Laboratory for Atmospheric and Space Physics

University of Colorado at Boulder Aerospace Engineering Sciences ASEN 5519 – Summer 2011

Technical Report

Re-entry Analysis

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Approvers List

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Revision History

Rev	Date	Change Description	Pages Affected
_	10/12/10	Initial Release	All
А	7/15/11	Updated orbit information in analysis & included de-orbit screenshot.	All

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1.0 Introduction

Materials in the CubeSat which will not burn up during re-entry are a risk to lives on the surface. A standard safety analysis is performed to ensure the CSSWE CubeSat meets all appropriate safety regulations. Requirements for re-entry safety are set by NASA in an official document^[1].

2.0 Analysis

There are two forms of analysis presented: the first is based on an email exchange with Scott H. Schaire

(scott.h.schaire@nasa.gov), while the second is based on a NASA document^[1] and associated model. Finally, CSSWE is shown to comply with NS 8719.14 4.6.1 which requires non-propelled spacecraft to de-orbit naturally within 25 years after launch.

2.1 Scott Schaire Analysis Method

It is assumed that all copper, silicon, aluminum, steel, plastic and fiberglass within the CubeSat will all burn up entirely during the reentry event. With these materials gone, the only remaining pieces are tungsten and tantalum. These pieces are shown in detail in Table 1 (assembled using mass & volume budget 200-002_J).

Figure 1: CSSWE CubeSat exterior / interior

It is assumed that the connectors between these pieces will not survive re-entry, leaving each of the pieces in Table 1 separate from other pieces. As shown, there are 18 parts within the CubeSat which are not expected to burn up during reentry.

Part Number	Material	1 x Mass [g]	Quantity	Total Mass [g]	Description
412-003_D	Tungsten	356.38	1	356.38	W shell, Main
412-004_D	Tungsten	312.99	1	312.99	W shell, Cap
412-009_B	Tantalum	9.33	7	65.31	Ta Collimator Tooth
412-010_A	Tantalum	23.15	3	69.46	Ta Collimator Spacer (6.9mm)
412-013_A	Tantalum	12.42	1	12.42	Ta Collimator Spacer (3.7mm)
412-014_A	Tantalum	6.71	1	6.71	Ta Collimator Spacer (2.0mm)
412-015_A	Tantalum	13.76	1	13.76	Ta Collimator Spacer (4.1mm)
422-001_A	Tantalum Alloy	5.20	3	15.60	Ta-W Threaded Rod



852.63

Total

Table 1: Materials within CSSWE which are not expected to burn up during re-entry

The following is from an email to Dr. Scott Palo from 9/1/2010

From: Schaire, Scott H. (WFF-8020) [mailto:scott.h.schaire@nasa.gov]
Sent: Wednesday, September 01, 2010 11:03 AM
To: Scott Palo
Cc: Moretto Jorgensen, Therese; Schaire, Scott H. (WFF-8020)
Subject: RE: CSSWE use of Tungsten

Scott,

I asked on of our Systems Engineers who specializes in re-entry analysis, to comment on the use of tungsten as a shield. Here is his preliminary assessment.

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Using tungsten is likely OK, but a more detailed look is needed.

When a previous analysis looked at a 1U Cubesat for re-entry, a worst case analysis stated that even if it were a 1kg cube of Titanium, it would not be an issue for re-entry. Here are the notes from that analysis. "To establish a maximum possible casualty expectation (CE) for unknown materials, the same 1 kg box made from titanium will not demise and produces a ground impact with an energy exceeding 750 J. Due to the small size, however, the casualty area (CA) is less than 0.5 m², which falls well under the maximum casualty area (CA) of 8 m². The equivalent calculated CE is 1:108,600."

There is a flaw in the argument that even if it were 1 kg of titanium or whatever that it will be safe. That argument assumes everything stays in one piece. If there are multiple pieces of tungsten shield, then each piece adds to the debris casualty area. By policy a 0.3 meter buffer is added to the size of each piece. The total debris casualty area must be less than 8 m², so having a few pieces impacting is probably OK, but there is a limit.

Scott

CSSWE has 18 pieces of tungsten / tantalum. Thus, there is a total casualty area (CA) of $6m^2$ when the buffer size of $0.3m^2$ is used for each piece. Because the calculated CA < $8m^2$, CSSWE is compliant with the NASA requirement.

2.2 NASA- STD-8719.14 Analysis Method

Requirement 4.7-1 Casualty Risk from Orbital Debris

The requirement for spacecraft using uncontrolled re-entry for debris mitigation is that the risk of human casualty is 0.0001 or less (or 1 in 10,000)^[1]. To check this, NASA supplies a simple model of atmospheric reentry which determines where (if anywhere) pieces of the spacecraft will burn up in the atmosphere. This data is used in combination with an estimate of population density on earth to generate a simple, worst-case number for risk of human casualty.

The model is called NASA Debris Assessment Software (DAS), and is available online^[2]. Figure 2 shows a screenshot of the software. Each of the components shown in Table 1 was imported into the model, which takes into account material, object shape / dimensions, and mass. These components are used to generate a total risk of human casualty of 1:153600, which is more than ten times less than the requirement. Thus, CSSWE is again found compliant with NASA debris requirements.

	1002000000		Quantity	Material Type		Object Shape	Thermal Mass	Diameter/Width	Lengti
							(kg)	(m)	(m)
1	CSSWE 3U	Cub	1	Aluminum 6061	l-T6	Box	3.05747	0.1	0.3
2	REPTile		1	Tantalum		Cylinder	1.37650	0.08	0.06
3	circuit boar	d	1	Copper Alloy		Flat Plate	0.16721	0.1	0.2
4	Si Detect, p	late	3	Silicon		Cylinder	0.01246	0.040	0.02
5	Si Detec, pl	ate	1	Silicon		Cylinder	0.01496	0.025	0.015
6	Ta Collimato	or T	7	Tantalum		Cylinder	0.00933	0.034011	0.015
7	Ta Collimato	or S	3	Tantalum		Cylinder	0.02315	0.034011	0.015
0 1	Po window		1	Popullium Flome		Culindar	0 00004	0.024011	0.015
<u>B</u> un put	Require	ement	Help	Risk of Human	SubComponent	Demise	Total Debris	Kinetic	
<u>R</u> un out	Require	ement	<u>H</u> elp ance	Risk of Human	SubComponent	Demise	Total Debris	Kinetic	
Bun but bject N	Require	Complia Status	<u>H</u> elp	Risk of Human Casualty	SubComponent Object	Demise Altitude (km)	Total Debris Casualty Area	Kinetic Energy (J)	
<u>R</u> un but bject N	Require	ement Complia Status Complia	Help ance	Risk of Human Casualty 1:153600	SubComponent Object	Demise Altitude (km)	Total Debris Casualty Area 0.45	Kinetic Energy (J)	
<u>B</u> un bject N SSWE	Require	complia Status Complia	Help ance	Risk of Human Casualty 1:153600	SubComponent Object REPTile	Demise Altitude (km)	Total Debris Casualty Area 0.45 0.45	Kinetic Energy (J) 5783	
Bun put object N.	Require	Complia Status Complia	Help ance	Risk of Human Casualty 1:153600	SubComponent Object REPTile circuit board Si Detect plat	Demise Altitude (km) 0.0 0.0	Total Debris Casualty Area 0.45 0.45 0.00	Kinetic Energy (J) 5783 0	
Bun put bbject N.	Require	ement Complia Status Complia	Help ance	Risk of Human Casualty 1:153600	SubComponent Object REPTile circuit board Si Detect. plat Si Detec. plate	Demise Altitude (km) 0.0 0.0 0.0 0.0	Total Debris Casualty Area 0.45 0.45 0.00 0.00	Kinetic Energy (J) 5783 0 0 0	
Bun put bject N	Require	Complia Status Complia	Help ance	Risk of Human Casualty 1:153600	SubComponent Object REPTile circuit board Si Detect. plat Si Detec. plate Ta Collimator T	Demise Altitude (km) 0.0 0.0 0.0 0.0 0.0 0.0 0.0	Total Debris Casualty Area 0.45 0.00 0.00 0.00 0.00 0.00	Kinetic Energy (J) 5783 0 0 0 0	

Figure 2: Screenshot of NASA Debris Assessment Software, with calculated risk of human casualty highlighted

Requirement 4.6-1 Post Mission Disposal

DAS is also used to ensure the satellite conforms to requirement 4.6-1 of NASA-STD-8719.14, ensuring de-orbit in < 25 years; see Figure 3 for confirmation via a screenshot of DAS.

Requirement Assessments							
	⊂ (Requirement 4.6·1 4.6·	3) Postmission Dispos	al of Space Structur	98			
— (Requirement 4.4-3) - Long-Term Risk from Planned Breakups — (Requirement 4.5-1) - Probability of Collision With Large Objects	Space Structure	Space Structure	Compliance	Suggested Perigee	Suggested A	pogee Perigee	
(Requirement 4.5-2) - Probability of Damage from Small Objects	Name	Туре	Status	Altitude (km)	Altitude (km)	Altitude (kr	n)
✓ (Requirements 4.6-1 to 4.6-3) - Postmission Disposal	CSSWE 3U CubeSat	Payload	Compliant			472	
	Requirement 4.6-2						<u>></u>
	Space Structure	Space Structur	e Complia	nce Sug	gested Perigee	Suggested Apogee	Pe
	Name	Туре	Status	Alti	tude (km)	Altitude (km)	Alt
	Requirement 4.6-3	Space Shuch r	e Complia		marted Devices	Suggested Apoge	
	Space Structure	Space Structur	e Compliai	nce Sug	gested Perigee	Suggested Apogee	Pe
		1.00		J			

Figure 3: CSSWE conforms to requirement 4.6.1, ensuring the satellite will de-orbit due to natural forces within 25 years after launch.

Requirement 4.5-1 Probability of Collision with Large Objects

DAS was also used to calculate the probability of collision with an object >10cm while in orbit. The probability was calculated to be p<0.00001, which meets the NASA requirement 4.5.1 of p<0.001 (Figure 4).

Requirement Assessments						
NS 8719.14 - Process for Limiting Orbital Debris (Requirement 4.3-1) - Mission-Related Debris Passing Through LEO (Requirement 4.3-2) - Mission-Related Debris Passing Near GEO (Requirement 4.3-2) - Loss-Term Pick from Planced Produces	Input Start Year 2012	_				
(Requirement 4.4-3) - Long-Term Risk from Planneu Breakups		Space	Perigee	Apogee	Inclinatio	
(Requirement 4.5-2) - Probability of Comson With Earge Objects		Structure	(km)	(km)	(deg)	
(Requirements 4.6-1 to 4.6-3) - Postmission Disposal	CSSWE 3U CubeSat	Payload	472	777	60	
(Requirement 4.8-1) - Collision Hazards of Space Tethers					>	
Requirement ?						
(Requirement 4.5-1) - Limiting debris generated by collisions with large objects when operating in Earth orbit. For each spacecraft and launch vehicle orbital stage in or passing	<u>B</u> un Requir	ement <u>H</u> el	Compliance	Collision	_	
through LEO, the program or project shall demonstrate that, during the		Structure	Status	Probability		
accidental collision with space objects larger than 10 cm in diameter is less than 0.001.	CSSWE 3U CubeSat	Payload	Compliant	0.00000		
	Messages					
Close	Requirement 4.5-1: Co	mpliant - CSSWE 3	IU CubeSat			

Figure 4: DAS calculated the probability of collision during orbit lifetime to be p<0.00000

3.0 References

^[1] "Process for Limiting Orbital Debris." NASA Technical Standard. Document # NASA-STD-8719.14 (with change 4). Revised 2009-9-14. Accessed 2010-10-12. http://www.hq.nasa.gov/office/codeq/doctree/871914.pdf>.

^[2]<u>http://orbitaldebris.jsc.nasa.gov/mitigate/das.html</u>. Version 2.0.1, Retrieved 2010-10-12.