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Orbital Debris Assessment for the HuskySat-I Mission per NASA-STD 8719.14A

Signature Page

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Reply to Attn of: VA-H1

April 9, 2019

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

FROM: Yusef Johnson, a.i. solutions/KSC/AIS2

SUBJECT: Orbital Debris Assessment Report (ODAR) for the HuskySat-I CubeSat

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. International Space Station Reference Trajectory, delivered May 2017
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
I. HQ OSMA Email:6U CubeSat Battery Non Passivation Suzanne Aleman to Justin Treptow, 8 August 2017

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for theHuskySat-I CubeSat, which will be deployed from a Cygnus spacecraft, post-ISS departure. 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.

RECORD OF REVISIONS		
REV	**DESCRIPTION**	**DATE**
0	Original submission	April 2019

The following table summarizes the compliance status of the HuskySat-I CubeSat to be deployed from the Cygnus spacecraft, post-ISS departure. HuskySat-I 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 3.5 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 for HuskySat-I

Section 1: Program Management and Mission Overview

HuskySat-I is sponsored by the Human Exploration and Operations Mission Directorate at NASA Headquarters. The Program Executive is John Guidi. Responsible program/project manager and senior scientific and management personnel are as follows:

HuskySat-I: Dr. Robert Winglee, Principal Investigator, University of Washington

Program Milestone Schedule	
Task	**Date**
CubeSat Selection	October 30th, 2018
Delivery to Nanoracks	August 1st, 2019
Launch	October 19th, 2019
Deployment	NET January 2020

Figure 1: Program Milestone Schedule

HuskySat-I will be launched as a payload on the Antares launch vehicle executing the NG-12 mission. HuskySat-I will be deployed from the Cygnus spacecraft post-ISS departure.

HuskySat-I weighs approximately 3.7 kg.

Section 2: Spacecraft Description

Table 2: outline the generic attributes of the spacecraft.

Table 2: HuskySat-I Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Masses (kg)
HuskySat-I	1	340.5 x 102 x 102	3.67

The following pages describe the HuskySat-I CubeSat.

HuskySat-I– University of Washington – 3U

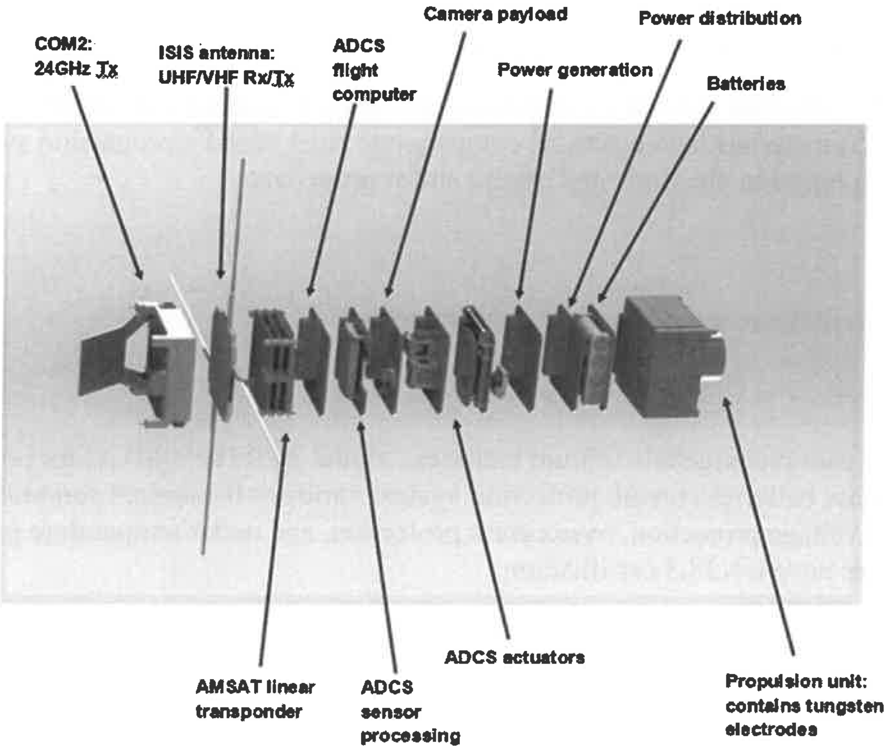

Figure 2: HuskySat-I exploded view

Overview

The HuskySat-I is a 3U CubeSat being developed by the University of Washington (UW). The two primary scientific payloads are a pulsed plasma thruster propulsion system and a software defined high frequency downlink system. In addition to these scientific payloads, the HuskySat-I is carrying an AMSAT radio. This mission is being licensed under part 5 with the FCC, and it is intended that once the University of Washington has completed its mission objectives, AMSAT will license the HuskySat under part 97.

CONOPS

After deployment from the Cygnus, the power distribution board will turn on as well as the COM1 communication system. After waiting 30min, the ISIS antenna will be deployed, and the beacon will begin. Beaconing consists of 10s transmissions every 2min at transmit level of 20dBm. Once contact is made with the ground station spacecraft health checkout will begin. After the state is known, if no anomalies are detected, normal operations will begin. Normal operations will consist of the pulsed plasma thruster, COM2 operation, and camera operation. After completing these objectives, the

HuskySat-I will be re-commissioned by AMSAT and will continue operating as an amateur radio repeater satellite until the satellite burns up in the atmosphere.

Materials

The CubeSat structure is made of aluminum. It contains standard commercial off the shelf (COTS) materials, and electrical components. HuskySat-I's propulsion system consists of a tungsten electrode and a solid sulfur propellant.

Hazards

There are no pressure vessels or hazardous materials.

Batteries

HuskySat-I uses rechargeable lithium batteries (Model APR18650M1A) for power storage. These batteries contain protection against various off-nominal conditions such as over/under voltage protection, overcurrent protection, and under temperature protection. The batteries have UN38.3 certification.

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.

Since there are no releases are planned for HuskySat-I, 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 HuskySat-I 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))

Limitations in space and mass prevent the inclusion of the necessary resources to disconnect the battery or the solar arrays at EOM. However, the low charges and small battery cells on the CubeSat's power system prevents a catastrophic failure, so that passivation at EOM is not necessary to prevent an explosion or deflagration large enough to release orbital debris.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum CubeSat lifetime of 3.5 years maximum, HuskySat-I 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.

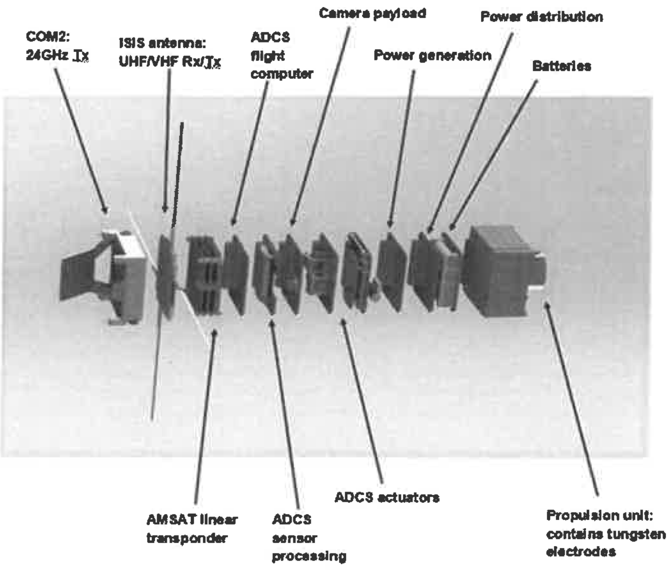

Figure 4: HuskySat-I Expanded View

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

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

The CubeSat evaluated for this ODAR are stowed in a convex configuration, indicating there are no elements of the CubeSat obscuring another element of the same CubeSat from view. Thus, the mean CSA for the stowed CubeSat was calculated using Equation 1. This configuration renders the longest orbital life times for all CubeSat.

Once a CubeSat has been ejected from the CubeSat dispenser 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 HuskySat-I (3.67 kg) orbit at deployment will be 500 km circular at a 51.6° inclination. With an area to mass ratio of 0.0083 m^2/kg, DAS yields ~3.5 years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability.

HuskySat-I is calculated to have a probability of collision of 0.0. Table 3 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.

	CubeSat	**HuskySat-I**
	Mass (kg)	3.67
Stowed*	Mean C/S Area (m^2)	0.0295
	Area-to Mass (m^2/kg)	.00803
	Orbital Lifetime (yrs)	**3.5**
	Probability of collision (10^X)	**0.0000**

Solar Flux Table Dated 12/18/2018

*Antennae area is negligible with respect to orbital lifetime calculations

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of HuskySat-I colliding 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.

HuskySat-I has no capability nor have plans for end-of-mission disposal, therefore requirement 4.5-2 is not applicable.

Assessment of spacecraft compliance with Requirements 4.5-1 shows HuskySat-I to be compliant. Requirement 4.5-2 is not applicable to this mission.

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

HuskySat-I 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 post-mission 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 disposa finds HuskySat-I in its stowed configuration as the worst case. The area-to-mass is calculated for is as follows:

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

Equation 3: Area to Mass

$$\frac{0.0295\ m^2}{3.67\ kg} = 0.008\frac{m^2}{kg}$$

The assessment of the spacecraft illustrates HuskySat-I are compliant with Requirements 4.6-1 through 4.6-5.

DAS 2.1.1 Orbital Lifetime Calculations:
DAS inputs are: 500 km circular orbit with an inclination of 51.6° at deployment no earlier than January 2020. An area to mass ratio of ~0.008 m^2/kg for the HuskySat-I CubeSat was used. DAS 2.1.1 yields a 3.5 years orbit lifetime for HuskySat-I 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 of HuskySat-I was performed. The assessment used DAS 2.1.1, 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 possess the same negligible risk as stainless steel components.

Table 4: HuskySat-I High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
PPT anode	Tungsten	.014	0	6
PPT electrode	Tungsten	.0001	0	0
Fasteners	Stainless Steel 18-8	.130	77.6	-

The majority of stainless steel components demise upon reentry and HuskySat-I complies with the 1:10,000 probability of Human Casualty Requirement 4.7-1. A breakdown of the determined probabilities follows:

Table 5: Requirement 4.7-1 Compliance for HuskySat-I

Name	Status	Risk of Human Casualty
HuskySat-I	Compliant	1:0

*Requirement 4.7-1 Probability of Human Casualty > 1:10,000

If a component survives to the ground but has less than 15 Joules of kinetic energy, it is not included in the Debris Casualty Area that inputs into the Probability of Human Casualty calculation. This is why HuskySat-I has a 1:0 probability as none of its components have more than 15J of energy.

HuskySat-I is shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

HuskySat-I will not be deploying any tethers.

HuskySat-I satisfies Section 8's requirement 4.8-1.

Section 9-14

ODAR sections 9 through 14 pertain to the launch vehicle, and are not covered here. Launch vehicle sections of the ODAR are the responsibility of the CRS provider.

If you have any questions, please contact the undersigned at 321-867-2098.

/original signed by/

Yusef A. Johnson
Flight Design Analyst
a.i. solutions/KSC/AIS2

cc: VA-H/Mr. Carney
VA-H1/Mr. Beaver
VA-H1/Mr. Haddox
VA-C/Mr. Higginbotham
VA-C/Mrs. Nufer
VA-G2/Mr. Treptow
SA-D2/Mr. Frattin
SA-D2/Mr. Hale
SA-D2/Mr. Henry
Analex-3/Mr. Davis
Analex-22/Ms. Ramos

Appendix Index:

Appendix A. HuksySat-1 Component List:

Appendix A. HuskySat-I Component List

Item Number	Name	Qty	Material	Body Type	Mass (g) (total)	Diameter / Width (mm)	Length (mm)	Height (mm)	High Temp	Melting Temp (F°)	Survivability
-	HuskySat-I	-	-	Box	3673	340.5	100	100	-	-	-
1	PPT anode	1	Tungsten	cylinder	14	4.8	40	-	Yes	6191°	0 km
2	PPT electrode	1	Tungsten	cylinder	0.1	1.5	3.5	-	Yes	6191°	0 km
3	CubeSat Structure	1	Aluminum 7075	Box	470	102	226	102	No	-	Demise
4	Propulsion Module	1	Aluminum 7075	Box	665	104	104	82	No	-	Demise
5	Battery Board	1	lithium batteries	Multiple Board Assembly	230	90	90	26	No	-	Demise
6	COM2 Module	1	Aluminum 7075	Box	426	90	90	49	No	-	Demise
7	COM1 antenna	1	Aluminum	Box	89	100	100	6	No	-	Demise
8	Solar Panels	3	FR4	Panel	243	82	277	3	No	-	Demise
9	AMSAT linear transponder	1	FR4	Board Stack Assembly	177	90	92.5	21	No	-	Demise
10	Battery Board	1	lithium batteries	Multiple Board Assembly	230	90	90	26	No	-	Demise
11	Power Generation Board	1	FR4	Board	48	90	90	10	No	-	Demise
12	Power Distribution Board	1	FR4	Board	53	90	90	10	No	-	Demise
13	Camera Board	1	FR4	Multiple Board Assembly	103	90	90	15	No	-	Demise
14	COM2 Module	1	Aluminum 7075	Box	480	90	90	49	No	-	Demise
15	ADCS Flight Computer	1	-	-	48	90	90	10	No	-	Demise
16	ADCS Sensor Board	1	-	-	81	90	90	10	No	-	Demise
17	ADCS Actuators	1	Copper	-	150	90	90	35	No	-	Demise
18	Fasteners	1	Stainless 18-8	Cylinder	130	#4 or #2	<3"	-	Yes	2500°	Demise
19	Cabling	1	Copper	-	50	<12ga	-	-	No	-	Demise