RECONSO Orbital Debris Assessment Report

Submitted by:

Program Manager: Francis Park

Document Revisions

Revision	Description	Date	Author
1	Initial Release	4/10/17	Francis Park

ODAR Section 1: Program Management and Mission Overview

Program Manager: Francis Park
Chief Systems Engineer: Lyndy Axom
Principle Investigator: Dr. Marcus Holzinger
Foreign Government or Space Agency Participation: None
Summary of NASA's Responsibility under the governing agreements: NA

Schedule of upcoming mission milestones:
Launch: O/A Late 2018

Mission Overview:
The RECONSO mission is designed to demonstrate visual detection and tracking of space debris from a small Cubesat platform. The spacecraft has been designed, fabricated and tested by a team of Georgia Tech undergraduate and graduate students who will also be responsible for mission operations. Photographs of the regions of interest will be acquired during the sunlight portion of the orbit. Onboard processing will occur during the eclipse periods. Image processing will detect moving objects in the acquired series of images and assign orbital parameters to the detected objects. Downlinked data will be the estimated orbital elements for the debris, not raw images. RECONSO contains no propulsion system, and is pointed using a 3°axis magnetorquer system.

Tentative Requested Orbit:
Apogee – 500 km
Perigee - 800 km
Inclination - 75 deg
Period: - 97.728 min

ODAR Section 2: Spacecraft Description

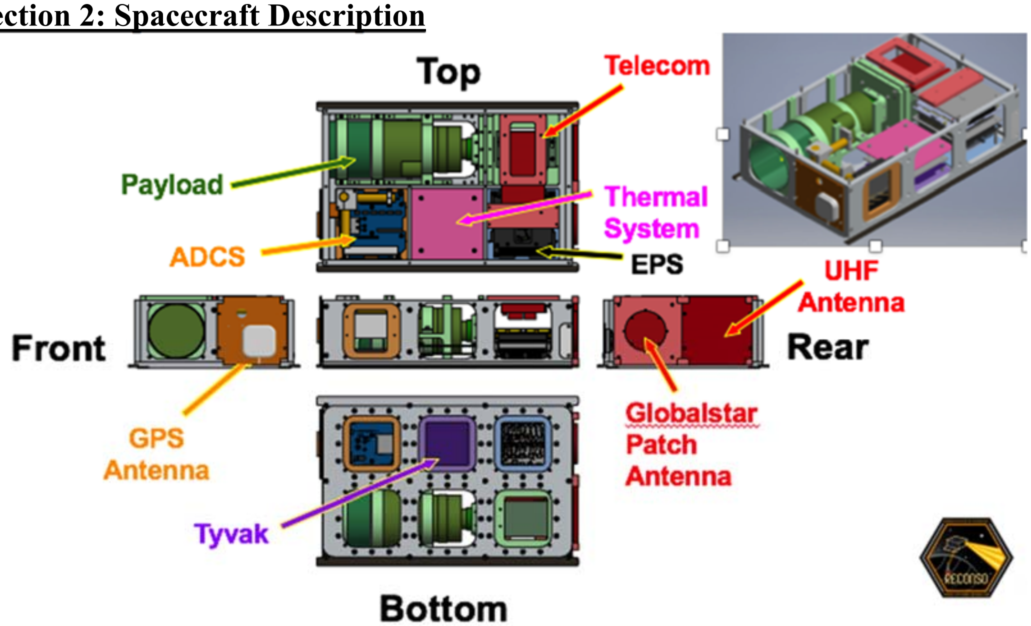

Figure 1: RECONSO Structure and CAD Model

Dimensions: 36.5 x 23.9 x 10.9 cm
Mass: ~8 kg
Total satellite mass at launch, including all propellants and fluids: ~8.0 kg
Dry mass of satellites at launch, excluding solid rocket motor propellants: ~8.0 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.
Description of attitude control system and indication of the normal attitude of the spacecraft with respect to the velocity vector: Comprised of 3 magnetorquers, which will allow the satellite to be aligned relative to the Earth's magnetic field. These will allow the satellite to de-spin and 'lock' to the magnetic field.
Description of any range safety or other pyrotechnic devices: None.
Description of the electrical generation and storage system: Standard COTS Lithium-Ion battery cells are charged before payload integration and provide electrical energy during the mission. Cells are recharged by solar arrays mounted on the satellite.
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: 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 v2.0.1)
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. However, RECONSO uses a space rated/fully tested Clydespace battery and EPS that have overcurrent, overvoltage, overcharge, overdicharge, and undertemperature protection. The system is qualified according to NASA standards EP-Wi-032. 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.

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: None.

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 lithium-polymer batteries (260 g) 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 thermal rise due to high load discharge rate.
Mitigation 1: Battery system has not been tested in a hot thermal environment. Once launch date approaches, environmental testing will be conducted prior to launch to ensure no defects or errors.

Failure Mode 2: 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 2: 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 3: Crushing.
Mitigation 3: 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.

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 cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft (Requirement 56450).

Compliance statement: RECONSO's battery charge circuits include overcharge protection (ClydeSpace) and a parallel design 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

Assessment of spacecraft compliance with Requirements 4.5-1 and 4.5-2 (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: 0.000001; 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).

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 reentry. 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: ~8.0kg
Cross-sectional Area: 0.0872 m^2
Area to mass ratio: 0.0872/8 = 0.0109 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: RECONSO satellite's reentry is COMPLIANT using method “a.”.

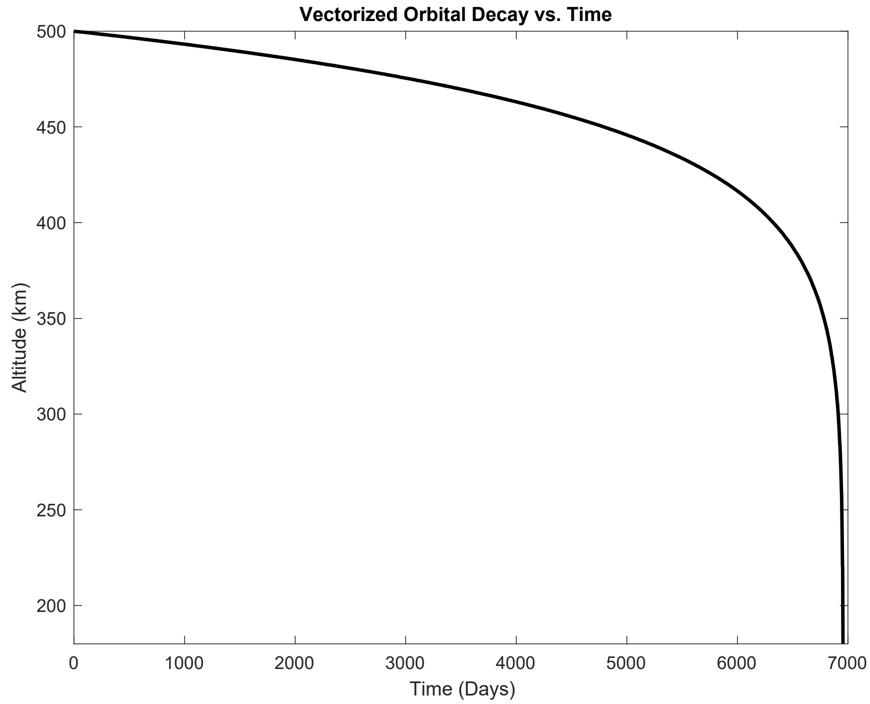

Figure 2: RECONSO Orbit History Requirement 4.6-2. Disposal for space structures near LEO.

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: Not applicable. The satellite 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 RECONSO is COMPLIANT with the requirement. Total human casualty probability is reported by the DAS software as 1:100000000. This is expected to represent the absolute maximum casualty risk, as calculated with DAS's limited modeling capability.

Analysis (per DAS v2.1.1

```
==============
Project Data
==============
```

```
**INPUT**

      Space Structure Name = RECONSO
      Space Structure Type = Payload

      Perigee Altitude = 500.000000 (km)
      Apogee Altitude = 800.000000 (km)
      Inclination = 75.000000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Area-To-Mass Ratio = 0.010110 (m^2/kg)
      Start Year = 2018.000000 (yr)
      Initial Mass = 8.636000 (kg)
      Final Mass = 8.636000 (kg)
      Duration = 1.000000 (yr)
      Station Kept = False
      Abandoned = True
      PMD Perigee Altitude = 504.420971 (km)
      PMD Apogee Altitude = 794.585587 (km)
      PMD Inclination = 75.001264 (deg)
      PMD RAAN = 50.637799 (deg)
      PMD Argument of Perigee = 213.950520 (deg)
      PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

      Suggested Perigee Altitude = 504.420971 (km)
      Suggested Apogee Altitude = 794.585587 (km)
      Returned Error Message = Passes LEO reentry orbit criteria.

      Released Year = 2035 (yr)
      Requirement = 61
      Compliance Status = Pass

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

=============== End of Requirement 4.6 ===============
10 04 2017; 00:09:08AM *********Processing Requirement 4.7-1
      Return Status :  Passed

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

name = RECONSO
quantity = 1
parent = 0
materialID = 8
type = Box
Aero Mass = 8.636000
Thermal Mass = 8.636000
Diameter/Width = 0.239000
Length = 0.365000
Height = 0.109000
```

```
name = Structure
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 1.122000
Thermal Mass = 1.122000
Diameter/Width = 0.239000
Length = 0.365000
Height = 0.109000

name = Solar Panels 6U
quantity = 2
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.298000
Thermal Mass = 0.298000
Diameter/Width = 0.239000
Length = 0.365000

name = Solar Panels 3U
quantity = 2
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.150000
Thermal Mass = 0.150000
Diameter/Width = 0.109000
Length = 0.365000

name = Solar Panels 1U
quantity = 2
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.050000
Thermal Mass = 0.050000
Diameter/Width = 0.109000
Length = 0.119000

name = Batteries
quantity = 3
parent = 1
materialID = -1
type = Box
Aero Mass = 0.133000
Thermal Mass = 0.133000
Diameter/Width = 0.090000
Length = 0.095000
Height = 0.020000

name = Camera
```

```
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.120000
Thermal Mass = 0.120000
Diameter/Width = 0.037000
Length = 0.038000
Height = 0.035000

name = Lens
quantity = 1
parent = 1
materialID = 8
type = Cylinder
Aero Mass = 1.430000
Thermal Mass = 1.430000
Diameter/Width = 0.078000
Length = 0.124000

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

name = RECONSO
Demise Altitude = 77.998672
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Structure
Demise Altitude = 74.949356
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Solar Panels 6U
Demise Altitude = 77.111443
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Solar Panels 3U
Demise Altitude = 77.255089
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Solar Panels 1U
Demise Altitude = 77.365952
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Batteries
```

```
Demise Altitude = 77.236336
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Camera
Demise Altitude = 72.636002
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Lens
Demise Altitude = 64.671761
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

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

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

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
Not Applicable.

End of ODAR for RECONSO