March 10, 2015

Orbital Debris Assessment for
GEARRSII on the
AFSC5 Atlas 5 Mission

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. *P-POD Status SpX-3 Agreement History* (Orbital Information) , ISS_CM_019 Rev 01/2011
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. *UL Standard for Safety for Household and Commercial Batteries, UL 2054*. UL Standard. 2nd ed. Northbrook, IL, Underwriters Laboratories, 2005
I. Opiela, John. “RE: DAS 2.0 Orbital Lifetime Inquiry” April 5, 2013. E-mail.

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the GEARRSII mission. 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 launch vehicle compliance assessment and are not presented here.

The following table summarizes the compliance status of the Nano Racks GEARRSII auxiliary payload mission flown on Orbital 2. The CubeSat manifested, comprising the GEARRsII mission are fully compliant with all applicable requirements.

Table 1: Orbital Debris Requirement Compliance Matrix

Requirement	Compliance Assessment	Comments
4.3-1a	Compliant	Lifetime of debris is days
4.3-1b	Compliant	Lifetime of debris is days
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 0.2yrs
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 tether release

Section 1: Program Management and Mission Overview

The GEARRSII mission is sponsored by the AFRL at Kirkland Air Force Base. Program/project manager and senior scientific and management personnel are as follows:

GEARR: Jeff Dailey, Project Manager

Program Milestone Schedule	
Task	**Date**
GEARRSII kick off meeting	1/2015
CubeSat Build, Test, and Integration	1/2015
Enviromental Testing	1/2015
CubeSat Delivery/integration to CalPoly	1/29/2015
Launch	4/16/2014

Figure 1: Program Milestone Schedule

The GEARRSII mission will deploy from Atlas 5.

GEARRSII CubeSat size 10cm x 10cm x 30 cm, with mass of 2.8 kg total. The GEARRSII is designed and built by Near Space Launch Inc.

The GEARRSII will launch on the AFSC5 Atlas 5 rocket. The current launch date is April 16^{th} 2015 in an orbit approximately 700 X 300 km at inclination of 60.0 deg (ref. (c)).

Section 2: Spacecraft Description

GEARRSII is a CubeSat Mission.

	CubeSat Quantity	CubeSat size	CubeSat Names	CubeSat Masses (kg)
	1	3U (10 cm X 10 cm X 30 cm)	GEARR	2.8

The following subsection contain descriptions of GEARRSII CubeSat.

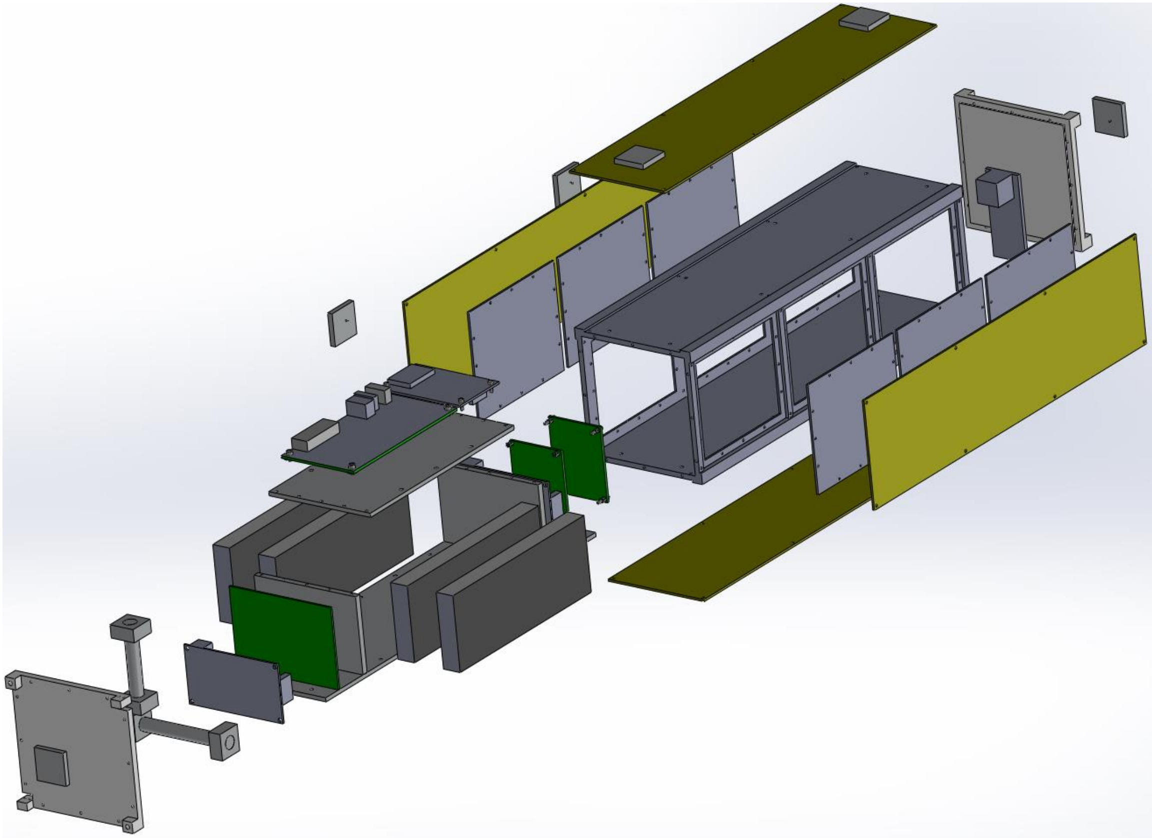

Figure 2: GEARRSII CubeSat Description

The primary mission of GEARRSII is to demonstrate a global Communications link to the GlobalStar network of satellites in orbit above us.

Once ejected from the atlas 5 power management comes online after 5 minutes. 30 minutes after ejection the GlobalStar communications link is powered on and system status data is transmitted. Once communications is verified and Instrument module power up and begins operation mode.

GEARRSII structure is made of 6061-T6 aluminum. Internal and external materials used are, standard electrical components, Printed circuit boards, Stainless steel hardware and solar cells. The GlobalStar radio uses a 25mm x 25mm ceramic patch antenna.

There are no hazardous materials used on GEARRSII.

The power system consists of Four Li-Poly batteries at 8.1V / 5500mA with a total power of 22Ah available to the system. A built in protection module on each pack for over/under charge and short circuit. The Li-Poly batteries carry the UL-listing number BBCV2.MH29381 and the protection circuit model 32005.

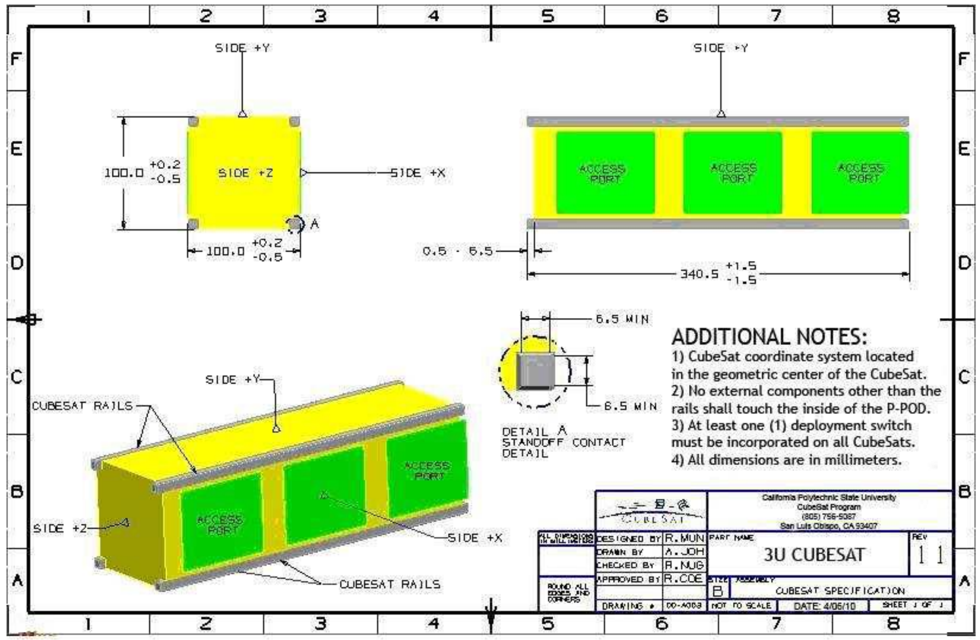

Figure 3: 3U CubeSat Specification

Section 3: Assessment of Spacecraft Debris Released during Normal Operations

Section 3 provides rationale/necessity for release of each object, time of release of each object relative to launch vehicle separation, release velocity of each object with respect to CubeSat, 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 GEARRSII mission therefore this section is not applicable.

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

Note: This entire section applies to GEARRSII mission.

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 0.9 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 GEARRSII 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.

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 4.4-2 shows that the GEARRSII is compliant. Requirements 4.4-3 and 4.4-4, addressing intentional break-ups are not applicable.

The following addresses requirement 4.4-2. The CubeSate not been designed to disconnect their onboard storage energy devices (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".

Table 2: GEARRSII CubeSat Cells

CubeSat	Technology	Manufactor	Model	UL Listing Number
GEARRSII	Lithium Polymer	YOKU Energy	Polypower 5500mAh	MH29381

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).

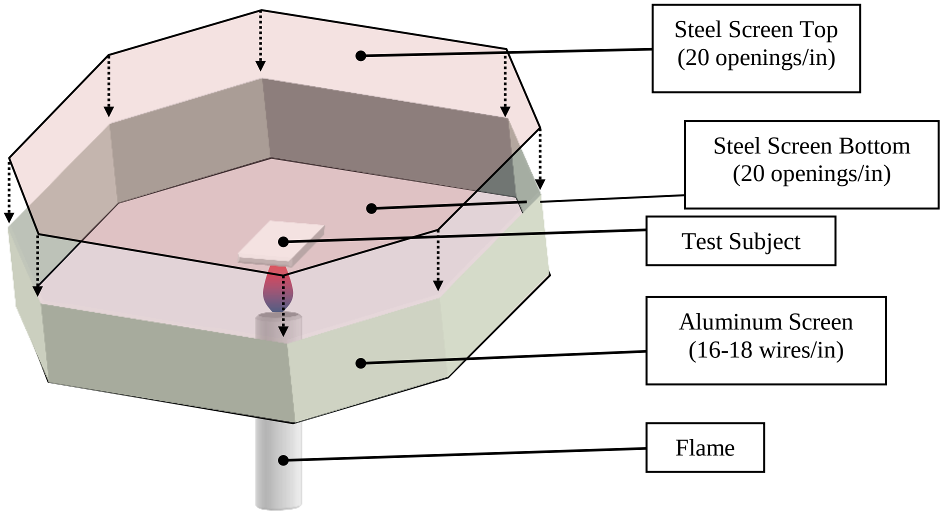

Figure 4: Underwriters Laboratory Explosion Test Apparatus

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.

Figure 5: GEARR 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 dimensions used in these calculations

The GEARRSII orbit at deployment is 700 km apogee altitude by 300 km perigee altitude, with an inclination of 60.0 degrees. With an area to mass (3.97 kg) ratio of 0.0346 m^2/kg, DAS yields 0.1 years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability. Orbital lifetime GEARR will see an average of $10^{-9.2}$ probability of collision. Table 4 below provides complete results.

Table 3: CubeSat Orbital Lifetime & Collision Probability

	CubeSat			**GEARRSII**		
	Mass			2.8		
Stowed	**Mean C/S Area (m^2)**			0.0214		
	Area-to Mass (m^2/kg)			0.0076		
	Orbital Lifetime (yrs)			0.2		
	Probability of collision (10^X)			-9.7		
Deployed	**Mean C/S Area (m^2)**			0.0277		
	Area-to Mass (m^2/kg)			0.0099		
	Orbital Lifetime (yrs)			0.1		
	Probability of collision (10^X)			-9.4		

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 GEARRSII spacecraft collision with debris and meteoroids greater than 10 cm in diameter and capable of preventing post-mission disposal is less than $10^{-8.4}$, for any configuration. This satisfies the 0.001 (10^{-6}) 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 GEARRSII to be compliant. Requirement 4.5-2 is not applicable to this mission.

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

GEARRSII 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 GEARRSII in its configuration as the worst case. The area-to-mass is calculated for is as follows:

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

Equation 3: Area to Mass

$$\frac{0.0214m^2}{2.8\,kg} = 0.0076\frac{m^2}{kg}$$

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

DAS inputs are: 700 km maximum perigee X 300 km maximum apogee altitudes with an inclination of 60.0 degrees at deployment in the year 2014. An area to mass ratio of 0.0076 m^2/kg for the GEARRSII CubeSat was imputed. DAS 2.0.2 yields a 0.2 year orbit lifetime for GEARRSII.

This meets requirement 4.6-1. For the complete list of CubeSat orbital lifetimes.

Assessment results show compliance.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on GEARRSII 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.

The remaining high temperature materials are shown to meet the human casualty requirement through a bounding DAS analysis of the highest temperature components, generally stainless steel (1500°C). A component of similar dimensions and possessing a melting temperature between 1000 °C and 1500°C, can be expected to posses as negligible risk similar to stainless steel components. Probability of human casualty was calculated if a component exceeded 15J of energy upon reentry. See

2. Table 4.

GEARRSII CubeSat comply with Requirement 4.7-1, to have less than 1:10,000 risk of human casualty.

As documented in,

Table 4: GEARRSII Survivability DAS Analysis, and Appendix A-E, mission are conservatively shown to be in compliance with Requirement 4.7-1 of NASA-STD-

8719.14A.

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

Table 4: GEARRSII Survivability DAS Analysis

CubeSat	Stainless Steel Components	Mass (g)	Length / Diameter (cm)	Widt h (cm)	Height (cm)		Demise Alt (km)	KE (J)
GEARRSII	Sep Switches	8.0	0.45	1.05	0.00		76.4	0
GEARRSII	Spring Plungers	2.0	0.35	1.50	0.00		76.5	0
GEARRSII	Motor / Gearhead	25.0	0.80	4.00	0.00		71.4	0
GEARRSII	Fasteners / Spacers	45.0	0.00	0.00	0.00		78	0
GEARRSII	GlobalStar Patch Antenna	10.0	2.50	2.50	0.20		0	3

Note: Components are modeled as stainless steel unless otherwise noted in component name.

Section 8: Assessment for Tether Missions

GEARRSII will not be deploying any tethers.

GEARRSII satisfy 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.

Appendix Index:

Appendix A. Component List for: GEARRSII

CubeSat	Row Number	Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	Low Melting	Melting Temp (C)	Comment
GEARR SII	1	GEARR									Yes		Demises
GEARR SII	2	External Structure	External - Major	1	Aluminum 6061	Box	350	100	100	227	Yes		Demises
GEARR SII	3	GlobalStar Patch Antenna	External - Major	1	Ceramic	Square	10	25	25	2	No	1400	Compliant (3J)
GEARR SII	4	Solar Panels	External - Major	4	Fiberglass	Panel	352	82	199	2.5	Yes		Demises
GEARR SII	5	Sep Switches	External - Minor	2	Steel / Gold	Round	8	4.5	10.5		No	1500	Demises
GEARR SII	6	Plasma Probe	External - Minor	1	Fiberglass / Copper / Gold	Square	7.5	45	45	3	Yes		Demises
GEARR SII	7	Spring Plungers	External - Minor	2	Steel / Stainless Steel	Round	2	3.5	15		No	1500	Demises
GEARR SII	10	End Plales	External - Major	2	Aluminum 6061	Square	150	100	100	2	Yes		Demises
GEARR SII	11	Batteries	Internal - Major	6	Aluminum Foil / Plastic / Lithium	Square	750	50	100	13	Yes		Demises
GEARR SII	13	Comm Board	Internal - Minor	1	Fiberglass / Copper	Square	45	61	82	1.7	Yes		Demises
GEARR SII	14	GlobalStar Board	Internal - Minor	1	Fiberglass / Copper	Square	60	61	82	1.7	Yes		Demises
GEARR SII	15	Power Management Board	Internal - Minor	1	Fiberglass / Copper	Square	125	61	140	1.7	Yes		Demises
GEARR SII	16	Instrument Microcontroller Baord	Internal - Minor	1	Fiberglass / Copper	Square	45	61	82	1.7	Yes		Demises
GEARR SII	27	Instrument Baord	Internal - Minor	1	Fiberglass / Copper	Square	50	61	82	1.7	Yes		Demises

GEARR SII	20	EMI Shield	Internal - Major	1	Aluminum 6061	Square	50	90	90	2	Yes		Demises
GEARR SII	21	Magnotometer	Internal - Minor	1	Fiberglass / Copper	Square	27	42	52	20	Yes		Demises
GEARR SII	22	Fasteners / Spacers	Internal - Minor		Stainless Steel / Aluminum		45				No	1500	Demises
GEARR SII	23	Cabling	Internal - Minor		Copper alloy		50				Yes		Demises
GEARR SII	24	Damping	Iternal - Minor		MU-Metal	Rod	40	10	75		Yes		Demises