AggieSat4 / Bevo-2

Orbital Debris Assessment Report (ODAR)

In accordance with NPR 8715.6A, this report is presented as compliance with the required reporting format, per NASA-STD-8719.14A (with Change 1), APPENDIX A.

Version: March 10, 2014

DAS 2.0.2 Software used in this analysis

AggieSat4 / Bevo-2

Orbital Debris Assessment Report (ODAR)

Approved By

Darryl May
Program Manager

Prepared By

Zane Singleton
Payload Integration Engineer

Table of Contents

Self-assessment and OSMA assessment of the ODAR using the format in Appendix A.2 of NASA-STD-8719.14A

Reqm't #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant or N/A	Not Compliant	Incomplete	
4.3-1.a			X		X			See Note 1. No debris released.
4.3-1.b			X		X			See Note 1. No debris released.
4.3-2			X		X			See Note 1. No debris released.
4.4-1			X		X			See Note 1.
4.4-2			X		X			See Note 1.
4.4-3			X		X			See Note 1. No planned breakups.
4.4-4			X		X			See Note 1. No planned breakups.
4.5-1			X		X			See Note 1.
4.5-2			X		X			See Note 1. No subsystems needed for EOM disposal.
4.6-1(a)			X		X			See Note 1.
4.6-1(b)			X		X			See Note 1.
4.6-1(c)			X		X			See Note 1.
4.6-2			X		X			See Note 1.
4.6-3			X		X			See Note 1.
4.6-4			X		X			See Note 1.
4.7-1			X		X			See Note 1.
4.8-1			X		X			See Note 1. No tethers used.

Notes:

1. This is a NASA primary mission and there are many other payloads manifested. Contact NASA for more information concerning the Launch Vehicle.

Assessment Report Format

ODAR Technical Sections Format Requirements:

This ODAR follows the format in NASA-STD-8719.14A, Appendix A.1 and includes the content indicated at a minimum in each section 2 through 8 below for the AggieSat4 satellite. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered here.

ODAR Section 1: Program Management and Mission Overview

Mission Directorate: NASA/JSC/EG

Program Manager: Darryl May, NASA/JSC

Principle Investigator:

AggieSat4: Dr. Helen Reed, Texas A&M University

Bevo-2: Dr. Glenn Lightsey, University of Texas at Austin

Foreign government or space agency participation: NASA International Space Station (ISS), with ancillary JAXA participation (Cyclops satellite deployer utilizes the ISS JAXA JEM airlock)

Schedule of upcoming mission milestones:

PSRP Phase III	July 2014
Hardware turnover	September 2014
Launch	November 2014

Mission Overview: AggieSat4 is planned for flight to the International Space Station (ISS) aboard a NASA SpaceX launch vehicle in the pressurized portion. It will then be deployed from ISS, via the Cyclops satellite deployment platform. Part of the AggieSat4 mission includes releasing a 3U CubeSat, Bevo-2, from within its structure and demonstrating basic communications with it while in range.

Launch vehicle and launch site: SpaceX Falcon 9, Cape Canaveral Air Force Station, FL

Proposed launch date and mission duration:

SpaceX: no earlier than November 2014

SpaceX mission duration: approximately 30 days

AggieSat4/Bevo-2 deploy from ISS: approximately 1-2 months after SpaceX launch

AggieSat4 mission duration: 1.210 years

Bevo-2 mission duration: 1.331 years

Launch and deployment profile: AggieSat4 will be deployed from ISS, which is at an approximate 407 km perigee, 415 km apogee, and 51.6 degree inclination orbit. Bevo-2 will be deployed from AggieSat4 shortly after, once a safe distance from the ISS, per the NASA Payload Safety Review Panel (PSRP) direction. AggiesSat4 and Bevo-2 do not contain any propellant for changing orbits, and therefore have no parking or transfer orbit.

Reason for selection of orbit: AggieSat4/Bevo-2 is being deployed from ISS, via the Cyclops satellite deployment platform.

Interaction with other spacecraft: AggieSat4 is inhibited from operating until after deployed from Cyclops and a safe distance from the ISS, per the NASA Payload Safety Review Panel process. Bevo-2 is further inhibited until deployed from AggieSat4. AggieSat4 is designed to communicate with the Bevo-2 satellite after releasing it.

ODAR Section 2: Spacecraft Description

AggieSat4 is a 54.9 kg satellite, designed by AggieSat Lab at Texas A&M University, which will carry and release Bevo-2, a 4.2 kg 3U CubeSat, designed and built by the University of Texas at Austin. AggieSat4 and Bevo-2 together will be demonstrating basic technologies that will feed forward to an autonomous rendezvous and docking demonstration, planned for the next satellite pair, at a later phase in the joint campaign. The major objectives are to demonstrate 3-axis stabilization, collect GPS data, capture evidence of Bevo-2 release, compute and crosslink relative navigation solutions, and track Bevo-2 based on these solutions.

AggieSat4's primary structure is 27.2" x 29.3" x 13.8". Body mounted solar cells (234 UTJ Solar Cells) will provide charging to two battery packs that power the spacecraft while on orbit. Each battery pack includes 9 Li-Ion LG ICR 18650 C1 cells in series; one battery box will be used to power AggieSat4 at any given time, while the other charges to provide redundancy. Each battery pack has a nominal voltage of 33.75 V, a maximum voltage of 39.15 V, and a capacity of 94.5 Wh (for a total capacity of 189 Wh). There will also be four coin cell batteries to power the timers for the power up inhibits; Panasonic CR 1220, with nominal voltage of 3 V and capacity of 35 mAh.

Two pairs of GPS antennas and four radio antennas are attached for attitude determination and ground communications. The two side panels (+ and –y) each have two handles for astronauts to use while on the ISS. The ISIS ISIPOD release mechanism and a camera are positioned on the front face (-x) to allow for the release of Bevo-2. On the interior of the spacecraft, there is also a reaction wheel and torque coil on each major axis for attitude control, two low-data-rate (LDR) radios, a high-data-rate (HDR) radio, a crosslink radio for short-range communication with the Bevo-2 satellite, six sun sensors, the ISIS ISIPOD, and the Bevo-2 satellite. See Figure 2-1.

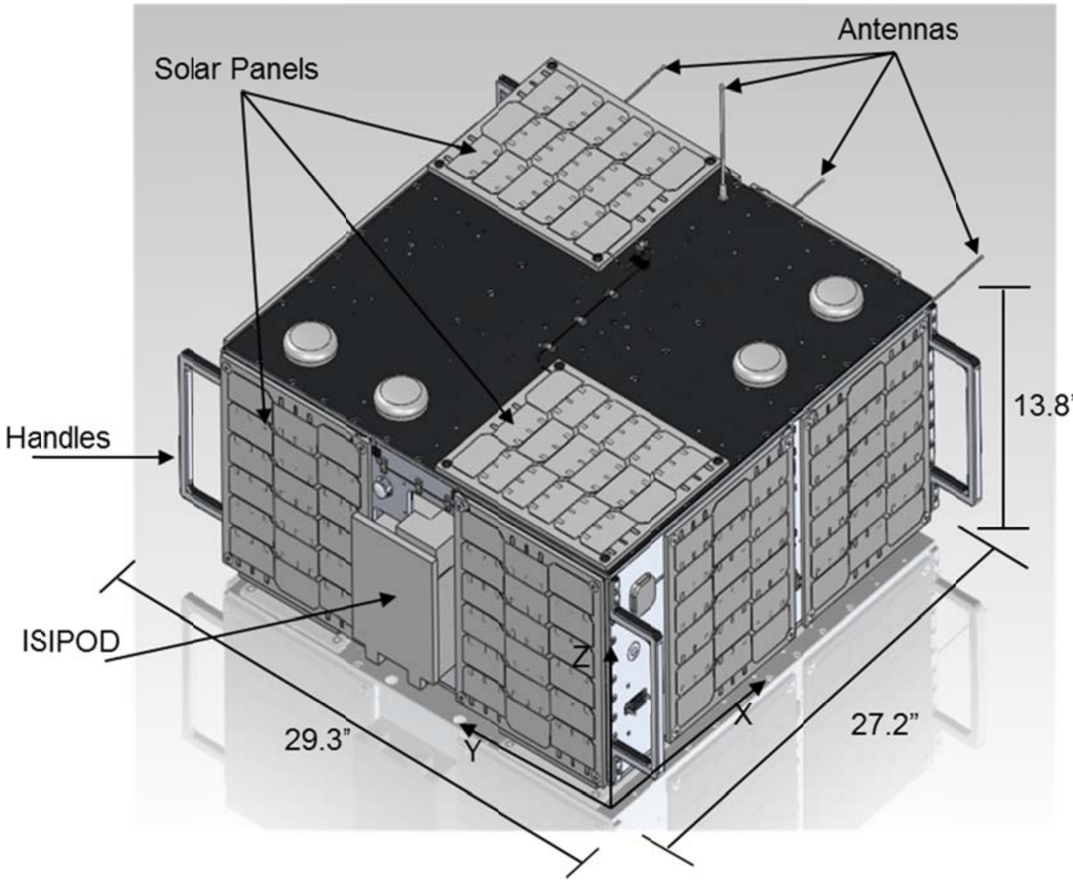

Figure 2-1 AggieSat4 Spacecraft

Bevo-2 is a 4.2 kg, 3U CubeSat (10 x 10 x 34 cm) that will be deployed from AggieSat4, after AggieSat4 has been deployed from the ISS, via Cyclops. Bevo-2 is contained within an ISIS ISIPOD that is mounted within the AggieSat4 structure. Body mounted solar cells (24 Spectrolab UTJ Solar Cells) will provide charging to a battery pack that powers the spacecraft while on orbit, once released from AggieSat4. The battery pack includes 6 Varta PoLiFlex PLF 503759 C cells, in a 2-series 3-parallel configuration, with a nominal voltage of 7.4 V and capacity of 3.6 Ah.

Bevo-2 has four 6" deployable radio antennas and GPS patch antennas for attitude determination and ground communications. Inside there are reaction wheels on each axis, gyros, magnetometer, magnetorquer, star tracker, sun sensor, a UHF/VHF radio, a crosslink radio for short-range communication with the AggieSat4 satellite, and a cold gas thruster module. The thruster module contains 90 grams of Dupont R-236fa refrigerant, at a pressure below 100 psia at 56 degrees C. The toxicity hazard level of the refrigerant is a "0", per NASA JSC assessment. See Figures 2-2.

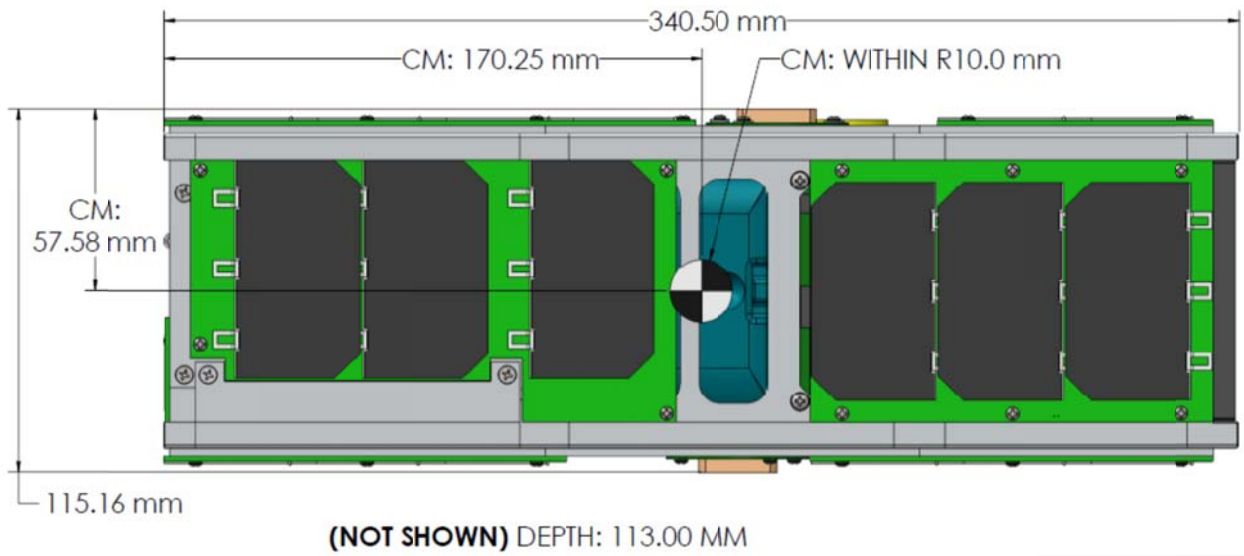

Figure 2-2 Bevo-2 Spacecraft

The normal attitude of the satellites will be LVLH, with the small faces into the ram, in order to maximize orbit lifetime.

AggieSat4/Bevo-2 is completing the NASA PSRP process, certifying its safety for flight to and deploy from the ISS, and including on-orbit lifetime and reentry safety.

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

Identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material: There are no intentional releases.

Rationale/necessity for release of each object: N/A.

Time of release of each object, relative to launch time: N/A.

Release velocity of each object with respect to spacecraft: N/A.

Expected orbital parameters (apogee, perigee, and inclination) of each object after release: N/A.

Calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO): N/A.

Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2 (per DAS v2.0.2)

4.3-1, Mission Related Debris Passing Through LEO: Compliant

4.3-2, Mission Related Debris Passing Near GEO: Compliant

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

Potential causes of spacecraft breakup during deployment and mission operations:

There is no credible scenario that would result in spacecraft breakup during normal deployment and operations.

Summary of failure modes and effects analyses of all credible failure modes which may lead to an accidental explosion:

In-mission failure of a battery cell protection circuit could lead to a short circuit resulting in overheating and a very remote possibility of battery cell explosion. The battery safety systems discussed in the FMEA (see requirement 4.4-1 below) describe the combined faults that must occur for any of the independent, mutually exclusive, failure modes that could lead to a battery explosion.

Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions:

There are no planned breakups.

List of components which shall be passivated at End of Mission (EOM) including method of passivation and amount which cannot be passivated:

None.

Rationale for all items which are required to be passivated, but cannot be due to their design:

Based on the DAS analysis, AggieSat4 will only be on orbit for 1.210 years, and Bevo-2 for 1.331 years, and they are planned to operate until deorbiting. Therefore, no postmission passivation will be performed, as the satellite will break up on re-entry at the end of the mission.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4:

Requirement 4.4-1: Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon:

For each spacecraft and launch vehicle orbital stage employed for a mission, the program or project shall demonstrate, via failure mode and effects analyses or equivalent analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle is less than 0.001 (excluding small particle impacts) (Requirement 56449).

Compliance statement:

Required Probability: 0.001.

Expected probability: 0.000.

Supporting Rationale and FMEA details:

Battery explosion:

Effect: All failure modes below might result in battery explosion with the possibility of orbital debris generation. However, in the unlikely event that a battery cell does explosively rupture, the small size, mass, and potential energy, of these batteries is such that while the spacecraft could be expected to vent gases, all debris from the battery rupture should be contained within the vessel due to the lack of penetration energy.

Probability: Very Low. It is believed to be less than 0.1%, given that multiple independent (not common mode) faults must occur for each failure mode to cause the ultimate effect (explosion). The failure modes listed below are per NASA JSC PSRP guidelines, certifying the satellite for launch, onboard ISS, and on-orbit lifetime.

Failure mode 1: Battery short circuit, internal/external.

Mitigation:

- Battery is designed with proper wire sizing, insulation, and fuse protection, per NASA JSC letter TA-92-038.
- Integrated circuitry, and testing of, providing external short circuit protection, allowing them to withstand an external short without creating a hazard and/or disconnecting the battery if current rises above the maximum limit.
- Complete battery/cell qualification testing per JSC ISS PSRP guidelines.
- Complete cell inspection and vibration acceptance testing to screen out defective cells.
- Perform functional testing following these tests.

Combined faults required for realized failure: **Multiple** of the above must be ineffective in discovery of the failure mode.

Failure Mode 2: Cell reversal or over-discharge

Mitigation:

- In addition to Failure Mode 1 mitigation:
- Cells matched to within 2% capacity to reduce the possibility of uneven discharge between cells.
- Integrated circuitry, and testing of, to monitor cell voltage and prevent over-discharge of the battery if any cell or battery is less than the safety cutoff voltage.
- Integrated circuitry, and testing of, to control over-discharge through current monitoring, with a cutoff threshold when the pack reaches 20% of its total capacity.

Combined faults required for realized failure: **Multiple** of the above must be ineffective in discovery of the failure mode.

Failure Mode 3: Overcharging

Mitigation:

- In addition to Failure Mode 1 mitigation:
- Integrated circuitry, and testing of, is used to monitor cell voltage and prevent overcharging of the battery if any cell or battery is greater than the safety cutoff voltage.

Combined faults required for realized failure: **Multiple** of the above must be ineffective in discovery of the failure mode.

Failure Mode 4: Thermal extremes

Mitigation:

- In addition to Failure Mode 1 mitigation:
- Thermal analysis to verify the battery cell temperatures are within the cell manufacturer's specifications.
- Testing at worst case temperatures to confirm that the batteries are safe under these conditions.

Combined faults required for realized failure: **Multiple** of the above must be ineffective in discovery of the failure mode.

Requirement 4.4-2: Design for passivation after completion of mission operations while in orbit about Earth or the Moon:

Design of all spacecraft and launch vehicle orbital stages shall include the ability to deplete all onboard sources of stored energy and disconnect all energy generation sources when they are no longer required for mission operations or post mission disposal or control to a level which can not cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft (Requirement 56450).

Compliance statement:

Based on the DAS software, AggieSat4 will only be on orbit for 1.210 years, and Bevo-2 for 1.331 years, and they are planned to operate until deorbiting. Therefore, no postmission passivation will be performed, as the satellite will break up on reentry at the end of the mission.

Therefore, the AggieSat4/Bevo-2 batteries will meet the above requirement.

Requirement 4.4-3: Limiting the long-term risk to other space systems from planned breakups:

Compliance statement:

This requirement is not applicable because there are no planned breakups.

Requirement 4.4-4: Limiting the short-term risk to other space systems from planned breakups:

Compliance statement:

This requirement is not applicable because there are no planned breakups.

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

Assessment of spacecraft compliance with Requirements 4.5-1 and 4.5-2 (per DAS v2.0, and calculation methods provided in NASA-STD-8719.14, section 4.5.4):

Requirement 4.5-1. Limiting debris generated by collisions with large objects when operating in Earth orbit: For each spacecraft and launch vehicle orbital stage in or passing through LEO, the program or project shall demonstrate that, during the orbital lifetime of each spacecraft and orbital stage, the probability of accidental collision with space objects larger than 10 cm in diameter is less than 0.001 (Requirement 56506).

Large Object Impact and Debris Generation Probability:

AggieSat4: Compliant; Probability 0.00000

Bevo-2: Compliant; Probability 0.00000

Requirement 4.5-2. Limiting debris generated by collisions with small objects when operating in Earth or lunar orbit: For each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and meteoroids sufficient to prevent compliance with the applicable postmission disposal requirements is less than 0.01 (Requirement 56507).

Small Object Impact and Debris Generation Probability:

AggieSat4: Not applicable; there are no subsystems that are vital to completing postmission disposal.

Bevo-2: Not applicable; there are no subsystems that are vital to completing postmission disposal.

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

Description of spacecraft disposal option selected:

The satellites will de-orbit naturally by atmospheric reentry.

Identification of all systems or components required to accomplish any postmission disposal operation, including passivation and maneuvering

None.

Plan for any spacecraft maneuvers required to accomplish postmission disposal:

None.

Calculation of area-to-mass ratio after postmission disposal, if the controlled reentry option is not selected:

Spacecraft Mass:

AggieSat4: 50.7 kg

Bevo-2: 4.2 kg

Average Cross-Sectional Area:

AggieSat4: 0.339 m^2

Bevo-2: 0.026 m^2

Area to mass ratio:

AggieSat4: 0.006687692 m^2/kg

Bevo-2: 0.006190476 m^2/kg

Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-4:

Requirement 4.6-1. Disposal for space structures passing through LEO: A spacecraft or orbital stage with a perigee altitude below 2000 km shall be disposed of by one of three methods: (Requirement 56557)

a. Atmospheric reentry option:
   - Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission but no more than 30 years after launch; or
   - Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission.

b. Storage orbit option: Maneuver the space structure into an orbit with perigee altitude greater than 2000 km and apogee less than GEO - 500 km.
c. Direct retrieval: Retrieve the space structure and remove it from orbit within 10 years after completion of mission.

Analysis: The AggieSat4/Bevo-2 satellites' reentry is Compliant using Method "a". Based on the DAS analysis (with the values above as inputs), AggieSat4 will only be on orbit for 1.210 years, and Bevo-2 for 1.331 years.

Requirement 4.6-2. Disposal for space structures near GEO.

Analysis: Not applicable; AggieSat4/Bevo-2 orbit is LEO.

***Requirement 4.6-3. Disposal for space structures between LEO and GEO*.**

Analysis: Not applicable; AggieSat4/Bevo-2 orbit is LEO.

Requirement 4.6-4. Reliability of Postmission Disposal Operations

Analysis: AggieSat4/Bevo-2 de-orbiting does not rely on de-orbiting devices. Release from the ISS, via Cyclops, with a downward and retrograde vector will result in de-orbiting without additional actions required.

ODAR Section 7: Assessment of Spacecraft Reentry Hazards

Assessment of spacecraft compliance with Requirement 4.7-1:

Requirement 4.7-1. Limit the risk of human casualty: The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules:

a. For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000) (Requirement 56626).

Analysis: Per DAS 2.0.2, and assuming a worst case where the satellite is represented as one item:

AggieSat4: Compliant; risk of human casualty 1:40,800

Bevo-2: Compliant; risk of human casualty 1:0

ODAR Section 8: Assessment of Tether Missions

Not applicable because there are no tethers in the AggieSat4/Bevo-2 mission.

END of ODAR for AggieSat4/Bevo-2