PhoneSat 1.0 and PhoneSat 2.0Beta Formal Orbital Debris Assessment Report (ODAR)

This report is presented as compliance with NASA-STD-8719.14, APPENDIX A.

Report Version: 2.4, 07/17/2012

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DAS Software Version Used In Analysis: v2.0.1

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Record of Revisions				
REV	**DATE**	**AFFECTED PAGES**	**DESCRIPTION OF CHANGE**	**AUTHOR (S)**
A	10/5/2011	All	Initial release	Kenny Boronowsky
B	10/17/2011	All	Incorporated updates from James Cockrell	Kenny Boronowsky
C	11/8/2011	5,6,7	Incorporated updates from Rich Morrison	Kenny Boronowsky
D	03/23/2012	All	Incorporated PhoneSat2.0Beta to mission objectives and subsequent sections	Jasper Wolfe
E	05/02/2012	1,2,4	Incorporated updates from James Cockrell	Jasper Wolfe
F	05/13/2012	2,4	Incorporated updates from Rich Morrison	Jasper Wolfe
G	07/16/2012	All	Incorporated changes to PhoneSat 1.0 Graham	Chris Hartney
H	07/17/2012	1,2,4	Incorporated updates from Rich Morrison, updated Launch date and removed updates from RevG.	Jasper Wolfe

Table of Contents

Self-assessment and OSMA assessment of the ODAR using the format in 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: PhoneSat 1.0&2.0Beta Mission

Requirement #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant	Not Compliant	Incomplete	
4.3-1.a	☐	☐	☒	☐	☒	☐	☐	No Debris Released in LEO. See note 1.
4.3-1.b	☐	☐	☒	☐	☒	☐	☐	No Debris Released in LEO. See note 1.
4.3-2	☐	☐	☒	☐	☒	☐	☐	No Debris Released in GEO. See note 1.
4.4-1	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.4-2	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.4-3	☐	☐	☒	☐	☒	☐	☐	No planned breakups. See note 1.
4.4-4	☐	☐	☒	☐	☒	☐	☐	No planned breakups. See note 1.
4.5-1	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.5-2					☒	☐	☐	No critical subsystems needed for EOM disposal
4.6-1(a)	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-1(b)	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-1(c)	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-2	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-3	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-4	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.6-5	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.7-1	☐	☐	☒	☐	☒	☐	☐	See note 1.
4.8-1					☒	☐	☐	No tethers used.

Notes:

1. The primary payload belongs to Orbital. This is not a NASA primary mission. All of the other portions of the launch stack are non-NASA and PhoneSat is not the lead.

Assessment Report Format:

ODAR Technical Sections Format Requirements:

This ODAR follows the format in NASA-STD-8719.14, Appendix A.1 and includes the content indicated at a minimum in each section 2 through 8 below for the PhoneSat 1.0 and PhoneSat 2.0Beta satellite. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered here.

PhoneSat 1.0 & PhoneSat 2.0Beta

ODAR Section 1: Program Management and Mission Overview

Mission Directorate: OCT, Office of the Chief Technologist (OCT), James Reuther, Director, Cross-cutting Demonstration Division (CCDD)

Program Executive: Andrew Petro, CCDD

Program/project manager: Bruce Yost, ARC

Senior Management: Al Weston, ARC

Foreign government or space agency participation: None.

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

Schedule of upcoming mission milestones:

FRR:	August 2012
Launch:	October 16, 2012

Mission Overview:
The PhoneSat mission is a group of three 1U CubeSats that will launch as secondary payloads on the Orbital Science Antares maiden flight. There will be two PhoneSat 1.0 units and one PhoneSat 2.0Beta unit. The primary payload is the Orbital Science Cygnus Mass Simulator and is a non functional mass dummy. The PhoneSat 1.0 and 2.0Beta satellites will orbit in Low Earth Orbit (LEO) and primarily determine the feasibility of using a modern smart phone as the main avionics and flight computer for satellites. The second PhoneSat 1.0 unit will be largely identical to the first with the exception of a Quake Global's Iridium modem attached to the side. The primary mission for both PhoneSat 1.0 satellites will last 10 days until the onboard batteries die. The primary mission for the PhoneSat 2.0 Beta satellite will function for 10 days with solar cells on each face charging the batteries when required. During the 10 day mission, subsystems will be scheduled for use so as not to exceed the charging capabilities of the solar cell power generation system. Following the 10 day mission, the PhoneSat 2.0 Beta will deplete the batteries over a 3 day period by turning on all subsystems. The mission ends with atmospheric reentry of all three satellites within a two week timeframe from launch due to the low altitude orbit.

All three PhoneSat satellites are integrated into a single ISIS ISIPOD CubeSat deployer at NASA Ames prior to launch and are shipped to the launch site where there ISIPOD will be bolted onto the upper stage of the Antares launch vehicle. The ISIPOD provides a full enclosure of the satellites until deployment in orbit. The two PhoneSat 1.0 satellites will operate in a circular orbit with no stabilization or attitude control systems or propulsion systems. The one PhoneSat 2.0Beta satellite will operate in the same circular orbit with three-axis reaction wheel and magnetorquer attitude control systems, and no propulsion systems.

Launch vehicle and launch site: Antares (formerly Taurus II), Wallops Flight Facility, VA.

Proposed launch date: 10/16/2012

Mission duration: 10 Days in LEO operations until reentry via atmospheric orbital decay ~10 days.

Launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination:

The primary payload belongs to Orbital. This is not a NASA primary mission. All of the other portions of the launch stack are non-NASA and PhoneSat is not the lead.

The Antares will launch into a circular orbit. Once the final stage has burned out, the secondary payloads will be dispensed. After the secondary payloads are clear, the primary payload will separate. All payloads including the primary will burn up and reenter within a couple of weeks of launch due to the low orbit.

The PhoneSat 1.0 and 2.0Beta satellites are deployed to, and decay naturally from an operational circular orbit defined as follows:

Apogee: 270 km

Perigee: 270 km

Inclination: 51 degrees.

The PhoneSat 1.0 and 2.0Beta satellites have no propulsion and therefore do not actively change orbits. There is no parking or transfer orbit.

ODAR Section 2: Spacecraft Description

Physical description of the spacecraft:

The PhoneSat mission consists of 3 satellites. Two of the satellites are PhoneSat version 1.0, “Graham” and “Bell”, and the third satellite is a PhoneSat version 2.0Beta, “Alexander”. The second PhoneSat 1.0 satellite, “Bell”, has an attached Quake Global’s Iridium modem experiment. Figure 2 shows the three satellites. Graham and Alexander have dimensions 11.13 cm x 11.13 cm x 11.13 cm (one PhoneSat 1.0 and one PhoneSat 2.0Beta). Bell is the same dimension except it has a cylindrical extension that is 4.5cm long and 7.2 cm in diameter on one side. None of the satellites have titanium parts. Graham and Bell have 12 Lithium-Ion batteries, and Bell has an additional 3 AA Lithium Iron Disulfide primary cells. Alexander has 4 Lithium-Ion batteries and solar panels on all 6 faces for charging. All of the batteries are described in more detail below.

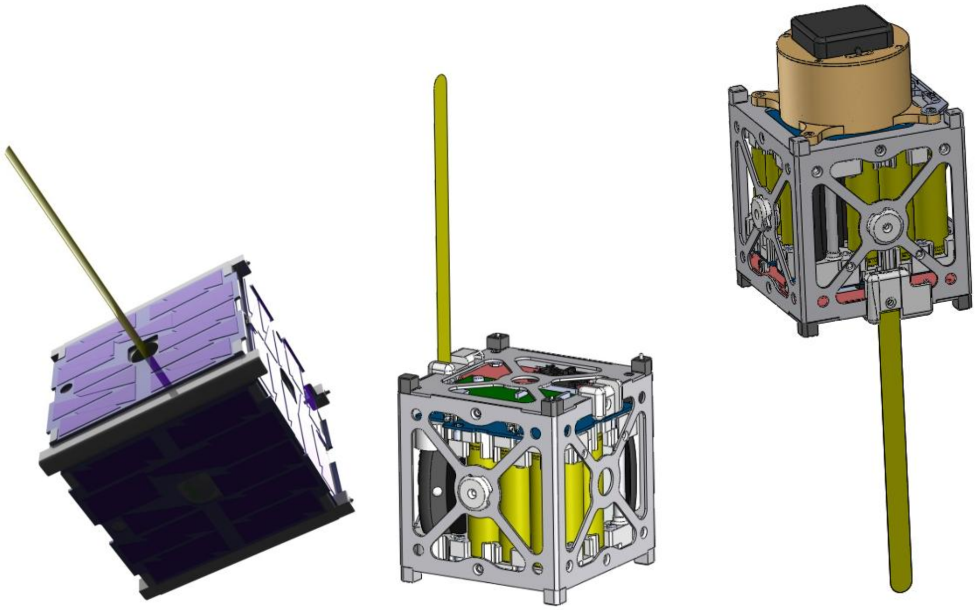

Figure 2: PhoneSat 2.0Beta (Left), PhoneSat 1.0 (Middle), PhoneSat 1.0 with attached experiment (Right)

Total satellite mass (3 satellites) at launch, including all propellants and fluids: ~3.666 kg.

Alexander Mass: ~1.12 kg
Graham Mass: ~1.12 kg
Bell Mass: ~ 1.426 kg

Dry mass of satellites at launch, excluding solid rocket motor propellants: ~3.666 kg

Alexander Mass: ~1.12 kg
Graham Mass: ~1.12 kg
Bell Mass: ~ 1.426 kg

Description of all propulsion systems (cold gas, mono-propellant, bi-propellant, electric, nuclear): None.

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: None

Fluids in Pressurized Batteries: None. PhoneSat 1.0 and PhoneSat 2.0Beta use unpressurized standard COTS Lithium-Ion battery cells. The Quake Global's Iridium modem use unpressurized standard COTS AA Lithium Iron Disulfide battery cells.

Description of attitude control system and indication of the normal attitude of the spacecraft with respect to the velocity vector: PhoneSat 1.0 has none. The two PhoneSat 1.0 satellites are in a free tumble and uncontrolled. PhoneSat 2.0Beta has active three-axis attitude control by means of three orthogonal reaction wheels and three orthogonal sets of two magnetorquer coils. The 2.0Beta satellite has one-axis attitude determination; limiting the capability of the three-axis control system. The satellites are cubical in shape – all of the sides have identical surface areas.

Description of any range safety or other pyrotechnic devices: No pyrotechnic devices are used.

Description of the electrical generation and storage system: Standard COTS Lithium-Ion battery cells and Lithium Iron Disulfide battery cells are charged before payload integration and provide electrical energy during the mission. For Graham and Bell, the battery holder and protection circuit is custom designed by Pumpkin Incorporated. For Alexander, the battery holder and protection circuit is a COTS item designed for the Lithium-Ion 18650 cell format batteries. For Graham, Bell and the Iridium modem extension to Bell; these batteries are used until depleted. For Alexander the solar panels and charging circuit recharge the batteries. Graham and Bell carry 12 Lithium-Ion battery cells in the 18650 cell format. Bell has 3 AA Lithium Iron Disulfide primary cells dedicated to the Iridium modem experiment. Alexander carries 4 Lithium-Ion battery cells in the 18650 cell format.

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

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 v2.0.1)

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 seven (7) independent, mutually exclusive failure modes to lead to explosion. The rationale is true for all batteries onboard the spacecrafts.

There is no credible scenario in which the reaction wheel energy would exceed the breakup/explosion energy required for the reaction wheel material to breakup/explode. The supporting analysis is described in the FMEA below.

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:

Alexander incorporates logic in the watchdog to turn on all subsystems at the completion of the mission to discharge the batteries.. Ground tests indicate that the battery packs for Alexander will be completely discharged within 3 days of turning on all subsystems.

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

Due to the extremely short duration of the mission before passive reentry and burn up, the Lithium-Ion batteries were deemed not necessary to passivate for EOM. Ground tests indicate that for Graham and Bell the battery packs will be completely discharged within 10 days of the mission from regular satellite power usage due to no power generation capabilities onboard the satellites. Similarly, the Lithium Iron Disulfide batteries on Bell will be completely discharged within 2 days of mission initiation.

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 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. The rationale is true for all batteries onboard the spacecrafts.
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).

Failure mode 1: Internal short circuit.
Mitigation 1: Complete shock, vibration, thermal cycling, and vacuum tests followed by functional testing of the satellite to prove that no internal short circuit sensitivity exists.
Combined faults required for realized failure: Environmental testing **AND** functional 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 were 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 were also tested in a hot environment to test the upper limit of the cells capability. No failures were seen.
*Combined faults required for realized failure: S*pacecraft thermal design must be incorrect **AND** external over current detection and disconnect function must fail to enable this failure mode.

Failure Mode 3: Excessive discharge rate or short circuit due to external device failure or terminal contact with conductors not at battery voltage levels (due to abrasion or inadequate proximity separation).

Mitigation 4: This failure mode is negated by a) design of battery packs and insulators for both PhoneSat 1.0 and 2.0 Beta such that no contact with nearby board traces is possible without being caused by some other mechanical failure, b) use of the COTS battery protection circuit on the battery holder for the 18650 cell format Lithium-Ion batteries on Alexander , c) obviation of such other mechanical failures by proto-qualification and acceptance environmental tests for PhoneSat 1.0 (shock, vibration, thermal cycling, and thermal-vacuum tests).
Combined faults required for realized failure: An external load must fail/short-circuit **AND** external over-current detection and disconnect function must all occur to enable this failure mode.

Failure Mode 4: Inoperable vents.
Mitigation 5: Battery vents are not inhibited by the battery holder design or the spacecraft.
Combined effects required for realized failure: The manufacturer fails to install proper venting.

Failure Mode 5: Crushing.
Mitigation 6: This mode is negated by spacecraft design. There are no moving parts in the proximity of the batteries.
Combined faults required for realized failure: A catastrophic failure must occur in an external system **AND** the failure must cause a collision sufficient to crush the batteries leading to an internal short circuit **AND** the satellite must be in a naturally sustained orbit at the time the crushing occurs.

Failure Mode 6: Low level current leakage or short-circuit through battery pack case or due to moisture-based degradation of insulators.
Mitigation 7: These modes are negated by a) battery holder/case design made of non-conductive plastic, and b) operation in vacuum such that no moisture can affect insulators.
Combined faults required for realized failure: Abrasion or piercing failure of circuit board coating or wire insulators **AND** dislocation of battery packs **AND** failure of battery terminal insulators **AND** failure to detect such failures in environmental tests must occur to result in this failure mode.

Failure Mode 7: Excess temperatures due to orbital environment and high discharge combined.
Mitigation 8: The spacecraft thermal design will negate this possibility. Thermal rise has been analyzed in combination with space environment temperatures showing that batteries do not exceed normal allowable operating temperatures which are well below temperatures of concern for explosions.
Combined faults required for realized failure: Thermal analysis **AND** thermal design **AND** mission simulations in thermal-vacuum chamber testing **AND** over-current monitoring and control must all fail for this failure mode to occur.

Reaction wheel breakup/explosion:

There is no credible scenario that would result in the reaction wheels on Alexander to breakup during normal deployment and operations. Each of the three reaction wheels are COTS with a moment of inertia of 81e-06 kg.m^2 and a maximum spin rate of 7000 RPM. The subsequent maximum stored energy in the Reaction Control System is 21.8 Joules; which is substantially less than the breakup/explosion energy required for a reaction wheel assembly breakup leading to material ejection. In addition, the Reaction Control System is encased by both the satellite shell and the solar panels.

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:
Graham and Bell are designed to completely discharge battery packs within 10 days during the mission since there is no re-charge or power generation capabilities onboard the satellites. The Quake Global's Iridium is designed to completely discharge battery packs within 2 days during the mission since there is no re-charge or power generation capabilities on board the extension to the Bell Satellite. Alexander is designed to completely discharge battery packs within 3 days of completion of the mission by turning on all subsystems simultaneous (nominal operation schedules subsystem usage).. The Graham and Bell satellites are programmed to continue functioning in normal operations until the battery packs are totally discharged.

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

Compliance statement:
This requirement is not applicable. 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. 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 v2.0.1, 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: 0.00000; COMPLIANT.

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:** 0.00000; COMPLIANT
- **Identification of all systems or components required to accomplish any postmission disposal operation, including passivation and maneuvering:**

  None.

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

6.1 Description of spacecraft disposal option selected: The satellite will de-orbit naturally by atmospheric re-entry. There is no propulsion system.

6.2 Plan for any spacecraft maneuvers required to accomplish postmission disposal: NONE.

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

Spacecraft Mass: ~1.426kg (greatest mass of three)

Cross-sectional Area: 0.01 m^2 (Calculated by DAS 2.0.1).

Area to mass ratio: 0.01/1.426 = 0.007 m^2/kg

6.4 Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5 (per DAS v 2.0.1 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)

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 PhoneSat satellites reentry is COMPLIANT using method "a.". The PhoneSats will be left in a 270 km circular orbit, reentering in **~10** days after launch with orbit history as shown in Figure 3 (analysis assumes an approximate random tumbling behavior).

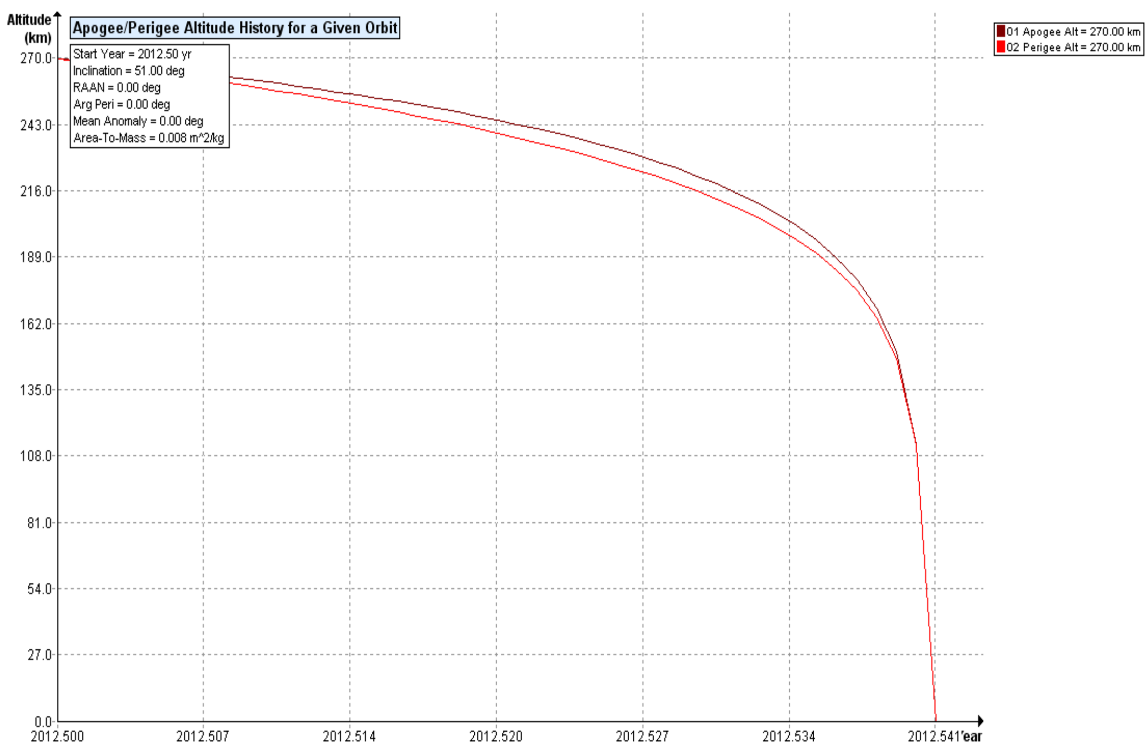

Figure 3, PhoneSat Orbit History (Identical for all three Satellites).

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

Analysis: Not applicable. The three satellite orbits are in LEO.

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

Analysis: Not applicable. The three satellite orbits are in LEO.

Requirement 4.6-4. Reliability of Postmission Disposal Operations

Analysis: Not applicable. The satellites will reenter passively without post mission disposal operations within allowable timeframe.

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).

Summary Analysis Results: DAS v2.0.1 reports that the PhoneSats are compliant with the requirement. No components reach the ground. Total human casualty probability is reported by the DAS software as 1:0. This is an erroneous output, presumably meaning a probability of zero.

Analysis (per DAS v2.0.1):

```
05 25 2012; 14:32:10PM  DAS Application Started
05 25 2012; 14:32:10PM  Opened Project C:\Program Files\NASA\DAS 
2.0\project\PhoneSat\
05 25 2012; 14:32:20PM  Processing Requirement 4.3-1: Return Status :  Not 
Run

=====================
No Project Data Available
=====================

=============== End of Requirement 4.3-1 ===============
05 25 2012; 14:32:22PM  Processing Requirement 4.3-2: Return Status : Passed

=====================
No Project Data Available
=====================

=============== End of Requirement 4.3-2 ===============
05 25 2012; 14:32:25PM  Requirement 4.4-3:  Compliant
```

```
=============== End of Requirement 4.4-3 ===============
05 25 2012; 14:32:29PM  Processing Requirement 4.5-1: Return Status :  Passed

==============
Run Data
==============

**INPUT**

      Space Structure Name = PhoneSat 2.0Beta (Alexander)
      Space Structure Type = Payload
      Perigee Altitude = 270.000000 (km)
      Apogee Altitude = 270.000000 (km)
      Inclination = 51.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass Ratio = 0.007700 (m^2/kg)
      Start Year = 2012.500000 (yr)
      Initial Mass = 1.120000 (kg)
      Final Mass = 1.120000 (kg)
      Duration = 0.027300 (yr)
      Station-Kept = False
      Abandoned = True
      PMD Perigee Altitude = -1.000000 (km)
      PMD Apogee Altitude = -1.000000 (km)
      PMD Inclination = 0.000000 (deg)
      PMD RAAN = 0.000000 (deg)
      PMD Argument of Perigee = 0.000000 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Collision Probability = 0.000000
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range
      Status = Pass

==============

**INPUT**

      Space Structure Name = PhoneSat 1.0 (Graham)
      Space Structure Type = Payload
      Perigee Altitude = 270.000000 (km)
      Apogee Altitude = 270.000000 (km)
      Inclination = 51.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass Ratio = 0.007700 (m^2/kg)
      Start Year = 2012.500000 (yr)
      Initial Mass = 1.120000 (kg)
      Final Mass = 1.120000 (kg)
```

```
      Duration = 0.027300 (yr)
      Station-Kept = False
      Abandoned = True
      PMD Perigee Altitude = -1.000000 (km)
      PMD Apogee Altitude = -1.000000 (km)
      PMD Inclination = 0.000000 (deg)
      PMD RAAN = 0.000000 (deg)
      PMD Argument of Perigee = 0.000000 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Collision Probability = 0.000000
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range
      Status = Pass

==============

**INPUT**

      Space Structure Name = PhoneSat 1.0 (Bell)
      Space Structure Type = Payload
      Perigee Altitude = 270.000000 (km)
      Apogee Altitude = 270.000000 (km)
      Inclination = 51.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass Ratio = 0.007700 (m^2/kg)
      Start Year = 2012.500000 (yr)
      Initial Mass = 1.426000 (kg)
      Final Mass = 1.426000 (kg)
      Duration = 0.027300 (yr)
      Station-Kept = False
      Abandoned = True
      PMD Perigee Altitude = -1.000000 (km)
      PMD Apogee Altitude = -1.000000 (km)
      PMD Inclination = 0.000000 (deg)
      PMD RAAN = 0.000000 (deg)
      PMD Argument of Perigee = 0.000000 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Collision Probability = 0.000000
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range
      Status = Pass

==============

=============== End of Requirement 4.5-1 ===============
05 25 2012; 14:32:32PM  Requirement 4.5-2:  Compliant
```

```
05 25 2012; 14:32:33PM  Processing Requirement 4.6    Return Status :  Passed

==============
Project Data
==============

**INPUT**

      Space Structure Name = PhoneSat 2.0Beta (Alexander)
      Space Structure Type = Payload

      Perigee Altitude = 270.000000 (km)
      Apogee Altitude = 270.000000 (km)
      Inclination = 51.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Area-To-Mass Ratio = 0.007700 (m^2/kg)
      Start Year = 2012.500000 (yr)
      Initial Mass = 1.120000 (kg)
      Final Mass = 1.120000 (kg)
      Duration = 0.027300 (yr)
      Station Kept = False
      Abandoned = True
      PMD Perigee Altitude = 225.835229 (km)
      PMD Apogee Altitude = 232.137354 (km)
      PMD Inclination = 50.995205 (deg)
      PMD RAAN = 305.428377 (deg)
      PMD Argument of Perigee = 21.906970 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Suggested Perigee Altitude = 225.835229 (km)
      Suggested Apogee Altitude = 232.137354 (km)
      Returned Error Message = Passes LEO reentry orbit criteria.

      Released Year = 2012 (yr)
      Requirement = 61
      Compliance Status = Pass

==============

**INPUT**

      Space Structure Name = PhoneSat 1.0 (Graham)
      Space Structure Type = Payload

      Perigee Altitude = 270.000000 (km)
      Apogee Altitude = 270.000000 (km)
      Inclination = 51.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
```

```
      Area-To-Mass Ratio = 0.007700 (m^2/kg)
      Start Year = 2012.500000 (yr)
      Initial Mass = 1.120000 (kg)
      Final Mass = 1.120000 (kg)
      Duration = 0.027300 (yr)
      Station Kept = False
      Abandoned = True
      PMD Perigee Altitude = 225.835229 (km)
      PMD Apogee Altitude = 232.137354 (km)
      PMD Inclination = 50.995205 (deg)
      PMD RAAN = 305.428377 (deg)
      PMD Argument of Perigee = 21.906970 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Suggested Perigee Altitude = 225.835229 (km)
      Suggested Apogee Altitude = 232.137354 (km)
      Returned Error Message = Passes LEO reentry orbit criteria.

      Released Year = 2012 (yr)
      Requirement = 61
      Compliance Status = Pass

==============

**INPUT**

      Space Structure Name = PhoneSat 1.0 (Bell)
      Space Structure Type = Payload

      Perigee Altitude = 270.000000 (km)
      Apogee Altitude = 270.000000 (km)
      Inclination = 51.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Area-To-Mass Ratio = 0.007700 (m^2/kg)
      Start Year = 2012.500000 (yr)
      Initial Mass = 1.426000 (kg)
      Final Mass = 1.426000 (kg)
      Duration = 0.027300 (yr)
      Station Kept = False
      Abandoned = True
      PMD Perigee Altitude = 225.835229 (km)
      PMD Apogee Altitude = 232.137354 (km)
      PMD Inclination = 50.995205 (deg)
      PMD RAAN = 305.428377 (deg)
      PMD Argument of Perigee = 21.906970 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Suggested Perigee Altitude = 225.835229 (km)
```

```
      Suggested Apogee Altitude = 232.137354 (km)
      Returned Error Message = Passes LEO reentry orbit criteria.

      Released Year = 2012 (yr)
      Requirement = 61
      Compliance Status = Pass

==============

=============== End of Requirement 4.6 ===============
05 25 2012; 14:32:37PM  *********Processing Requirement 4.7-1
      Return Status :  Passed

***********INPUT****
 Item Number = 1

name = PhoneSat 2.0Beta (Alexander)
quantity = 1
parent = 0
materialID = 2
type = Box
Aero Mass = 1.120000
Thermal Mass = 1.120000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.100000

name = CubeSat Structure (Alexander)
quantity = 1
parent = 1
materialID = 7
type = Box
Aero Mass = 0.381300
Thermal Mass = 0.381300
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.100000

name = Solar Cells (Alexander)
quantity = 100
parent = 1
materialID = 24
type = Flat Plate
Aero Mass = 0.000239
Thermal Mass = 0.000239
Diameter/Width = 0.012700
Length = 0.031650

name = Magnetorquer Board (Alexander)
quantity = 6
parent = 1
materialID = 19
type = Flat Plate
Aero Mass = 0.033900
```

```
Thermal Mass = 0.033900
Diameter/Width = 0.082600
Length = 0.104800

name = Reaction Control System (Alexander)
quantity = 1
parent = 1
materialID = 76
type = Box
Aero Mass = 0.040000
Thermal Mass = 0.040000
Diameter/Width = 0.025400
Length = 0.076200
Height = 0.025400

name = PCB (Alexander)
quantity = 6
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.020000
Thermal Mass = 0.020000
Diameter/Width = 0.080000
Length = 0.080000

name = Nexus S (Alexander)
quantity = 1
parent = 1
materialID = 76
type = Box (Alexander)
Aero Mass = 0.102600
Thermal Mass = 0.102600
Diameter/Width = 0.060000
Length = 0.100000
Height = 0.015000

name = Batteries (Alexander)
quantity = 4
parent = 1
materialID = 58
type = Cylinder
Aero Mass = 0.045600
Thermal Mass = 0.045600
Diameter/Width = 0.019100
Length = 0.061900

name = Microhard MHX2420 (Alexander)
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 0.051000
Thermal Mass = 0.051000
Diameter/Width = 0.053400
```

```
Length = 0.089000
Height = 0.017800

name = StenSat (Alexander)
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 0.059300
Thermal Mass = 0.059300
Diameter/Width = 0.091100
Length = 0.095500
Height = 0.010000

name = Battery Holder (Alexander)
quantity = 1
parent = 1
materialID = 76
type = Box
Aero Mass = 0.029300
Thermal Mass = 0.029300
Diameter/Width = 0.085000
Length = 0.086800
Height = 0.021200

name = Fasteners (Alexander)
quantity = 4
parent = 1
materialID = 54
type = Cylinder
Aero Mass = 0.005000
Thermal Mass = 0.005000
Diameter/Width = 0.003000
Length = 0.100000

*************OUTPUT****
Item Number = 1

name = PhoneSat 2.0Beta (Alexander)
Demise Altitude = 77.992957
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = CubeSat Structure (Alexander)
Demise Altitude = 73.126168
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Solar Cells (Alexander)
Demise Altitude = 77.968605
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

```
************************************
name = Magnetorquer Board (Alexander)
Demise Altitude = 76.983074
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Reaction Control System (Alexander)
Demise Altitude = 77.522011
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = PCB (Alexander)
Demise Altitude = 77.396707
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Nexus S (Alexander)
Demise Altitude = 77.372535
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Batteries (Alexander)
Demise Altitude = 69.239136
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Microhard MHX2420 (Alexander)
Demise Altitude = 75.899238
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = StenSat (Alexander)
Demise Altitude = 76.056168
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Battery Holder (Alexander)
Demise Altitude = 77.837933
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Fasteners (Alexander)
Demise Altitude = 76.024605
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

```
*************************************

***********INPUT****
 Item Number = 2

name = PhoneSat 1.0 (Graham)
quantity = 1
parent = 0
materialID = 2
type = Box
Aero Mass = 1.120000
Thermal Mass = 1.120000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.100000

name = CubeSat Structure (Graham)
quantity = 1
parent = 1
materialID = 7
type = Box
Aero Mass = 0.381300
Thermal Mass = 0.381300
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.100000

name = PCB (Graham)
quantity = 1
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.020000
Thermal Mass = 0.020000
Diameter/Width = 0.080000
Length = 0.080000

name = Nexus One (Graham)
quantity = 1
parent = 1
materialID = 76
type = Box
Aero Mass = 0.102600
Thermal Mass = 0.102600
Diameter/Width = 0.060000
Length = 0.100000
Height = 0.015000

name = Battery Holder (Graham)
quantity = 1
parent = 1
materialID = 76
type = Box
```

```
Aero Mass = 0.029300
Thermal Mass = 0.029300
Diameter/Width = 0.085000
Length = 0.086800
Height = 0.021200

name = Batteries (Graham)
quantity = 12
parent = 1
materialID = 58
type = Cylinder
Aero Mass = 0.045600
Thermal Mass = 0.045600
Diameter/Width = 0.019100
Length = 0.061900

name = Fasteners (Graham)
quantity = 4
parent = 1
materialID = 54
type = Cylinder
Aero Mass = 0.005000
Thermal Mass = 0.005000
Diameter/Width = 0.003000
Length = 0.100000

**************OUTPUT****
Item Number = 2

name = PhoneSat 1.0 (Graham)
Demise Altitude = 77.992722
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = CubeSat Structure (Graham)
Demise Altitude = 73.173613
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = PCB (Graham)
Demise Altitude = 77.399761
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Nexus One (Graham)
Demise Altitude = 77.375722
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Battery Holder (Graham)
```

```
Demise Altitude = 77.838543
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Batteries (Graham)
Demise Altitude = 69.312011
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Fasteners (Graham)
Demise Altitude = 76.052433
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************

***********INPUT****
 Item Number = 3

name = PhoneSat 1.0 (Bell)
quantity = 1
parent = 0
materialID = 2
type = Box
Aero Mass = 1.426000
Thermal Mass = 1.426000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.100000

name = CubeSat Structure (Bell)
quantity = 1
parent = 1
materialID = 7
type = Box
Aero Mass = 0.381300
Thermal Mass = 0.381300
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.100000

name = PCB (Bell)
quantity = 1
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.020000
Thermal Mass = 0.020000
Diameter/Width = 0.080000
Length = 0.080000

name = Nexus One (Bell)
```

```
quantity = 1
parent = 1
materialID = 76
type = Box
Aero Mass = 0.102600
Thermal Mass = 0.102600
Diameter/Width = 0.060000
Length = 0.100000
Height = 0.015000

name = Battery Holder (Bell)
quantity = 1
parent = 1
materialID = 76
type = Box
Aero Mass = 0.029300
Thermal Mass = 0.029300
Diameter/Width = 0.085000
Length = 0.086800
Height = 0.021200

name = Batteries (Bell)
quantity = 12
parent = 1
materialID = 58
type = Cylinder
Aero Mass = 0.045600
Thermal Mass = 0.045600
Diameter/Width = 0.019100
Length = 0.061900

name = Fasteners (Bell)
quantity = 4
parent = 1
materialID = 58
type = Cylinder
Aero Mass = 0.005000
Thermal Mass = 0.005000
Diameter/Width = 0.003000
Length = 0.100000

name = Quake Iridium Modem (Bell)
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 0.114000
Thermal Mass = 0.114000
Diameter/Width = 0.064000
Length = 0.064000
Height = 0.016000

name = Iridium Antenna (Bell)
quantity = 1
```

```
parent = 1
materialID = 5
type = Box
Aero Mass = 0.043000
Thermal Mass = 0.043000
Diameter/Width = 0.043400
Length = 0.046000
Height = 0.011400

name = Iridium 9602 (Bell)
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 0.027000
Thermal Mass = 0.027000
Diameter/Width = 0.041000
Length = 0.045000
Height = 0.013000

name = Batteries Iridium (Bell)
quantity = 4
parent = 1
materialID = 58
type = Cylinder
Aero Mass = 0.045600
Thermal Mass = 0.045600
Diameter/Width = 0.019100
Length = 0.061900

name = Iridium Electronics (Bell)
quantity = 1
parent = 1
materialID = 19
type = Flat Plate
Aero Mass = 0.010000
Thermal Mass = 0.010000
Diameter/Width = 0.030000
Length = 0.030000

name = Iridium Canister (Bell)
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.020000
Thermal Mass = 0.020000
Diameter/Width = 0.070000
Length = 0.070000
Height = 0.003000

**************OUTPUT****
Item Number = 3
```

```
name = PhoneSat 1.0 (Bell)
Demise Altitude = 77.999074
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = CubeSat Structure (Bell)
Demise Altitude = 73.670019
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = PCB (Bell)
Demise Altitude = 77.471379
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Nexus One (Bell)
Demise Altitude = 77.450238
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Battery Holder (Bell)
Demise Altitude = 77.863543
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Batteries (Bell)
Demise Altitude = 70.180488
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Fasteners (Bell)
Demise Altitude = 76.383035
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Quake Iridium Modem (Bell)
Demise Altitude = 72.268175
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Iridium Patch Antenna (Bell)
Demise Altitude = 74.116121
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
```

```
name = Iridium 9602 (Bell)
Demise Altitude = 75.467902
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Batteries Iridium (Bell)
Demise Altitude = 70.180488
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Iridium Electronics (Bell)
Demise Altitude = 76.595996
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Iridium Canister (Bell)
Demise Altitude = 77.094457
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************

=============== End of Requirement 4.7-1 ===============
```

Requirements 4.7-1b, and 4.7-1c below are non-applicable requirements because PhoneSat 1.0 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 8: Assessment for Tether Missions

Not applicable. There are no tethers in the PhoneSat 1.0 and PhoneSat 2.0Beta mission.

END of ODAR for PhoneSat.

Appendix A: Acronyms

ARC	Ames Research Center
Arg peri	Argument of Perigee
CDR	Critical Design Review
cm	centimeter
COTS	Commercial Off-The-Shelf (items)
DAS	Debris Assessment Software
EOM	End Of Mission
FRR	Flight Readiness Review
GEO	Geosynchronous Earth Orbit
ITAR	International Traffic In Arms Regulations
kg	kilogram
km	kilometer
LEO	Low Earth Orbit
Li-Ion	Lithium Ion
m^2	Meters squared
ml	milliliter
mm	millimeter
N/A	Not Applicable.
ODAR	Orbital Debris Assessment Report
OSMA	Office of Safety and Mission Assurance
PDR	Preliminary Design Review
PL	Payload
ISIPOD	ISIS CubeSat Deployer
PSIa	Pounds Per Square Inch, absolute
RAAN	Right Ascension of the Ascending Node
SMA	Safety and Mission Assurance
Ti	Titanium
USAF	United States Air Force
yr	year

8/21/12

BROCK,

THIS NEEDS TO BE FORWARDED TO PROGRAM (ANDREW PETRO) EXEC. FOR DELIVERY TO FRANK GROEN, NASA HQ, OFFICE OF SAFETY AND MISSION ASSURANCE ORBITAL DEBRIS MANAGER.

AFTER HE SIGNS THE HARD COPY HE WILL DELIVER IT TO TERRY WILCUTT, NASA HQ, CHIEF OF SAFETY AND MISSION ASSURANCE FOR FINAL SIGNATURE.

RICH MORRISON ARC-SMA ext#4-4923