Orbital Debris Assessment Report

WVSAT

per NASA-STD 8719.14A

Signature Page

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REFERENCES:

A. *NASA Procedural Requirements for Limiting Orbital Debris Generation,* NPR 8715.6A, *5* February 2008

B. *Process for Limiting Orbital Debris,* NAS A-STD-8719.14A, 25 May 2012

C. International Space Station Reference Trajectory, delivered May 2017

D. McKissock , Barba ra, 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.* 1JL 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 Emai1:6U CubcSat Battery Non Passivation Suzanne Aleman to Justin Treptow, 8 August 2017

This report is intended to satisfy the orbital debris requirements listed in *NASA Procedural Requirements for Limiting Orbital Debris Generation,* NPR 8715.6A, *5* February 2008, for the ThinSat-2 mission.

Sections 1 through 8 of *Process for Limiting Orbital Debris*, NAS A-STD-8719.14A, 25 May 2012, are addressed in this document; sections 9 through 14 are in the domain of the launch provider and are addressed by others.

RECORD OF REVISIONS		
REV	**DESCRIPTION**	**DATE**
0	Original submission	August 2021

The following table summarizes the compliance status of the WVSAT spacecraft. They all are fully compliant with all applicable requirements.

Requirements	**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	Batteries incapable of debris producing failure
4.4-2	Compliant	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	

Table 1 Compliance Assessment per Requirement

Section 1: Mission Overview

The overall goal of the WVSAT mission, is to deploy small satellites with two distinct form factors, to test ground station radar tracking, and in doing so, demonstrate rapid turnaround and deployment of these satellites.

The experiment will use a total of 4 satellites, 2 ThinSats and 2 1U CubeSats, deployed from the Sherpa-FX Transporter 3 spacecraft ("Sherpa"). The Sherpa, owned by Spaceflight Inc., will be launched on SpaceX SXRS-6, NET December 1, 2021, into a sun synch orbit. The ThinSats unfold accordion style as they exit the deployer; the two CubeSats are separate from the ThinSats. Transmission will begin upon deployment, and cease when de-orbiting occurs.

Section 2: Spacecraft Description

Two styles of spacecraft will be flown; ThinSats, and Cubesats.

Each of the two ThinSats (WVSAT A and B) is comprised of three ThinSat units.

Each of the two Cubesats (WVSAT C and D) will be a 1U Cubesat, nominally 10 x 10 x 10 cm.

Figure 1 shows a single frame ThinSat unit; Figures 2 shows a double frame ThinSat unit. Figures 3 and 4 show how single and double frame units are assembled to form WVSAT A and WVSAT B.

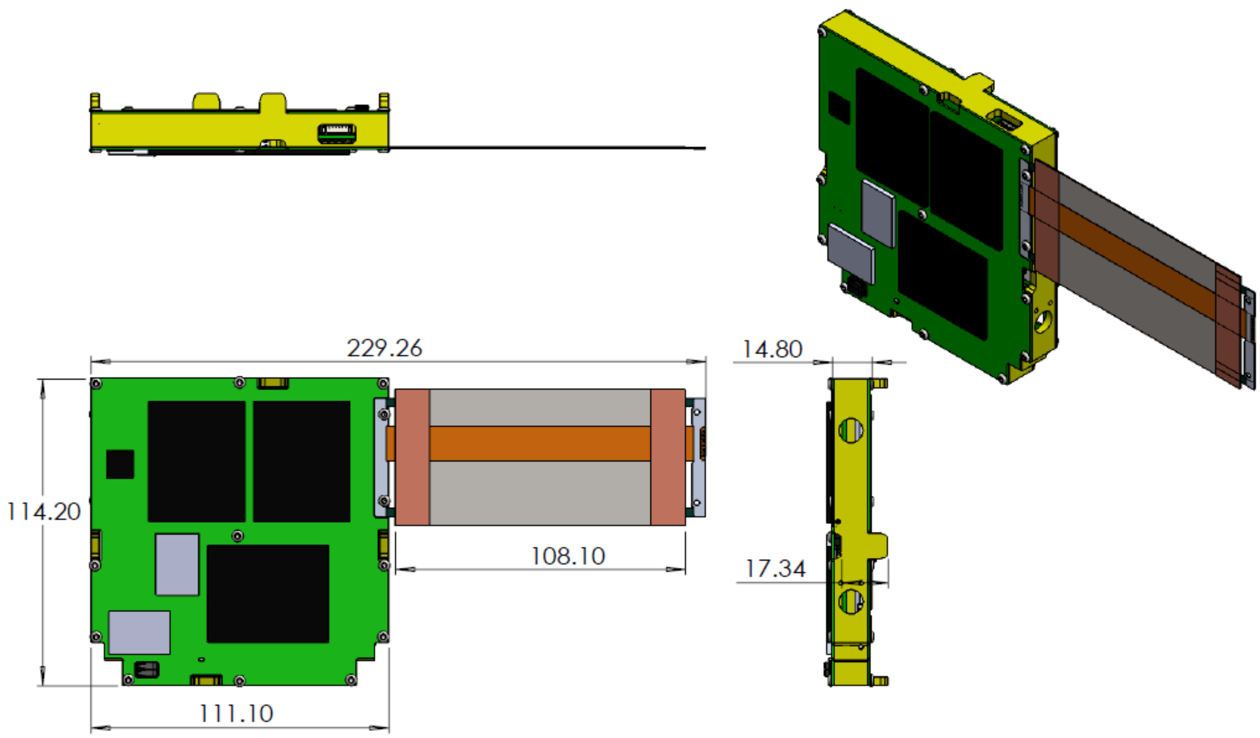

Figure 1 Single Frame ThinSat Unit ("1T") Detail

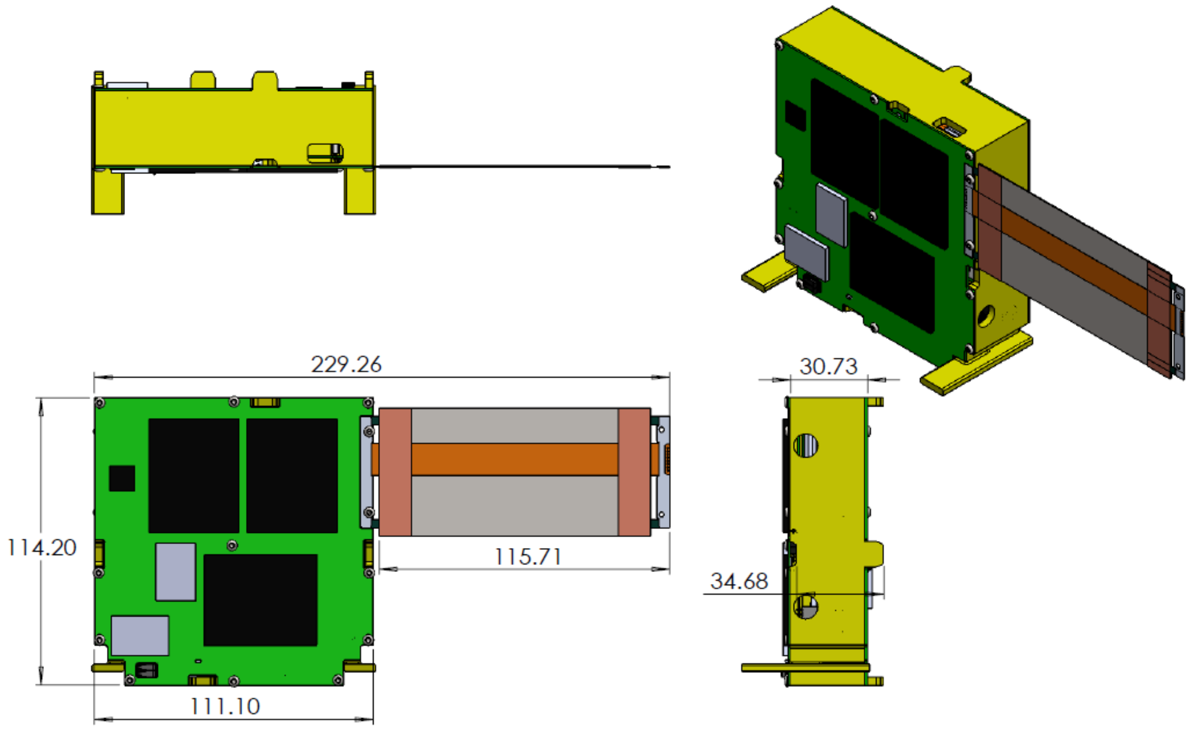

Figure 2 Double Frame ThinSat Unit ("2T") Detail

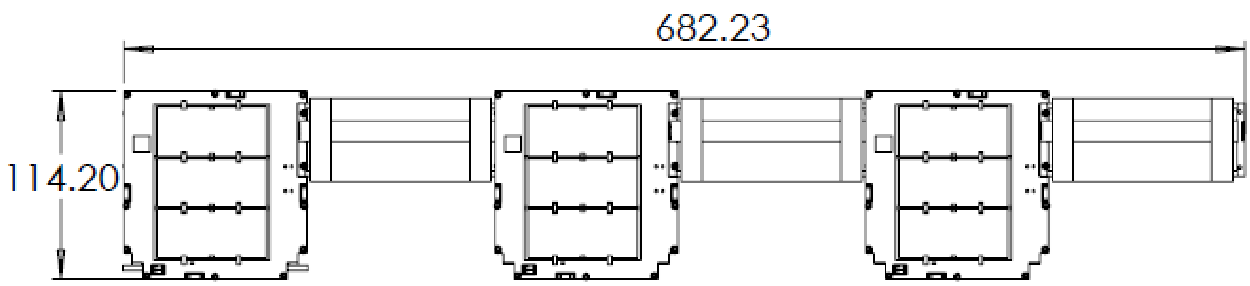

Figure 3 WVSAT A 1 x 2T and 2 x 1T

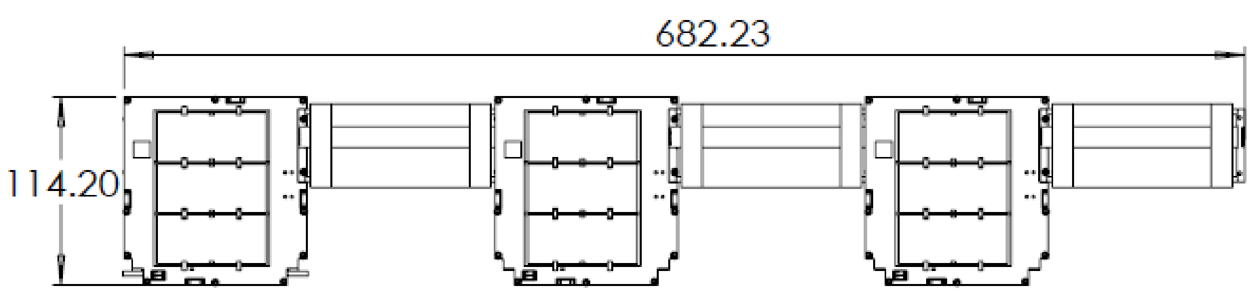

Figure 4 WVSAT B 3 x 1T

Figure 5 shows the configuration for the two Cubesats, WVSAT C and WVSAT D.

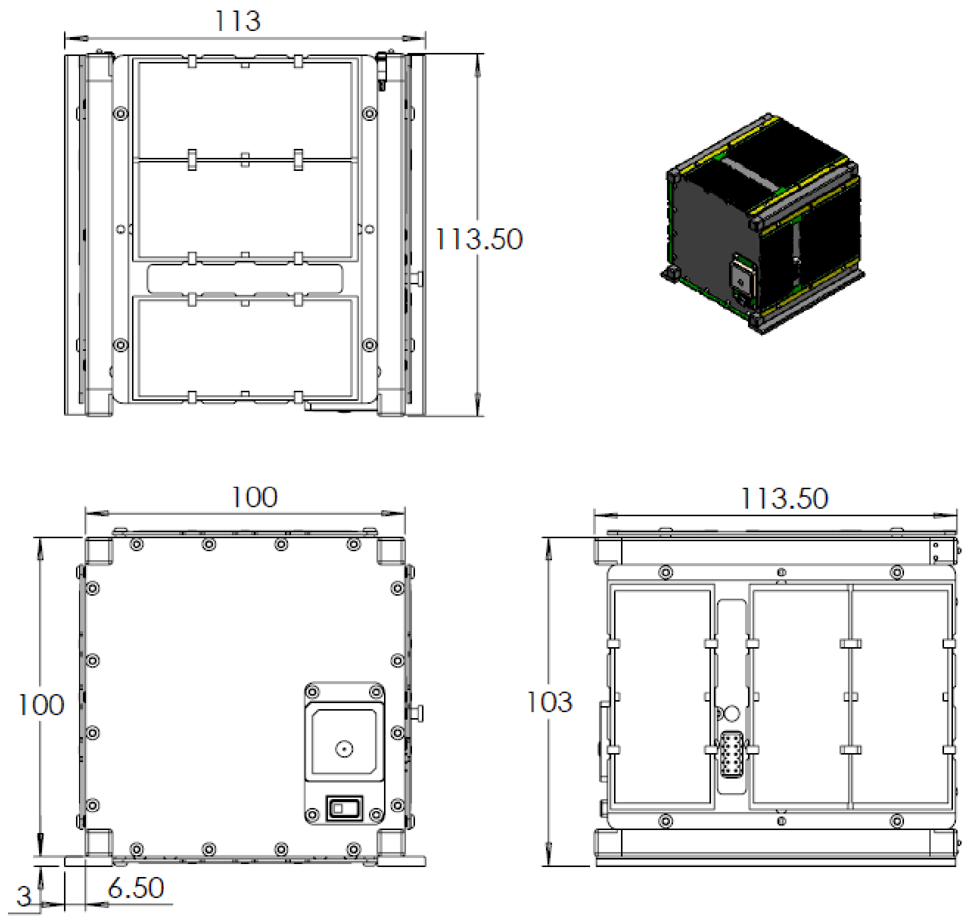

Figure 5 WVSAT C and D 1U

The Appendix lists all of the components in each spacecraft, with the characteristics of each, as input to the DAS software.

Hazards

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

Batteries

The NSL battery NSL140743 is a pouch type cell, using Polymer Li-ion chemistry. It stores 700 mAh at 3.7 volts. The UL listing number of the battery is BBCV2.MH50009. It is used with a battery circuit protection module providing over-charge/over-current protection and over-discharge circuitry.

Tests have been conducted to demonstrate compliance with JSC EP-WI-032 “Statement of Work: Engineering Evaluation, Qualification and Flight Acceptance Tests for Lithium-ion Cells and Battery Packs for Small Satellite Systems.”

NSL140743(UL Listing:BBCV2.MH50009)(UN38.4: ZKS1912000469-1)

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, 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.

The probability of battery explosion is very low, and, due to the very small mass of the satellites, and the pouch type construction, the effect of an explosion on the far-term LEO environment is negligible, per HQ OSMA Policy Memo/Email to 8719.14: CubeSat Battery Non-Passivation, Suzanne Aleman to Justin Treptow, 10, March 2014

The batteries meet Reg. 56450 (4.4-2), per this reference, by virtue of the HQ OSMA policy regarding battery disconnect stating "Cube Sats as a satellite class need not disconnect their batteries if flown in LEO with orbital lifetimes less than 25 years."

Passivation of the batteries at end of mission is provided for in the command structure. However, the low amount of energy stored and small battery cells 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 the WVSAT spacecraft are 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 (MCSA) and orbital lifetime.

This analysis considers the nominal case where all of the spacecraft deploy, separate and unfold, and aerodynamic forces orient them in the ram direction as planned, as well as the contingent cases where they do not unfold, and/or they tumble instead of orienting.

Case 1: Deployed with Aerodynamic Stabilization to Minimum Cross Section (Nominal)

Per NASA STD-8719.14, "..an object may be considered to be tumbling randomly, or it may be assumed to have a stable attitude relative to the velocity vector." Drag is expected to stabilize attitude with minimal cross section in the ram direction.

The minimal cross section for each of the 4 spacecraft is given in Table 2.

Satellite	Diagram	Cross Sectional Area, m^2 RAM Stabilized
WVSAT A	Figure 3	0.0069
WVSAT B	Figure 4	0.0051
WVSAT C/D	Figure 5	0.0128

Table 2 MCSA for WVSAT Configurations, Deployed and Stabilized

For each of the 4 spacecraft, the total mass, obtained by summing the masses of the components of the spacecraft as shown in the Appendix, was used to determine the Area to Mass ratio for each, shown in the following Table 3. Table 3 also shows the orbit lifetime, and the probability of collision, provided by the DAS calculations. See Appendix for DAS Analysis Input Data and Output Results. The longest lifetime is about 13 years. For the ThinSats, if further analysis were done to take into account nonzero angle of attack, or potential oscillations, the effective cross sectional area would increase, and the lifetime would be reduced.

Spacecraft Name	Mass kg	Area/Mass m^2/ kg	Orbit Lifetime Years (DAS)	Probability of Collision (DAS)
WVSAT A	1.133	0.0061	12.923	1.6289 e-07
WVSAT B	0.84	0.0061	12.205	1.2077 e-07
WVSAT C/D	1.5	0.0085	6.965	1.9981 e-07

Table 3
Mass, Area to Mass Ratio, Lifetime and Probability of Collision for each Spacecraft, Deployed and Stable

Case 2: Deployed and Tumbling

A deployed, tumbling ThinSat or Cubesat can be regarded as a complex object. The formula for the MCSA of a complex object, tumbling, is given by NASA STD-8719.14.

MCSA = $(A_{max} + A_1 + A_2)/2$, where

A_{max} is the area of the orthogonal view with the greatest area

A_1 and A_2 are the areas of the other two orthogonal views. Note that for the smallest side, referred to as RAM facing in Case 1, and A_2 here, the same assumption is made as in Case 1, e.g. the second, third and every unit experiences drag comparable to the first unit, in proportion to the area presented.

From this formula, the deployed MCSA of each satellite given in table 4. All dimensions given are in square meters.

For each of the 4 spacecraft, the total mass of the components shown in the Appendix was used to determine the area to mass ratio shown in the following table. Table 4 also shows the orbit lifetime, and the probability of collision, provided by the DAS calculations. See Appendix for DAS Analysis Input Data and Output Results. The tumbling case, which is not the expected case, yields significantly reduced lifetimes compared to the nominal case.

Spacecraft Name	Deployed and Tumbling MCSA m^2	Mass, kg	MCSA/Mass m^2/ kg	Orbit Lifetime, Years	Probability of Collision
WVSAT A	.03291	1.133	.0291	3.559	2.7113 e-07
WVSAT B	.03113	0.84	.0371	2.519	2.4228 e-07
WVSAT C/D	.01741	1.5	.0116	5.070	2.2761 e-07

Table 4
Area to Mass Ratio, Lifetime and Probability of Collision for each Spacecraft, Deployed and Tumbling

Case 3: Un-Deployed With Aerodynamic Stabilization

The longest orbit lifetime would result if the entire cluster, the contents of the canister, did not deploy, and if it stabilized with the minimum area face in the direction of flight. This yields an area of 0.111 x 0.114, or 0.013 m^2. From Table 5, the maximum orbit lifetime in this contingency case, which is the maximum for all cases considered, would be 23 years.

Launcher Tube	Spacecraft in Un Deployed Cluster	RAM Area, m^2	Mass of Cluster, kg	Area to Mass Ratio	Orbit Life Years	Probability of Collision
CSD-1	A, B, C, D	0.013	4.973	.0026	**22.390**	**5.6975 e-07**

Table 5 Orbit Lifetime and Probability of Collision, Un-Deployed and Stable

Case 4: Un-Deployed with Tumbling

As a contingency we consider the unexpected case where all of the spacecraft, when ejected from the launcher tube, remained un deployed, e.g., do not unfold, and tumble. The cluster can be regarded as a convex object. The formula for the MCSA of a complex object, tumbling, is given by NASA STD-8719.14.

MCSA = Surface Area / 4 (which reduces to the formula used in Case 2 also)

The cluster has a length of 364.34 mm, 0.36434 m.

From the cluster dimensions given in Case 3,

Cluster MCSA = {[2 * (0.111 x 0.114)] + [2 * (0.111 x 0.365)] + [2 * 0.114 * 0.365)]}/4

= 0.0474 m^2

This yields from DAS, a lifetime of 6.74 years.

Cluster	Spacecraft in Un Deployed Cluster	MCSA, m2	Mass of Cluster, kg	Area to Mass Ratio, m2/kg	Orbit Life, Years	Probability of Collision
1	A, B, C, D	0.0474	4.973	0.0095	6.073	**6.8907 e-07**

Table 6 Orbit Lifetime and Probability of Collision, Un Deployed and Tumbling

Review of All Cases

In summary, the probability of any collision, in any configuration, with debris or meteoroids greater than 10 cm in diameter is “less than 0.00000”, per DAS for any configuration. This satisfies the 0.001 maximum probability requirement 4.5-l.

The spacecraft have 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 all spacecraft to be compliant. Requirement 4.5-2 is not applicable to this mission.

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

The spacecraft all will naturally decay from orbit within 25 years after end of the mission, satisfying requirement 4.6- l.

Planning for spacecraft maneuvers to accomplish post-mission disposal is not applicable. Disposal is achieved via passive atmospheric reentry.

Summary of DAS 3.1.2 Orbital Lifetime Calculations:

DAS inputs are: 525 km maximum apogee 525 km maximum perigee altitudes with an inclination of 97° at deployment Q4, 2021.

From Section 5, Table 3, in the nominal operation case, the lifetimes of the 4 spacecraft are estimated to cover the range of 6.965 to 12.939 years, based on the Area / Mass ratio of each.

As an extreme outer limit for orbit lifetime, the contingency mode of all satellites remaining clustered as when contained in the canister, and assumed stable in flight, yields a value of 22.39 years.

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

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components of the spacecraft was performed using DAS 3.1.21, to verify Requirement 4.7-1. See Appendix for a complete log of DAS inputs and outputs for all cases. The analysis provides a bounding analysis for characterizing the survivability of a component during re-entry. It is conservative in that when it shows terminal energy of a component surviving reentry, it is does not consider any loss material from ablation or charring. Both of these may for some materials decrease the mass and dimensions of the re-entering components, reducing the risk below that calculated.

The surviving components are shown in Table 7.

Satellite / Surviving Components	Original Mass, kg	Impact Kinetic Energy, Joules*	Casualty Area, m^2*	Spacecraft Risk of Human Casualty
WVSAT A/				**1:100000000**
Separation Switch (2)	**0.0003**	**0.02**	**0.74**	
Solar Fold Out	**0.015**	**0.6**	**0.46**	
Damping	**0.01**	**5.2**	**0.38**	
Separation Switch a (4)	**0.0003**	**0.02**	**1.5**	
Solar Fold Out a (2)	**0.015**	**0.6**	**0.92**	
Damping a (2)	**0.01**	**5.2**	**0.76**	
WVSAT B/				**1:100000000**
ISS Solar Cell (3)	**0.005**	**0.06**	**1.39**	
Sep Switches (6)	**0.0003**	**0.02**	**2.2**	
Solar Fold Out (3)	**0.015**	**0.61**	**1.38**	
Fasteners / Spacers (12)	**0.0002**	**0.71**	**4.44**	
Damping (3)	**0.010**	**5.16**	**1.14**	
WVSAT C/				**1:100000000**
Magnetorquer Short (4)	**0.03**	**7.24**	**1.66**	
WVSAT D/ Same as C				

() Indicates quantity other than 1

Table 7: Surviving Component Analysis

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 all of the spacecraft have a calculated Risk of Human Casualty from DAS, of 1:100000000. The maximum terminal energy among all the surviving components is 7.24 Joules.

The majority of components demise upon reentry, and all spacecraft comply with the less than 1:10,000 probability of Human Casualty Requirement 4.7-1.

The WVSAT spacecraft thus are in compliance with Requirement 4.7-1 of NASA-STD-8719.14A.

Section 8: Assessment for Tether Missions

No tethers are used. Requirement 4.8-1 is satisfied.

Section 9 through 14:

ODAR sections 9 through 14 pertain to the launch vehicle, and are not covered here.

Appendix

The document “Appendix to WVSAT ODAR - DAS Activity Log”, file ActivityLog.pdf, is incorporated by reference into this document.