CubeSat Team		
CubeSat name / number	US02 Atlantis & US04 Columbia	
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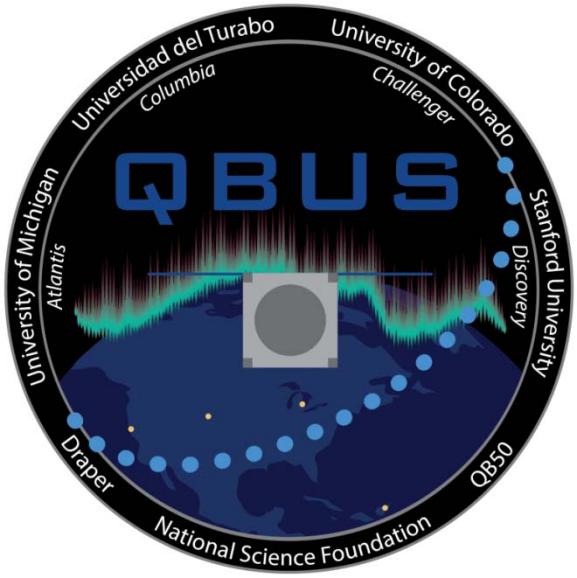
QB50
Orbital Debris Assessment Report (ODAR)



Rev A • 18 February 2016

Prepared for NASA HQ in compliance with NASA-STD-8719.14 by the University of Michigan
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NASA Debris Analysis Software (DAS) version 2.02 was used in preparing this report.

Submitted by:

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Table of Contents

Self-Assessment and OSMA Assessment of the ODAR

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.

Req. #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant	Not Compliant	Incomplete	
4.3-1.a	☐	☐	☒	☐	☒	☐	☐	N/A
4.3-1.b	☐	☐	☒	☐	☒	☐	☐	N/A
4.3-2	☐	☐	☒	☐	☒	☐	☐	N/A
4.4-1	☐	☐	☒	☐	☒	☐	☐	Compliant
4.4-2	☐	☐	☒	☐	☒	☐	☐	Compliant
4.4-3	☐	☐	☒	☐	☒	☐	☐	N/A
4.4-4	☐	☐	☒	☐	☒	☐	☐	N/A
4.5-1	☐	☐	☒	☐	☒	☐	☐	Compliant
4.5-2	☐	☐	☒	☐	☒	☐	☐	N/A
4.6-1(a)	☐	☐	☒	☐	☒	☐	☐	Compliant
4.6-1(b)	☐	☐	☒	☐	☒	☐	☐	N/A
4.6-1(c)	☐	☐	☒	☐	☒	☐	☐	N/A
4.6-2	☐	☐	☒	☐	☒	☐	☐	N/A
4.6-3	☐	☐	☒	☐	☒	☐	☐	N/A
4.6-4	☐	☐	☒	☐	☒	☐	☐	N/A
4.7-1	☐	☐	☒	☐	☒	☐	☐	Compliant
4.8-1	☐	☐	☒	☐	☒	☐	☐	N/A

Assessment Report Format

ODAR Technical Sections Format Requirements

- This ODAR follows the format in NASA-STD-8719.14, Appendix A.1, and include the content indicated at a minimum in each section 2 through 8 below for the Atlantis & Columbia satellites. Sections 9 through 14 apply to the launch vehicle ODAR, and are not covered here.

ODAR Section 1: Program Management and Mission Overview

- Aaron Ridley, Principal Investigator, ridley@umich.edu
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Foreign government or space agency participation: The overall QB50 project is supported through the European Commission's FP7 program.

Summary of NASA's responsibility under the governing agreement(s): N.A.

Schedule of mission design and development milestones from NASA mission selection through proposed launch date, including spacecraft PDR and CDR (or equivalent) dates:

Milestone	Date
Preliminary Design Review	April 1, 2015
Critical Design Review	April 1, 2016
Flight Readiness Review	July 1, 2016
CubeSat Delivery to Nanoracks	August 1, 2016
CubeSat Integration into Deployers	August 15, 2016
Anticipated Launch Date	November 1, 2016
Release from ISS, Begin Operation	January 1, 2016

Mission Overview

This ODAR is for two satellites (Atlantis & Columbia) within the QB50 constellation mission. This constellation of satellites will measure how the thermospheric and ionospheric density changes in the auroral zone across multiple spatial and temporal scales in the hope of determining the dynamics and propagation of high latitude effects to the equatorial zone. This mission is a unique opportunity to measure the dynamics of the lower thermosphere and ionosphere with a variety of sensors spread throughout an orbital plane.

The QB50 mission, if successful, will provide upper atmospheric data continuously over an entire orbit. The community has never had such an opportunity before, and, most likely, will not for many years to come. The CubeSat described within this document integrate thoroughly tested commercial off the shelf (COTS) components into satellites that have been designed for missions with lower costs and shorter lifetimes than traditional NASA-funded satellites. The majority of these components have flown on at least one mission and many of them will fly on at least two other missions before the two satellites described here are delivered for flight.

Atlantis & Columbia will be launched as a secondary payload on the to the ISS. The satellite will be ejected from the ISS, placed into an orbit approximately 400 x 420 km at an inclination of 51.6 deg.

Launch Vehicle and Launch Site:
The launch vehicle is a Cygnus CRS-8 Orb-7/Antares scheduled for launch from Cape Canaveral AFS.

Proposed Launch Date: Dec 30, 2016

- No earlier than September 1, 2016

Mission Duration:

- 90 days to 2.3 years in LEO operation, until atmospheric reentry via orbital decay.

Launch and deployment profile, including all parking, transfer, and operation orbits with apogee, perigee, and inclination.

- Atlantis & Columbia and Columbia are a secondary Nanoracks payload and will be deployed from the ISS.
- The rocket will deliver the Nanoracks manifest to the ISS. The Atlantis & Columbia spacecraft will remain within the Nanoracks deployer and will be later ejected from the ISS. They will be deployed by an externally mounted deployment system.
- The Atlantis & Columbia satellite has no propulsion and therefore does not actively station keep. There is no parking or transfer orbit.
- At this time, we know of no potential interaction of physical interference between Atlantis & Columbia and any other operational spacecraft.

ODAR Section 2: Spacecraft Description

Atlantis & Columbia are a two identical 2U CubeSat carrying the FIPEX payload. Structurally, they're made of Aluminum 6061-T6 and structurally based on heritage designs for 1U and 3U CubeSats at the University of Michigan. The structure is specifically designed for rigidity, while minimizing mass, and has been previously qualified and flown in the other configurations. The attitude determination and control block is again based off of heritage components previously flown at the University of Michigan. It will include three magnetorquers made in house, coarse sun sensors, a series of off-the-shelf magnetometers mounted on deployed panels, and an inertial measurement unit. The electrical power system will consist of solar cells, a voltage regulation system, a simple set-point tracker and two Panasonic lithium-ion batteries (18650) with over-charge/current protection circuitry. The on-board data handling system will employ a STAMP9G20 processor, 2 SD cards, and a watchdog timer baselined from previous missions. This will allow the telemetry, tracking, and control system to employ a monopole antenna, which has been flight proven, along with heritage radio systems, in order to relay FIPEX data back to our ground stations at the University of Michigan, or any of the other ground stations in the United States QB50 network.

The overall deployed satellite form will be a 10x10x24 cm rectangle with four wing style polycarbonate dart panels deploying off the 10x20 cm. The total spacecraft mass is expected to be approximately 1.9 kg.

There are no pressure vessels, hazardous or exotic materials.

ODAR Section 3: Assessment of Spacecraft Debris Released during Normal Operations

The assessment of spacecraft debris requires the identification of an 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 the 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 of each object after release, calculated orbital lifetime of each object, including time spent in Low Earth Orbital (LEO), and an assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2.

No objects (>1 mm) are expected to be released from the spacecraft any time after launch. Therefore Atlantis & Columbia is COMPLIANT with Requirements 4.3-1 and 4.3-2.

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

There are NO plans for designed spacecraft breakups, explosions, or intentional collisions on the QB50 mission. No passivation of components is place at the End of Mission for the Atlantis & Columbia Spacecraft.

The probability of battery explosion is very low, and, due to the very small mass of the satellite and the short orbital lifetime, the effect of an explosion on the far-term LEO environment is negligible.

The CubeSats batteries still meet Requirement 56450 (4.4-2) by virtue of the HW OSMA policy regarding CubeSat battery disconnect stating:

> "CubeSats as a satellite class need not disconnect their batteries if flown in LEO with orbital lifetimes less than 25 years"

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that, with a lifetime of 2.3 years maximum, the Atlantis & Columbia CubeSat are COMPLIANT.

ODAR Section 5: Assessment of Spacecraft Potential for On-Orbit Collisions

Lifetime Analysis

The orbital lifetime of Atlantis & Columbia were calculated using DAS 2.0.2. The Atlantis & Columbia orbit at deployment is 420 km apogee by 400 km perigee altitude at 51.6 deg inclination. The mass of the spacecraft is approximately 1.6 kg and the ram direction cross sectional area (location of drag force from atmosphere) is 0.1m x 0.1m producing an area-to-mass ratio of 0.00625 m^2/kg. With these parameters, the calculated orbit lifetime before reentry is 2.3 years.

Assessment of spacecraft compliance with Requirements 4.5-1 and 4.5-2 (per DAS v2.0.2):

Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during orbital lifetime of the spacecraft takes into account the largest single face cross sectional area and orbital lifetime.

The largest single face cross section of Atlantis & Columbia is the anti-nadir face which, with the two wing panels deployed, is approximately 0.25m x 0.226m yielding a cross sectional area of 0.0565m^2. Figure 1 below shows this anti-nadir face with the wing panels deployed.

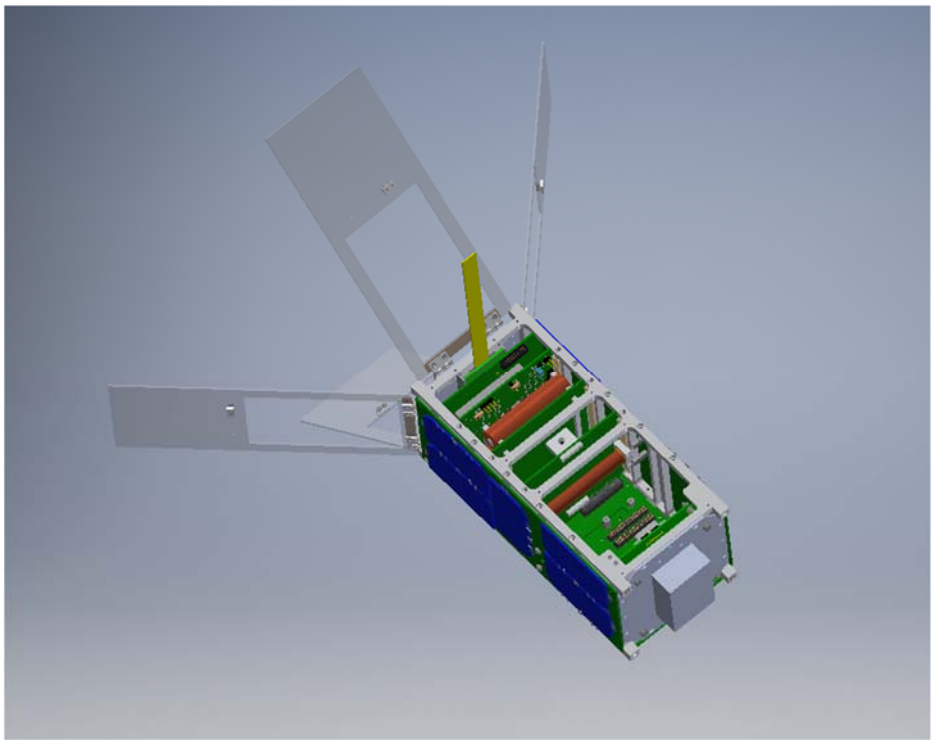

Figure 1: Atlantis & Columbia CubeSat with Wing Panels and Antenna Deployed

The probability of the Atlantis & Columbia spacecraft colliding with space objects larger than 10cm in diameter is calculated using DAS 2.0.2 to be 0.00000 (lower than the significant figure limit of the program). This shows that Atlantis & Columbia are COMPLIANT with Requirement 4.5-1 (56506) which requires that this probability be less than 0.001.

Since Atlantis & Columbia has no capability or plan for end-of-mission disposal beyond atmospheric reentry, requirement 4.5-2 is not applicable.

ODAR Section 6: Assessment of Spacecraft Post Mission Disposal Plans and Procedures

The Atlantis & Columbia spacecraft will naturally decay from orbit within 25 years after end of the mission, satisfying Requirement 4.6-1a detailing the spacecraft disposal option.

The orbital lifetime of Atlantis & Columbia was calculated using DAS 2.0.2. The Atlantis & Columbia orbit at deployment is 420 km apogee by 400 km perigee altitude at 51.6 deg inclination. The mass of the spacecraft is approximately 1.6 kg and the ram direction cross sectional area (location of drag force from atmosphere) is 0.1m x 0.1m producing an area-to-mass ratio of 0.00625 m^2/kg. With these parameters, the calculated orbit lifetime before reentry is 2.3 years.

Requirements 4.6-2 and 4.6-3 are not applicable as Atlantis & Columbia is in a LEO orbit.

Planning for spacecraft maneuvers to accomplish post mission disposal and assessment of the reliability of post mission disposal operations are not applicable. Atlantis & Columbia have no propulsion system and disposal is achieved via passive atmospheric reentry. These two statements show that Requirement 4.6-4 is not applicable for the Atlantis & Columbia spacecraft.

ODAR Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on Atlantis & Columbia was performed. The assessment used DAS 2.0.2, a conservative tool used by the NASA Orbital Debris Office to verify Requirement 4.7-1. The analysis is intended to provide a bounding analysis for characterizing the survivability of a CubeSat's component during re-entry. For example, when DAS shows a component surviving reentry it is not taking into account the material ablating away or charring due to oxidative heating. Both physical effects are experienced upon reentry and will decrease the mass and size of the real-life components as the reenter the atmosphere, reducing the risk they pose still further.

The following steps are used to identify and evaluate a components potential reentry risk relative to the 4.7-1 requirement of having less than 15 J of kinetic energy and a 1:10,000 probability of a human casualty in the event the survive reentry.

1. Low melting temperature (less than 1000 °C) components are identified as materials that would never survive reentry and pose no risk to human casualty. This is confirmed through DAS analysis that showed materials with melting temperatures equal to or below that of copper (1080 °C) will always demise upon reentry for any size component up to the dimensions of a 1U CubeSat.

2. The remaining high temperature materials are shown to pose negligible risk to human casualty through a bounding DAS analysis of the highest temperature components, stainless steel (1500°C). If a component is of similar dimensions and has a melting temperature between 1000 °C and 1500°C, it can be expected to possess the same negligible risk as stainless steel components. See Table 1.

Table 1: Atlantis & ColumbiaSurvivability DAS Analysis

High Temp Component	Material	Mass (g)	Length / Diameter (m)	Width (m)	Height (m)	Demise Alt (km)	KE (J)
FIPEX	Aluminum	160					
UHF Whip Antenna	Steel 410	10	0.1	0.013	0.164	0	1
SEP Switch Plunger	Stainless Steel 18-8	2.35	0.0045	0.027	0.005	74.9	0
Mounting Screw	316 Stainless Steel	0.1	0.004	0.007	-	77.6	0

The majority of high temperature components demise upon reentry. The components that DAS conservatively identifies as reaching the ground have less than or equal to 1 joule of kinetic energy, far below the requirement of 15 joules. No high temperature component will pose a risk to human casualty as defined by the Range Commander's Council. In fact, an injury incurred or inflicted by an object with such low energy would be negligible and wouldn't require the individual to seek medical attention.

Through the method described above and the full component list in the Appendix, Atlantis & Columbia are conservatively shown to be COMPLIANT with Requirement 4.7-1.

ODAR Section 7A: Assessment of Spacecraft Hazardous Materials

Not Applicable. There are no hazardous materials contained on the spacecraft.

ODAR Section 8: Assessment for Tether Missions

No tether will be used; this section is not applicable. Atlantis & Columbiais COMPLIANT with Requirement 4.8.1.

ODAR Sections 9-14

ODAR sections 9-14 for the launch vehicle are not covered by this document.

Appendix:

Satellite Name: Atlantis & Columbia					
Material	**Quantity**	**Unit Mass (g)**	**Total Mass (g)**	**Unit Surface Area mm^2**	**Usage**
STRUCTURE					
6061-T6 Al / Anodizing	1	89.268	89.268	23434.6	Structure
6061-T6 Al / Anodizing	1	122.414	122.414	34130.9	Structure
6061-T6 Al / Anodizing	2	107.524	215.048	32526.4	Structure
6061-T6 Al / Anodizing	1	47.784	47.784	18821.3	Structure
GaLnP2 / Gallium Arsenide / Germanium Substrate	15	3	45	1750.0	Power Supply
FR4 glass-reinforced epoxy laminate	4	18	72	106.0	PCB
FR4 glass-reinforced epoxy laminate	5		0	212.0	PCB
Polycarbonate	4	0.00005	0.0002	38213.0	Deployables
316 Steel	8	0.232	1.856	80.0	Deployables
6061-T6 Al/Anodizing	8	1.344	10.752	695.0	Deployables
6061-T6 Al / Anodizing	8	0.234	1.872	389.0	Deployables
ULTEM	5	69	345	84.6	Battery mount
Omron D2F-L-T	2	0.5	1		Sep Switch Plunger
Omron D2F-L2-T	1	0.5	0.5		Sep Switch Roller
Black Oxide Alloy Steel	30	10	300	56.0	Screws (M6)
CRES Steel Alloy	30	4	120	88.6	Nuts (M6)
ADCS					
Copper Wire	1	37.4	37.4		ADCS Magnetorquer
Iron Cores	3	22.6	67.8		ADCS Magnetorquer
Aluminum 6061	2	5.6	11.2		ADCS Magnetorquer Supports
ULTEM	2	7	14		ADCS Magnetorquer Wire Stops
SFH 2430	12		0		Angled Photodiodes
Epson M-G362PDC1	1	7	7		IMU
Teflon Coated Wire			0		Wiring and Harnesses
Epoxy: EPOTEK-H20 E	5	2.5	12.5	30.6	Potting Material
Epoxy: EPOTEK-921	5	2.5	12.5	31.6	Potting Material
Loctite	5	2	10	33.6	Adhesive
Wire	5	12	60	34.6	PCB interconnects

Solder	5	1	5	35.6	PCB Interconnects
CD&H					
410 Steel	1	3	3	28.6	UHF Whip Antenna
FR4 glass-reinforced epoxy laminate	1				Antenna Board
Honeywell HMC5883L	1	0.018	0.018		Magnetometer
DS3234			0		RTC (SPI)
DS3231			0		RTC (I2C)
EPS					
Panasonic Li-Ion	4	46.5	186		Batteries