April 2, 2013

Orbital Debris Assessment for ChargerSat-1 on the ORS-3 /ELaNa-4 Mission per NASA-STD 8719.14A

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. *ORS-3 LV to IPS ICDORS-3 LV to IPS ICD* (Orbital Information), Orbital Document, #1047-0111 Rev Draft
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. *ORS-3 LV to IPS ICD*, Orbit Description, Orbital Document, #1047-0111 Rev Draft.
I. *UL Standard for Safety for Household and Commercial Batteries, UL 2054*. UL Standard. 2nd ed. Northbrook, IL, Underwriters Laboratories, 2005.
J. *Common Risk Criteria Standards for National Test Ranges*, Standard 321-10, December 2010.

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the ChargerSat-1 auxiliary mission launching in conjunction with the ORS3 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 Department of Defense's Operationally Responsive Space Office and are not presented here.

The following table summarizes the compliance status of the ChargerSat-1 auxiliary payload mission flown on ORS3. ChargerSat-1 as part of the ELaNa-4 mission is 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 2.0 yrs
4.6-1(b)	Not applicable	
4.6-1(c)	Not applicable	
4.6-2	Not applicable	
4.6-3	Not applicable	
4.6-4	Not applicable	Passive disposal
4.6-5	Compliant	
4.7-1	Compliant	Non-credible risk of human casualty
4.8-1	Compliant	No planned tether release under ChargerSat-1 mission

Section 1: Program Management and Mission Overview

The ELaNa-4 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:

ChargerSat: Point of Contact – Eric Becnel, Principle Investigator

Program Milestone Schedule

Task	Date
CubeSat Selection	5/16/12
CubeSat Build, Test, and Integration	1/1/12 through 3/31/13
MRR	3/1/13
Pre-Ship Review	3/25/13
CubeSat Delivery to KAFB	4/1/13
CubeSat Integration into P-PODs	4/2/13 through 4/9/13
Launch	9/30/13

Figure 1: Program Milestone Schedule

The ELaNa-4 mission will deploy 11 pico-satellites (or CubeSats) as a secondary payload on the ORS3 mission. The CubeSat slotted position is identified in Table 2: ELaNa-4 CubeSats. The ELaNa-4 manifest includes: Ho`oponopono-2, KySat-2, DragonSat-1, Trailblazer, ChargerSat, PhoneSat, Vermont Lunar Orbiter/Lander, COPPER, SwampSat, CAPE-2, and TJ3Sat.

Each CubeSat ranges in sizes from a 10 cm cube to 10 cm x 10cm x 15 cm, with masses from about 1 kg to 4 kg total. The CubeSats have been designed and built by universities and government agencies and each have their own mission goals.

The ELaNa-4 mission will be launched as an auxiliary payload on the ORS3 mission on a Minotaur launch vehicle from Wallops Flight Facility, Virginia. The current launch date is 30 September, 2013. The eleven CubeSats will be ejected from a PPOD carrier attached to the launch vehicle, placing the CubeSats in an orbit approximately 500 X 500 km at inclination of 40.5 deg (ref. (h)).

Section 2: Spacecraft Description

There are eleven CubeSats flying on the ELaNa-4 Mission. They will be deployed out of five PPODs, as shown in Table 2: ELaNa-4 CubeSats below.

Table 2: ELaNa-4 CubeSats

PPOD Slot	CubeSat Quantity	CubeSat size	CubeSat Names	CubeSat Masses (kg)
2.2	1	3U (10 cm X 10 cm X 30 cm)	Ho`oponopono-2	4
2.3A	2	1U (10 cm X 10 cm X 10 cm)	KySat-2	1.2
2.3B		1U (10 cm X 10 cm X 10 cm)	DragonSat-1	0.99
2.5 A	3	1U (10 cm X 10 cm X 10 cm)	Trailblazer	1.2
2.5 B		1U (10 cm X 10 cm X 10 cm)	ChargerSat	1
2.5 C		1U (10 cm X 10 cm X 10 cm)	PhoneSat	1.12
2.6 A	2	1U (10 cm X 10 cm X 10 cm)	Vermont Lunar	1.01
2.6 B		1U (10 cm X 10 cm X 10 cm)	COPPER	1.25
2.7 A	3	1U (10 cm X 10 cm X 10 cm)	SwampSat	1.21
2.7 B		1U (10 cm X 10 cm X 10 cm)	CAPE-2	0.98
2.7 C		1U (10 cm X 10 cm X 10 cm)	TJ3Sat	0.89

The following subsections contain descriptions of ChargerSat-1.

ChargerSat CubeSat Description

University of Alabama in Huntsville – 1U

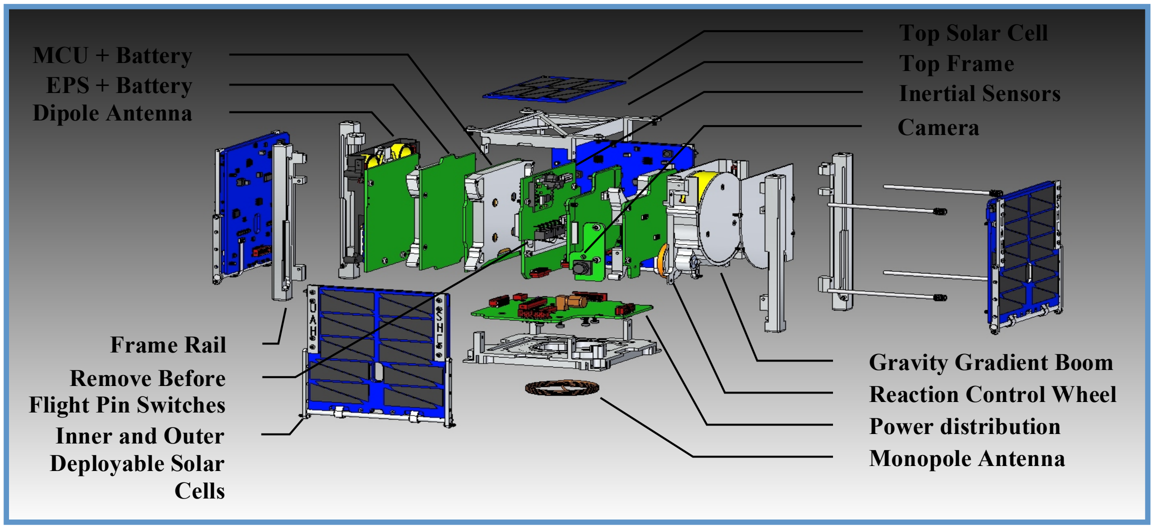


Figure 2: ChargerSat Expanded View

ChargerSat is the first CubeSat for University of Alabama - Huntsville students. ChargerSat demonstrates three primary objectives in addition to the core operations of the satellite and ground station. Demonstration of the technologies will raise the involved technologies to TRL 9.

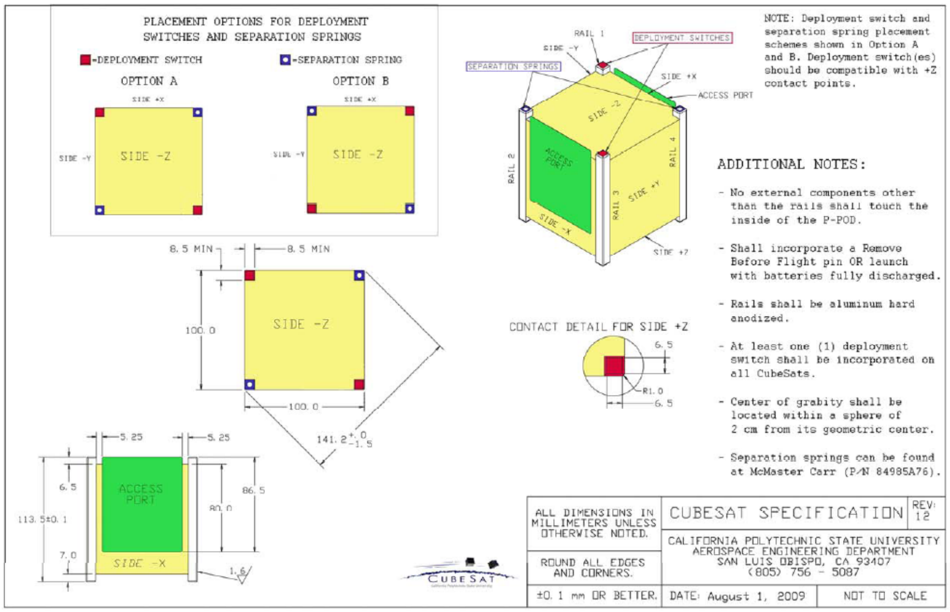
The primary mission is to improve communications for picosatellite operations, provide demonstration of the passive nadir axis stabilization for picosatellite attitude control, and improve solar power collection for picosatellite operations. The secondary mission is to capture and downlink images.

The concept of operations is devised of the following sequential activities:

Wait for required delays before deployments or transmitting
Deploy the dipole antenna for initial beacon
Deploy gravity gradient boom for passive attitude control
After stabilization perform correction flip if needed (reaction control wheel)
Deploy monopole antenna
Deploy 4 solar panels
End of Primary Mission
Perform secondary mission of capturing images and down-linking data

ChargerSat is constructed using the following materials: 7075 T6 Aluminum frame, Stainless steel fasteners, FR4 and copper printed circuit boards, Macor Ceramic dipole antenna deployment boom, Steel tape measure for gravity gradient boom and dipole antenna, AL4750 - Magnetic hysteresis rods, and Nitinol springs for monopole, dipole, and solar cell deployment.

There are no pressure vessels, hazardous or exotic materials.
There are two Lithium Ion Polymer battery cells on board with battery protection circuitry, both of model H605060 from Hangzhou Wanma High-Energy Battery CO. See Table 3: ELaNa-4 CubeSat Cells for UL Listing.



NOTE: Deployment switch and separation spring placement schemes shown in Option A and B. Deployment switch(es) should be compatible with +Z contact points.

ADDITIONAL NOTES:

- No external components other than the rails shall touch the inside of the P-POD.
- Shall incorporate a Remove Before Flight pin OR launch with batteries fully discharged.
- Rails shall be aluminum hard anodized.
- At least one (1) deployment switch shall be incorporated on all CubeSats.
- Center of grabity shall be located within a sphere of 2 cm from its geometric center.
- Separation springs can be found at McMaster Carr (P/N 84985A76).

ALL DIMENSIONS IN MILLIMETERS UNLESS OTHERWISE NOTED.	CUBESAT SPECIFICATION	REV: 12
ROUND ALL EDGES AND CORNERS.	CALIFORNIA POLYTECHNIC STATE UNIVERSITY AEROSPACE ENGINEERING DEPARTMENT SAN LUIS OBISPO, CA 93407 (805) 756 - 5087	
±0.1 mm OR BETTER.	DATE: August 1, 2009	NOT TO SCALE

Figure 3: 1U 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 ChargerSat-1 CubeSat mission therefore this section is not applicable.

Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions.

Malfunction of lithium ion or lithium polymer batteries and/or associated control circuitry has been identified as a potential cause for spacecraft breakup during deployment and mission operations.

While no passivation of batteries will be attempted, natural degradation of the solar cell and battery properties will occur over the post mission period, which may be as long as 2.5 years. These conditions pose a possible increased chance of undesired battery energy release. The battery capacity for storage will degrade over time, possibly leading to changes in the acceptable charge rate for the cells. Individual cells may also change properties at different rates due to time degradation and temperature changes. The control circuit may also malfunction as a result of exposure to the space environment over long periods of time. The cell pressure relief vents could be blocked by small contaminants. Any of these individual or combined effects may theoretically cause an electro-chemical reaction that result in rapid energy release in the form of combustion.

There are NO plans for designed spacecraft breakups, explosions, or intentional collisions on the ChargerSat-1 mission.

Section 4 asks for a list of components, which shall be passivated at End of Mission (EOM), as well as the method of passivation and description of the components, which cannot be passivated. No passivation of components is planned at the End of Mission for the ChargerSat-1 CubeSat.

Since the batteries used do not present a debris generation hazard even in the event of rapid energy release (see assessment directly below), passivation of the batteries is not necessary in order to meet the requirement 4.4-2 (56450) for passivation of energy sources “to a level which cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft.” Because passivation is not necessary, and in the interest of not increasing the complexity of the CubeSats, there was no need to add this capability to their electrical power generation and storage systems.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that the ChargerSat-1 CubeSat is compliant. Requirements 4.4-3 and 4.4-4 are not applicable.

The following addresses requirement 4.4-2. The CubeSats that have been selected to fly on the ORS3 mission have not been designed to disconnect their onboard storage energy devices (lithium ion and lithium polymer batteries). However, the CubeSats batteries still meet Req. 56450 by virtue of the fact that they cannot “cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft”.

The batteries used in the eleven CubeSats are of similar manufacture, design, and performance. Ten of the battery cells utilize lithium ion technology and are compliant with Underwriters Laboratory (UL) Standard 1642. The remaining one utilizes nickel metal hydride technologies and complies with Air Force standards for space flight acceptability. In general, these batteries are similar in size and power to cell phone batteries.

Table 3: ELaNa-4 CubeSat Cells

CubeSat	Technology	Manufacturer	Model	UL Listing Number
ChargerSat	Li-Ion Polymer	HANGZWANMA HIGH-ENERGY BATTERY CO	H605060	MH10008

The batteries are all consumer-oriented devices. All battery cells have been recognized as Underwriters Laboratories (UL) tested and approved. Furthermore, safety devices incorporated in these batteries include pressure release valves, over current charge protection and over current discharge protection.

The fact that these batteries are UL recognized indicates that they have passed the UL standard testing procedures that characterize their explosive potential. Of particular concern to NASA Req. 56450 is UL Standard 1642, which specifically deals with the testing of lithium batteries. Section 20 Projectile Test of UL 1642 (ref. (e)) subjects the test battery to heat by flame while within an aluminum and steel wire mesh octagonal box, "[where the test battery] shall remain on the screen until it explodes or the cell or battery has ignited and burned out"(UL 1642 20.5). To pass the test, "no part of an exploding cell or battery shall penetrate the wire screen such that some or all of the cell or battery protrudes through the screen" (UL 1642 20.1).

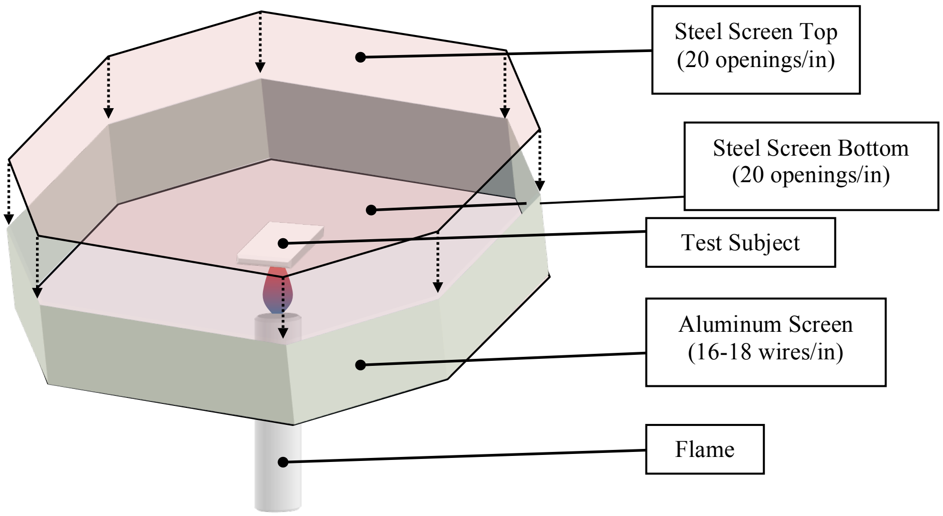


Figure 2: Underwriters Laboratory Explosion Test Apparatus

The batteries being launched via CubeSat will experience conditions on orbit that are generally much less severe that those seen during the UL test. While the source of failure would not be external heat on orbit, analysis of the expected mission thermal environment performed by NASA LSP Flight Analysis Division shows that given the very low (<=41.44 W-hr, maximum for PhoneSat) power dissipation for CubeSats, the batteries will be exposed to a maximum temperature that is well below their 212^{o}F safe operation limit (ref. (f)). It is unlikely but possible that the continual charging with 2 to 6 W of average power from the solar panels over an orbital life span greater than 2 years may expose the two to four batteries (per CubeSat) to overcharging which could cause similar heat to be generated internally. Through the UL testing, it has been shown that these batteries do not cause an explosion that would cause a fragmentation of the spacecraft.

A NASA Glenn Research Center guideline entitled Guidelines on Lithium-ion Battery Use in Space Applications (ref. (d)) explains that the hazards of Li-Ion cells in an overcharge situation result in the breakdown of the electrolyte found in Li-ion cells causing an increase in internal pressure, formation of flammable organic solvents, and the release of oxygen from the metal oxide structure. From a structural point of view a battery in an overcharge situation can expect breakage of cases, seals, mounting provisions, and internal components. The end result could be “unconstrained movement of the battery” (ref. (d), pg 13). This document clearly indicates that only battery deformation and the escape of combustible gasses will be seen in an overcharging situation, providing further support to the conclusion that CubeSat fragmentation due to explosion is not a credible scenario for this application. It is important to note that the NASA guide to Li-ion batteries makes no mention of these batteries causing explosions of any magnitude whatsoever.

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 thirteen CubeSats is that of the Ho`oponopono-2 CubeSat with antennas deployed (10 X 10 X 30 cm with one deployable antenna 2.3 X 500 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

ChargerSat-1 evaluated for this ODAR is 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 ChargerSat-1 orbit at deployment is 500 km apogee altitude by 500 km perigee altitude, with an inclination of 40.5 degrees. With an area to mass (1.0 kg) ratio of 0.016 m^2/kg, DAS yields 2.0 years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability. Table 4 below provides complete results.

Table 4: CubeSat Orbital Lifetime & Collision Probability

	CubeSat	ChargerSat
	Mass (kg)	1.0
Stowed	Mean C/S Area (m^2)	0.015
	Area-to Mass (m^2/kg)	0.016
	Orbital Lifetime (yrs)	2.0
	Probability of collision (10^X)	-7.7
Deployed	Mean C/S Area (m^2)	0.049
	Area-to Mass (m^2/kg)	0.053
	Orbital Lifetime (yrs)	0.5
	Probability of collision (10^X)	-7.7

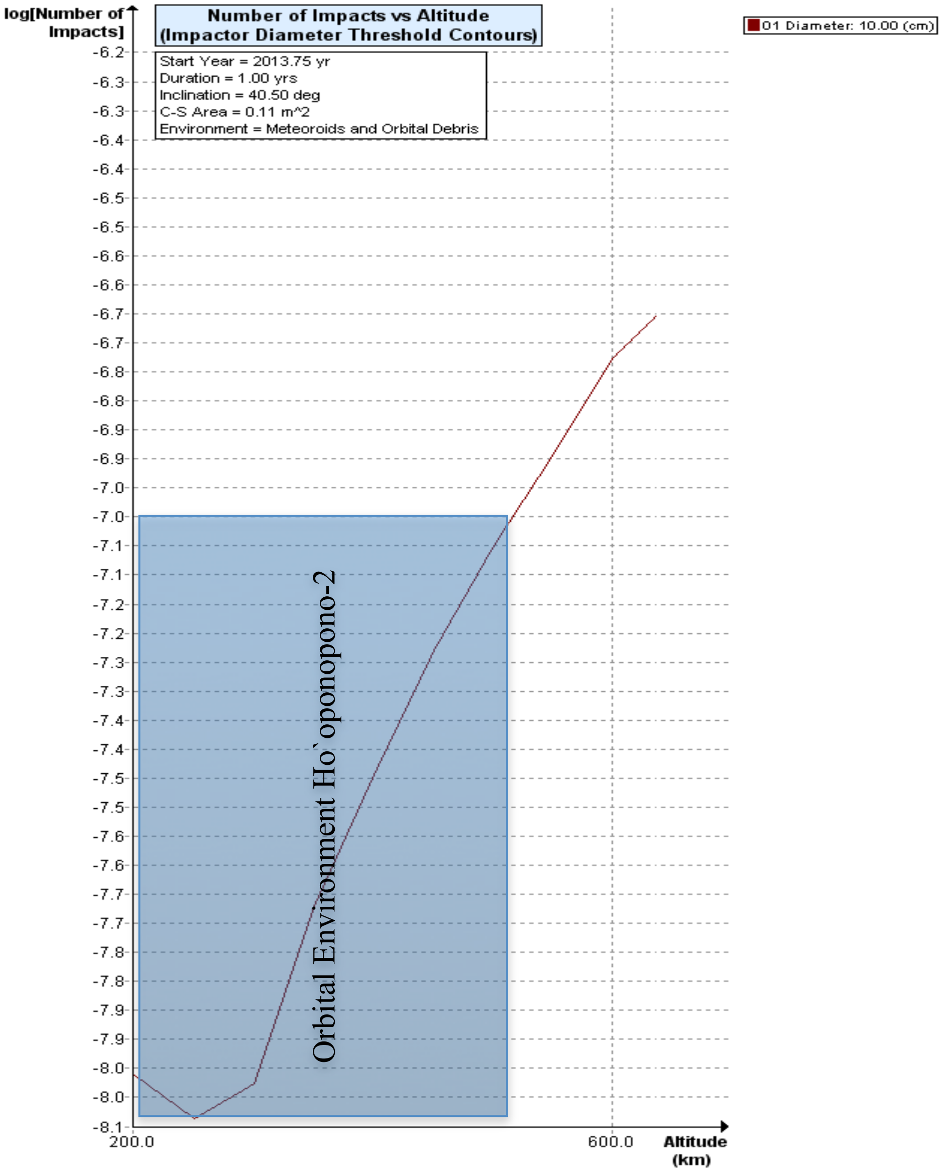


Figure 43: Highest Risk of Orbit Collision vs. Altitude (Ho`oponopono-2 Deployed)

The Ho`oponopono-2 deployed state is worst case and bounds the ChargerSat-1 deployed state.

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-4 spacecraft collision with debris and meteoroids greater than 10 cm in diameter and capable of preventing post-mission disposal is less than $10^{-7.0}$, 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 ChargerSat-1 to be compliant. Requirement 4.5-2 is not applicable to this mission.

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

The ChargerSat-1 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 worst case (smallest Area-to-Mass) post-mission disposal is ChargerSat-1 in stowed configuration. The area-to-mass is calculated as follows:

$$\frac{\boldsymbol{Mean\ {}^{C}/_{S}\,Area\ (m^2)}}{\boldsymbol{Mass\ (kg)}} = \boldsymbol{Area - to - Mass\ (\frac{m^2}{kg})}$$

Equation 3: Area to Mass

$$\frac{0.015\,m^2}{1.0\,kg} = 0.016\frac{m^2}{kg}$$

The assessment of the spacecraft illustrates it is 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 perigee X 500 km maximum apogee altitudes with an inclination of 40.5 degrees at deployment in the year 2013. An area to mass ratio of 0.016 m^2/kg for the ChargerSat-1 CubeSat was input. DAS 2.0.2 yields a 2.0 year orbit lifetime for ChargerSat-1 in its stowed state.

This meets requirement 4.6-1.

Assessment results show compliance.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on ELaNa-4 was performed. The assessment used DAS 2.0 to provide bounding analysis to characterize component's risk. DAS 2.0 is a conservative tool used by the NASA Orbital Debris Office to verify Requirement 4.7-1.

DAS employs a conservative analysis methodology to determine if a component will survive reentry. Since DAS does not explicitly model the oxidative or ablative heating that a given component will experience during reentry, it generally over-predicts component survivability. This is an especially relevant consideration for small components that are on the edge of survivability, particularly those that are predicted to survive with very low residual kinetic energy.

The following steps are used to identify and evaluate a component's potential reentry risk.

1. Low melting temperature (less than 1000 °C) components are identified as materials that will never survive reentry and pose no risk to human casualty. This is confirmed through DAS analysis that shows that 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 higher temperature materials are shown to pose negligible risk to human casualty through a bounding analysis of the highest temperature components. For the CubeSats comprising the ELaNa-4 mission, the material with the highest melting temperature is 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 5)

Table 5: ELaNa-4 Stainless Steel DAS Analysis

CubeSat	ELaNa-4 Stainless Steel Components	Mass (g)	Length / Diameter (cm)	Width (cm)	Height (cm)		Demise Alt (km)	KE (J)
ChargerSat	Boom	27	200	1.3	0.013		0	1
	Dipole Antenna	1	0.635	0.2	0.013		0	<1

The majority of stainless steel components demise upon reentry. The components that DAS conservatively identifies as reaching the ground have one joule of kinetic energy or less, far below fifteen joule threshold. Since any injury incurred or inflicted by an object with such low energy would be negligible and would not require the individual to seek medical attention, these objects pose no risk of human casualty as defined by the Range Commander's Counsel ref (j).

Through the method described above, Table 5: ELaNa-4 Stainless Steel DAS Analysis, and the full component lists in the Appendix the ChargerSat-1 CubeSat launching under the ELaNa-4 mission is 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 components.

Section 8: Assessment for Tether Missions

ChargerSat-1 will not be deploying any tethers.

ChargerSat-1 satisfies Section 8’s requirement 4.8-1.

Section 9-14

ODAR sections 9 through 14 for the launch vehicle are addressed in ref. (g), and are not covered here.

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

/original signed by/

Justin Treptow
Flight Design Analyst
NASA/KSC/VA-H1

cc: VA-H/Mr. Carney
VA-H1/Mr. Beaver
VA-H1/Mr. Haddox
VA-G2/Mr. Atkinson
VA-C/Mr. Skrobot
VA-G2/Mr. Poffenberger
CP-02/Mr. Higginbotham
SA-D2/Mr. Frattin
SA-D2/Mr. Hale
SA-D2/Mr. Henry
Analex-3/Mr. Davis
Analex-22/Ms. Ramos

Appendix Index:

Appendix A. ChargerSat-1 Component List

CubeSat	**Row Number**	**Name**	**External/Internal (Major/Minor Components)**	**Qty**	**Material**	**Body Type**	**Mass (g)**	**Diameter/ Width (mm)**	**Length (mm)**	**Height (mm)**	Low Melting Temp	Melting Temp	Comment
ChargerSat	2	top frame	External - Major	1	Aluminum 7075	Bar	24	24	82	18	y		Demises
ChargerSat	3	base frame	External - Major	1	Aluminum 7075	Box	73	73	82	23	y		Demises
ChargerSat	4	dipole metal	Internal - Minor	1	Aluminum 7075	Box	55	55	82	10	y		Demises
ChargerSat	5	dipole rod	External - Minor	1	Macor Ceramic	Bar	10	10	12	75	High Melt	1000	Negligible Risk, bounded by larger SS components. See Table 5.
ChargerSat	6	dipole pcb	Internal - Major	1	PCB	Board	21	21	72	2	y		Demises
ChargerSat	7	battery	Internal - Major	2	lipo	Box	40	80	50	6	y		Demises
ChargerSat	8	battery holder	Internal - Minor	2	Aluminum 7075	Box	16	32	80	7	y		Demises
ChargerSat	9	EPS	Internal - Major	1	PCB	Board	27	27	80	4	y		Demises
ChargerSat	10	CDH	Internal - Major	1	PCB	Board	23	23	80	4	y		Demises
ChargerSat	11	sensor board	Internal - Major	1	PCB	Board	27	27	80	4	y		Demises
ChargerSat	12	RBF pin holder	Internal - Minor	1	Aluminum 7075	Bar	5	5	67	7	y		Demises
ChargerSat	13	camera IO	Internal - Minor	1	pcb	Board	19	19	80	4	y		Demises
ChargerSat	14	GG IO frame	Internal - Minor	1	Aluminum 7075	Box	17	17	80	7	y		Demises
ChargerSat	15	GG IO board	Internal - Major	1	PCB	Board	15	15	80	4	y		Demises
ChargerSat	16	camera	Internal - Minor	1	PCB	Board	3	3	41	6	y		Demises
ChargerSat	17	power distributon	Internal - Major	1	PCB	Board	30	82	82	2	y		Demises
ChargerSat	18	gg box	Internal - Major	1	Aluminum 7075	Box	70	81	79	18	y		Demises
ChargerSat	19	gg electronics	Internal - Minor	1	PCB	Round board	8	46	2	x	y		Demises

ChargerSat	20	gg end box	External - Minor	1	Aluminum 7075	Cylinder	33	65	17	x	y		Demises
ChargerSat	21	Boom	External - Minor	1	Steel	Tape Measure	27	13	2000	0.13	High Melt	1500	Negligible Risk: KE ~ 1 J See Table 5.
ChargerSat	22	solar panel side (2 layers)	External - Major	4	PCB	Board	72	88	98	7	y		Demises
ChargerSat	23	frame rail	External - Major	4	Aluminum 7075	Bar	20	113.5	15	15	y		Demises
ChargerSat	24	solar panel top	External - Major	1	PCB	Board	19	50	82	2	y		Demises
ChargerSat	25	hysterysis	Internal - Minor	2	AL4750	Bar	3	1.9	3.8	50	y		Demises
ChargerSat	26	fasteners	Internal - Minor	1	stainless steel	random	20	N/A	N/A	N/A	High Melt		Negligible Risk, bounded by larger SS components. See Table 5.
ChargerSat	27	Dipole Antenna	External - Minor	2	Steel	Tape Measure	1	6.35	223	0.13	High Melt		Negligible Risk: KE ~ 0 J See Table 5.
ChargerSat	28	Monopole Antenna	External - Minor	1	Nitinol	Cylinder	1	0.84	508	x	High Melt	1300	Negligible Risk, bounded by larger SS components. See Table 5.