AeroCube-5 (AC5) Summary Orbital Debris Assessment Report (ODAR)

Revision 4
November 13, 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

Software Used in This Analysis: The Aerospace Corporation MEANPROP and TRACE, Programs, and NASA DAS V2.02

FINAL APPROVAL*: *Approval signatures are acceptance of the ODAR-defined risk.

____
David Hinkley
Picosat Project Leader
The Aerospace Corporation

____
Richard Welle
Director, Mechanics Research Department
The Aerospace Corporation

____
Gary Hawkins
Principal Director, Space Materials Laboratory
The Aerospace Corporation

Record of Revisions

Rev	Date	Pages	Description	Author
1.0	2013/03/31	11	First revision, requires signatures	D. Hinkley
1.1	2013/04/16	11	Wording changes	D. Hinkley
2	2013/10/23	11	Wording changes	D. Hinkley
2.1	2013/11/4	11	Revised Tether and DAS2 analysis; changed numbers in table “Orbital Debris Self-Assessment Report Evaluation: AeroCube-5 Mission” and edited Section 5 to update impact of tether.	D. Hinkley
2.2	2013/11/5	11	Finalized section 8.	D. Hinkley
3	11/13/13	10	Edited section 3 for object-years explanation. Edited section 5 for cumulative collision and small object collision.	D. Hinkley

4	5/9/15	10	Corrected references to space debris	D. Hinkley

Table of Contents

Attachments

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: AeroCube-5 Mission

Requirement		**Compliance Assessment**	**Comments**
4.3-1a	planned debris in LEO	Compliant	Worst case lifetime 3.7 yrs, DAS2.02 and A-011113-1
4.3-1b	object x time <100	Compliant	22 object-years (DAS2.02)
4.3-2	planned debris in GEO	Compliant	No planned debris release in GEO
4.4-1	risk of explosion <.001	Compliant	On board energy source (batteries) incapable of debris-producing failure
4.4-2	explosion passivation plan	Compliant	On board energy source (batteries) incapable of debris-producing failure
4.4-3	planned breakup	Compliant	No planned breakups
4.4-4	planned breakup	Compliant	No planned breakups
4.5-1	10 cm collision <0.001	Compliant	DAS2.02 and A-011413-1
4.5-2	disabling collision <.01	Compliant	DAS2.02
4.6-1(a)	LEO decay <25 years	Compliant	Worst case lifetime 23 yrs, DAS2.02 and A-010813-1
4.6-1(b)	storage orbit	Compliant	N/A - natural decay
4.6-1(c)	direct retrieval	Compliant	N/A - natural decay
4.6-2	GEO	Compliant	N/A – LEO mission
4.6-3	MEO	Compliant	N/A – LEO mission
4.6-4	disposal plan reliability	Compliant	Passive disposal
4.6-5	orbit passivation plan	Compliant	No passivation needed
4.7-1	human casualty 1:10,000	Compliant	DAS2.02
4.8-1	10 cm collision <.001	Compliant	A-011413-1

ODAR Section 1: Program Management and Mission Overview

Mission Directorate: The Aerospace Corporation, PicoSatellite Group
Program Executive: Gary Hawkins
Program Manager: Richard Welle
Project Leader: David Hinkley

Mission Overview:
Mission type: Technology demonstration
Developer: The Aerospace Corporation, El Segundo, CA USA
Organization: Private Non-profit Federally Funded Research and Development Center

An identical pair of 1.5U AeroCube-5 CubeSat picosatellites each weighing 2.1 kg will eject from a P-POD launcher into a 469 x 972 x 120 degree inclination orbit. Each AeroCube-5 consists of a communication payload and a suite of 2 mega pixel cameras. The satellites will communicate with each other at different ranges and take pictures of each other. They will also point to the ground and take pictures of the earth.

The AeroCube-5 was built with funding from The Aerospace Corporation's Independent Research and Development (IR&D) program. Please contact the project leader David Hinkley at 310-336-5211 or david.a.hinkley@aero.org for more information.

ODAR Section 2: Spacecraft Description

Physical description of the spacecraft: The AeroCube-5 is a 1.5U picosatellite with dimensions of approximately 10.5 cm x 10.5 cm x 16.5 cm that weighs 2.1 kg.

The AeroCube-5 satellites contain the following systems: one Flight Computer system, one GPS system, one Commercial Radio system, one Advanced Radio system, one Attitude control system, one beacon, and one Solar Power system. In addition, each satellite has a deployable de-orbit device called a "Cube Satellite Tether Terminator" or CSTT, manufactured by Tether's Unlimited, Inc.

- The Flight computer system is the central processing system of the satellite to coordinate commands between the subsystems.
- The GPS system will have a patch antenna and control electronics
- The Commercial Radio system will have a patch antenna and control electronics. It operates at 915 MHz.

- The Advanced Radio system will have a patch antenna and control electronics. It operates at 915 MHz.
- The Attitude control system will have triaxial reaction wheels, triaxial torque coils, triaxial magnetometers, one rate gyro, and earth and sun sensors.
- The beacon will have one beacon module, one MoliCel IBR18650B Lithium Ion battery and control electronics.
- The Solar Power system will have two MoliCel ICR18650J Lithium Ion batteries and control electronics.
- The CSTT is a 12 meter long x 75 mm wide ribbon stowed under a panel on the outside of the spacecraft. Upon ground command, the panel is detached and the ribbon unfurls. No debris is created but the satellite cross section increases.

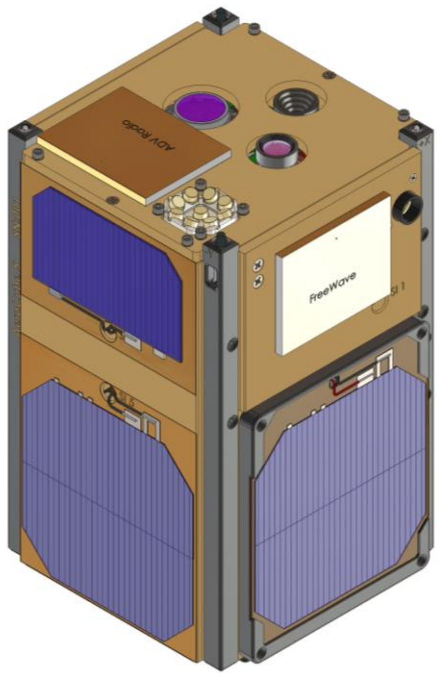

Figure: AeroCube-5 1.5U CubeSat (2 total)

Total satellite mass: 2.1 kg

Description of all propulsion systems (cold gas, mono-propellant, bi-propellant, electric, nuclear): There is no propulsion on any of the AeroCube-5 satellites

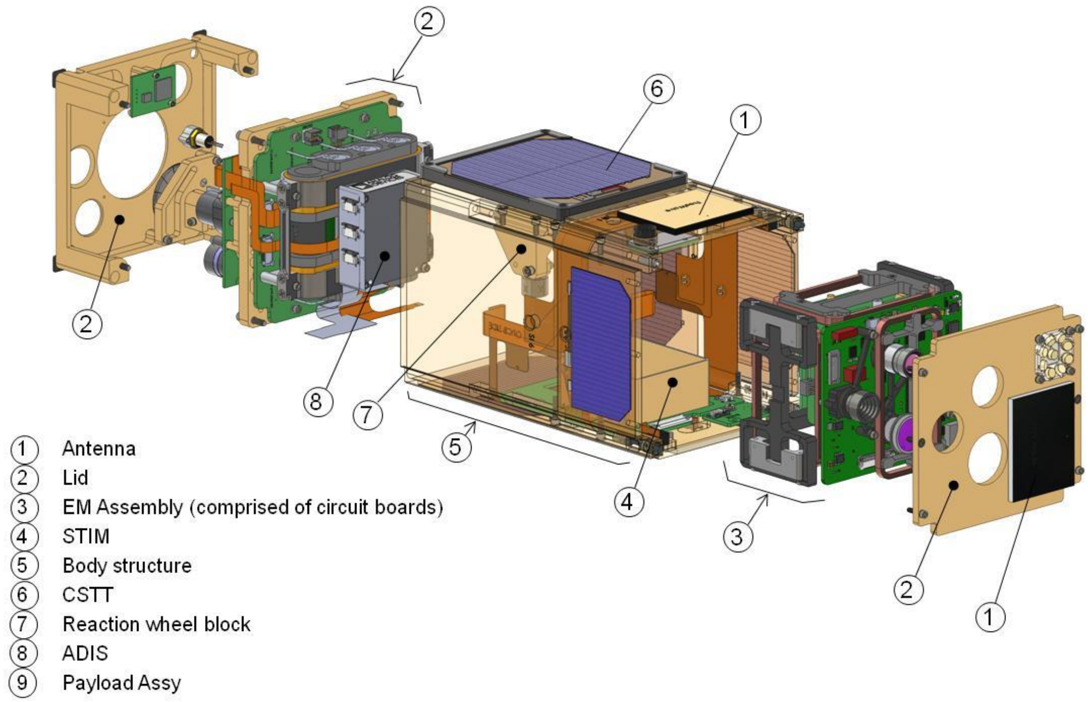

Figure: AeroCube-5 Expanded View

Identification, including mass and pressure, of all fluids (liquids and gases) planned to be on board and a description of the fluid loading plan or strategies, excluding fluids in sealed heat pipes: Not applicable. There are no fluids or gasses on board.

Fluids in Pressurized Batteries: Not applicable. The batteries are unpressurized.

Description of attitude control system and indication of the normal attitude of the spacecraft with respect to the velocity vector: The AeroCube-5 satellites typically tumble in their orbit with an uncontrolled attitude. During operations, the satellites can orient one face in the nadir direction or perform inertial pointing.

Description of any range safety or other pyrotechnic devices: The AeroCube-5 satellites do not have any pyrotechnic devices.

Description of the electrical generation and storage system: Power will be generated using solar panels and stored in three lithium ion batteries. These batteries have flown on multiple previous missions with the exception of the IBR18650B. The dimensions of each battery are 18 mm diameter x 65 mm length and the weight is 45 grams.

Identification of any other sources of stored energy not noted above: None.

Identification of any radioactive materials on board: None.

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. Section 3 requires rationale/necessity for 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 (apogee, perigee, and inclination) of each object after release, calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO), and an assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2.

The satellites themselves will become debris after they are decommissioned 1 or 2 years after launch. In the worst case where the tether is not deployed (which would deorbit the satellites in less than 1 year), the orbit lifetime is predicted to be 23 years. This is acceptable because it is less than the 100 year limit listed in NASA-STD-8719.14 Requirement 4.3-1b: “The total object-time product shall be no larger than 100 object-years per mission.”

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

The assessment of spacecraft compliance with Requirements 4.4-1 and 4.4-2 considers items on the satellite that might explode and the plan for their passivation. The batteries are the only stored potential energy on the satellite. The possible malfunction of Lithium ion batteries or of their charge control circuitry has been generically identified by NASA as a potential cause for spacecraft breakup during deployment and mission operations. However, the batteries specific to AeroCube-5 have been short circuit and overcharge tested at Aerospace and by Underwriters Laboratories (see Table below) demonstrating that no explosion and subsequent fragmentation occurs. Therefore, no passivation of batteries is planned at the End of Mission for AeroCube-5.

Table: AeroCube-5 CubeSat Li-Ion Cells

CubeSat Name	Model Number (UL Listing)	Manufacturer	Number of Cells	Total Energy Stored
AeroCube-5	ICR-18650J (MH 27672)	Molicel	2	18 W-hr

	IBR-18650B (MH 27672)	Molicel	1	7.6W-hr

The AeroCube-5 batteries are UL recognized. They have passed the UL standard testing procedures that characterize their explosive potential. Of particular concern to NASA Req. 56450 is UL Standard 1642, which specifically deals with the testing of lithium batteries. Section 20 Projectile Test of UL 1642 (ref. (e)) subjects the test battery to heat by flame while within an aluminum and steel wire mesh octagonal box, "[where the test battery] shall remain on the screen until it explodes or the cell or battery has ignited and burned out" (UL 1642 20.5). To pass the test, "no part of an exploding cell or battery shall penetrate the wire screen such that some or all of the cell or battery protrudes through the screen" (UL 1642 20.1).

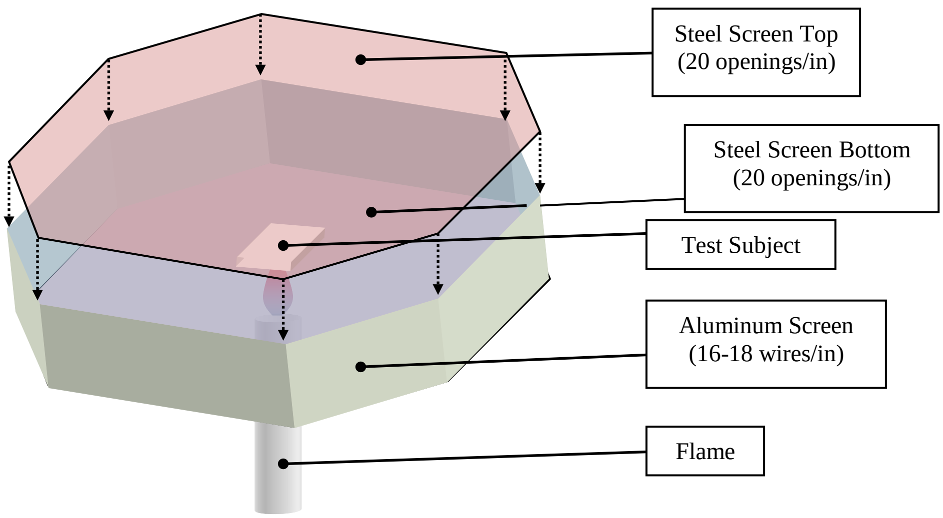

Figure: Underwriters Laboratory Explosion Test Apparatus

It is acceptable to expect the batteries being launched via CubeSat to experience similar conditions during their orbital life span. While the source of failure would not be external heat on orbit, analysis of the expected mission thermal environment performed by NASA LSP Flight Analysis Division shows that given the very low (<=26 W-h, maximum for AeroCube-5) power dissipation for CubeSats, the batteries will be exposed to a maximum temperature that is well below their 212°F safe operation limit (ref. (f)). Continual charging with 2 to 6 W of average power from the solar panels over an orbital life span greater than 12 years may expose the batteries to overcharging which could cause similar heat to be generated internally. Through the UL recognition and testing, it has been shown that these batteries do not cause an explosion that would cause a fragmentation of the spacecraft.

Through a combination UL certification, compliance with AFSPCMAN 91-710 V3 requirements, and an understanding of the general behavior of the failure modes associated with these types of batteries it is possible to conclude that Requirement 56450 is satisfied. Specifically, these batteries will "not cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft" (Requirement 56450).

The AeroCube-5 has no plans for intentional breakup and instead is predicted to decay naturally in 23 years (Aerospace Corporation analysis A-010813-1). Requirements 4.4-3 and 4.4-4 are therefore not applicable.

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

The calculation of the 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 mean cross sectional area and orbital lifetime. The nominal end-of-life configuration of AeroCube-5 is with a deployed tether. Within this configuration space, cases were considered where the tether was deployed but severed, creating two objects at the worst possible place. Of all the cases analyzed, Case 2 (tether in gravity gradient alignment, no libration) in Aerospace analysis A-110513-1 predicts the large object collision probability: 8.1×10^{-5}. The cumulative large object collision probability for the mission is the sum of the two satellites (tether deployed in gravity gradient alignment, no libration). The total probability is 0.9×10^{-4}. This meets the 0.001 threshold in the AFI 91-217. See FCC application exhibits for references cited.

Calculation of spacecraft probability of collision with small debris and meteoroids during the orbital lifetime of the spacecraft takes into account both the mean cross sectional area and orbital lifetime. AeroCube-5 will deorbit in 23 years after launch with no tether deployed. However, the plan is to deploy the tether after a 1 or 2 year mission. The tether will deorbit the satellite within 1 year after tether deployment. DAS 2.02 predicted the probability of small debris impact of less than the 0.01 threshold in the AFI 91-217. See FCC application DAS 2.02 Output exhibit.

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

AeroCube-5 complies with requirements 4.6-1 through 4.6-5. It is predicted to naturally decay from its LEO orbit in 23 years without a tether deployment (DAS2.02, Aerospace analysis A-010813-1) and substantially quicker with a tether deployment (Aerospace analysis A-010813-1), satisfying requirement 4.6-1a of an orbit lifetime of less than 25 years.

ODAR Section 7: Assessment of Spacecraft Re-entry Hazards

AeroCube-5 does not plan for any spacecraft controlled reentry. No preliminary plan for spacecraft controlled reentry is provided.

The AeroCube-5 CubeSats are primarily constructed of aluminum and PCB electronic board material. The only components with a higher density or resistance to melting are the stainless steel screws, ceramic patch antennas and three small stainless steel reaction wheels. The bill of materials for AeroCube-5 was distilled to a short list of components of mass larger than 10 grams that was input to DAS2.02 for analysis of casualty risk.

The AeroCube-5 CubeSat satisfies the 4.7-1 Requirement, Reentry Debris Casualty Risk as determined by DAS 2.02. See attached document with DAS2.02 output. AeroCube-5 complies with Requirement 4.7-1. The total debris casualty area is zero. Casualty expectation is zero.

ODAR Section 8: Assessment for Tether Missions

Each AeroCube-5 CubeSat deploys a 75mm x 12 meter tether to speed reentry. This was not assessed by DAS2.02 because the program provided an error message stating that it would not do this calculation because, “the orbit is elliptical.” Instead, a separate Aerospace Corporation analysis (A-110513-1) concludes that the collision probability with the tether deployed nominally but also with the tether severed at the worst location, using the MSFC 50th percentile, are less than the 0.001 threshold required by AFI 91-217.