ELVL-2015-xxxxxxx (DRAFT)
September 29, 2015

Orbital Debris Assessment for CSUNSat1 Mission per NASA-STD 8719.14A

Signature Page

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ELVL-2015-xxxxxx

Reply to Attn of: VA-H1

September 29, 2015

TO: Scott Higginbotham, LSP Mission Manager, NASA/KSC/VA-C

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

SUBJECT: Orbital Debris Assessment Report (ODAR) for the ELaNa [TBD] Mission (DRAFT)

FEERENCES:

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. Email, "FW: ISS Orbital Parameters" Scott Higginbotham to Justin Treptow, March 7, 2014
D. Kwas, Robert. Thermal Analysis of ELaNa-4 CubeSat Batteries, ELVL-2012-0043254; Nov 2012
E. Range Safety User Requirements Manual Volume 3- Launch Vehicles, Payloads, and Ground Support Systems Requirements, AFSCM 91-710 V3.
F. HQ OSMA Policy Memo/Email to 8719.14: CubeSat Battery Non-Passivation, Suzanne Aleman to Justin Treptow, 10, March 2014

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

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the ELaNa [TBD] mission. Sections 1 through 8 of ref. (b) are addressed in this document; sections 9 through 14 are not applicable and are not presented here.

The following table summarizes the compliance status of the ELaNa [TBD] auxiliary payload mission flown on the [TBD] CRS launch, inside the [Orbital Sciences Cygnus or Falcon 9] vehicle. The ELaNa [TBD] CubeSat 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	Minimal risk to orbital environment, mitigated by orbital lifetime.
4.4-2	Compliant	Minimal risk to orbital environment, mitigated by orbital lifetime.
4.4-3	Not applicable	No planned breakups
4.4-4	Not applicable	No planned breakups
4.5-1	Compliant	
4.5-2	Not applicable	
4.6-1(a)	Compliant	Worst case lifetime 1.1 yrs
4.6-1(b)	Not applicable	
4.6-1(c)	Not applicable	
4.6-2	Not applicable	
4.6-3	Not applicable	
4.6-4	Not applicable	Passive disposal
4.6-5	Compliant	
4.7-1	Compliant	Non-credible risk of human casualty
4.8-1	Compliant	No planned tether release

Section 1: Program Management and Mission Overview

The ELaNa [TBD] mission is sponsored by the Space Operations Mission Directorate at NASA Headquarters and is made of the CSUNSat1 CubeSat. The Program Executive is Jason Crusan. Responsible program/project manager and senior scientific and management personnel are as follows:

CSUNSat1: Sharlene Katz, Ph.D, Principle Investigator;

Program Milestone Schedule	
Task	**Date**
CubeSat Selection	[TBD]
CubeSat Delivery to NanoRacks	[TBD]
CubeSat Integration into NanoRacks CubeSat Dispenser (NRCSD)	[TBD]
Launch	Late 2016

Figure 1: Program Milestone Schedule

The ELaNa [TBD] mission will be launched as a payload of the [Cygnus / Dragon] resupply vehicle on the [CRS] mission on an [Atlas V / Falcon 9] launch vehicle from CCAFS, Fl. The CubeSat slotted position is identified in Table 2: ELaNa [TBD] CubeSat and in the Appendix. The current launch date is in late 2016. CSUNSat1 will be deployed from a NRCSD dispenser from the ISS, placing the CubeSats in an orbit approximately 400 X 400 km at inclination of 51.6 deg (ref. (c)).

CSUNSat1 is in a 2U form factor of 10 cm x 10cm x 22.7 cm, with mass of 2.16kg.

Section 2: Spacecraft Description

The primary CubeSat will be deployed out of an individual dispenser, as shown in Table 2: ELaNa [TBD] CubeSat below.

Table 2: ELaNa [TBD] CubeSat

Dispenser Slot	CubeSat Quantity	CubeSat size	CubeSat Names	CubeSat Masses (kg)
A	1	2U (10 cm X 10 cm X 22.7 cm)	CSUNSat1	2.16

CSUNSat1 CubeSat Description

CSUNSat1 – California State University Northridge (CSUN) / Jet Propulsion Laboratory(JPL) – 2U

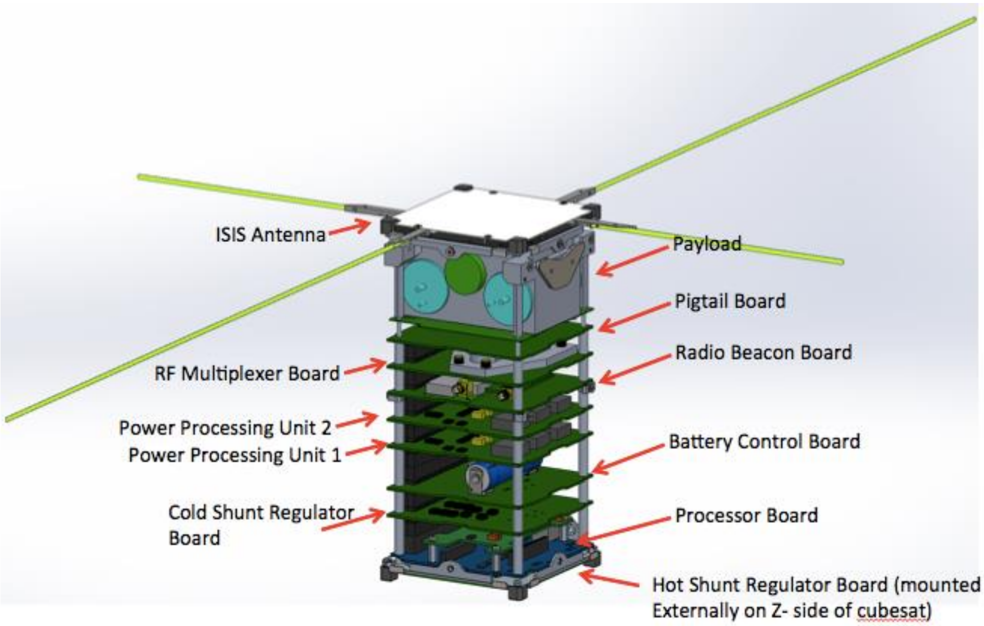

Figure 2: CSUNSat1 Xray View

CSUNSat1 is a 2U CubeSat jointly developed by California State University Northridge (CSUN) and the Jet Propulsion Laboratory (JPL). The objective of the CSUNSat1 mission is to space test a new low-temperature capable, Li-ion battery/supercapacitor hybrid power system. This innovation would reduce the mass and volume of power systems and eliminate the need for wasteful battery heaters and thereby increase the amount of energy and power available at for low-temperatures science and engineering operations encountered in deep space missions.

30 minutes after release from the deployer, CSUNSat1 will power up and execute an initialization process that includes charging the spacecraft battery and deploying the antenna. After initialization the follow mission phases will be executed.

- Spacecraft Checkout: A set of tests to verify spacecraft performance and charge the spacecraft battery
- Payload Checkout: A single charge/discharge cycle of the payload battery
- Primary Experiments: A series of ground station controlled designed to characterize the battery, supercapacitors, and hybrid system at several temperatures
- Extended Mission: Based on the successful performance of the primary experiments, the satellite will switch from the spacecraft to the payload battery as the primary source of stored energy for the remainder of the mission.

The primary CSUNSat1 structure is made of 5052-H32 Aluminum. The radio and beacon use an ISIS Deployable Antenna System (Double UHF Dipole) made from Aluminum 6082, Polycarbonate, and Nitinol. The solar panel substrates are made of Aluminum 6061 with XTJ cells mounted on them. The remaining components contain all standard commercial off the shelf (COTS) materials, electrical components, and PCBs. CSUNSat1 has no propulsion and no attitude control.

There are no pressure vessels, hazardous or exotic materials.

The spacecraft's electrical power storage system consists of Panasonic NCR18650 Lithium batteries. The payload experiment battery is a A123 Systems/Navitas 26650 Li-ion Cell (Manufacturer Serial # TXN10293).

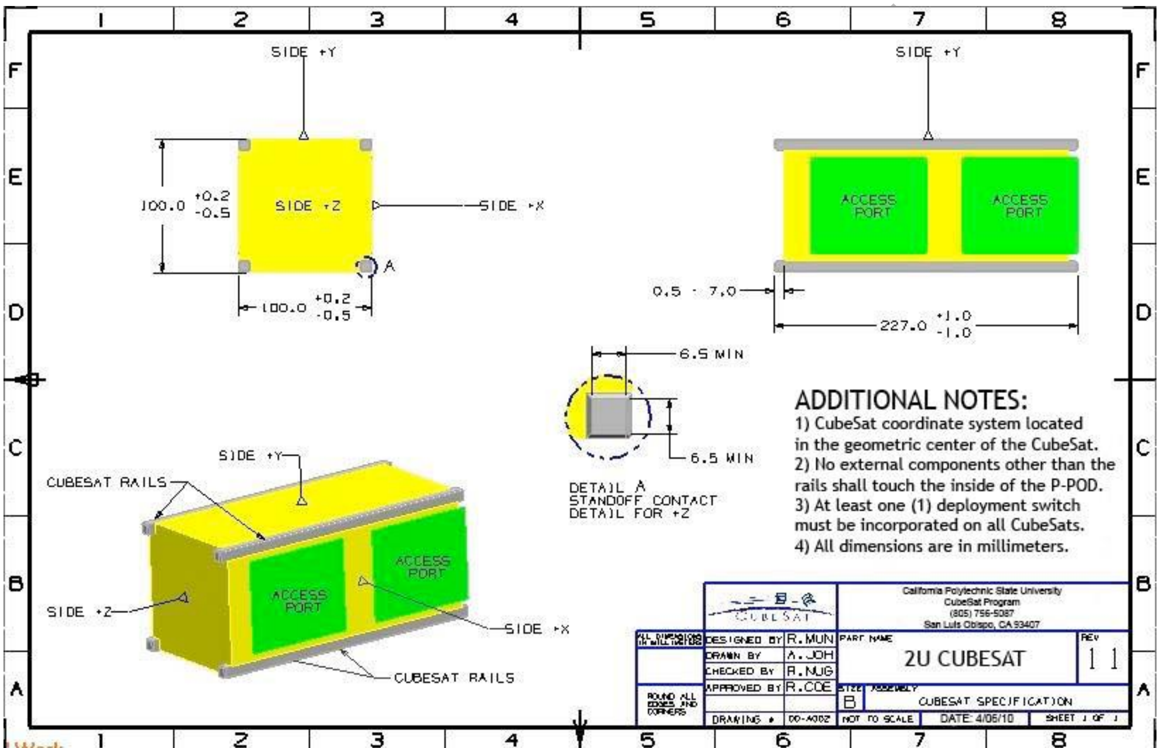

Figure 3: 2U CubeSat Specification

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.

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 [TBD] 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 [TBD] mission. No passivation of components is planned at the End of Mission for the CubeSats on this 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 (f)).

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. (f))

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a lifetime of 1.1 years maximum the CSUNSat1 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.

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

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

CSUNSat1 is evaluated for this ODAR, 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

CSUNSat1 orbit at deployment is 400 km perigee altitude by 400 km apogee altitude, with an inclination of 51.6 degrees. With an area to mass (2.16 kg) ratio of 0.0128 m^2/kg, DAS yields 1.1 years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability. CSUNSat1 sees less than 0x10^-5 probability of collision. Table 4 below provides complete results.

Table 3: CubeSat Orbital Lifetime & Collision Probability

		CSUNSat1
	Mass (kg)	2.16
Stowed	**Mean C/S Area (m^2)**	0.0277
	Area-to Mass (m^2/kg)	0.0128
	Orbital Lifetime (yrs)	1.1
	Probability of collision (1:X)	0.00000
Deployed	**Mean C/S Area (m^2)**	0.0289
	Area-to Mass (m^2/kg)	0.0134
	Orbital Lifetime (yrs)	1.0
	Probability of collision (1:X)	0.00000

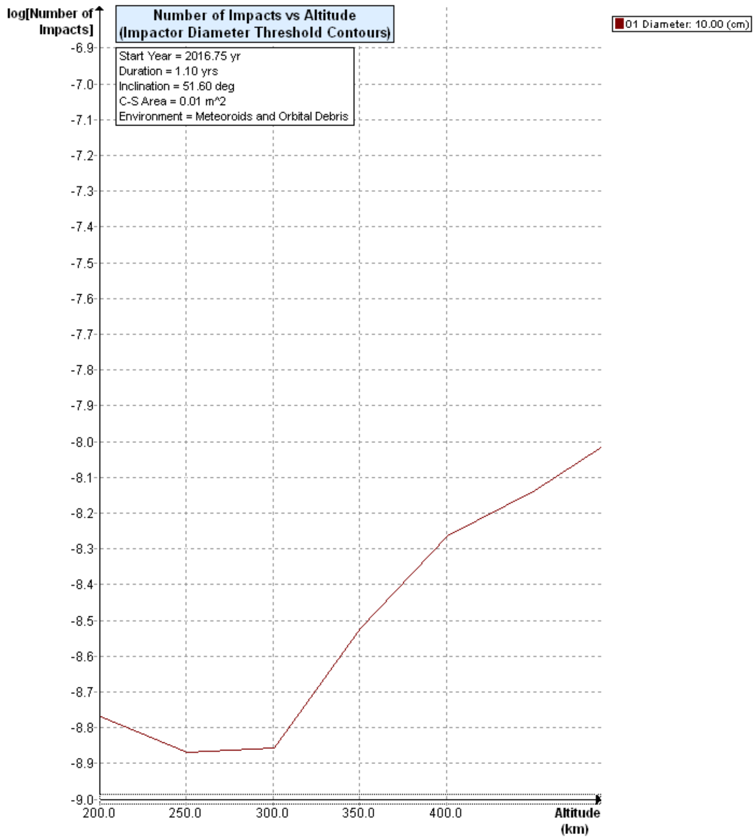

Figure 4: Orbit Collision vs. Altitude (CSUNSat1 Stowed)

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 the CSUNSat1 spacecraft collision with debris and meteoroids greater than 10 cm in diameter and capable of preventing post-mission disposal has been calculated to be less than 0x10^-5 probability of collision, for any configuration. This satisfies the 0.001 maximum probability requirement 4.5-1.

Since the CubeSat 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 CSUNSat1 to be compliant. Requirement 4.5-2 is not applicable to this mission.

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

The CSUNSat1 spacecraft will naturally decay from orbit within 1.0 years after being deployed, 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 of CSUNSat1, 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

$$\frac{0.0227\ m^2}{2.16\ kg} = \ 0.0128\frac{m^2}{kg}$$

CSUNSat1 results in the worst case orbital lifetime of 1.1 years. The assessment of the spacecraft illustrates they are compliant with Requirements 4.6-1 through 4.6-5.

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

DAS inputs are: 400 km maximum perigee 400 km maximum apogee altitudes with an inclination of 51.6 degrees at deployment from the ISS sometime after September of 2016. The area to mass ratio of 0.0128 m^2/kg was imputed for the CSUNSat1. DAS 2.0.2 yields a 1.1 years of orbit lifetime of CSUNSat1 in its stowed / non-deployed 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 [TBD] 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, where the risk to human casualty shall not exceed 1:10,000. There is not enough energy to cause a human casualty if the surviving reentry component has less than 15J.

1. Low melting temperature (less than 1000 °C) components are identified as materials that would not survive reentry and pose no risk to human casualty. This is confirmed through DAS analysis that showed materials with melting temperatures equal to or below that of copper (1080 °C) will always demise upon reentry for any size component up to the dimensions of a 1U CubeSat.

2. The remaining high temperature materials are shown to pose negligible risk to human casualty through a bounding DAS analysis of the highest temperature components, stainless steel (1500°C). If a component is of similar dimensions and has a melting temperature between 1000 °C and 1500°C, it can be expected to posses the same negligible risk as stainless steel components. See Table 4.

Table 4: ELaNa [TBD] High Temperature DAS Analysis

CubeSat	KickSat-2 High Temp Components	Mass (g)	Length / Diameter (mm)	Width (mm)	Height (mm)	Total Debris Casualty Area (m^2)	KE (J)	Probability
CSUNSAT1	ISIS Deployable Antenna Elements	10	1.5	120	5	0.39	0	1:0
CSUNSAT1	LiFePO4 Battery (contains Stainless Steel)	63	33	-	65	0.42	0	1:0

The majority of components demise upon reentry. The components that survive re-entry show 0 J of energy on impact. From the Debris Casualty Area and the deployment orbit, the probability of human casualty is calculated by DAS results in a 0 probability, satisfying the requirement (1/10,000).

Through the method described above, Table 4: ELaNa [TBD] High Temperature DAS Analysis, and the full component lists in the Appendix the KickSat-2 mission components are conservatively shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

ELaNa [TBD] will not be deploying any tethers.

ELaNa [TBD] satisfy, Section 8's requirement 4.8-1.

Section 9-14

ODAR sections 9 through 14 for the launch vehicle 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-C/Mr. Higginbotham
VA-G2/Mr. Poffenberger
SA-D2/Mr. Hale
SA-D2/Mr. Hidalgo
SA-D2/Mr. Hibshman
AIS-22/Ms. Nighswonger

Appendix Index:

Appendix A. ELaNa [TBD] Component List

CubeSat	Row Number	Name	External/Internal (Major/Minor Components)	QTY	Material	Body Type	Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	Melting Temp (°C)	Comment
CSUNSat1		CSUNSat1(Entire Assembly)	-	-	-	Assembly	2160	100	100	227	-	-
CSUNSat1	1	CubeSat Structure	External - Major	1	Aluminum 5052-H32, Stainless Steel	Box	254	100	100	227	Low Melting Temp	Demise
CSUNSat1	2	ISIS UHF Antenna (undeployed)	External - Major	1	Aluminum 6061	Box	100	98	98	7	Low Melting Temp	Demise
CSUNSat1	3	ISIS Deployable Antenna Elements	External - Major	4	NiTi Alloy	Strip metal	10	1.5	120	5	1981	See Table 4
CSUNSat1	4	Solar Panels	External - Major	4	Aluminum 6061	Panel	100	1.6	82	224	Low Melting Temp	Demise
CSUNSat1	5	Hot Shunt Regulator Board	External - Major	1	FR4/ Sn solder/Cu	Board	37	96	92	5	Low Melting Temp	Demise
CSUNSat1	6	Processor Board	Internal - Major	1	FR4/ Sn solder/Cu	Board	93	96	92	5	Low Melting Temp	Demise
CSUNSat1	7	Cold Shunt Regulator Board	Internal - Major	1	FR4/ Sn solder/Cu	Board	49	96	92	5	Low Melting Temp	Demise
CSUNSat1	8	Battery Control Board	Internal - Major	1	FR4/ Sn solder/Cu	Board	104	96	92	5	Low Melting Temp	Demise
CSUNSat1		Panasonic NCR18650B Battery	Internal - Minor	1	Li-ion	Cylinder	46	19		65	Low Melting Temp	Demise
CSUNSat1	9	Power Processing Unit 1	Internal - Major	1	FR4/ Sn solder/Cu	Board	77	96	92	5	Low Melting Temp	Demise
CSUNSat1	10	Power Processing Unit 2	Internal - Major	1	FR4/ Sn solder/Cu	Board	49	96	92	5	Low Melting Temp	Demise
CSUNSat1	11	Radio Beacon Board	Internal - Major	1	FR4/ Sn solder/Cu	Board	79	96	92	5	Low Melting Temp	Demise
CSUNSat1	12	RF Multiplexer Board	Internal - Major	1	FR4/ Sn solder/Cu	Board	106	96	92	5	Low Melting Temp	Demise
CSUNSat1	13	Pigtail Board	Internal - Major	1	FR4/ Sn solder/Cu	Board	50	96	92	5	Low Melting Temp	Demise
CSUNSat1	14	Payload Board	Internal - Major	1	FR4/ Sn solder/Cu	Board	50	96	92	5	Low Melting Temp	Demise
CSUNSat1		Battery	Internal - Major	1	LiFePO4/Stainless steel	Cylinder	75	26		65	1500	See Table 4
CSUNSat1		Supercapacitors	Internal - Major	2	1100 Aluminum	Cylinder	63	33		65	Low Melting Temp	Demise
CSUNSat1		Battery/Capacitor Clamp	Internal - Major	1	Aluminum	Box	315	10	10	5	Low Melting Temp	Demise
CSUNSat1	15	Standoffs, nuts, screws	Internal - Minor	mulitiple	Aluminum/ Copper	various	48	various	various	various	Low Melting Temp	Demise