SHERPA Orbital Debris Assessment Report (ODAR)

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

Report Version: 1, 10/27/2015

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This document contains no proprietary, ITAR, or export controlled information.

DAS Software Version Used In Analysis: v2.0.2

VERSION APPROVAL and/or FINAL APPROVAL*:

Jason Andrews/ Curt Blake

*Approval signatures indicate acceptance of the ODAR-defined risk.

Table Contents

Self-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.

Orbital Debris Self-Assessment Report Evaluation: SHERPA Mission

Requirement #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant or N/A	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.
4.4-4	☐	☐	☐	☐	☒	☐	☐	No planned breakups.
4.5-1	☐	☐	☐	☐	☒	☐	☐	See note 1.
4.5-2	☐	☐	☐	☐	☒	☐	☐	See note 1.
4.6-1(a)	☐	☐	☐	☐	☒	☐	☐	See note 1.
4.6-1(b)	☐	☐	☐	☐	☒	☐	☐	See note 1.
4.6-1(c)	☐	☐	☐	☐	☒	☐	☐	See note 1.
4.6-2	☐	☐	☐	☐	☒	☐	☐	Spacecraft does not go to GEO.
4.6-3	☐	☐	☐	☐	☒	☐	☐	Spacecraft does not go beyond LEO.
4.6-4	☐	☐	☐	☐	☒	☐	☐	See note 1.
4.7-1	☐	☐	☐	☐	☒	☐	☐	DAS reports human casualty probability < 1:10,000
4.8-1					☒	☐	☐	No tethers used.

Notes:

1. This launch has several spacecraft manifested and the SHERPA spacecraft is not the primary mission.

Assessment Report Format:

ODAR Technical Sections Format Requirements:

As Spaceflight, Inc. is a US company; this ODAR follows the format recommended 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 SHERPA satellite. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered here.

ODAR Section 1: Program Management and Mission Overview

Project Manager: Adam Hadaller

Foreign government or space agency participation: No foreign participation

Schedule of upcoming mission milestones:

SRR:	January 2016
Launch:	No Earlier Than April 2016

Mission Overview:
SHERPA will be deployed as a secondary payload into a planned elliptical orbit of 450 x 720 km at 97.4 degrees inclination. Once deployed, SHERPA will deploy satellites attached to the 5 ports on the exterior. (*These satellites must receive an FCC license and do not constitute debris*). After a mission lifetime of under 1 day, SHERPA will await atmospheric drag to fully de-orbit the satellite. SHERPA has no solar panels, attitude control, propulsion, or pressure vessels.

ODAR Summary:

No debris released in normal operations; no credible scenario for breakups; the collision probability with other objects is compliant with NASA standards; and the estimated nominal decay lifetime due to atmospheric drag is under 25 years following operations (16.4 years after <12 hours of nominal operations, as calculated by DAS 2.0.2).

Launch vehicle and launch site: Vandenberg AFB, CA

Proposed launch date: No Earlier Than April 2016

Mission duration: Maximum Nominal Operations: <12 hours, Post-Operations Orbit lifetime: 16.4 years until reentry via atmospheric orbital decay (~16.4 years in total).

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

	Apogee Altitude	Perigee Altitude	Inclination	Max. Dwell
Deployment	720 km	450 km	97.4 deg	<5 days
End-of-Life Orbit*	720 km	450 km	97.4 deg	<20 years

*These orbits are the same because SHERPA has no attitude changing capability.

ODAR Section 2: Spacecraft Description

Physical description of the spacecraft:

SHERPA is an EELV Secondary Payload Adapter (ESPA)-derived spacecraft. All avionics are mounted within the Moog ESPA Grande structure with approximate dimensions of 1.42 m height by 1.6 m diametrical (including a conical payload adapter). Excursions from this volume include 5 adapters, which are fitted to the five ports on the spacecraft. The maximum spacecraft envelope with these adapters is 2742 mm x 2608 mm x 1423 mm.

The SHERPA load bearing structure is the Moog ESPA Grande ring, composed of a 7050 aluminum alloy.

SHERPA does not have attitude control capability.

Total satellite mass at launch, including all propellants and fluids: ~1268 kg.

Dry mass of satellites at launch, excluding solid rocket motor propellants: ~1268 kg

Dry mass of satellites at end of mission, excluding solid rocket motor propellants: ~603 kg
Description of all propulsion systems (cold gas, mono-propellant, bi-propellant, electric, nuclear):

The SHERPA spacecraft has no propulsion system.

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: N/A

Fluids in Pressurized Batteries: None. SHERPA uses two unpressurized standard COTS Lithium-Ion battery cells. Each cell has a height of 28mm, a width of 76mm, a length of 140mm, and a mass of 890 grams. The cells are mounted inside an aluminum housing / containment device.

Description of attitude control system and indication of the normal attitude of the spacecraft with respect to the velocity vector:

None. SHERPA has no attitude control.

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 are charged before payload integration and provide electrical energy during the mission.

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 other than payload deployments (see Mission Overview).

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.

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.

In addition to the battery protection mentioned about, the SHERPA battery unit features two thermal switches that completely isolate the battery electrically if the temperature gets too high.

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:

No components require passivation at EOM.

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

SHERPA's battery charge circuits include overcharge protection and a parallel design to limit the risk of battery failure. However, in the unlikely event that a battery cell does explosively rupture, the size, mass, and potential energy of these small batteries is such that while the spacecraft could be expected to vent gases, debris from the battery rupture should be contained within the battery housing / containment device due to the lack of penetration energy. Note that SHERPA does not have solar panels or any means to charge the battery while on-orbit.

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 theoretically 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 the selected COTS batteries is such that while the spacecraft could be expected to vent gases, most debris from the battery rupture should be contained within the battery housing / containment device due to the lack of penetration energy.
Probability: Extremely Low. It is believed to be a much less than 0.1% probability 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 like likelihood and impact 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) 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 failure 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 final assembler 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 failure modes 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.

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:
SHERPA battery charge circuits include overcharge protection 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 (per DAS v2.0.2, 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:

Collision Probability: 0.00011; 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 post-mission disposal requirements is less than 0.01 (Requirement 56507).

Small Object Impact and Debris Generation Probability:
Collision Probability: 0.0000; COMPLIANT.

SHERPA's mission duration of <12 hours is so short that the probability of collisions with small objects in Earth orbit affecting its mission is effectively zero.

Identification of all systems or components required to accomplish any postmission disposal operation, including passivation and maneuvering:
SHERPA has no post-mission maneuvering or disposal operations. Post-mission passivation consists of draining battery power. SHERPA has no propellant or pressure vessels.

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

6.1 Description of spacecraft disposal option selected: The satellite will de-orbit naturally by atmospheric re-entry. For atmospheric drag / re-entry calculations in DAS, a cross-section drag area of 3.383 m^2 was assumed. This was determined via analysis of 180 equally-spaced orientations of a 3D model of the spacecraft.

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

SHERPA does not have propulsion or attitude control. There is no plan for post-mission disposal maneuvers..

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

Spacecraft Mass: ~603 kg

Cross-sectional Area: 3.383 m^2 (arithmetic mean for random tumbling)

Area to mass ratio: 0.0056103 m^2/kg (arithmetic mean for random tumbling)

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.

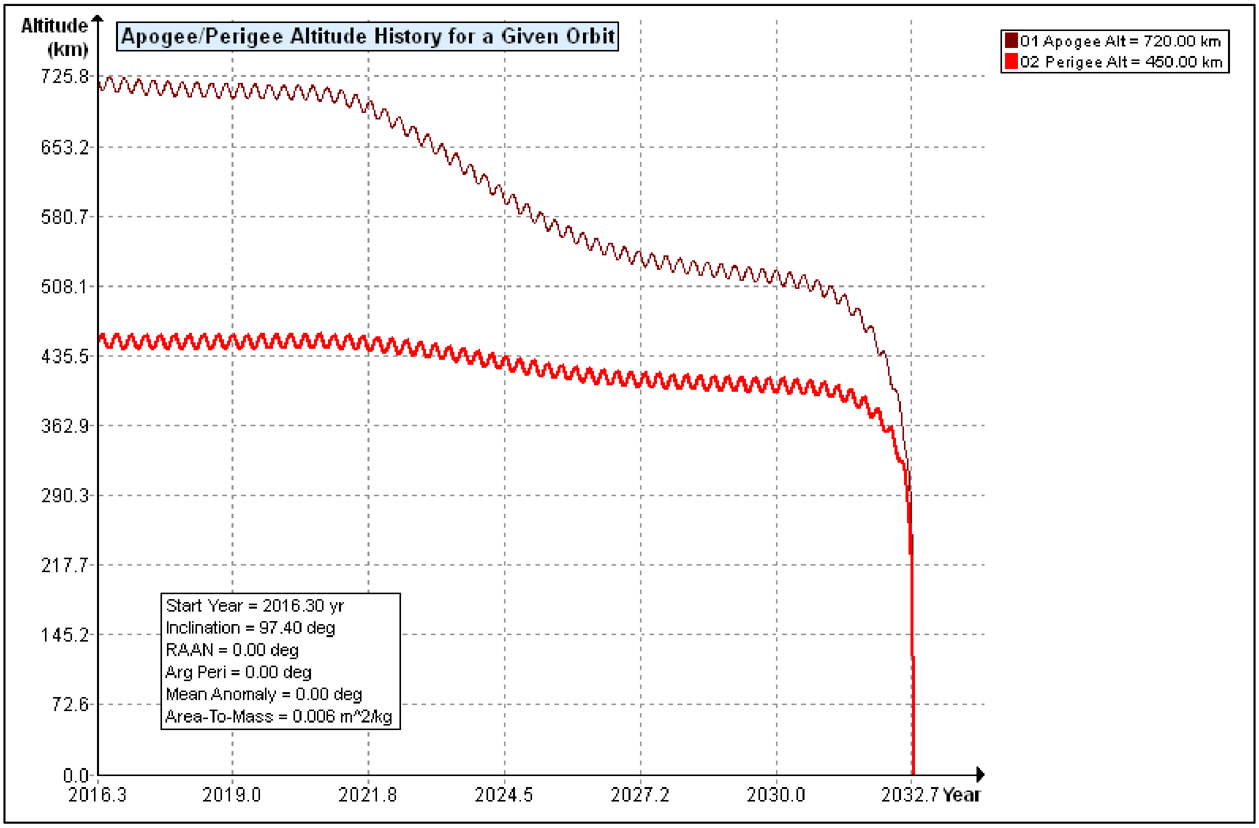

Figure 2 SHERPA orbit history with apogee (brown) & perigee (red)

Analysis: The SHERPA satellite reentry is COMPLIANT using method “a”.

Satellite Name	SHERPA
BOL Orbit (Drop off)	450 x 720 km
Operational Orbit	450 x 720 km
EOM Orbit*	450 x 720 km
Total Lifetime	16.4 years
Post-ops Life	16.4 years
Lifetime if Total Mission Failure	24.3 years

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: The arithmetic mean of random orientation drag configuration was assumed for atmospheric re-entry analysis. Even if SHERPA trimmed to its minimum drag configuration for the entirety of its post-mission lifetime, DAS reports that it will re-enter in 19.8 years.

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 v2.0.2 reports that SHERPA is compliant with the requirement. According to DAS calculations, there is a low probability that some[1] spacecraft components (the ESPA Grande ring itself with bolted-on aluminum adapters) may reach the ground (see DAS input data below for input parameters). However, the DAS software does not currently allow explicit modeling of a the specific geometries for these components, so these numbers are expected to be larger than anticipated due to conservatism in the inputs provided to DAS. Total human casualty probability is reported by the DAS software as **1:18,900** for each SHERPA spacecraft. This is expected to represent the absolute maximum casualty risk, as calculated with DAS's limited modeling capability.

Analysis (per DAS v2.0.2):

```
10 27 2015; 15:09:22PM     DAS Application Started
10 27 2015; 15:15:05PM     *********Processing Requirement 4.7-1
     Return Status :  Passed

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

name = SHERPA-Zero
quantity = 1
parent = 0
materialID = 5
type = Cylinder
Aero Mass = 603.000000
Thermal Mass = 603.000000
Diameter/Width = 3.000000

name = ESPA_assembly
quantity = 1
parent = 1
materialID = 9
type = Cylinder
```

[1] Other components that were modeled (i.e. wire harnesses, PM struts, shim, etc.) are not likely to survive reentry due to the inability to accurately model these with sufficient fidelity within the limitations imposed by DAS. Even with these components accounted for, SHERPA is still compliant with this requirement.

```
Aero Mass = 445.500000
Thermal Mass = 445.500000
Diameter/Width = 1.574800
Length = 1.420000

name = QP
quantity = 21
parent = 1
materialID = 9
type = Box
Aero Mass = 7.500000
Thermal Mass = 7.500000
Diameter/Width = 0.272000
Length = 0.404000
Height = 0.272000

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

name = SHERPA-Zero
Demise Altitude = 77.993621
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = ESPA_assembly
Demise Altitude = 0.000000
Debris Casualty Area = 4.390694
Impact Kinetic Energy = 800968.750000

*************************************
name = QP
Demise Altitude = 69.397441
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 SHERPA 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 SHERPA mission.

END of ODAR for SHERPA