide Transition	1	Brass	Flanged Cylinder	24.9	19.1	0.0	27.9	No	-	Demise
CHEFSat	Waveguide J Bend	1	Brass	Flanged Tube	29.9	80.1	43.4	19.1	No	-	Demise
CHEFSat	Low Noise Amplifier	1	Al 6061-T6	Block	42.2	31.2	21.8	21.8	No	-	Demise
CHEFSat	Preselect Filter	1	Al 6061-T6	Block	18.1	25.4	19.3	19.3	No	-	Demise
CHEFSat	Isolator	1	Al 6061-T6	Block	43.5	30.5	25.4	21.6	No	-	Demise
CHEFSat	Mixer	1	Al 6061-T6	Block	22.2	25.4	19.3	19.1	No	-	Demise
CHEFSat	Bandpass Filter	1	Al 6061-T6	Block	15.0	25.4	19.3	19.3	No	-	Demise
CHEFSat	6X Multiplier	1	Al 6061-T6	Block	44.9	41.4	25.4	15.2	No	-	Demise
CHEFSat	Frequency Synthesizer	1	Al 6061-T6	Block	48.5	63.5	27.9	10.2	No	-	Demise

(CHEFSat 2/2)

CUBESAT	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter/ Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (C)	Survivability
CHEFSat	Clock Board	1	FR-4 & Electronics	Electronics Board	27.2	58.4	45.7	14.5	No	-	Demise
CHEFSat	LNA Brackets	2	Al 6061-T651	Block	5.8	36.0	35.7	11.8	No	-	Demise
CHEFSat	Multiplier Brackets	2	Al 6061-T651	Block	5.2	52.5	15.2	7.6	No	-	Demise
CHEFSat	Heat Strap	1	Al 1100	Blocks with Foil	15.5	39.4	32.0	31.8	No	-	Demise
CHEFSat	Wire Harness Assembly	N/A	Copper, PTFE Jacket	Cylinders	54.4	3.0	557.0	N/A	No	-	Demise
CHEFSat	RF Coax	N/A	CuAg wire,PTFE, polyimide tap, SS braid, FEP jacket	Cylinders	13.6	2.0	730.0	N/A	No	-	Demise
CHEFSat	Hardware	100+	A286, CRES, Al Alloys	Cylinders	72.7	2.8	4.8	Various	Yes	~1500	Demise
CHEFSat	Bus Structure	1	Al 7075-T6	Flat Panels	175.0	Various	Various	Various	No	-	Demise
CHEFSat	Inertial Reference Module	1	Al 7075-T6, Lens Glass, FR-4 & electronics, Multi- wires with PTFE jacket	Box	646.0	82.0	82.0	57.0	No	-	Demise
CHEFSat	Reaction Wheel Flywheel	3	C18000 Copper, Nickel Plated	Rotor	39.7	41.4	41.4	7.5	No	-	Demise
CHEFSat	Battery Module	1	Li-Ion 18650 Battery Cell (x6), Al 6061, FR-4	Block	460.0	84.5	63.4	41.7	No	-	Demise
CHEFSat	GPS Module	1	FR-4 & Electronics, Al 7075-T6	Block, with mounting ears	155.0	77.1	51.7	13.5	No	-	Demise
CHEFSat	Deploy Panels	2	FR-4, Solar Cells, Ag-PTFE Tape, Aluminum Supports	Flat Panel	200.0	157.4	318.0	1.5	No	-	Demise
CHEFSat	+X Body Panel	1	FR-4, Solar Cells, Polyimide	Flat Panel	150.0	82.0	309.0	1.3	No	-	Demise
CHEFSat	+/-Y Body Panel PCBs	2	FR-4 & Electronics	Flat Panel	55.0	82.0	156.7	0.8	No	-	Demise
CHEFSat	-X Body Panel PCB	1	FR-4 & Electronics	Flat Panel	10.0	81.5	49.6	0.8	No	-	Demise
CHEFSat	+Z Body Panel	1	FR-4 & Electronics, Delrin, Al 7075-T6	Flat Panel	105.0	85.1	99.4	1.6	No	-	Demise
CHEFSat	UHF Antenna Elements	2	Be-Cu	Flat Sheet	4.0	3.2	177.8	0.3	No	-	Demise
CHEFSat	S-Band Radio	1	FR-4 & Electronics, SS Housing	Block	42.0	31.8	86.4	7.6	Yes	1510	Survives - See Table 4
CHEFSat	Bus S-Band Antenna	1	Ceramic	Block	13.0	40.0	40.0	5.2	No	-	Demise
CHEFSat	GPS Antenna	1	Ceramic, FR-4 & Electronics	Block on flat-panel	12.0	35.1	35.1	9.6	No	-	Demise
CHEFSat	Thermal Straps	2	C110 Copper	Block	13.7	20.0	12.0	.3.8	No	-	Demise
CHEFSat	Star Tracker Lens Shade	2	Windform XT2.0	Block	0.2	30.0	25.0	18.3	No	-	Demise
CHEFSat	Deployment Switch	2	Stainless Steel	Cylinder	5.0	4.9	17.0	-	Yes	1510	Demise
CHEFSat	Bus Harnessing	N/A	Copper, PTFE Jacket	Wires	75.0	Various	Various	Various	No	-	Demise
CHEFSat	Bus Fasteners	60+	316SS, A286	Cylinders	125.0	2.8	9.525	Various	Yes	1400-1430	Demise