DANDE Orbital Debris Assessment Report

(ODAR)
Revision 2.0
March 2, 2013

In accordance with NPR 8715.6A, this report is presented as compliance with the reporting format per requirement set by Launch Provider and Mission Integrator

DAS Software Used in This Analysis: DAS V2.02

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Revision	Date	Pages	Description	Author
1.0	2/22/13	1-22	Initial	Brenden Hogan, Miranda Link, Mark Sakaguchi
2.0	3/2/13	1-23	Refinements and Editing	Brenden Hogan, Miranda Link, Mark Sakaguchi

Record of Revisions

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Self-assessment and OSMA assessment of the ODAR using the format in the Appendix

A.2 of NASA-STD-8719.14:

A self-assessment is provided below in accordance with the assessment format provided in Appendix A.2 of NASA-STD-8719.14. In the final ODAR document, this assessment will reflect any inputs received from OSMA as well.

Orbital Debris Self-Assessment Report Evaluation: DANDE Mission

Requirement	**Compliance Assessment**	**Comments**
4.3-1a	Compliant	All mission related objects (DANDE, LAB) decay within 25 years
4.3-1b	Compliant	All mission related objects (DANDE, LAB) decay within 25 years
4.3-2	Compliant	Not traversing GEO
4.4-1	Compliant	NiCad batteries tested and approved as safe
4.4-2	Compliant	No passivation requirements for DANDE
4.4-3	Compliant	No planned explosions or intentional collisions
4.4-4	Compliant	No planned explosions or intentional collisions
4.5-1	Compliant	DANDE probability of collisions with objects larger than 10 cm: 0.00001 LAB probability of collisions with objects larger than 10 cm: 0.0
4.5-2	Compliant	DANDE, LAB probability of collisions with orbital debris and meteoroids is less than 0.01
4.6-1(a)	Compliant	Atmospheric reentry option
4.6-1(b)	Compliant	No plan to enter orbit with perigee altitude greater than 2000 km and apogee less than 500 km
4.6-1(c)	Compliant	No direct retrieval

4.6-2	Compliant	Not near GEO
4.6-3	Compliant	Not between LEO and GEO, no parking orbit plan
4.6-4	Compliant	No post-mission disposal plans
4.7-1	Compliant	Risk of human casualty does not exceed 1/10000
4.8-1	Compliant	No tether used

ODAR Section 1: Program Management and Mission Overview

Satellite Name: DANDE

Responsible Organization: Colorado Space Grant Consortium

Principle Investigator: Chris Koehler, Daily Manager – Brian Sanders

Project Managers: Mark Sakaguchi, Miranda Link, Brenden Hogan

Mission design and development milestones:

Mission PDR:	August, 17, 2007
Mission CDR:	March, 21, 2008
Flight Unit Build:	September, 21, 2011
Flight Unit Vibe:	January, 31, 2013
Flight Unit Bakeout:	February, 07, 2013
Mission Readiness Review:	February, 19, 2013
Delivery:	May, 14, 2013
Launch:	June, 15, 2013

DANDE, developed and built by students from the Colorado Space Grant Consortium, is a spherical micro-satellite with a diameter of 46 cm and a mass of 46 kg (with LAB). DANDE will explore the spatial and temporal variability of the neutral thermosphere at altitudes below 500 km, to investigate how wind and density variability translate to drag forces on satellites. DANDE will be launching from Vandenberg AFB in California, on a Falcon-9 launch vehicle with CU-Sat and other secondary payloads from Space Exploration Technologies. The intended orbit is 325 km perigee by 1500 km apogee, with an inclination of 79 degrees, and an argument of perigee at 170 +/- 90 degrees.

Figure 1: DANDE

ODAR Section 2: Spacecraft Description

DANDE
Stowed dimensions ~ 46 cm sphere
Deployable antennas – none
LAB – Lightband Adapter Bracket, see part 17 of Figure 2

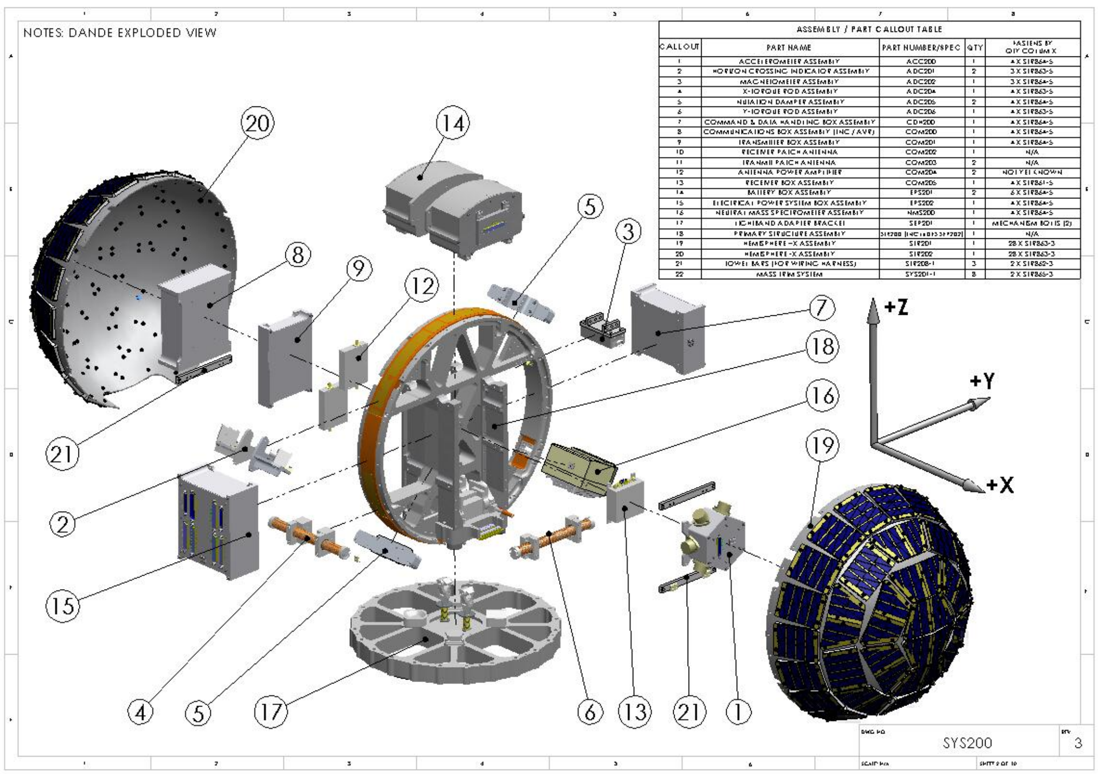


Figure 2: DANDE Expanded View

The primary DANDE structure is made of Aluminum 6061. It contains all standard commercial off the shelf (COTS) materials, electrical components, PCBs and solar cells.

There are no pressure vessels, hazardous or exotic materials.

The electrical power storage system consists of nickel-cadmium batteries with over-charge/current protection circuitry.

Concept of Operations

1. Satellite Preliminary Operations
    a. Deploy from launch vehicle
    b. Wait 30 minutes
    c. Broadcast DANDE beacon
    d. Establish command link
2. Activation Phase I: Listening/Commanding
3. Activation Phase II: System Checkout Commanding
4. Separation Phase
5. Attitude Phase
6. Primary Mission (Science)
    a. Schedule time to take science in-situ measurements by ground command
    b. Wait until scheduled time
    c. Activate science instrument and take measurements, store to memory
    d. On next pass over ground station, downlink payload

ODAR 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 DANDE payload expects to release a Lightband Adapter Bracket (LAB) after launch. The Lightband Adapter Bracket is approximately 0.4 meters in diameter, and 0.04 meters in height. The Lightband Adapter Bracket is 8 kg in mass and made out of Aluminum 6061.

The rationale behind releasing the LAB from the DANDE spacecraft after launch is due to the DANDE spacecraft's specific need of a very known ballistic coefficient, (circular shape) to better study atmospheric drag. In order to complete its mission objectives, the DANDE spacecraft must be able to spin-up to 10 rpm so that the angular momentum vector of the DANDE spacecraft is aligned within 2 degrees with a vector parallel to the orbit normal vector. If the LAB is not released from the DANDE spacecraft, its center of mass will shift and proper spinning orientation will not be achieved. The LAB will be released by firing of two High Output Paraffin Actuators, each of which take approximately 2 minutes to activate. Therefore, the time of release of the LAB will be approximately 4 minutes. The CONOPS plan for releasing the LAB from the DANDE spacecraft occurs in the "Separation Phase" of the DANDE mission. After ejection from the launch vehicle, the mission operations team will locate and communicate with the DANDE spacecraft. Once the DANDE spacecraft has been checked out, the mission operations team will initiate the "Separation Phase" and release the LAB from the spacecraft. It is expected that this maneuver will occur within the first few weeks of launch. The LAB will be released at 1 m/s velocity with respect to the DANDE spacecraft and have the expected orbital parameters: apogee – 1500 km, perigee – 325 km, and inclination 79 degrees. Using these orbital parameters and the mass, cross-sectional area, and material of the LAB in Satellite Tool Kit, the LAB is expected to have an orbital lifetime of approximately 9.577 years. The release of the LAB from the DANDE spacecraft is compliant with Requirements 4.3-1 and 4.3-2.

ODAR Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions

A possible malfunction of Nicad batteries has been identified as a possible, but not probable, cause for spacecraft breakup during deployment and mission operations.

While no passivation of batteries will be attempted, natural degradation of the solar cell and battery properties will occur over the post mission period, which may be as long as 22 years. These conditions pose a low probability of the existence of several contributors to undesired battery energy release. Nickel Cadmium batteries have been tested repeatedly by many companies, and no explosion documentation could be found.

There are NO plans for designed spacecraft breakups, explosions, or intentional collisions on the DANDE mission, so requirements 4.4-2, -3, and -4 are not applicable to the DANDE spacecraft.

In regard to requirement 4.4-1, there is a very small probability of an accidental explosion. The only concern would be the batteries, but DANDE houses 20 NiCads, which are extremely safe and rigorously tested by many companies. The batteries meet the assembly requirement put in place by NASA/JSC Specification PRC-0009 Rev. D, *Process Specification for the Resistance Spot Welding of Battery and Electronic Assemblies,* Feb. 2004

Section 4 asks for a list of components that shall be passivated at End of Mission (EOM), as well as the method of passivation and description of the components that cannot be passivated. No passivation of components is planned at the End of Mission for DANDE because there are no propellants or pressurized systems on board the spacecraft.

Since the NiCad batteries used do not present a debris generation hazard, passivation of the batteries is not necessary in order to meet the requirement 4.4-2 (56450) for passivation of energy sources “to a level which cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft.” Because passivation is not necessary, and because of the inability to contact DANDE before re-entry due to a solar radiation analysis, there was no need to modify the NiCad’s electrical generation and storage systems.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that the DANDE Micro-sat is compliant. Requirements 4.4-2, 4.4-3 and 4.4-4 are not applicable.

Table: DANDE NiCad Cells

Micro-Sat Name	Model Number	Manufacturer	Number of Cells	Total Energy Stored
DANDE	N-4000DRL	Sanyo	20	96 W-hr

ODAR 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 average cross sectional area and orbital lifetime.

According to NASA-STD 8719.14 section 4.3.4.1, the average cross sectional area (CSA) for DANDE is as follows:

DANDE:
Maximum CSA (A_{max}) from view V of a 46 cm diameter sphere = $(0.46 / 2)^2$ m X π = 0.16619 m^2
CSA from views orthogonal to V (A_1 and A_2) = $(0.46 / 2)^2$ m X π = 0.16619 m^2
Average CSA = (A_{max} + A_1 + A_2) / 3 = 3 X 0.16619 m^2 / 3 = 0.16619 m^2

Mass of DANDE = 38 kg

Mean CSA to mass ratio = 0.16619 m^2 / 38 kg = 0.00432035 m^2/kg

LAB:
Maximum CSA (A_{max}) from view V of a 0.2 m radius disk = 0.2^2 m X π = 0.12566 m^2
CSA from views orthogonal to V (A_1 and A_2) = 0.2 m X π X 0.04 m = 0.025 m^2
Average CSA = (A_{max} + A_1 + A_2) / 3 = (0.12566 m^2 + 0.025 m^2 0.025 m^2) / 3 = 0.05855 m^2

Mean CSA to mass ratio = 0.05855 m^2 / 8 kg = 0.00744 m^2/kg

DANDE orbit parameters:

Perigee = 325 km
Apogee = 1500 km
Inclination = 79°
Launch Date = June 15, 2013 = 2013.455

DAS yields 13.426 years for orbit lifetime which in turn is used to obtain the collision probability.

LAB orbit parameters:

Perigee = 325 km
Apogee = 1500 km
Inclination = 79°

Launch Date = June 15, 2013 = 2013.455

DAS yields 9.577 years for orbit lifetime which in turn is used to obtain the collision probability.

==============
Run Data
==============

INPUT

Space Structure Name = DANDE
Space Structure Type = Payload
Perigee Altitude = 325.000000 (km)
Apogee Altitude = 1500.000000 (km)
Inclination = 79.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Final Area-To-Mass Ratio = 0.00432 (m^2/kg)
Start Year = 2013.000000 (yr)
Initial Mass = 46.00000 (kg)
Final Mass = 38.000000 (kg)
Duration = 1.000000 (yr)
Station-Kept = False
Abandoned = True
PMD Perigee Altitude = -1.000000 (km)
PMD Apogee Altitude = -1.000000 (km)
PMD Inclination = 0.000000 (deg)
PMD RAAN = 0.000000 (deg)
PMD Argument of Perigee = 0.000000 (deg)
PMD Mean Anomaly = 0.000000 (deg)

OUTPUT

Collision Probability = 0.000007
Returned Error Message: Normal Processing
Date Range Error Message: Normal Date Range
Status = Pass

==============

INPUT

Space Structure Name = LAB
Space Structure Type = Payload
Perigee Altitude = 325.000000 (km)
Apogee Altitude = 1500.000000 (km)
Inclination = 79.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 0.000000 (deg)
Mean Anomaly = 0.000000 (deg)
Final Area-To-Mass Ratio = 0.007440 (m^2/kg)
Start Year = 2013.000000 (yr)
Initial Mass = 8.00000 (kg)
Final Mass = 8.000000 (kg)
Duration = 0.010000 (yr)
Station-Kept = False
Abandoned = True
PMD Perigee Altitude = -1.000000 (km)
PMD Apogee Altitude = -1.000000 (km)
PMD Inclination = 0.000000 (deg)
PMD RAAN = 0.000000 (deg)
PMD Argument of Perigee = 0.000000 (deg)
PMD Mean Anomaly = 0.000000 (deg)

OUTPUT

Collision Probability = 0.000002
Returned Error Message: Normal Processing
Date Range Error Message: Normal Date Range
Status = Pass

==============

=============== End of Requirement 4.5-1 ================

The probability of the DANDE spacecraft collision with debris and meteoroids, greater than 10 cm in diameter and capable of preventing post-mission disposal, is 7×10^{-6} which meets the 0.001 maximum probability requirement 4.5-1.

The probability of the Lightband Adapter Bracket collision with debris and meteoroids, greater than 10 cm in diameter and capable of preventing post-mission disposal, is 2×10^{-6} which meets the 0.001 maximum probability requirement 4.5-1.

Since the DANDE spacecraft has no capability or plan for end-of-mission disposal, requirement 4.5-2 is not applicable.

Assessment of spacecraft compliance with Requirements 4.5-1 shows the DANDE spacecraft to be compliant. Requirement 4.5-2 is not applicable to this mission (stated above).

ODAR Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

The spacecraft 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 postmission disposal is not applicable. Disposal is achieved via passive atmospheric reentry.

The area to mass ratio for DANDE will be fixed as no deployments are used on the satellite. Area to mass ratio is calculated using the SolidWorks Program.

The assessment of the spacecraft shows it is compliant with Requirements 4.6-1 through 4.6-5.

<u>DAS Orbital Lifetime Calculations:</u>

DAS inputs are: 325 km apogee X 1500 km perigee altitudes with an inclination of 79 degrees with launch in the year 2013.455. An area to mass ratio of 0.00432 m^2/kg for DANDE was entered (Calculated using SolidWorks). DAS yields an estimated orbital lifetime of 13.426 years well within the requirement. Presented is the DAS input and output:

INPUT

Start Year = 2013.000000 (yr)
Perigee Altitude = 325.000000 (km)
Apogee Altitude = 1500.000000 (km)
Inclination = 79.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 270.000000 (deg)
Area-To-Mass Ratio = 0.004320 (m^2/kg)

OUTPUT

Orbital Lifetime from Startyr = 13.426420 (yr)
Time Spent in LEO during Lifetime = 13.426420 (yr)
Last year of Propagation = 2026 (yr)
Returned Error Message: Object reentered
02 21 2013; 10:07:51AM Processing Requirement 4.6 Return Status : Passed

Also provided is a plot of DANDE's apogee and perigee altitudes over the course of its lifetime. As can be seen they decay in the same amount of time but give a better idea of how DANDE's orbit will change as time goes on.

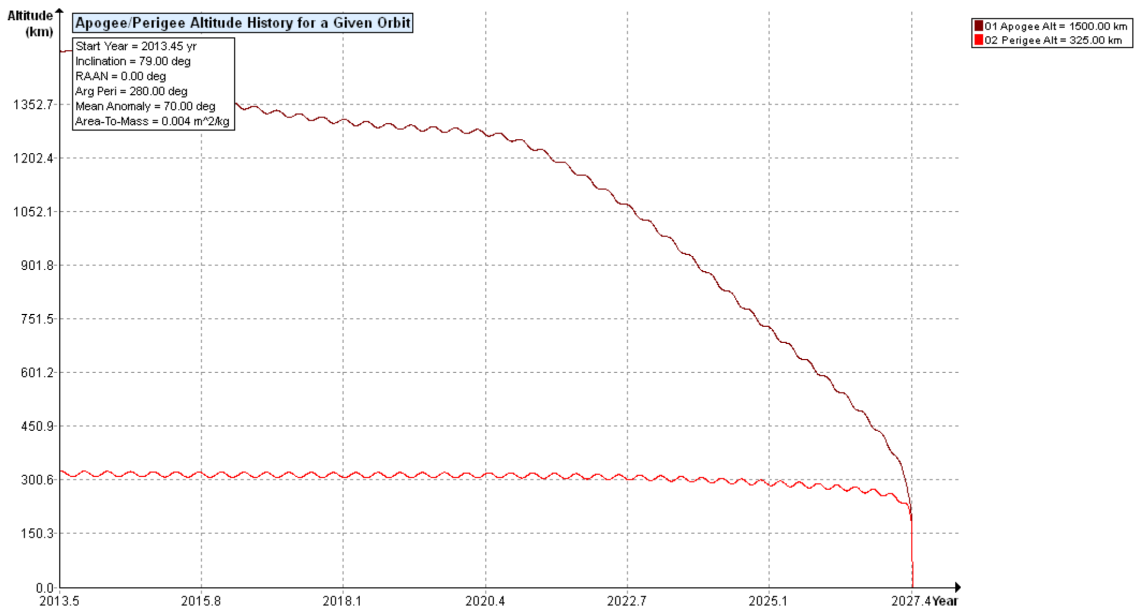


Figure: Deorbit Analysis for DANDE

The LAB's lifetime is slightly different than that of DANDE due to having a different area to mass ratio of 0.00744 (also calculated using SolidWorks). The projected orbital lifetime of the LAB by the DAS software is 9.577 years; also well within the 25 year requirement. Given below is the input and output from the DAS analysis

INPUT

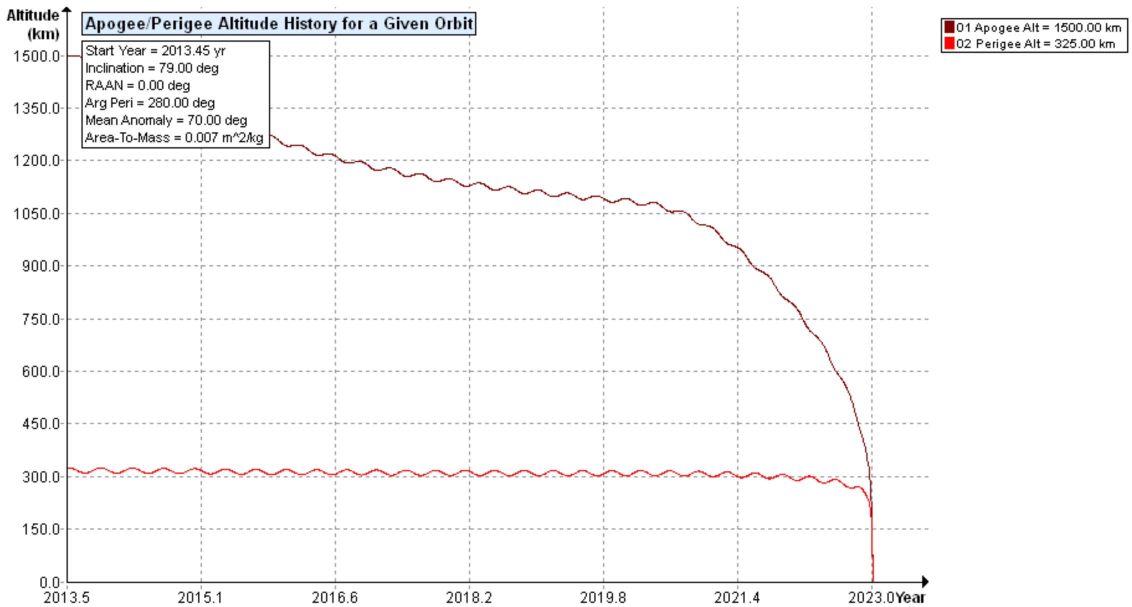
Start Year = 2013.000000 (yr)
Perigee Altitude = 325.000000 (km)
Apogee Altitude = 1500.000000 (km)
Inclination = 79.000000 (deg)
RAAN = 0.000000 (deg)
Argument of Perigee = 270.000000 (deg)
Area-To-Mass Ratio = 0.007440 (m^2/kg)

OUTPUT

Orbital Lifetime from Startyr = 9.577002 (yr)
Time Spent in LEO during Lifetime = 9.577002 (yr)
Last year of Propagation = 2022 (yr)

Returned Error Message: Object reentered

Also provided like above is a plot of the Apogee and Perigee altitudes for the LAB over the course of its life.



Assessment results show compliance with requirement 4.6-1.

ODAR Section 7: Assessment of Spacecraft Re-entry Hazards

A detailed but approximated description of spacecraft components by size, mass, material, shape, and original location on the space vehicle is provided below when/if the atmospheric reentry option is selected.

The DANDE Micro Sat is primarily constructed of aluminum and PCB electronic board material. The only components with a higher density are the stainless steel screws used in the kinetic mount for the LAB which is also steel. These screws and mount will not survive reentry and DANDE does not contain any exotic high density materials.

The DANDE Micro Sat satisfies the 4.7-1 Requirement, Reentry Debris Casualty Risk as determined by DAS using DANDE dimensions. This assessment completes the summary of objects expected to survive an uncontrolled reentry, using NASA Debris Assessment Software (DAS). The input and output of the DAS software are shown at the end of this section.

Probability calculations of human casualty for the expected year of uncontrolled reentry and the spacecraft orbital inclination show that there is no credible risk of human casualty. In the highly unlikely event that any object from a DANDE does survive reentry, the components left would be too small to cause an impact of greater than 15J.

DANDE does not plan for any spacecraft controlled reentry. No preliminary plan for spacecraft controlled reentry is provided.

Assessment of spacecraft compliance with Requirement 4.7-1 shows compliance. The total debris casualty area is zero. Casualty area is $0.0m^2$ with a 1:0 casualty risk for the LAB and $0.0m^2$ with a 1:0 casualty risk for the DANDE Micro Sat. The following section addresses this requirement in detail. (In revision 1.0 components were overestimated and resulted in an unrealistic analysis. This was refined in Revision 2.0 and was determined not to be a problem)

In the very unlikely event that a piece of debris or a fraction of a component object reaches the ground, the necessarily small mass of the component along with the types of materials used in the DANDE Micro Sat virtually ensure that the impact energy of the debris object will be less than 15 J. The only way that DANDE could violate this requirement is through the use of tungsten. It is the only component with a melting point high enough to survive. However, early on the DANDE project realized this and made sure not to use tungsten in the build process. Throughout the DANDE design process the reentry hazard was always held in mind. As such the DANDE Micro Sat possess little to no risk of reentry hazard.

03 02 2013; 11:41:22AM *********Processing Requirement 4.7-1
Return Status : Passed
***********INPUT****
Item Number = 1

name = DANDE
quantity = 1
parent = 0
materialID = 8
type = Sphere
Aero Mass = 38.000000
Thermal Mass = 38.000000
Diameter/Width = 0.460000

name = Sep Box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 6.000000
Thermal Mass = 6.000000
Diameter/Width = 0.200000
Length = 0.250000
Height = 0.200000

name = ACC Box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.220000
Thermal Mass = 1.220000
Diameter/Width = 0.100000
Length = 0.110000
Height = 0.100000

name = ADC Box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.950000
Thermal Mass = 0.950000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.050000

name = Com Box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.390000
Thermal Mass = 1.390000
Diameter/Width = 0.080000
Length = 0.100000
Height = 0.080000

name = CDH Box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.962000
Thermal Mass = 0.962000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.050000

name = EPS Box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.600000
Thermal Mass = 0.600000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.050000

name = Solar Cells
quantity = 72
parent = 1
materialID = 24
type = Box
Aero Mass = 0.020000
Thermal Mass = 0.020000
Diameter/Width = 0.060000
Length = 0.060000
Height = 0.005000

name = Battery
quantity = 20
parent = 1
materialID = 46
type = Cylinder
Aero Mass = 0.270000
Thermal Mass = 0.270000
Diameter/Width = 0.030000
Length = 0.070000

name = NMS Box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.400000
Thermal Mass = 1.400000
Diameter/Width = 0.100000
Length = 0.150000
Height = 0.100000

name = Structure
quantity = 1
parent = 1
materialID = 8
type = Sphere
Aero Mass = 12.000000
Thermal Mass = 12.000000
Diameter/Width = 0.250000

name = Sys Box
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 2.900000
Thermal Mass = 2.900000
Diameter/Width = 0.200000
Length = 0.200000
Height = 0.150000

name = Mount additional
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 2.750000
Thermal Mass = 2.750000

Diameter/Width = 0.100000
Length = 0.150000
Height = 0.100000

name = Bolts
quantity = 1
parent = 1
materialID = 54
type = Cylinder
Aero Mass = 0.103400
Thermal Mass = 0.103400
Diameter/Width = 0.010000
Length = 0.170000

**************OUTPUT****
Item Number = 1

name = DANDE
Demise Altitude = 77.996449
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Sep Box
Demise Altitude = 67.386699
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = ACC Box
Demise Altitude = 71.201847
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = ADC Box
Demise Altitude = 69.898417
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Com Box
Demise Altitude = 68.812011
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = CDH Box
Demise Altitude = 69.799816
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = EPS Box
Demise Altitude = 72.702691
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Solar Cells
Demise Altitude = 77.813504
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Battery
Demise Altitude = 66.897214
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = NMS Box
Demise Altitude = 72.120269
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Structure
Demise Altitude = 46.724873
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Sys Box
Demise Altitude = 70.266480
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Mount additional
Demise Altitude = 67.296917
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Bolts
Demise Altitude = 73.246980
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****

***********INPUT****
Item Number = 2

name = LAB
quantity = 1
parent = 0
materialID = 8
type = Cylinder
Aero Mass = 8.000000
Thermal Mass = 8.000000
Diameter/Width = 0.400000

name = Mounts
quantity = 4
parent = 1
materialID = 54
type = Box
Aero Mass = 0.069750
Thermal Mass = 0.069750
Diameter/Width = 0.030000
Length = 0.030000
Height = 0.010000

**************OUTPUT****
Item Number = 2

name = LAB
Demise Altitude = 77.997910
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****
name = Mounts
Demise Altitude = 63.514648

Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

****

================ End of Requirement 4.7-1
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ODAR Section 8: Assessment for Tether Missions

Since the DANDE satellite does not involve tether deployments, Section 8's requirement 4.8-1 is not applicable and therefore compliant.