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DEBRIS ANALYSIS - OCULUS ASR

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REVISION HISTORY

Revision	Revised By:	Revised On	Changes
-	Robert Matthews	11/21/2013	Initial Release
1	Robert Matthews	12/13/2013	Update to reflect new orbit parameters given by SpaceX

REQUIREMENT VERIFICATION

RVM ID	Requirement Text	Compliant?	See Pages
Requirement 4.3-1	For missions leaving debris in orbits passing through LEO, released debris with diameters of 1 mm or larger shall satisfy both of the following conditions: a. All debris released during the deployment, operation, and disposal phases shall be limited to a maximum orbital lifetime of 25 years from date of release. b. The total object-time product shall be no larger than 100 object-years per mission. The object-time product is the sum over all debris of the total time spent below 2000 km altitude (i.e. LEO dwell time) during the orbital lifetime of each object.	Yes	8
Requirement 4.5-1	Limit catastrophic collisions during orbital lifetime to a probability of collision between a spacecraft or orbital stage and other large objects to less than 0.001.	Yes	8
Requirement 4.5-2	The probability of a disabling collision with small debris and meteoroids must be less than 0.01.	Yes	8,9
Requirement 4.6-1	Space programs and projects shall plan for the disposal of spacecraft and launch vehicle orbital stages and space structures at the end of their respective missions. Postmission disposal shall be used to remove a space structure from Earth orbit in a timely manner or to leave a space structure in a disposal orbit where the structure will pose as small a threat as practical to other space systems.	Yes	9
Requirement 4.7-1	For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001.	Yes	9

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1 ABSTRACT

Oculus ASR will be disposed of using an uncontrolled, atmospheric reentry option. It will be left in orbit where atmospheric drag will limit the lifetime and slow the spacecraft enough to be pulled into the denser atmosphere for disposal. Any space program that uses atmospheric reentry as a means of disposal is required to limit the amount of debris that can survive reentry and pose a threat to people on the surface of the Earth and limit the amount of debris that stays in orbit for future missions' sakes [1]. This applies to full spacecraft as well as jettisoned components, which Oculus ASR has six of: two releasable spheres and four frangibolt heads. NASA's Debris Assessment Software, or DAS, will be used to analyze the requirements for Oculus ASR's atmospheric reentry.

2 INTRODUCTION AND BACKGROUND

2.1 ORBITAL LIFETIME OF DEBRIS RELEASED DURING OPERATION

All debris released during the operation of a spacecraft shall have a maximum orbital lifetime of 25 years in order to limit the amount of debris in the environment over the next 100 years. Debris that is released in LEO will generally have lifetimes of less than 25 years, but the analysis will be run to ensure that Oculus ASR's releasable spheres comply to this requirement.

2.2 LIMITING COLLISONS WITH OTHER OBJECTS IN SPACE

In order to limit the amount of debris that stays in orbit above Earth, the probability of collision with other objects must be analyzed. Any collision with another object by Oculus ASR will produce unwanted debris in orbit, so the probability of collision with a large object must be less than .0001, ensuring the average probability of an operating spacecraft colliding with collision fragments larger than 1 mm from the subject spacecraft or orbital stage will be less than per "average spacecraft" [1]. A collision with a small object while in orbit could render Oculus ASR unable to perform its mission, thus making space debris. In limiting the amount of debris in the space environment, the probability of such a collision must be limited to less than .01.

2.3 DISPOSAL FOR SPACE STRUCTURES PASSING THROUGH LEO

Any space structure in LEO shall be disposed of in a timely manner in order to present as little threat as possible to other space systems. DAS analyzes the structure's orbit and determines compliance by determining whether or not the structure's orbit will decay and ensure destruction.

2.4 RISK OF HUMAN CASUALTY ON SPECECRAFT RE-ENTRY

"The risk of human casualty is determined for objects returning to Earth's surface with a kinetic energy exceeding 15 Joules. The expected debris casualty area is based on the quantity of each surviving object multiplied by its casualty area. The casualty risk is the product of the total expected debris casualty area and the statistical population density based on the orbital inclination and the year of return." [1]. In order to calculate the risk of human casualty, the organization of components within a spacecraft must be defined. DAS uses a hierarchy of components that the user inputs, with "child" objects being exposed to the reentry model only after the "parent" object it is contained within has been destroyed. The software was designed to provide very conservative results, meaning it will classify objects that clearly do not meet NASA-STD-8719.14 as non-compliant, but may also classify some borderline-compliant missions as non-compliant. The objective of this analysis is to determine whether Oculus ASR's structure is compliant with NASA-STD-8719.14, in that the risk for human casualty is less than 1:10,000.

3 SOFTWARE SETUP AND PROCEDURE

3.1 ORBITAL LIFETIME OF DEBRIS RELEASED DURING OPERATION

DAS requires a description of each piece of mission-related debris' orbit, area-to-mass ratio, and release year. Oculus ASR's mission –related debris can be seen in Table 1.

Table 1: Oculus ASR Mission Related Debris

Debris Name	Released Year	Quantity of Each Element	Area-To-Mass (m^2/kg)	Perigee Alt (km)	Apogee Alt (km)	Inclination (deg)
Releasable Sphere	2016	2	.023445	300	844	28.4

3.2 LIMITING COLLISONS WITH OTHER OBJECTS IN SPACE

When DAS analyzes the probability of collisions with other large objects in space, the spacecraft's orbit, area-to-mass ratio, mission duration, and final mass must be supplied to the program. Oculus ASR's information can be seen in Table 2.

Table 2: Oculus ASR Large Object Collision Information

	Space Structure	Perigee (km)	Apogee (km)	Inclination (deg)	RAAN (deg)	Argument ... Perigee (d...	Mission Duration (yrs)	Final Area-To-M... Ratio (m^2/kg)
Oculus-ASR	Payload	300	844	28.4			1	.004887

When analyzing possibly disabling collisions with small objects, DAS requires payload critical surfaces to be identified and described, and a description of the outer walls surrounding these critical surfaces in order to determine if they could possibly be penetrated. The two payload critical surfaces for Oculus ASR are the battery and radio. Figures 1 and 2 show the inputs for both the battery and the radio, respectively.

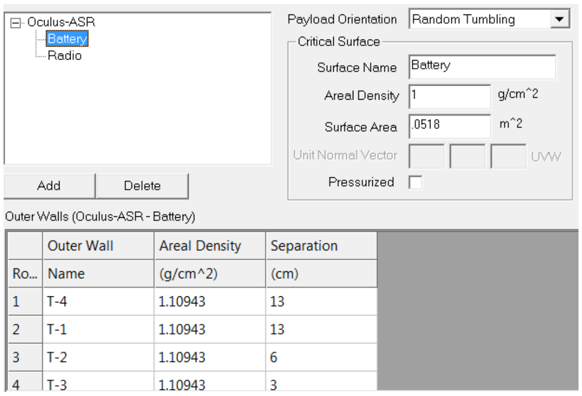

Figure 1: Battery Critical Surface Data

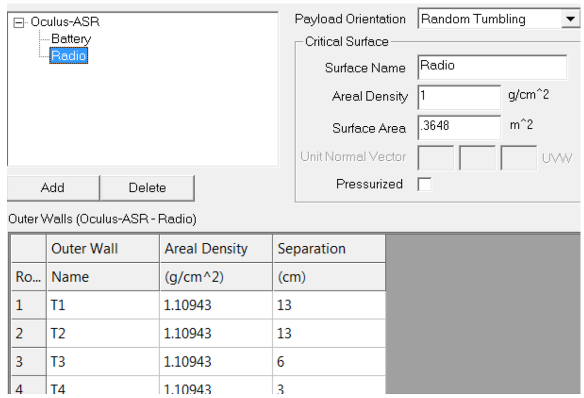

Figure 2: Radio Critical Surface Data

3.3 DISPOSAL FOR SPACE STRUCTURES PASSING THROUGH LEO

In order for DAS to determine if a spacecraft is going to decay in its orbit, the final area-to-mass ratio must be provided, in addition to all orbit information. The input table for Oculus ASR can be seen in Table 3.

Table 3: Orbit Decay Information for Oculus ASR

Space Structu... Name	Perigee Altitude (k...	Apogee Altitude (k...	Inclination (deg)	Final Area-To-M... Ratio (m^2/kg)	PMD Perigee Altitude (km)	PMD Apogee Altitude (km)	PMD Inclinati... (deg)	PMD RAAN (deg)	PMD Argument ... Perigee (deg)	PMD Mean Anomaly (deg)
Oculus-ASR	300	844	28.4	0.005	295	730	28.4	94.5	355.6	0.0

3.4 RISK OF HUMAN CASUALTY ON SPECECRAFT RE-ENTRY

When analyzing atmospheric reentry for the purpose of casualty risk assessment, DAS requires a description of spacecraft components by mass, material, and shape. There is a built-in material database, and the shape of a component can be defined as one of four pre-determined objects: sphere, cylinder, flat plate, or box. All major structural components, component boxes, and large brackets were included in the analysis. No fasteners were analyzed because of their relatively miniscule size and mass when compared to other components; since all fasteners are in the same “parent/child” level of the component hierarchy as the component boxes, it can be assumed that if the large brackets are destroyed before impacting Earth’s surface, the fasteners will also be destroyed in that same time frame. The outer layer of solar panels covering Oculus ASR is the top component in the hierarchy, assumed by the software to demise at 78 km [1], followed by the outer, metal shell and deployable panels. All components contained within Oculus ASR’s body were then made “child” components to the metal shell. The full entry of components into the software can be found in the Appendix, but a sample portion of the entries can be seen in Table 4.

Table 4: Sample Portion of Component Entries into DAS

	Name	Quantity	Material Type	Object Shape	Thermal Mass	Diameter/Width	Length	Height
					(kg)	(m)	(m)	(m)
15	Battery Box	1	Aluminum 6061-T6	Box	1.40	.095	.167	.073
16	Wiring Plate	1	Aluminum 6061-T6	Box	.520	.177	.221	.006
17	Magnetometer	1	Aluminum 6061-T6	Box	.320	.089	.110	.027
18	Power Distribution Box	1	Aluminum 6061-T6	Box	1.40	.155	.170	.069
19	Gyro Box	1	Aluminum 6061-T6	Box	.649	.066	.155	.064
20	Corner Brackets	16	Aluminum 6061-T6	Box	.042	.014	.08	.014

4 ANALYSIS & RESULTS

4.1 ORBITAL LIFETIME OF DEBRIS RELEASED DURING OPERATION

Oculus ASR is compliant with Requirement 4.3-1, having an orbital lifetime of 0.8 years and a total object lifetime of 1.6 object-years. Table 5 shows the DAS output for this requirement.

Table 5: DAS Output for Requirement 4.3-1

Row	Debris Name	Compliance Status	Lifetime (yrs)	Object Time (obj-yrs)
1	Releasable...	Compliant	0.8	1.6

4.2 LIMITING COLLISONS WITH OTHER OBJECTS IN SPACE

Oculus ASR is in compliance with Requirement 4.5-1, with a catastrophic collision probability of 0. This can be seen in Table 6.

Table 6: DAS Output for Requirement 4.5-1

	Space Structure	Compliance Status	Collision Probability
Oculus-ASR	Payload	Compliant	0.00000

Oculus ASR is also compliant with Requirement 4.5-2, having a probability for PMD failure through a collision with a small object in space of 0.000001. The battery and radio both have a penetration probability of 0. This can be seen in Table 7.

Table 7: DAS Output for Requirement 4.5-2

Spacecraft	Compliance Status	Probability of PMD Failure	Critical Surface	Probability of Penetration
Oculus-ASR	Compliant	0.000001	Battery	0.000000
			Radio	0.000000

4.3 DISPOSAL FOR SPACE STRUCTURES PASSING THROUGH LEO

Oculus ASR has been determined by DAS analysis to comply with Requirement 4.6-1. This can be seen in Table 8.

Table 8: DAS Output for Requirement 4.6-1

Space Structu... Name	Space Structu... Type	Compliance Status	Suggested Perig... Altitude (km)	Suggested Apo... Altitude (km)
Oculus-ASR	Payload	Compliant		

Suggested perigee and apogee altitude have been left blank because Oculus ASR's planned orbit is already sufficient to enter an atmospheric disposal.

4.4 RISK OF HUMAN CASUALTY ON SPECECRAFT RE-ENTRY

Oculus ASR is in compliance with Requirement 4.7-1, having a probability for human casualty of .000054 (1:18,600) upon re-entry for disposal. Table 9 shows the compliance output by DAS.

Table 9: DAS Output for Requirement 4.7-1

Object Name	Compliance Status	Risk of Hu... Casualty	SubCompo... Object	Demise Altitude (k...	Total Debris Casualty Ar...	Kinetic Energy (J)
Oculus-ASR	Compliant	1:18600			2.67	

The full listing of components in the results of this analysis can be found in the Appendix.

4.5 CONCLUSIONS

Oculus ASR has been found in compliance with every requirement analyzed, and conforms to all required end of life standards.

5 WORKS CITED

[1] John N. Opiela *et al.,* "DAS 2.0 User's Guide," NASA, Houston, TX, January 2012

6 APPENDIX

Full Component List

	Name	Quantity	Material Type	Object Shape	Thermal Mass (kg)	Diameter/Width (m)	Length (m)	Height (m)
1	Oculus-ASR	1	FR4	Box	45	.423	.759	.423
2	Deployable Panels	4	Aluminum 6061-T6	Flat Plate	.75	.293	.417	
3	Metal Shell	1	Aluminum 6061-T6	Box	17.6	.417	.756	.417
4	ASR Struts	4	Aluminum 6061-T6	Box	.6	.038	.287	.038
5	ASR Lower Mounts	4	Aluminum 6061-T6	Box	.373	.038	.329	.02
6	Magtorquers	3	Aluminum 6061-T6	Box	.465	.038	.206	.038
7	Shared Struts	4	Aluminum 6061-T6	Box	.328	.032	.737	.032
8	Interface Plate	1	Aluminum 6061-T6	Box	1.817	.405	.405	.006
9	Charge Controller Box	1	Aluminum 6061-T6	Box	1.443	.147	.221	.056
10	OBDC Box	1	Aluminum 6061-T6	Box	1.946	.147	.221	.094
11	Telcom Box	1	Aluminum 6061-T6	Box	.684	.124	.124	.073
12	Magcontroller Box	1	Aluminum 6061-T6	Box	.672	.085	.160	.039
13	OBDC Oculus Box	1	Aluminum 6061-T6	Box	1.90	.147	.221	.094
14	Center Panel	1	Aluminum 6061-T6	Box	1.30	.405	.405	.006
15	Battery Box	1	Aluminum 6061-T6	Box	1.40	.095	.167	.073
16	Wiring Plate	1	Aluminum 6061-T6	Box	.520	.177	.221	.006
17	Magnetometer	1	Aluminum 6061-T6	Box	.320	.089	.110	.027
18	Power Distribution Box	1	Aluminum 6061-T6	Box	1.40	.155	.170	.069
19	Gyro Box	1	Aluminum 6061-T6	Box	.649	.066	.155	.064
20	Corner Brackets	16	Aluminum 6061-T6	Box	.042	.014	.08	.014
21	Lower Brackets	8	Aluminum 6061-T6	Box	.055	.022	.08	.014
22	Releasable Sphere	2	Aluminum 6061-T6	Sphere	.336	.1		

Requirement 4.7-1 Full Results

Object Name	Compliance Status	Risk of Human Casualty	SubComponent Object	Demise Altitude (km)	Total Debris Casualty Area (m**2)	Kinetic Energy (J)
Oculus-ASR	Compliant	1:18600			2.67	
			Deployable Panels	75.0	0.00	0
			Metal Shell	67.6	0.00	0
			ASR Struts	62.1	0.00	0
			ASR Lower Mounts	63.4	0.00	0
			Magtorquers	61.7	0.00	0
			Shared Struts	66.4	0.00	0
			Interface Plate	0.0	0.79	441
			Charge Controller ...	51.8	0.00	0
			OBDC Box	52.7	0.00	0
			Telcom Box	58.2	0.00	0
			Magcontroller Box	59.3	0.00	0
			OBDC Oculus Box	53.2	0.00	0
			Center Panel	0.0	0.79	226
			Battery Box	55.4	0.00	0
			Wiring Plate	0.0	0.55	148
			Magnetometer	61.3	0.00	0
			Power Distribution ...	0.0	0.54	936
			Gyro Box	61.4	0.00	0
			Corner Brackets	65.5	0.00	0
			Lower Brackets	65.2	0.00	0
Releasable...	Compliant	1:0		65.0	0.00	0