Phoenix CubeSat Orbital Debris Statement

In accordance with 47 CFR 5.64, the Phoenix CubeSat complies with all orbital debris mitigation criteria. The assessment below was performed in NASA DAS 2.1.1

Phoenix ODAR Self-Assessment Evaluation

Req. No.	**Spacecraft**			**Comments**
	Compliant	Not Compliant	Incomplete	
4.3-1.a	X			No debris released in LEO
4.3-1.b	X			No debris released in LEO
4.3-2	X			No debris released in GEO
4.4-1	X			See Note 1
4.4-2	X			See Note 1
4.4-3	X			No planned breakups
4.4-4	X			No planned breakups
4.5-1	X			
4.5-2	X			
4.6-1.a	X			
4..6-1.b	X			
4.6-1.c	X			
4.6-2	X			
4.6-3	X			
4.6-4	X			
4.6-5	X			
4.7-1	X			
4.8-1	X			No tethers used

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

Identification of any object (>10 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material:
There are no intentional releases. All elements on board the satellite are fixed to the spacecraft.

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)

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

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

The only potential scenarios for on board failures which could result in an explosion would be in the case of either a battery cell or thermal subsystem failure. An in-mission failure of the protection circuitry in the battery cell would lead to a short circuit, causing the component to become overheated and potentially explode.

Supporting Rationale and FMEA details:

Payload Pressure Vessel Failure:

The payload is an airtight system, making the pressure differential within the camrea a significant risk as the satellite launches from standard atmospheric conditions to the space environment. An accumulation of positive pressure inside of the payload during ascent would cause the lens to explode, and the satellite would be unable to perform the mission objective. Therefore procedures will taken in order to properly vent the camera, thereby eliminating the risk of a potential explosion.

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

Assessment of Spacecraft Compliance with Requirement 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).*

Compliance: COMPLIANT
Large Object Impact and Debris Generation Probability: 0.000

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).*

Compliance: COMPLIANT
Small Object Impact and Debris Generation Probability:
On Board Computer: 2.2×10^{-5}
Li-Ion Batteries: 0.0
UHF Receiver: 1.9×10^{-5}

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

Identification of any object (>10 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material:
There are no intentional releases. All elements on board the satellite are fixed to the spacecraft.

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)

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 for Spacecraft Breakup
There are no scenarios which would result in a breakup of the satellite during mission lifetime.

Summary of failure modes and effects analysis of all credible failure modes which may lead to an accidental explosion:
The only potential scenarios for on board failures which could result in an explosion would be in the case of either a battery cell failure. An in-mission failure of the protection circuitry in the battery cell would lead to a short circuit, causing the component to become overheated and potentially explode.

Detailed Plan for any designed spacecraft breakup, including explosions and intentional collisions:
No planned breakups

List of components passivated at EOM:
No components are scheduled to be passivated at the end of the mission lifetime.

Rationale for all items required to be passivated that cannot be due to design:
N/A.

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: COMPLIANT
Required Probability: 0.001.
Expected probability: 0.000

Supporting Rationale and FMEA details:
Payload Pressure Vessel Failure:
The payload is airtight and will be vented with a #66 bit to prevent burst.

Battery Explosions

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 small batteries is such that while the spacecraft could be expected to vent gases, most debris from the battery rupture should be contained within the vessel due to the lack of penetration energy.

Probability: Extremely Low. It is believed to be less than 0.01% given that multiple independent (not common mode) faults must occur for each failure mode to cause the ultimate effect (explosion).

Failure mode 1: Internal short circuit.

Mitigation 1: Qualification and acceptance vibration, thermal cycling, and vacuum tests followed by maximum system rate-limited charge and discharge to prove that no internal short circuit sensitivity exists.

Combined faults required for realized failure: Environmental testing **AND** functional charge/discharge tests must both be ineffective in discovery of the failure mode.

Failure Mode 2: Internal thermal rise due to high load discharge rate.

Mitigation 2: Cells will be tested in lab for high load discharge rates in a variety of flight like configurations to determine if the feasibility of an out of control thermal rise in the cell. Cells will also be also tested in a hot environment to test the upper limit of the cells capability.

Combined faults required for realized failure: Spacecraft thermal design must be incorrect **AND** external over current detection and disconnect function must fail to enable this failure mode.

Failure Mode 3: Overcharging and excessive charge rate.

Mitigation 3: The satellite bus battery charging circuit design eliminates the possibility of the batteries being overcharged if circuits function nominally with the inclusion of battery control regulator circuitry. This circuit has been protoqualification tested for survival in shock, vibration, and thermal-vacuum environments prior to shipment. The charge circuit disconnects the incoming current when the discharge current exceeds 2A for a period of time larger than 10 ms. If this circuit fails to operate, continuing charge can cause gas generation. The batteries include overpressure release vents that allow gas to escape, virtually eliminating any explosion hazard.

Combined faults required for realized failure:

1) **For overcharging:** The battery control regulator circuit must fail to function **AND** the PTC device must fail (or temperatures generated must be insufficient to cause the PTC device to modulate) **AND** the overpressure relief device must be inadequate to vent generated gases at acceptable rates to avoid explosion.
2) **For excessive charge rate:** The maximum charging rate from a single solar panel when in AM 1.5G conditions (in space, perpendicular to the sun) is 434 mA. The maximum charge rate our battery can accept is 8 A. The battery is a proto-qualified manned flight ISS compatible 3U battery cell, provided by Clyde Space. The battery itself has four parallel strings of 2 cells connected in series, and thus having 8 cells. Due to solar panel current limits and their direction-facing arrangement on the satellite, there is no physical means of exceeding charging rate limits, even if only a single string from the battery was accepting charge. For this failure mode to become active one string must fail to accept a charge **AND** the charge control circuit on the remaining string fails. The overpressure relief vent keeps the battery cells from rupturing, and is thus limited to worst-case effects of overcharging.

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 on-board 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: COMPLIANT

Requirement 4.4-3: *Limiting the long-term risk to other space systems from planned breakups*
Compliance: Not applicable. There are no planned breakups throughout the mission lifetime

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

Compliance: Not applicable. There are no planned breakups throughout the mission lifetime

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

Assessment of Spacecraft Compliance with Requirement 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).*

Compliance: COMPLIANT
Large Object Impact and Debris Generation Probability: 0.000

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).*

Compliance: COMPLIANT
Small Object Impact and Debris Generation Probability:
On Board Computer: 2.2×10^{-5}
Li-Ion Batteries: 0.0
UHF Receiver: 1.9×10^{-5}

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

6.1 Description of spacecraft disposal option selected

The satellite will naturally decay in orbit to burn up in the Earth's atmosphere upon reentry. There will be no deorbiting assistance through the use of propulsion systems.

6.2 Plan for any spacecraft maneuvers required to accomplish postmission disposal

There will be no maneuvers. The satellite has no propulsion.

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

Mass: 3.5 kg

Spacecraft Average Cross-Sectional Area: $0.053 m^2$ (calculated by DAS 2.1.1 for the configuration shown in Figure 1)

Area/Mass Ratio (m^2/kg): $\frac{0.053}{3.5} = 0.0151\ m^2/kg$

6.4 Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5 (per DAS v 2.0 and NASA-STD-8719.14 section):

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):*

Analysis: The Phoenix CubeSat will naturally reenter the atmosphere after 2 years

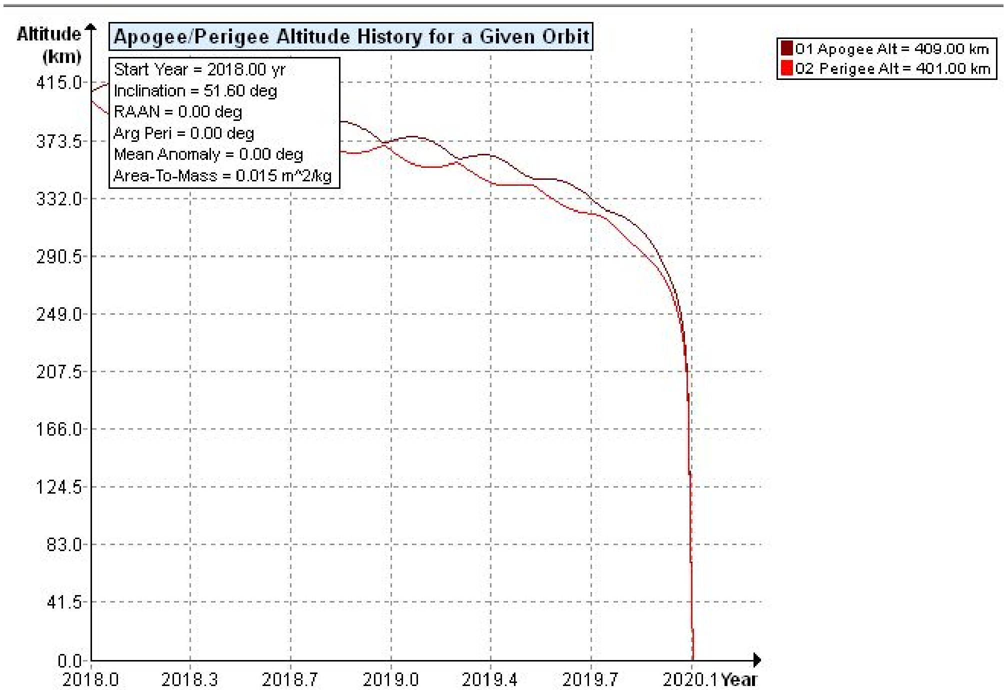

Figure 2: Satellite Altitude History for Orbit Lifetime

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

Analysis: N/A - Phoenix will orbit in LEO for the full mission duration.

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

Analysis: N/A

Requirement 4.6-4. Reliability of Postmission Disposal Operations:

Analysis: The disposal of Phoenix does not rely on de-orbiting devices. The planned release from the ISS with a downward, retrograde vector will result in de-orbiting in approximately 2 years with no disposal or de-orbiting actions required.

ODAR Section 7: Assessment of Spacecraft Reentry Hazards

Assessment of 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 and Report (performed through DAS 2.0)
   The analysis performed with DAS 2.1.1 demonstrates that the Phoenix CubeSat is compliant with Requirement 4.7-1, and predicts that no components from the satellite will reach the ground upon entering the atmosphere at the end of the mission life. In addition, the risk of human casualty was reported to be 1:100,000,000. As seen in the report outlined below, the kinetic energy upon impact is 0 Joules and impact casualty areas are 0.00 m^2.

Requirements 4.7-1b and 4.7-1c below are non-applicable requirements because *Phoenix* does not use controlled reentry.

4.7-1, b) NOT APPLICABLE.
For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica (Requirement 56627).

4.7-1 c) NOT APPLICABLE.
For controlled reentries, the product of the probability of failure of the reentry burn (from Requirement 4.6-4.b) and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000) (Requirement 56628).

ODAR Section 7A: Assessment of Hazardous Materials

This section is not applicable. Phoenix will not incorporate any hazardous materials

ODAR Section 8: Assessment for Tether Missions

This section is not applicable, as no tethering will be used.

END OF THE PHOENIX ODAR