Laboratory for Atmospheric and Space Physics
University of Colorado at Boulder
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Technical Report

Re-entry Analysis

Document No. 300-006

Requirement Ref. NA **Action Item Ref. NA**

Approvers List

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Revision History

Rev	**Date**	**Change Description**	**Pages Affected**
–	10/12/10	Initial Release	All
A	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.

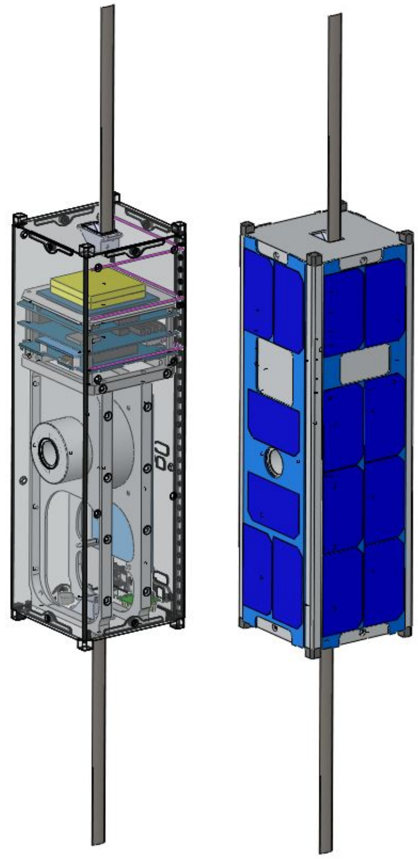

Figure 1: CSSWE CubeSat exterior / interior

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).

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

18	**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.

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 m^2, which falls well under the maximum casualty area (CA) of 8 m^2. 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 m^2, 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.

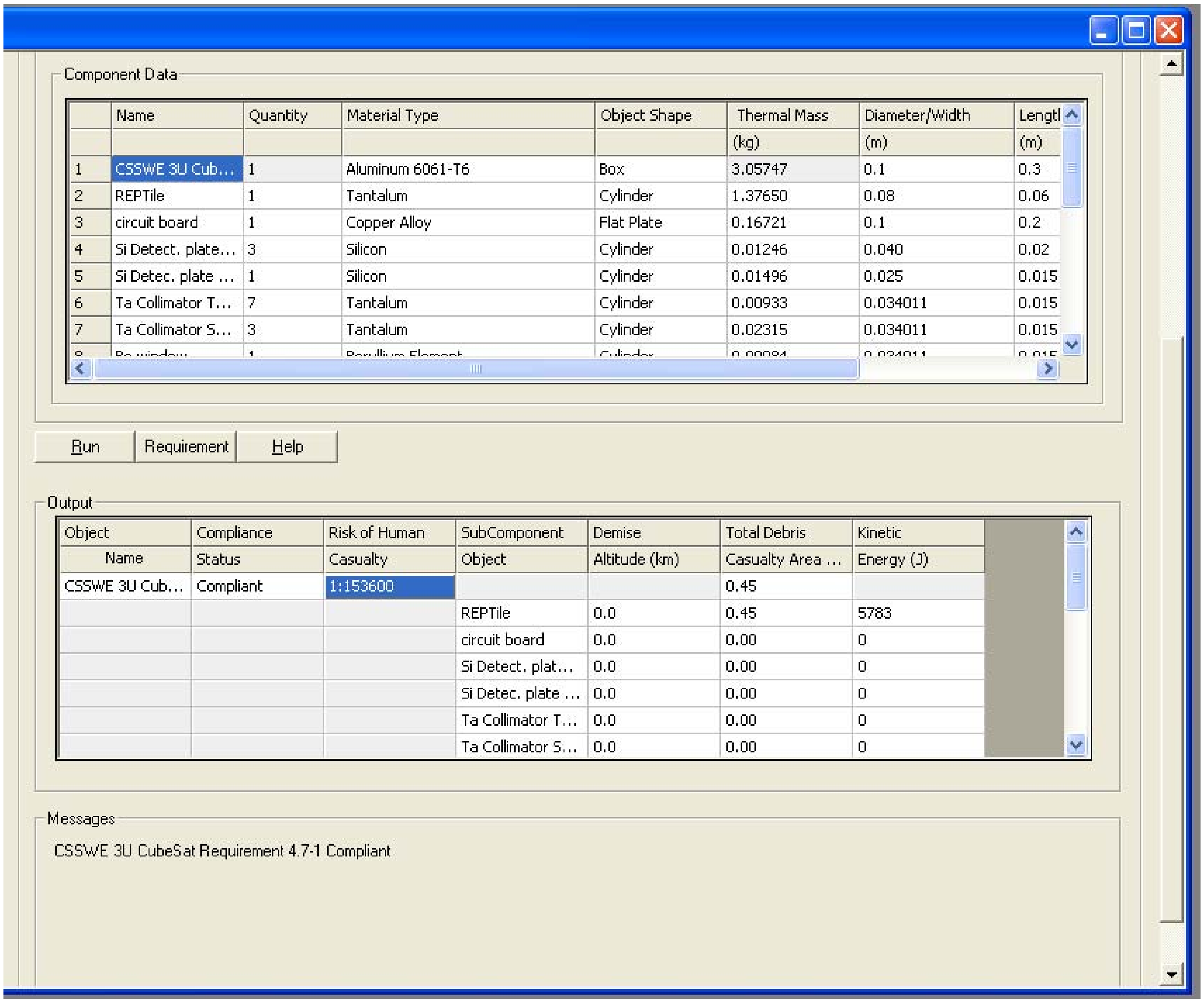

Figure 2: Screenshot of NASA Debris Assessment Software, with calculated risk of human casualty highlighted

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.

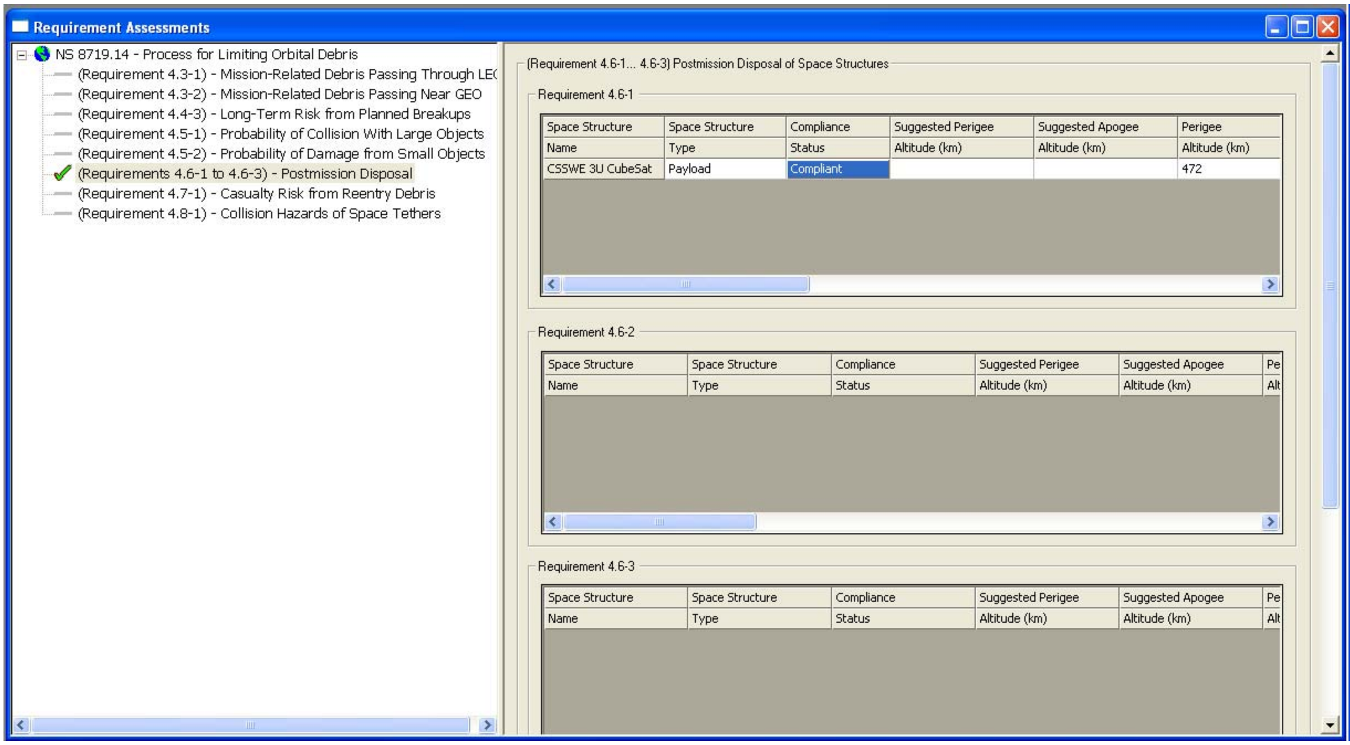

Figure 3: CSSWE conforms to requirement 4.6.1, ensuring the satellite will de-orbit due to natural forces within 25 years after launch.

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).

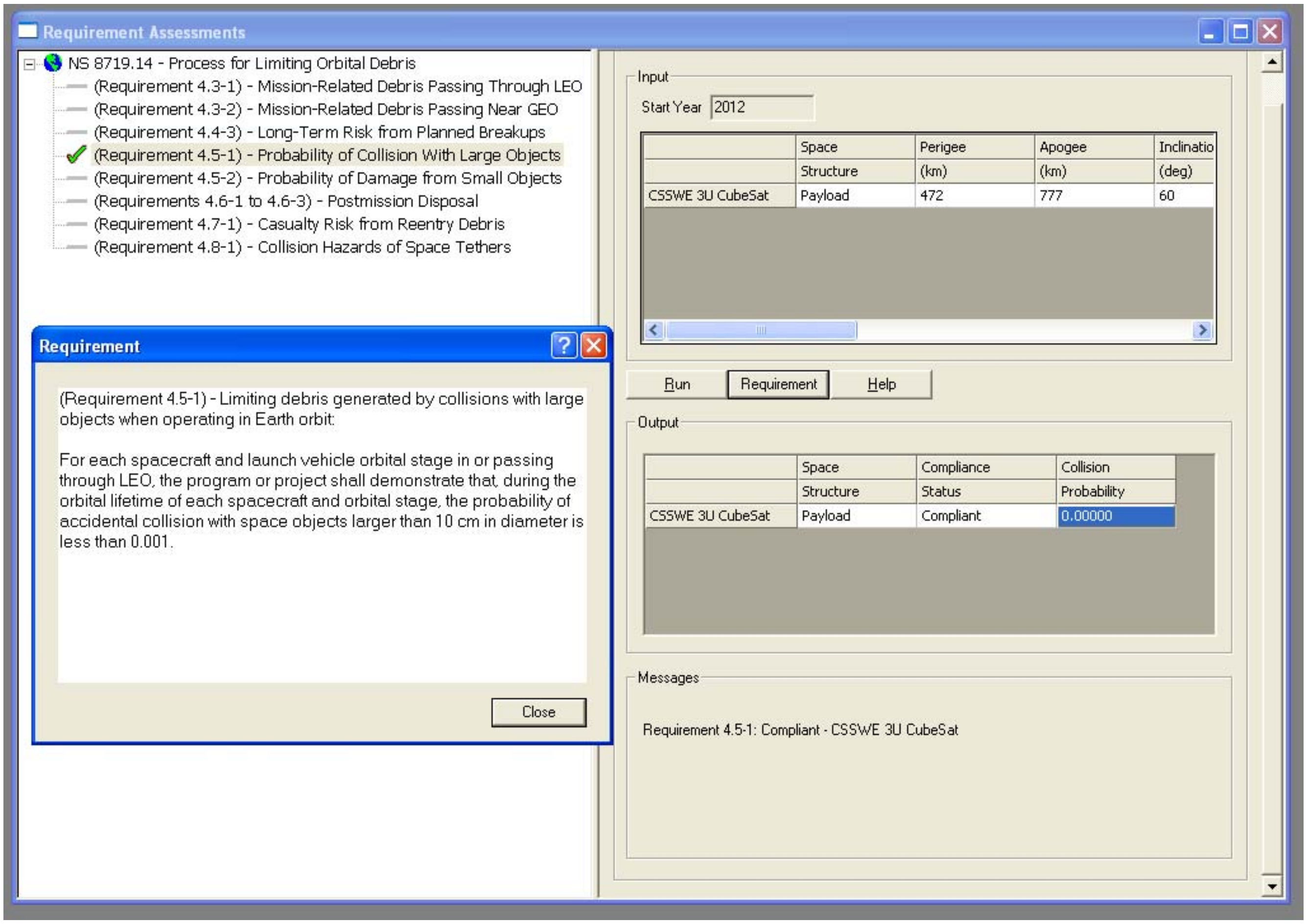

Figure 4: DAS calculated the probability of collision during orbit lifetime to be p<0.00000

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] http://orbitaldebris.jsc.nasa.gov/mitigate/das.html. Version 2.0.1, Retrieved 2010-10-12.