ELVL-2015-0044145
September 28, 2015

Orbital Debris Assessment for KickSat-2 Mission per NASA-STD 8719.14A

Signature Page

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ELVL-2015-0044145

Reply to Attn of: VA-H1

September 28, 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 KickSat-2 Mission

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
G. Email, "RE: KickSat-2" Jer-Chyi Liou to Scott Higginbotham, August 3, 2015

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the KickSat-2 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 KickSat-2 auxiliary payload mission flown on the OA-6, inside the Orbital Sciences Cygnus vehicle. The KickSat-2 CubeSat is fully compliant with all applicable requirements.

Table 1: Orbital Debris Requirement Compliance Matrix

Requirement	Compliance Assessment	Comments
4.3-1a	Compliant	Sprites will have lifetime of 2-6 days
4.3-1b	Compliant	Object-time product is < 2.5 years
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 0.8 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 KickSat-2 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:

KickSat-2: Zack Manchester, Principle Investigator;

Program Milestone Schedule	
Task	**Date**
CubeSat Selection	6/22/2015
CubeSat Delivery to NanoRacks	12/8/15
CubeSat Integration into NanoRacks CubeSat Dispenser (NRCSD)	12/9/15
Launch	3/10/16

Figure 1: Program Milestone Schedule

The KickSat-2 mission will be launched as a payload of the Cygnus resupply vehicle on the OA-6 mission on an Atlas V launch vehicle from CCAFS, Fl. The CubeSat slotted position is identified in Table 2: KickSat CubeSats and in the Appendix. The current launch date is in 3/10/2016. KickSat-2 will be deployed from a NRCSD dispenser from the ISS, placing the CubeSats in an orbit approximately 410 X 400 km at inclination of 51.6 deg (ref. (c)).

KickSat-2 is in a 3U form factor of 10 cm x 10cm x 30 cm, with mass of 2.256kg.

Section 2: Spacecraft Description

The primary CubeSat will be deployed out of an individual dispenser, as shown in Table 2: KickSat CubeSats below.

Table 2: KickSat CubeSats

Dispenser Slot	CubeSat Quantity	CubeSat size	CubeSat Names	CubeSat Masses (kg)
A	1	3U (10 cm X 10 cm X 30 cm)	KickSat-2	2.256

KickSat-2 CubeSat Description

Cornell University – 3U

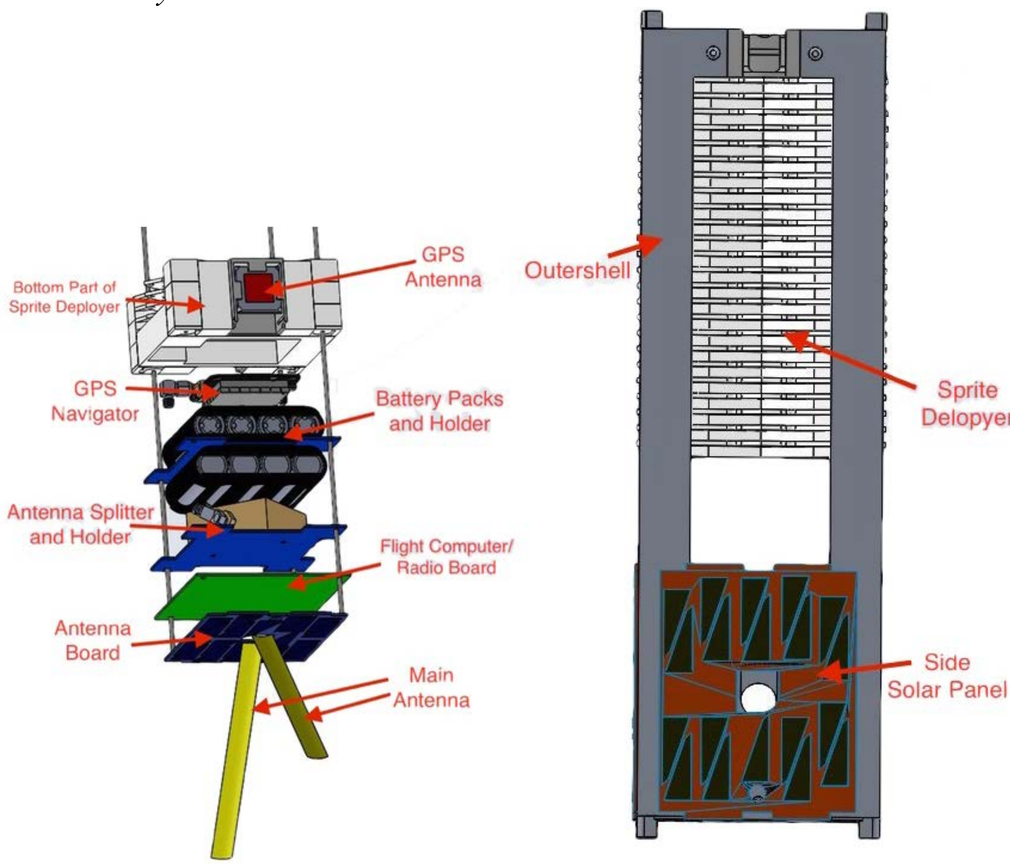

Figure 2: KickSat-2 Expanded View

KickSat-2 is a technology demonstration mission for the Sprite centimeter-scale "ChipSat" developed at Cornell University. The Sprite is a 3.5-by-3.5 centimeter printed circuit board spacecraft that is capable of collecting and processing sensor measurements and communicating directly with ground stations. KickSat-2 is designed to deploy 100 Sprites in low-Earth orbit. The primary mission objective is to demonstrate the Sprite's CDMA communication architecture.

Upon deployment from the PPOD, KickSat-2 will power up and start a countdown timer. After 45 minutes, a dipole antenna will be deployed and a UHF beacon will be activated. An onboard GPS receiver will be used to perform orbit determination. Once the spacecraft's orbital altitude has decayed to 325 km, Sprite deployment will be triggered by a command from Cornell's ground station.

The primary CubeSat structure is made of 5052-H32 aluminum. The majority of its internal components are made of 6061 aluminum, ABS plastic, and FR4 printed circuit boards. There are few steel components (fasteners, deployment spring). There are no pressure vessels, hazardous or exotic materials. The electrical power storage system consists of common lithium-ion batteries with over-charge/current protection circuitry. The lithium batteries carry the UL-listing number MH19896.

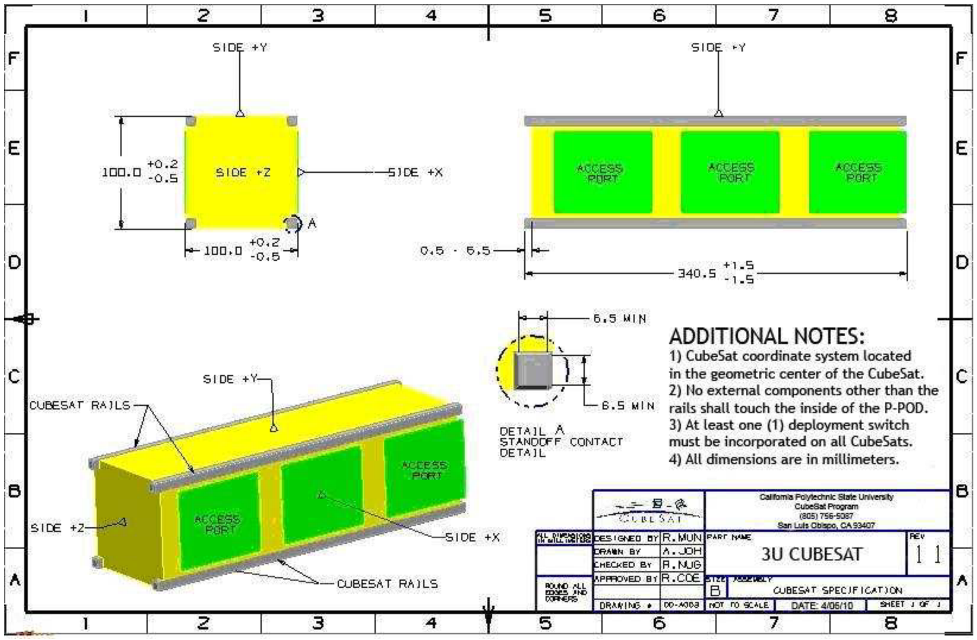

Figure 3: 3U CubeSat Specification

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.

KickSat-2 will be releasing 100 "Sprites" as part of its primary mission to provide a technology demonstration for the use of CDMA communications across multiple vehicles to one ground station.

After being deployed from the ISS, KickSat-2 will wait 45 minutes before deploying its primary antenna and activating its radio beacon. The spacecraft will then calculate its orbital position and velocity and set its real-time clock using the onboard GPS receiver. It is expected that contact will be established with either Cornell's ground station or partner ground stations within the spacecraft's first few orbits.

After performing checkout operations, the spacecraft will be put into a power-safe mode with its radio beacon transmitting at regular intervals. Orbital elements will be propagated by the flight computer and updated using the onboard GPS receiver once per day. KickSat's orbit will be allowed to decay until an altitude of 325 km is reached. Simulations, performed by the project, indicate that this will take several months given the current altitude of the ISS.

Once the target altitude of 325 km has been reached, the Sprites will be deployed. The Sprite deployer contains 100 Sprites stacked 2-by-2 in four columns. Each Sprite is housed in an individual slot and constrained by a carbon fiber rod that runs the length of each column and passes through a hole in the corner of the Sprites. The nitinol wire antennas on the Sprites are coiled in such a way that they act as springs, pushing the Sprites out of their slots. When the carbon fiber rod is removed, the Sprites' antennas will push them from the deployer housing with an estimated ΔV of 5-10 cm/sec.

The Sprites are expected to have an orbital lifetime of approximately 5 days before reentry under typical atmospheric conditions. Bounding test cases with extremely high and extremely low atmospheric density give a range of orbital lifetimes between approximately 2 and 14 days (Figure 4). DAS simulations reflect this sprite orbital lifetime.

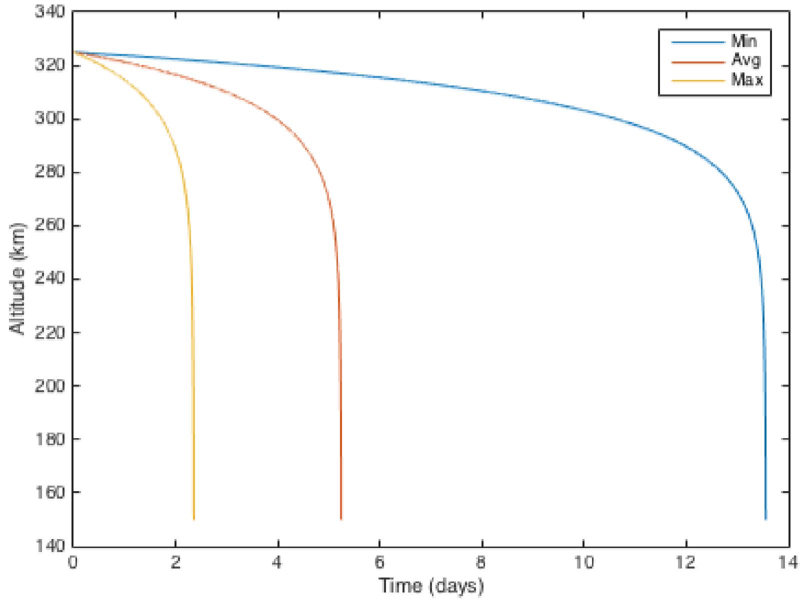

Figure 4: KickSat-2 Provided Sprite Orbital Lifetime

The short orbital lifetime of the Sprites satisfies the Requirements 4.3-1. Total object-time of the 100 sprites (worst-case 6 day orbit lifetime) and KickSat-2 deployed structure (0.7 years) is summed to be 2.34 years, which satisfies the Requirement 4.3-2.

The release of the Sprite's from KickSat-2 has been pre-coordinated with the NASA Orbital Debris Planning Office.

J.C. Liou replied to a question by Scott Higginbotham (ELaNa Mission Manager) on August 3, 2015:

> "For KickSat-2, releasing 100 Sprites from 325 km altitude has no long-term negative impact to the environment. The ODPO is fine with the plan."
> (ref (g))

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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 KickSat-2 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 0.8 years maximum the KickSat-2 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

KickSat-2 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

KickSat-2 orbit at deployment is 400 km perigee altitude by 4106 km apogee altitude, with an inclination of 51.6 degrees. With an area to mass (2.256 kg) ratio of 0.0.0166 m^2/kg, DAS yields 0.8 years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability. KickSat-2 sees less than 0x10^-5 probability of collision. Table 4 below provides complete results, a Sprite has been included for comparison.

Table 3: CubeSat Orbital Lifetime & Collision Probability

		KickSat-2	Sprite*
	Mass (kg)	2.2562	0.0051
Stowed	**Mean C/S Area (m^2)**	0.0375	n/a
	Area-to Mass (m^2/kg)	0.0166	n/a
	Orbital Lifetime (yrs)	0.8	n/a
	Probability of collision (1:X)	0.00000	n/a
Deployed	**Mean C/S Area (m^2)**	0.0409	0.00067375
	Area-to Mass (m^2/kg)	0.0181	0.132107843
	Orbital Lifetime (yrs)	0.7	~2-4 days
	Probability of collision (1:X)	0.00000	0.00000

* Sprite is being deployed from KickSat-2 at 325km circular orbit

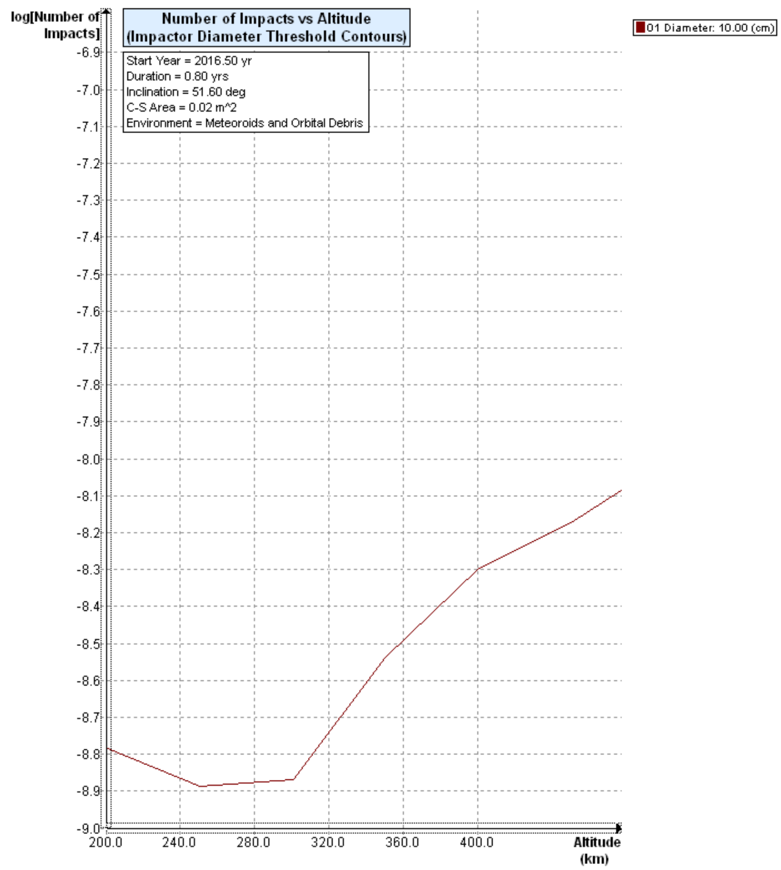

Figure 5: Orbit Collision vs. Altitude (KickSat-2 Failure to Deploy)

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 KickSat-2 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 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 KickSat-2 to be compliant. Requirement 4.5-2 is not applicable to this mission.

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

The KickSat-2 spacecraft will naturally decay from orbit within 0.8 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 KickSat-2, in its stowed configuration as the worst case. The area-to-mass is calculated for is 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

$$\frac{0.0375\ m^2}{2.26\ kg} = 0.0166\frac{m^2}{kg}$$

KickSat-2 results in the worst case orbital lifetime of 0.8 years. The assessment of the spacecraft illustrates they are compliant with Requirements 4.6-1 through 4.6-5.

DAS 2.0.2 Orbital Lifetime Calculations:

DAS inputs are: 400 km maximum perigee 410 km maximum apogee altitudes with an inclination of 51.6 degrees at deployment from the ISS after March of 2016. The area to mass ratio of 0.0166 m^2/kg was imputed for the KickSat-2. DAS 2.0.2 yields a 0.8 years of orbit lifetime of KickSat-2 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 KickSat-2 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: KickSat-2 High Temperature DAS Analysis

CubeSat	KickSat-2 High Temp Components	Mass (g)	Length / Diameter (mm)	Width (mm)	Height (mm)	Demise Alt (km)	KE (J)	Probability
KickSat-2	Threaded Rods	14	3	3	320	76	0	0
KickSat-2	Sprite Deployer Spring	22.9	63	63	199	0	0.51	0
KickSat-2	Antenna	2.1	12.7	170	0.15	0	0.84	0
KickSat-2	Fasteners	3	-	-	-	74.8	0	0

The majority of high temperature components demise upon reentry. The components that survive re-entry show < 1J 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: KickSat-2 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

KickSat-2 will not be deploying any tethers.

KickSat-2 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. KickSat-2 Component List

Name	External/Internal (Major/Minor Components)	QTY	Material	Body Type	Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	Low Temperature	Melting Temp (°C)	Comment
CubeSat Name	KickSat	-	-	-	-	-	-	-	-	-	Demise on reentry
CubeSat Structure	External - Major	1	Aluminum 5052-H32	Box	477.3	100	100	340.5	yes	-	Demise on reentry
Threded Rods	Internal - Major	4	Steel	Cylinder	14	3	3	320	no	1500	Demise on reentry, see Table 4
Sprite Deployer Housing	Internal - Major	1	ABS Plastic	Box	206.5	96	96	201	yes	-	Demise on reentry
Sprite Deployer Pusher	Internal - Major	1	ABS Plastic	Box	59	102	102	15	yes	-	Demise on reentry
Sprite Deployer Spring	Internal - Major	1	Steel	Cylinder	22.9	63	63	199	no	1500	Survives reentry with 0J, see Table 4
Sprite ChipSat	Internal - Major	100	FR4 PCB	Flat Plate	5.1	35	35	1.75	yes	-	Demise on reentry
Antenna	External - Major	2	Steel	Flat Plate	2.1	12.7	170	0.15	no	1500	Survives reentry with 0J, see Table 4
GPS Antenna	External - Minor	2	Aluminum	Box	18.2	27	27	9.3	yes	-	Demise on reentry
RF Divider	Internal - Minor	1	Aluminum	Box	114	50.5	50.5	19.1	yes	-	Demise on reentry
Solar Cells	External - Major	100	Gallium Arsenide	Flat Plate	0.26	31.8	12.9	0.15	yes	-	Demise on reentry
Magnetorquer/Solar Panel Boards	External - Major	6	FR4 PCB	Flat Plate	33.9	104.8	82.6	2.5	yes	-	Demise on reentry
Batteries	Internal - Major	8	Lithium Ion	Cylinder	46.3	19.1	19.1	61.9	yes	-	Demise on reentry
Flight Computer/Radio Board	Internal - Major	1	FR4 PCB	Flat Plate	46.6	80	80	2.5	yes	-	Demise on reentry
GPS Board	Internal - Major	1	FR4 PCB	Box	31.6	52.9	52.9	12.8	yes	-	Demise on reentry
Battery Mount	Internal - Major	1	6061 Aluminum	Flat Plate	37.9	88.5	93.25	0.65	yes	-	Demise on reentry
Fasteners	Internal - Minor	18	Stainless Steel	Cylinder	3				no	1450	Demise on reentry, see Table 4
Cabling	Internal - Minor		Copper Alloy	-	18.7	-	-	-	yes	-	Demise on reentry
Loctite 222 Threadlocker	Internal - Minor	1	Acrylic	-	-	-	-	-	yes	-	Demise on reentry