ELVL-2019-0045524
April 11, 2019

Orbital Debris Assessment for the SwampSat II Mission per NASA-STD 8719.14A

Signature Page

Yusef Johnson, Analyst, a.i. solutions, AIS2

Scott Higginbotham, Mission Manager, NASA KSC VA-C

National Aeronautics and
Space Administration

John F. Kennedy Space Center, Florida
Kennedy Space Center, FL 32899

ELVL-2019-0042254

Reply to Attn of: VA-H1

April 11, 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 SwampSat II 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 the SwampSat II 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 SwampSat II CubeSat to be deployed from the Cygnus spacecraft. SwampSat II 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 3.63 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 SwampSat II

Section 1: Program Management and Mission Overview

SwampSat II 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:

SwampSat II: Norman Fitz-Coy, Principal Investigator, University of Florida

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

Figure 1: Program Milestone Schedule

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

SwampSat II weighs approximately 3.72 kg.

Section 2: Spacecraft Description

Table 2: outlines the generic attributes of the spacecraft.

Table 2: SwampSat II Attributes

CubeSat Names	CubeSat Quantity	CubeSat size (mm^3)	CubeSat Masses (kg)
SwampSat II	1	340.5 x 100 x 100	3.72

The following pages describe the SwampSat II CubeSat.

SwampSat II – University of Florida – 3U

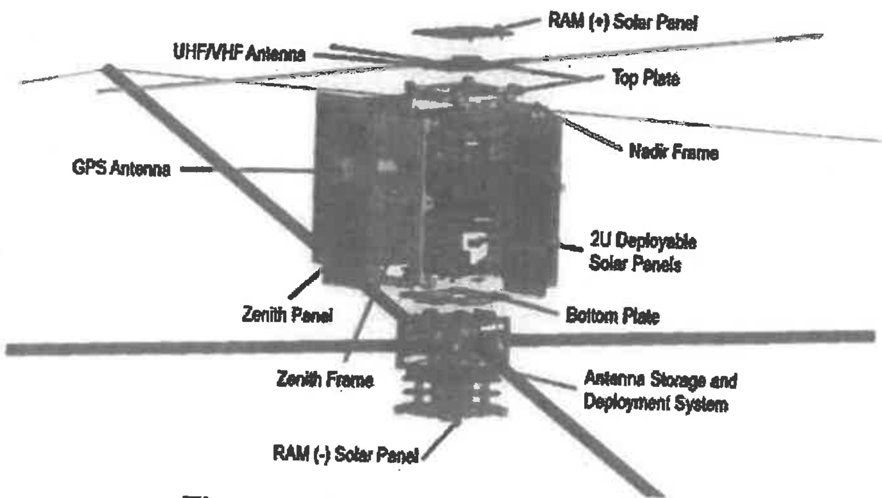

Figure 2: SwampSat II exploded view

Overview

SwampSat-II is a 3U CubeSat designed to characterize very low frequency (VLF) wave propagation in the upper ionosphere. There exists a limited number of VLF experiments to date and most measurements are 20-30 dB lower than existing models predict. The objective of this mission is to provide additional experimental measurements of narrowband VLF transmitter signals and lightning-generated VLF sferics in low Earth orbit.

CONOPS

After ejection from the deployment container, SwampSat-II will power up and perform health checks. After 30 minutes, the satellite will deploy the UHF/VHF antennas, beacon housekeeping telemetry, and begin to detumble. After detumble, the solar panels and the magnetometer will be deployed. Once the checkouts of the satellite are completed, the payload antenna will be deployed and the science mission will begin, continuing for at least one year.

Materials

The CubeSat structure is made of Aluminum 7075-T6. It contains commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells. The payload includes carbon fiber booms, a copper wire element, and a VLF receiver board. All materials and/or components are appropriate for space application.

Hazards

There are no pressure vessels, hazardous, or exotic materials.

Batteries

The electrical power storage system consists of common lithium polymer batteries with over-charge/current protection circuitry. The lithium polymer batteries carry the UL-listing number 1642.

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 for SwampSat II, 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 SwampSat II 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 3.72 years maximum, SwampSat II 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.

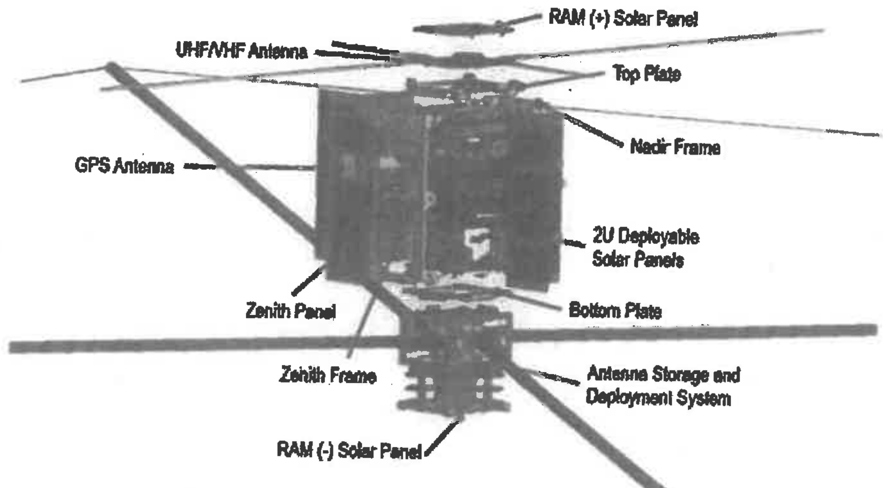

Figure 4: SwampSat II Expanded View

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

Equation 1: Mean Cross Sectional Area for Convex Objects

$$\textbf{Mean CSA} = \frac{(A_{max} + A_1 + A_1)}{2}$$

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 SwampSat II (3.72) orbit at deployment will be 500 km circular at a 51.6° inclination. With an area to mass ratio of 0.00726 m^2/kg, DAS yields approximately 3.63 years for orbit lifetime for its stowed state, which in turn is used to obtain the collision probability. SwampSat II 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	SwampSat II
	Mass (kg)	3.72
Stowed	Mean C/S Area (m^2)	0.027
	Area-to Mass (m^2/kg)	0.007
	Orbital Lifetime (yrs)	3.6
	Probability of collision (10^X)	0.0000
Deployed	Mean C/S Area (m^2)	0.137
	Area-to Mass (m^2/kg)	0.038
	Orbital Lifetime (yrs)	1.7
	Probability of collision (10^X)	0.0000

Solar Flux Table Dated
12/18/2018

Table 3: CubeSat Orbital Lifetime & Collision Probability

The probability of SwampSat II 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.

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

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

SwampSat II 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 disposal finds SwampSat II in its stowed configuration as the worst case. The area-to-mass is calculated for is as follows:

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

Equation 3: Area to Mass

$$\frac{0.027\ m^2}{3.72\ kg} = 0.007\frac{m^2}{kg}$$

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

<u>DAS 2.1.1 Orbital Lifetime Calculations:</u>
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 ~0.007m^2/kg for the SwampSat II CubeSat was used. DAS 2.1.1 yields an approximate 3.62 year orbit lifetime for SwampSat II 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 SwampSat II 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: SwampsSat II High Melting Temperature Material Analysis

Name	Material	Total Mass (kg)	Demise Alt (km)	Kinetic Energy (J)
Fasteners	Stainless Steel	.150	77.8	0
***Deployable Dipole Antenna Assembly Brackets	Nickel-Titanium	.036	0	0

***Based on an evaluation of this specific product, only the high temperature components of the deployable dipole antenna (~.036 kg of Ni-Ti) were analyzed for re-entry casualty risk.

All stainless steel components demise upon reentry and SwampSat II 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 SwampSat II

Name	Status	Risk of Human Casualty
SwampSat II	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 SwampSat II has a 1:0 probability of human casualty as that none of its components have more than 15J of energy.

SwampSat II is shown are shown to be in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

SwampSat II will not be deploying any tethers.

SwampSat II 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. SwampSat II 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
1	SwampSat II (3U CubeSat)	1			3721.0	100.0	340.5.0	100	No	-	Demise
2	Payload (antenna deployment system)	1	Aluminum 7075	box	792.7	Ø2.1	16000.0	N/A	No	-	Demise
3	Payload antenna	1	Copper	wire	297.7	200.0	100.0	6.4	No	-	Demise
4	Deployable 2U solar panels	2	Fiberglass (FR-4)	flat plate	296.0	100.0	100.0	200.0	No	-	Demise
5	CubeSat structure	1	Aluminum 7075	box	183.4	Ø13.0	3000.0	N/A	No	-	Demise
6	Payload antenna booms	4	CFRP	tube	184.0	100.0	100.0	5.0	No	-	Demise
7	Deployable dipole antenna (UHF/VHF)	1	Aluminum/Ni-Ti	box	85.0	200.0	100.0	1.5	No	-	Demise
8	2U body mounted solar panels	1	Fiberglass (FR-4)	flat plate	84.0	100.0	100.0	1.5	No	-	Demise
9	1U body mounted solar panels	2	Fiberglass (FR-4)	flat plate	84.0	89.0	89.0	4.0	No	-	Demise
10	Patch antenna	1	Aluminum (RF shield)	round plate	37.0	35.0	35.0	7.3	No	-	Demise
11	GPS antenna	1	Aluminum (RF shield)	box	18.0	84.0	15.0	6.5	No	-	Demise
12	Deployable magnetometer	1	Aluminum	box	12.2	3.8	11.0	1.7	No	-	Demise
13	Sun sensors	6	Fiberglass (FR-4)	box	8.4	100.0	100.0	26.0	No	-	Demise
14	Batteries (40 Whr)	1	Lithium polymer	box	343.6	100.0	100.0	43.0	No	-	Demise
15	ADCS package (Reaction wheel, magnet coils, circuit boards)	1	Fiberglass (FR-4) and components	box	260.9	100.0	100.0	26.0	No	-	Demise
16	Payload receiver board	1	Fiberglass (FR-4) and copper	box	215.8	100.0	100.0	14.0	No	-	Demise
17	EPS board	1	Fiberglass (FR-4) and components	box	177.2	100.0	100.0	15.0	No	-	Demise
18	Comms board 1 (UHF/VHF)	1	Fiberglass (FR-4) and aluminum (RF shield)	box	98.7	100.0	100.0	15.0	No	-	Demise
19	Comms board 2 (S-Band)	1	Fiberglass (FR-4) and aluminum (RF shield)	box	87.8	100.0	100.0	10.0	No	-	Demise
20	OBC board	1	Fiberglass (FR-4)	box	63.0	71.0	46.0	11.0	No	-	Demise

21	GPS receiver	1	Fiberglass (FR-4)	box	24.0	34.0	34.0	16.0	No	-	Demise
22	Camera	1	Fiberglass (FR-4)	box	14.4	6.4	20.0	14.0	No	-	Demise
23	Separation switches	2	Glass fiber reinforced polyamide	box	3.2	100.0	100.0	140.0	No	-	Demise
24	Fasteners (M1.2, M2, M2.5, M3 with lengths 2 mm to 14 mm) (4.5 mm hex standoffs with lengths 8 mm to 20 mm)	1	Stainless steel	cylinder	150.0	Various	Various	Various	Yes	2500*	Demise
25	Cabling	1	Copper with PVC coatings	-	100.0				No	-	Demise
26	Epoxy, Kapton, etc.	1	Silicone and Kapton	-	100.0				No	-	Demise