Orbital Sidekick

Orbital Debris Assessment Report (ODAR)

DAS Software v3.1.2

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Applicable Programs: GHOSt

Revision History

Revision	Date	Comment
1.0	December 17, 2021	Initial Release

Contents

SELF-ASSESSMENT (APPENDIX A.2 NASA-STD-8719.14)

A self-assessment is provided below in accordance with the assessment format provided in Appendix A.2 of NASA-STD-8719.14B.

Requirement	Description	Compliance	Comments
4.3-1	Mission-related debris passing through LEO	Compliant	
4.3-2	Mission-related debris passing through GEO	N/A	
4.4-1	Limiting the risk to other space systems from accidental explosions during deployment and mission operations	Compliant	
4.4-2	Design for passivation after completion of mission operations while in orbit	Compliant	
4.4-3	Limiting the long-term risk to other space systems from planned breakups	Compliant	
4.4-4	Limiting the short-term risk to other space systems from planned breakups	Compliant	
4.5-1	Limiting debris generated by collisions with large objects	Compliant	
4.5-2	Limiting debris generated by collisions with small objects	Compliant	
4.6-1	Disposal for space structures in or passing through LEO	Compliant	5.2 years at 525 km
4.6-2	Disposal for space structures near GEO	N/A	
4.6-3	Disposal for space structures between LEO and GEO	N/A	
4.6-4	Reliability of post-mission disposal maneuver operations	Compliant	
4.7-1	Limit the risk of human casualty	Compliant	
4.8-1	Mitigate the collision hazards of space tethers in protected regions of space	N/A	

ASSESSMENT REPORT FORMAT

This ODAR follows the format prescribed in NASA-STD-8719.14B, Appendix A.1 and includes the content indicated as a minimum requirement in each of Sections 1 through 8. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered here.

1. PROGRAM MANAGEMENT AND MISSION OVERVIEW

Project Manager: Peter Friedhoff, Director of Space Systems

Senior Management: Daniel Katz, Chief Operating Officer

Mission Overview: GHOSt is a hyperspectral imaging ("HSI") Earth observation remote sensing mission, consisting of six ~91 kg ESPA class satellites and a ground sample distance of approximately 8 meters. GHOSt will capture more than 400 spectral bands in the visible to shortwave infrared range of 400 – 2500 nm to feed OSK's Spectral Intelligence Global Monitoring Application (SIGMA™) platform.

Schedule of Upcoming Mission Milestones: The first launch of GHOSt spacecraft (GHOSt-01 and -02) is expected in Q2 2022 aboard a Falcon 9 launch vehicle. The first launch will be no earlier than June 2022.

Launch Vehicle and Launch Site: The GHOSt spacecraft will be launched in three pairs using SpaceX Falcon 9 Rideshare from either Vandenberg Air Force Base, California, or Cape Canaveral, FL, at the launch provider's discretion.

Mission Duration: Nominal operations for each GHOSt satellite is 3 years, plus a post-operations orbital lifetime of less than 3 years, during which the spacecraft will re-enter via atmospheric orbital decay. Worst case scenario provides for an orbital duration of less than 6 years in total.

Launch and Deployment Profile: The GHOSt spacecraft will be integrated and launch in pairs on a SpaceX Falcon 9 Rideshare vehicle, which will transport multiple mission payloads simultaneously. The GHOSt spacecraft will be deployed between 500 km and 550 km at the discretion of the launch service provider. The anticipated average altitude of the operational GHOSt spacecraft is 525 km in a circular sun synchronous orbit.[1]

2. SPACECRAFT DESCRIPTION

Physical Description of the Spacecraft: The exterior dimensions of the satellite are 57.8 cm x 57.8 cm x 111.4 cm. The mass of the satellite is 91.4 kg. The payload is a nadir pointing line scanner and the satellites do not have low vs. high drag orientations for nominal operation. This imaging mission is performed with the X-axis nadir and either the Z-axis and/or Y-axis velocity pointing.

The satellite avionics are enclosed inside the Data Power Module ("DPM"), which consists of: (i) a flight computer with integrated GPS and Inertial Management Units, (ii) a secondary GPS, (iii) two TT&C transceivers, (iii) two battery packs, (iv) a charging module, and (v) two power distribution modules. The spacecraft also contains a third battery pack consisting of two Direct

[1] OSK has assumed a 525 km deployment orbit altitude for purposes of this orbital debris analysis.

Energy Packs ("DEPs") to regulate the high loads generated by the main solar panels ("MSPs") and provide a secondary source of power to the payload. All the avionics components are mission-proven.

The attitude determination and control system consists of flight-proven external hardware with two star trackers, gyroscope, reaction wheels and torque rods. The optical payload consists of two payload computers, hyperspectral sensor, and telescope.

A 15-inch Planetary Systems Lightband will be used to deploy the spacecraft from the launch vehicle, from which no debris will be generated.

The GHOSt spacecraft is depicted in Figure 1.

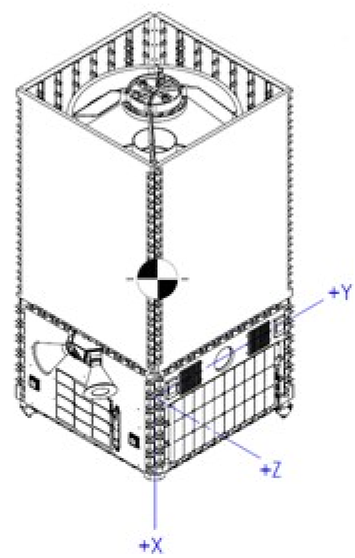

Figure 1: GHOSt Spacecraft

Total Mass of Satellite at Launch, Including All Propellants and Fluids: 91.4 kg.

Dry Mass of the Satellite: 91.4 kg.

Identification of All Fluids On-Board: No propellants or fluids on-board.

Description of Propulsion System: The GHOSt spacecraft will not be equipped with propulsion.

Description of Attitude Control System: Following separation from the launch vehicle, the GHOSt spacecraft will autonomously de-tumble and be oriented into sun-pointing mode. The following chart describes the attitude determination and control subsystem ("ADCS") modes that will be employed, using a combination of magnetometers, sun sensors, gyroscopes, reaction wheels, torque rods, and star trackers, to orient the GHOSt spacecraft.

ADCS Mode	Description
Sun Pointing	The nominal power-generating mode of the satellite, in which the incident angle on each MSP is approximately 45°.
Target Tracking	Used to communicate with the ground station; the satellite can point towards a fixed reference point on Earth while it passes through the ground station's line of sight.
Nadir Pointing	Used for payload operation when the satellite enters the sun or exits eclipse.
Sun Clocking	To generate additional power, this mode permits the satellite to rotate around its fixed inertial axis towards the sun, while also operating in the Target Tracking or Nadir Pointing modes.

Fluids in Pressurized Batteries: None. The GHOSt spacecraft employ unpressurized standard lithium ion battery cells.

Description of Pyrotechnic Devices: None.

Description of Electrical and Power System: Power will be generated by six solar panels mounted on the satellite: four MSPs and two Smart Solar Panels ("SSPs"). The MSPs provide the primary power source for the spacecraft, while the SSPs function as a backup power generation mechanism when detumbling or performing clocking maneuvers.

The spacecraft will also have four battery packs: two encased in the DPM and two backup DEPs. The battery packs are all equipped with power regulation ICs which regulate the discharge state of the individual battery cells. All of the battery packs are charged by the solar panels.

The satellite bus nominally consumes 18W of power, with certain modes reducing or increasing the load. The payload is expected to consume an average of 72W. The charge/discharge cycle is managed by a power management system overseen by the Flight Computer and Electrical Power Subsystem.

Identification of Other Stored Energy: None.

Identification of Any Radioactive Materials: None.

3. ASSESSMENT OF SPACECRAFT DEBRIS RELEASE DURING NORMAL OPERATIONS

REQUIREMENT 4.3-1: DEBRIS PASSING THROUGH LEO.

No release of debris will occur during the lifetime of the GHOSt satellites. All GHOSt deployments use a 15-inch Planetary Systems Lightband to deploy the spacecraft from the launch vehicle, from which no debris will be generated. Additionally, there is no probable scenario for unintentional debris generation.

Result for Requirement 4.3-1: COMPLIANT

REQUIREMENT 4.3-2: DEBRIS PASSING NEAR GEO.

There will be no intentional release of debris near Geostationary Orbit during the lifetime of the mission, as the GHOSt mission is contained in Low Earth Orbit.

Result for Requirement 4.3-2: COMPLIANT

4. ASSESSMENT OF SPACECRAFT INTENTIONAL BREAKUPS AND POTENTIAL FOR EXPLOSIONS

REQUIREMENT 4.4-1: LIMITING THE RISK TO OTHER SPACE SYSTEMS FROM ACCIDENTAL EXPLOSIONS DURING DEPLOYMENT AND MISSION.

The in-orbit 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. Due to the small mass of the satellite and its short orbital lifetime, the long-term effects of an unlikely explosion on the LEO environment are negligible. The battery safety systems discussed in the FMEA describe the combined faults that must occur for any of seven (7) independent, mutually exclusive failure modes to lead to such an explosion.

Result for Requirement 4.4-1: 0.000; COMPLIANT.

Supporting Rationale and FMEA Details:

- **Failure Mode 1:** Internal short circuit.
  - Mitigation: Qualification and acceptance shock, vibration, thermal cycling, and vacuum tests followed by maximum system rate-limited charge and discharge will prove that no internal short circuit sensitivity exists.
  - Combined Faults Required for Realized Failure: Environmental testing and functional charge and 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: Battery cells were tested in the 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, thermal vacuum environment in order to test the upper limits of the cells capability. No failures were observed via satellite telemetry or external monitoring circuitry.
    - Combined Faults Required for Realized Failure: Spacecraft thermal design must be incorrect *and* external over-current detection and disconnect function must fail to enable this failure mode.

- **Failure Mode 3:** 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: This failure mode will be negated by:
        a) Qualification-tested short circuit protections on each external circuit;
        b) Design of battery packs and insulators such that no contact with nearby board traces is possible without being cause by some other mechanical failure; and
        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 or short- circuit *and* external over-current detection and disconnect function must all occur to enable this failure mode.

- **Failure Mode 4:** Inoperable vents.
    - Mitigation: Battery venting is not inhibited by the battery holder design or the spacecraft design. The battery is capable of venting gases to the external environment.
    - Combined Faults Required for Realized Failure: The cell manufacturer or the satellite integrator fails to install proper venting.

- **Failure Mode 5:** Crushing.
    - Mitigation: 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: This failure mode is mitigated by:
        a) Battery holder and 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: 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 under a variety of modeled cases, including worst-case orbital scenarios. Analysis shows these temperatures to be 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.

REQUIREMENT 4.4-2: DESIGN FOR PASSIVATION AFTER COMPLETION OF MISSION OPERATIONS.

Each GHOSt satellite has the capability to fully disconnect the lithium ion cells from the charging current of its respective solar arrays. At end of life, this feature will be used to disconnect all energy generation sources and deplete all remaining stores. In the unlikely event that a battery cell explosively ruptures, the small size, mass, and potential energy of these batteries is such that while the spacecraft could be expected to vent gases, the debris from the battery rupture will be contained within the spacecraft due to the lack of penetration energy to the multiple enclosures surrounding the batteries.

Result for Requirement 4.4-2: COMPLIANT.

List of components which shall be passivated at End of Mission:

- Sixteen (16) lithium ion battery cells[2] – spacecraft will be configured to keep solar array pointed away from sun and let batteries deplete completely;
- Solar array charging circuit – will be disabled, discharging all cells fully within a few days;
- Reaction wheels – will have the power removed and spacecraft will be configured to keep solar array pointed away from sun.

[2] Each DPM battery pack has two lithium ion cells; each DEP battery pack has six lithium ion cells.

Rationale for all items which are required to be passivated, but cannot be due to their design: None.

REQUIREMENT 4.4-3: LIMITING THE LONG-TERM RISK TO OTHER SPACE SYSTEMS FROM PLANNED BREAKUPS.

There are no planned breakup during the mission.

Result for Requirement 4.4-3: COMPLIANT.

REQUIREMENT 4.4-4: LIMITING THE SHORT-TERM RISK TO OTHER SPACE SYSTEMS FROM PLANNED BREAKUPS.

There are no planned breakup during the mission.

Result for Requirement 4.4-4: COMPLIANT.

5. ASSESSMENT OF POTENTIAL FOR ON-ORBIT COLLISIONS

REQUIREMENT 4.5-1: LIMITING DEBRIS GENERATED BY COLLISIONS WITH LARGE OBJECTS.

OSK will use all design and operational strategies available to minimize the potential for in-orbit collision with crewed spacecraft and all other objects. OSK will be proactive in ensuring that any risks to inhabitable orbiting objects posed by a GHOSt satellite are mitigated. This will include coordinating with NASA to ensure protection of the International Space Station on an ongoing basis, and coordinating with the China National Space Agency with respect to Tiangong-2 and successor vehicles. OSK will provide all relevant agencies with any information they need to assess risks and ensure safe flight profiles, as well as contact information for OSK personnel on a 24 hours per-day/7 days per-week basis. Through these measures, OSK will be able to avoid collisions on an ongoing basis. No proximity operations are planned.

OSK confirms that it intends to perform collision avoidance procedures, including conjunction assessment, execution of avoidance maneuvers, and trajectory planning for any significant planned alterations of satellite trajectory, and notification to other potentially affected operators of any planned alteration of a satellite's trajectory for all phases of operations. OSK certifies that upon receipt of a space situational awareness conjunction warning, it will review and take all possible steps to assess the collision risk and will mitigate the collision risk if necessary. As appropriate, steps to assess and mitigate the collision risk may include, but are not limited to: contacting the operator of any active spacecraft involved in such a warning; sharing ephemeris data and other appropriate operational information with any such operator; and modifying space station attitude and/or operations.

The GHOSt satellites do not have propulsive capabilities but OSK can perform necessary collision avoidance maneuvers by altering the orientation, and thus the drag profile, of a GHOSt satellite to modify the orbit. GHOSt can achieve a 1.1 km altitude change within 48 hours after a collision notification**.**

Prior to deployment, OSK will register the GHOSt satellites with the 18th Space Control Squadron (or a successor entity). Following deployment, OSK will actively identify and track its satellites using its authorized ground station network. OSK certifies that each of its satellites will have a unique telemetry marker allowing it to be distinguished from other satellites or space objects.[3] OSK routinely performs precise orbit determination and orbit prediction and will share that information to the 18th Space Control Squadron (or a successor entity) and other satellite operators to aid collision avoidance response, including conjunction assessment and maneuver planning. OSK plans to share information regarding initial deployment, ephemeris, and significant planned maneuvers with the 18th Space Control Squadron (or a successor entity) and other entities that engage in space situational awareness or space traffic management functions.

OSK participates in a sharing agreement with the Combined Space Operations Center ("CSpOC") to better coordinate collision avoidance measures and receive conjunction threat reports. OSK receives updated two-line element sets from CSpOC, which facilitate the identification and tracking of OSK satellites. CSpOC will be able to contact the OSK satellite operations team, accessible 24 hours per day/seven days per week, to ensure that OSK can take immediate action to coordinate collision avoidance measures.

Result for Requirement 4.5-1: 0.0000093; COMPLIANT.

REQUIREMENT 4.5-2. LIMITING DEBRIS GENERATED BY COLLISIONS WITH SMALL OBJECTS.

The spacecraft will be disposed of via atmospheric re-entry and do not require a specific orientation and drag state to meet the disposal requirements. Therefore, no element or component is required to complete post-mission operations.

Result for Requirement 4.5-2: Not applicable.

6. ASSESSMENT OF SPACECRAFT POST-MISSION DISPOSAL PLANS AND PROCEDURES

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

Plan for any spacecraft maneuvers required to accomplish post-mission disposal: None.

Calculation of area-to-mass ratio after post-mission disposal:

- Mass: 91.4 *kg*
- Cross-sectional Area: 0.91 m^2

[3] The GHOSt satellites are larger than 10 cm in their smallest dimension, and are therefore presumed trackable pursuant to the Commission's rules.

- Area-to-mass Ratio: 0.0100 m^2/kg

REQUIREMENT 4.6-1: DISPOSAL FOR SPACE STRUCTURES IN OR PASSING THROUGH LEO.

The GHOSt spacecraft will be disposed using method "A", atmospheric re-entry. At a nominal initial orbital altitude of 525 km re-entry is calculated to be within 5.2 years post-deployment per DAS v3.1.2. Figure 2 shows the output from the orbital lifetime analysis.

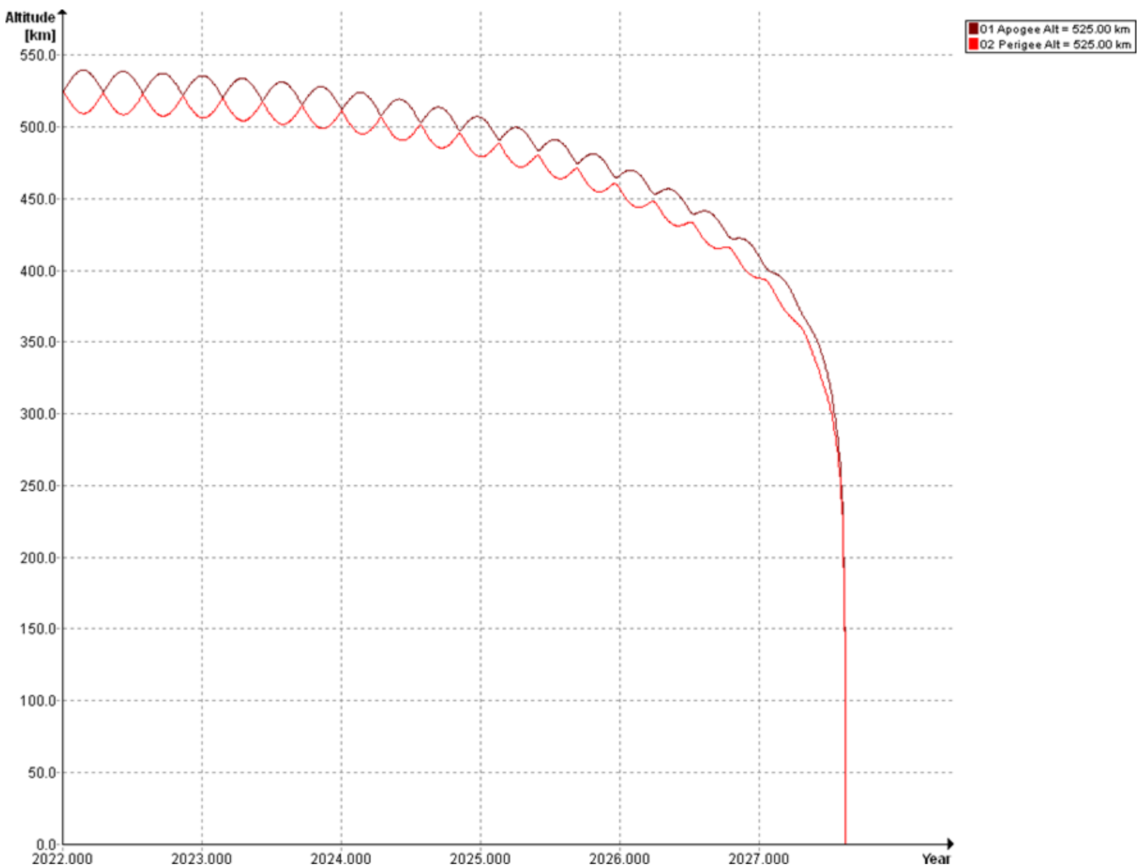

Figure 2: GHOSt Orbital History from 525 km

After the spacecraft has completed payload operations, it will be passivated and decommissioned to passively tumble for the remainder of its orbital lifetime, which will be approximately 2.2 years assuming a full 3 year operational mission. In the unlikely event the spacecraft is deployed from the launch vehicle, but unresponsive or nonfunctional, the calculated orbital lifetime is 5.9 years based on the average area-to-mass in tumble.

Result for Requirement 4.6-1: COMPLIANT.

REQUIREMENT 4.6-2. DISPOSAL FOR SPACE STRUCTURES NEAR GEO.

Result for Requirement 4.6-2: Analysis is not applicable.

REQUIREMENT 4.6-3. DISPOSAL FOR SPACE STRUCTURES BETWEEN LEO AND GEO.

Result for Requirement 4.6-3: Analysis is not applicable.

REQUIREMENT 4.6-4. RELIABILITY OF POST-MISSION DISPOSAL OPERATIONS.

The above analysis has been performed with an average area-to-mass ratio, which means that even in the case of massive power or ADCS failure, a tumbling spacecraft, the spacecraft will deorbit within the allowable timeframe under the Commission's Part 25 Streamlined Rules.

Result for Requirement 4.6-4: COMPLIANT.

7. ASSESSMENT OF RE-ENTRY HAZARDS

REQUIREMENT 4.7-1(A): LIMIT THE RISK OF HUMAN CASUALTY.

The risk of human casualty was computed by DAS v3.1 for an uncontrolled re-entry to be 1:100000000 for the GHOSt spacecraft. This is the lowest output of the DAS software. Considering 0 energy makes it to the ground during re-entry, the risk of human casualty is effectively 0.

Result for Requirement 4.7-1(a): COMPLIANT.

8. COLLISION RISK POSED BY TETHER SYSTEMS

REQUIREMENT 4.8-1: MITIGATE THE COLLISION HAZARDS OF SPACE TETHERS.

No tethers are to be used in the GHOSt mission.

Result for Requirement 4.8-1: COMPLIANT.