SkyCube

Orbital Debris Assessment Report (ODAR)

Revision C • 7 January 2013

Prepared for NASA HQ in compliance with NASA-STD-8719.14 by Southern Stars Group, LLC.
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NASA Debris Analysis Software (DAS) version 2.02 was used in preparing this report.

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Record of Revisions

Revision	Date	Affected Pages	Description of Change	Authors
A	24 October 2012	All	Initial Revision	Tim DeBenedictis, Chris Phoenix
B	27 October 2012	All	Included comments from K. Brown & M. Caviezel, DAS output	Tim DeBenedictis, Kevin Brown, Mark Caviezel
C	7 January 2013	7-8, 20-25	Corrected mass of CO_2 cartridge from 8g to 4g; corrected DAS output	Chris Phoenix, Tim DeBenedictis

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Self-Assessment and OSMA Assessment of the ODAR

A self assessment is provided below, in accordance with the assessment format provided in Appendix A.2 of NASA-STD-8719.14. In the final ODAR document, this assessment will reflect any inputs received from OSMA as well.

Req. #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant	Not Compliant	Incomplete	
4.3-1.a			x		x			
4.3-1.b			x		x			
4.3-2			x		x			
4.4-1			x		x			
4.4-2			x		x			
4.4-3			x		x			
4.4-4			x		x			
4.5-1			x		x			
4.5-2			x		x			
4.6-1(a)			x		x			
4.6-1(b)			x		x			
4.6-1(c)			x		x			
4.6-2			x		x			
4.6-3			x		x			
4.6-4			x		x			
4.6-5			x		x			
4.7-1			x		x			
4.8-1			x		x			

Notes:

1. The primary payload belongs to SpaceX. This is not a Southern Stars Group, LLC primary mission. All of the other portions of the launch stack are non-Southern Stars, and SkyCube is not the lead.

Assessment Report Format

ODAR Technical Sections Format Requiremnents:

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

ODAR Section 1: Program Management and Mission Overview

SkyCube is a privately funded mission owned and operated by Southern Stars Group, LLC, a California limited liability corporation with its principal place of business at 123 10th Sreet, San Francisco, CA 94103.

Senior Manager and Program Management:

- Tim DeBenedictis, timmyd@southernstars.com, (415) 671-6254.

Key engineering personnel:

- Chris Phoenix, Southern Stars, cphoenix@southernstars.com, (650) 776-5195.
  Firmware engineering.

- Kevin Brown, Astronautical Development, kbrown303@gmail.com, (408) 373-2756.
  Satellite hardware engineering, excluding de-orbit mechanism.

- Mark Caviezel, Global Western, kmcaviezel@global-western.com, (405) 600-0328.
  Satellite hardware engineering, de-orbit mechanism.

Foreign government or space agency participation:

- No foreign agency is participating in this mission. All personnel are United States citizens.

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

- Not Applicable.

Schedule of upcoming mission milestones:

3 December 2012	Integrated system testing begins.
16 January 2013	Integrated system testing complete.
22 Febrary 2013	Spacecraft delivery to Launch Service Provider.
3 April 2013	Earliest possible launch.

Mission Overview

SkyCube is a 1U CubeSat that will be launched as a secondary payload on a SpaceX Falcon 9 LV into a circular orbit at 600 km altitude. It will orbit for about 90 days, transmitting down low-resolution pictures and broadcasting beaconing pings moduled with sponsors messages as “tweets from space”.

The mission duration may be optionally extended to a maximum of 6 momths. At EOM, SkyCube will deploy a large balloon for rapid de-orbit via uncontrolled re-entry.

Launch Vehicle and Launch Site:

- The launch vehicle is a SpaceX Falcon 9, scheduled for launch from Cape Canaveral AFS .

Proposed Launch Date:

- No earlier than April 2013.

Mission Duration:

- 90 days to 6 months in LEO operation, until atmospheric reentry via orbital decay.

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

- The SpaceX Falcon 9 will launch into a circular orbit. Once the final stage has burned out, the secondary payloads will be dispensed. After the secondary paylads are clear, the primary payload will separate.

- The destination orbit is entirely determined by the primary payload; SkyCube is a secondary payload. Its orbital parameters are defined as follows:

Apogee:	600 km
Perigee:	600 km
Inclination:	52 degrees

- SkyCube has no propulsion system and therefore does not actively change orbits. There is no parking or transfer orbit.

- At this time, we know of no potential interaction or physical interference between SkyCube and any other operational spacecraft.

ODAR Section 2: Spacecraft Description

SkyCube is a 1U CubeSat, 10 cm on a side, with four solar panel "wings" that fold out to a length of 20 cm after deployment. It contains two small COTS LiIon batteries, several circuit boards, three VGA-resolution CMOS cameras, and a Colony-II radio.

About half of the spacecraft's volume is occupied by a tightly-packed balloon that will be inflated at EOM using a cartridge containing 4 grams of CO_2. The balloon's inflated diameter of 8 – 10 meters will cause rapid de-orbit and reentry.

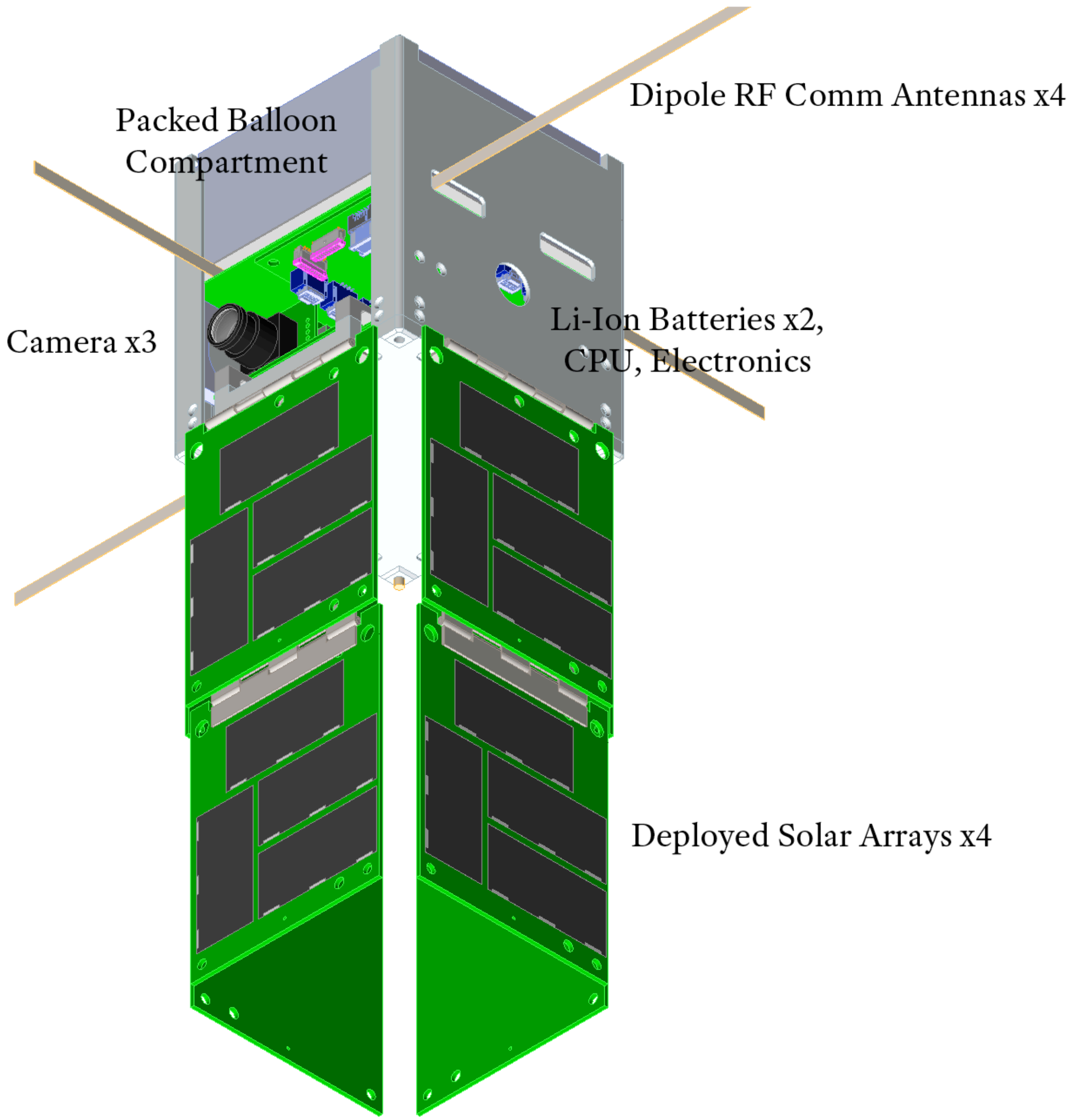

Figure 1. Detailed illustration of SkyCube spacecraft in deployed on-orbit operation configuration.

Total spacecraft mass at launch:

- 1.7 kg

Dry mass of spacecraft at launch:

- 1.7 kg, minus 4g CO_2 for balloon inflation

Propulsion systems:

- None.

On-board fluids:

- 4 grams CO_2 in a COTS cartridge located near the center of the cube.

Attitude control:

- Attitude will be partially controlled by passive magnetic stabilization. Normal attitude will present the long axis of the spacecraft parallel to terrestrial magnetic field lines.

Range safety or other pyrotechnic devices:

- SkyCube utilizes a NiChrome wire heating element for use in antenna and solar panel deployment.

Electrical generation and storage system:

- Solar cells charging 2x Li-Ion batteries in 18650 form factor. The batteries have been pre-qualified by NASA for use in spaceflight applications.

Other sources of stored energy:

- A coiled rotary spring restrained by Spectra with NiChrome string cutter with 300 angular degrees of preload to a torque of 4 Nm will be used to dispense a small amount (0.09 moles, 4 grams, 0.072 std cu feet) of CO_2 into the balloon envelope. The dispense action is not aggressively energetic, taking approximately 2 minutes. The dispense rate of gas is about 0.036 std cu feet per minute. The restraining Spectra line has over 12 factor of safety in tension.

- Compressed gas in a small COTS hemertically sealed nickel plated steel cylinder. The gas is inert CO_2 gas. The quantity of gas is 0.09 moles or 4 grams, or 0.072 std cu feet. Energy release from the compressed gas is greatest at a high system temperature before deployment. The maximum amount of gas expansion energy is 45 foot pounds.

Radioactive materials:

- None.

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

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

Identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material:

- None.

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

There are no intentional breakups scheduled during on orbit operations. We are aware of no known potential causes of spacecraft breakup during deployment and mission operations.

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:

- The battery safety systems discussed in the FMEA (see requirement 4.4-1 below) describe the combined faults that must occur for any of nine independent, mutually exclusive failure modes that could lead to a battery venting. If the LiIon batteries fail, they are expected to vent gas rather than explode.

- The CO_2 cartridge is US DOT rated for commercial over the road transportation and thus has a >4 Factor of Safety against maximum expected operating pressure (MEOP). This greatly surpasses the conventional 1.5 factor of safety versus MEOP stipulated in Mil Spec 1522A, which is more conventional in larger satellites. In the very unlikely event of a misfire, the resulting rate of gas release is slow, dispensing at about 0.036 std cu feet per minute. There is no credible scenario in which a fast release of inflation gas may occur.

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

- There are no plans for any intentional spacecraft breakup by explosion, collision, nor by any other means.

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

- SkyCube contains no components which are passivated at EOM. The spacecraft will be destroyed by atmospheric reentry. The CO2 cartridge will be punctured and completely emptied by the end of the mission. There is no plan to passivate the batteries, but even in the event of mechanical damage or short-circuit they will not explode.

- An affirmative method of permanently preventing battery charging would introduce another failure point into the mission, potentially compromising the deorbit mechanism which uses electrical power to trigger it.

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, it was deemed unnecessary to passivate the two lithium-ion batteries (total mass of 52 grams) for EOM.

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.

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 shock, 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 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: 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. This circuit has been proto- qualification tested for survival in shock, vibration, and thermal-vacuum environments. The charge circuit disconnects the incoming current when battery voltage indicates normal full charge at 8.4 V. 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 charge control 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 gasses 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 124 mA. The maximum charge rate our battery can accept is 3 A. The battery is a proto-qualified Molicell from the JSC ISS program, and has two 18650 cells. The battery itself has one string of 2 cells connected in series. 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 the single string from the battery was accepting charge. The overpressure relief vent keeps the battery cells from rupturing, and is thus limited to worst-case effects of overcharging.

Failure Mode 4: 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) qualification tested short circuit protection on each external circuit, b) design of battery packs and insulators such that no contact with nearby board traces is possible without being caused by some other mechanical failure, c) obviation of such other mechanical failures by proto-qualification and acceptance environmental tests (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 5: 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 6: 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 7: 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 8: 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** the PTC device must fail **AND** over-current monitoring and control must all fail for this failure mode to occur.

Failure Mode 9: Polarity reversal due to over-discharge caused by continuous load during periods of negative power generation vs. consumption.

Mitigation 9: In nominal operations, the spacecraft EPS design negates this mode because the processor will stop when voltage drops too low, below 7 V. This disables ALL connected loads, creating a guaranteed power-positive charging scenario. The spacecraft will not restart or connect any loads until battery voltage is above the acceptable threshold. At this point, only the safemode processor and radio receiver are enabled and charging the battery. Once the battery reaches 90% of the peak voltage (around 7.5 V), it will switch to nominal mode and will be able to receive ground commands for continuing mission functions.

Combined faults required for realized failure: The microcontroller must stop executing code **AND** significant loads must be commanded/stuck "on" **AND** power margin analysis must be wrong **AND** the charge control circuit must fail for this failure mode to occur.

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 postmission 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:**

  SkyCube's battery charge circuits include overcharge protection and to limit the risk of battery failure. 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.

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

We computed the probability of spacecraft collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft (assumptions: 600 km altitude, 52° inclination, 0.01 m^2 area), using the DAS 2.0.2 sofware, as 0.000.

We also computed probability of collision with space objects, including orbital debris and meteoroids, of sufficient size to prevent postmission disposal (assumptions: 0.01 m^2 circuit board, 0.1 g/cm^2, randomly tumbling, with a shield of 0.2 g/cm^2, 0.5 cm away) as 0.007.

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: 0.000; 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: 0.007; COMPLIANT

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

Disposal of SkyCube will be accomplished using a drag-enhancing device – specifically, a large balloon – causing rapid orbital decay and uncontrolled atmospheric reentry.

6.1 Description of spacecraft disposal option selected:

- To inflate, the balloon requires electrical power and functional CPU to trigger the inflation mechanism. It does not require affirmative command or control from the ground; software will include a timer which is robust in the face of unexpected (e.g. radiation-induced) system resets.

- The balloon is likely to be punctured at some point, but even if it partially deflates and collapses, an area of just 0.1 m^2 is sufficient to deorbit 1 kg from 600 km in 1.3 years.

6.2 Plan for any spacecraft maneuvers required to accomplish postmission disposal:

- No spacecraft maneuvers are required to accomplish post-mission disposal.

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

Spacecraft Mass: 1.7 kg
Cross-sectional Area: 0.039 m^2 (Calculated by DAS 2.0.2 for the configuration in Figure 1).
Area to mass ratio: 0.039/1.7 = 0.0229 m^2/kg

6.4 Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5 (per DAS v 2.0 .2 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 SkyCube satellite reentry is COMPLIANT using Method "a." SkyCube will re-enter approximately 0.033 yr (12 days) after balloon inflation with orbit history as shown in Figure 2 (analysis assumes an approximate random tumbling behavior).

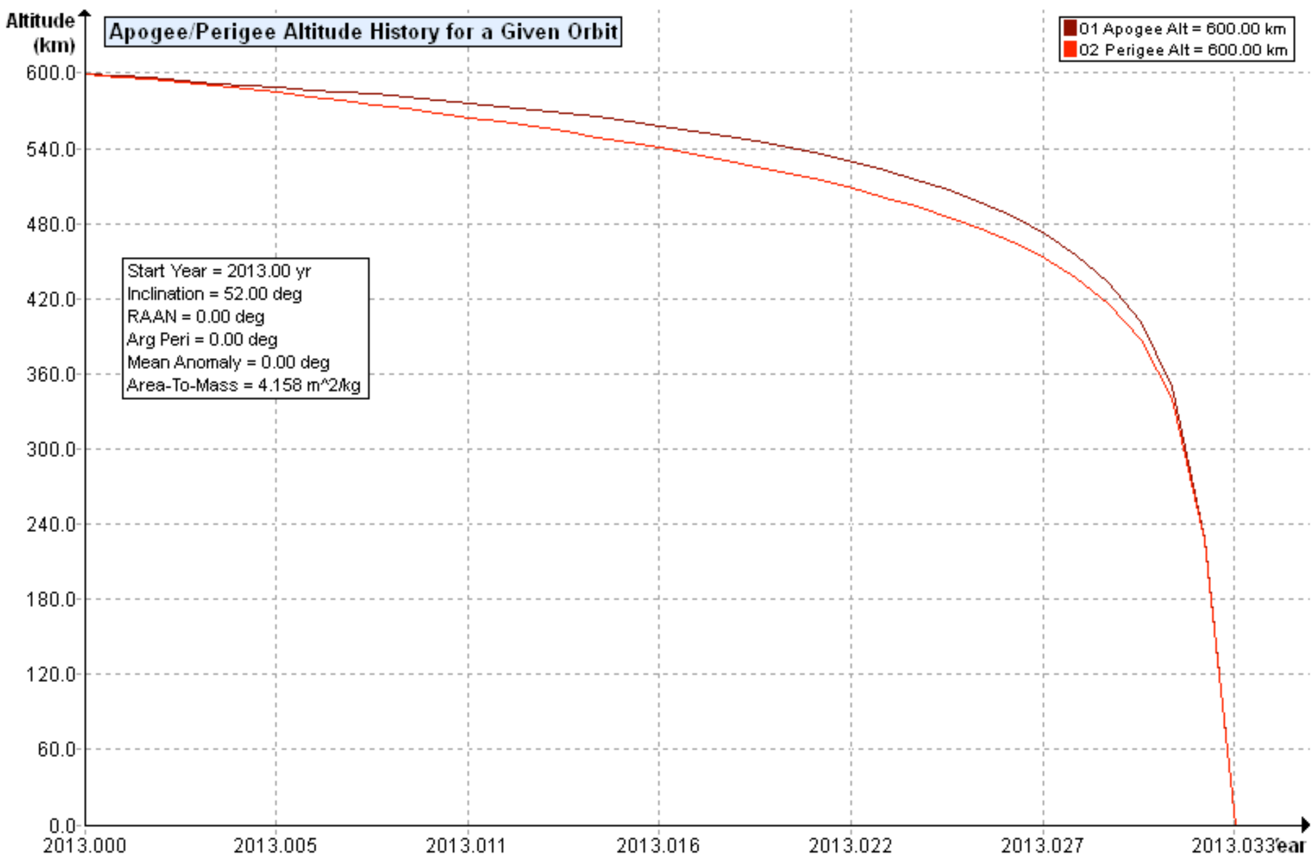

Figure 2. SkyCube orbit history, assuming successful balloon inflation immediately upon orbit insertion at T=2013.0

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

- **Analysis:** Not applicable.

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

- **Analysis:** Not applicable.

Requirement 4.6-4. Reliability of Postmission Disposal Operations

- **Analysis:** SkyCube does not rely the de-orbiting balloon device to ensure post mission disposal within the allowed 25-year timeframe. Even if the balloon inflation mechanism fails, the satellite will reenter passively approximately 11.5 years after launch, as shown in Figure 3, below.

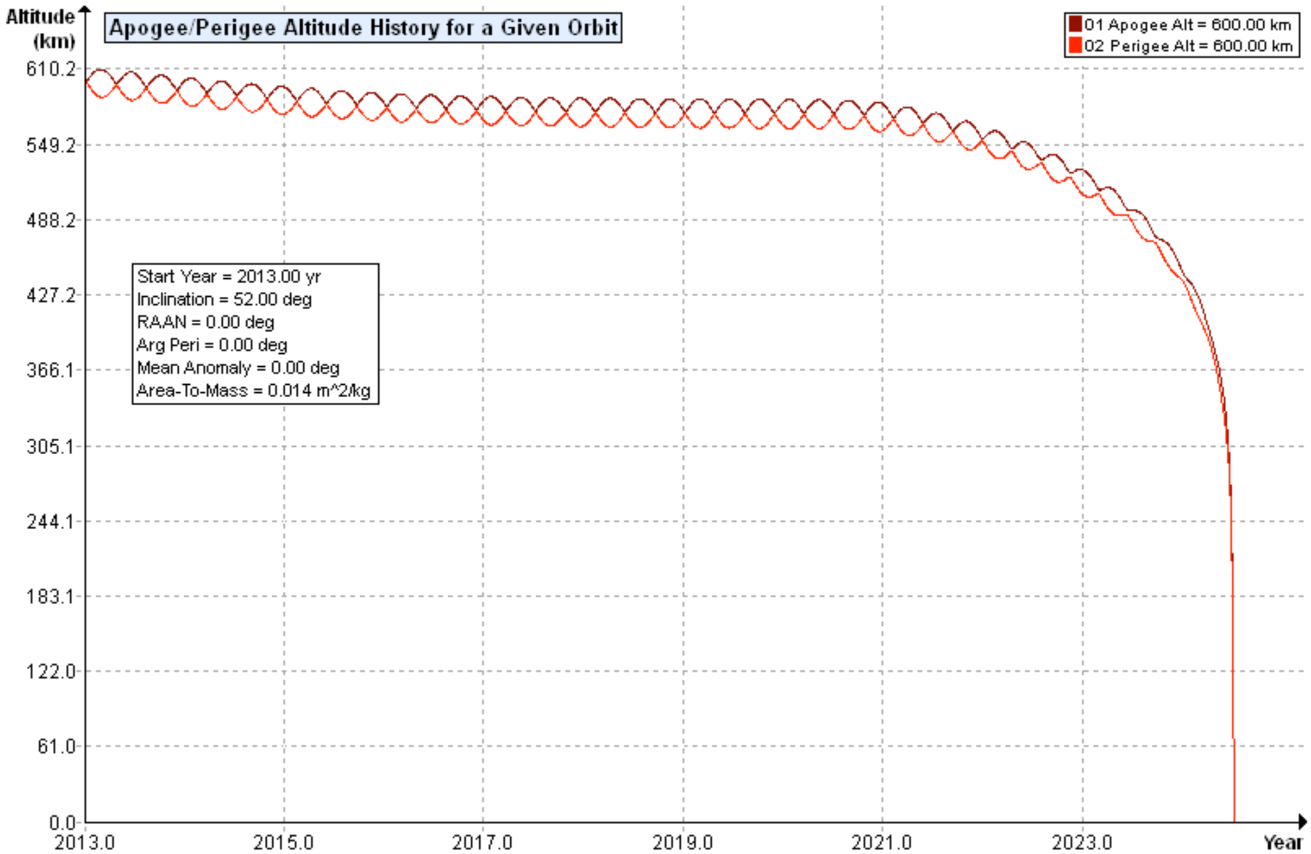

Figure 3. SkyCube orbit history, assuming no balloon inflation after orbit insertion at T=2013.0.

ODAR Section 7: Assessment of Spacecraft Reentry Hazards

A detailed description of spacecraft components includes small Li-ion batteries; a thin aluminum framework; cameras and other circuitry; solar cells. All components will vaporize. The CO_2 supply is a steel cylindrical cartridge surrounded by an aluminum cylinder.

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 v2.0.2 reports that SkyCube is COMPLIANT with the requirement. No components are predicted by NASA DAS software to survive re-entry. The probability of human casualty due to uncontrolled reentry is 0.000000.

Analysis (per DAS v2.0.2):

```
01 07 2013; 14:23:33PM    DAS Application Started
01 07 2013; 14:40:05PM    Processing Requirement 4.6Return Status :  Passed

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

**INPUT**

     Space Structure Name = SkyCube
     Space Structure Type = Payload

     Perigee Altitude = 600.000000 (km)
     Apogee Altitude = 600.000000 (km)
     Inclination = 52.000000 (deg)
     RAAN = 0.000000 (deg)
     Argument of Perigee = 0.000000 (deg)
     Mean Anomaly = 0.000000 (deg)
     Area-To-Mass Ratio = 0.022900 (m^2/kg)
     Start Year = 2013.250000 (yr)
     Initial Mass = 1.700000 (kg)
     Final Mass = 1.700000 (kg)
     Duration = 0.500000 (yr)
     Station Kept = False
     Abandoned = True
     PMD Perigee Altitude = 583.249929 (km)
     PMD Apogee Altitude = 603.589626 (km)
     PMD Inclination = 51.997317 (deg)
     PMD RAAN = 260.300497 (deg)
     PMD Argument of Perigee = 107.710289 (deg)
     PMD Mean Anomaly = 0.000000 (deg)
```

```
**OUTPUT**

     Suggested Perigee Altitude = 583.249929 (km)
     Suggested Apogee Altitude = 603.589626 (km)
     Returned Error Message = Passes LEO reentry orbit criteria.

     Released Year = 2022 (yr)
     Requirement = 61
     Compliance Status = Pass

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

=============== End of Requirement 4.6 ===============
01 07 2013; 14:40:05PM    *********Processing Requirement 4.7-1
     Return Status :  Passed

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

name = SkyCube
quantity = 1
parent = 0
materialID = 5
type = Box
Aero Mass = 1.700000
Thermal Mass = 1.700000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.100000

name = Camera
quantity = 3
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.011000
Thermal Mass = 0.005000
Diameter/Width = 0.032000
Length = 0.032000

name = Lens assy
quantity = 3
parent = 2
materialID = 76
type = Cylinder
Aero Mass = 0.006000
Thermal Mass = 0.006000
Diameter/Width = 0.020000
Length = 0.020000

name = Boards
quantity = 3
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.040000
```

```
Thermal Mass = 0.040000
Diameter/Width = 0.100000
Length = 0.100000

name = Batteries
quantity = 2
parent = 1
materialID = 58
type = Cylinder
Aero Mass = 0.045000
Thermal Mass = 0.045000
Diameter/Width = 0.018000
Length = 0.069000

name = Radio Amp
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 0.045000
Thermal Mass = 0.045000
Diameter/Width = 0.040000
Length = 0.050000
Height = 0.010000

name = Balloon
quantity = 1
parent = 1
materialID = -1
type = Sphere
Aero Mass = 0.230000
Thermal Mass = 0.230000
Diameter/Width = 2.000000

name = Solar Panels
quantity = 8
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.040000
Thermal Mass = 0.040000
Diameter/Width = 0.100000
Length = 0.100000

name = Balloon Box
quantity = 1
parent = 1
materialID = -1
type = Box
Aero Mass = 0.197000
Thermal Mass = 0.020000
Diameter/Width = 0.100000
Length = 0.100000
Height = 0.050000

name = Cracker
quantity = 1
```

```
parent = 9
materialID = 5
type = Cylinder
Aero Mass = 0.127000
Thermal Mass = 0.087000
Diameter/Width = 0.025000
Length = 0.072000

name = CO2 Cylinder
quantity = 1
parent = 10
materialID = 54
type = Cylinder
Aero Mass = 0.040000
Thermal Mass = 0.040000
Diameter/Width = 0.018000
Length = 0.083000

name = Lid
quantity = 1
parent = 9
materialID = 5
type = Flat Plate
Aero Mass = 0.050000
Thermal Mass = 0.050000
Diameter/Width = 0.100000
Length = 0.100000

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

name = SkyCube
Demise Altitude = 77.996285
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Camera
Demise Altitude = 77.486652
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Lens assy
Demise Altitude = 77.227386
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Boards
Demise Altitude = 77.311285
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Batteries
Demise Altitude = 70.963042
```

```
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Radio Amp
Demise Altitude = 74.912199
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Balloon
Demise Altitude = 77.996285
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Solar Panels
Demise Altitude = 77.311285
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Balloon Box
Demise Altitude = 77.960433
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Cracker
Demise Altitude = 73.543019
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = CO2 Cylinder
Demise Altitude = 67.410800
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Lid
Demise Altitude = 76.592019
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

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

=============== End of Requirement 4.7-1 ===============
10 25 2012; 13:04:48PM   Processing Requirement 4.5-1:    Return Status :  Passed

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

**INPUT**

     Space Structure Name = SkyCube
```

```
     Space Structure Type = Payload
     Perigee Altitude = 600.000000 (km)
     Apogee Altitude = 600.000000 (km)
     Inclination = 52.000000 (deg)
     RAAN = 0.000000 (deg)
     Argument of Perigee = 0.000000 (deg)
     Mean Anomaly = 0.000000 (deg)
     Final Area-To-Mass Ratio = 0.022900 (m^2/kg)
     Start Year = 2013.250000 (yr)
     Initial Mass = 1.700000 (kg)
     Final Mass = 1.700000 (kg)
     Duration = 0.500000 (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 = 0.000001
     Returned Error Message: Normal Processing
     Date Range Error Message: Normal Date Range
     Status = Pass

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

=============== End of Requirement 4.5-1 ===============
10 25 2012; 13:05:35PM   Project Data Saved To File
10 25 2012; 13:09:56PM   Requirement 4.5-2:  Compliant

==================================================
Spacecraft = SkyCube
Critical Surface = CPU Board
==================================================

**INPUT**

     Apogee Altitude = 600.000000 (km)
     Perigee Altitude = 600.000000 (km)
     Orbital Inclination = 52.000000 (deg)
     RAAN = 0.000000 (deg)
     Argument of Perigee = 0.000000 (deg)
     Mean Anomaly = 0.000000 (deg)
     Final Area-To-Mass = 0.022900 (m^2/kg)
     Initial Mass = 1.700000 (kg)
     Final Mass = 1.700000 (kg)
     Station Kept = No
     Start Year = 2013.250000 (yr)
     Duration = 0.500000 (yr)
     Orientation = Random Tumbling
     CS Areal Density = 0.180000 (g/cm^2)
     CS Surface Area = 0.010000 (m^2)
     Vector = (0.000000 (u), 0.000000 (v), 0.000000 (w))
```

```
     CS Pressurized = No
     Outer Wall 1   Density: 0.200000 (g/cm^2)  Separation: 1.000000 (cm)

**OUTPUT**

     Probabilty of Penitration = 0.000142
     Returned Error Message: Normal Processing
     Date Range Error Message: Normal Date Range
```

Requirements 4.7-1b and 4.7-1c below are non-applicable requirements because SkyCube 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 Spacecraft Hazardous Materials

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

ODAR Section 8: Assessment for Tether Missions

No tether will be used; this section is not applicable.

END of ODAR for SkyCube

Appendix A: Acronyms

Al	Aluminum
cm	centimeter
COTS	Commercial Off-The-Shelf
DAS	Debris Assessment Software
EOM	End Of Mission
GEO	Geosynchronous Earth Orbit
ISIPOD	ISIS CubeSat Deployer
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
P-POD	Poly Picosatellite Orbital Deployer
Ti	Titanium
yr	year