SOCON-Seahawk ODAR
Orbital Debris Assessment Report

TN-2124 - Rev A

Date: 13 Jun 2017

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Clyde Space approval signatures

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Document control

Rev	Date	Section	Description of change	Reason for change
A	13/06/17	All	First release	

Related documents / software

No.	Document name	Document reference
[RD-1]	Process for Limiting Orbital Debris	NASA-STD-8719.14A
[RD-2]	NASA DAS Software 2.1 and User Guide	DAS 2.1.1 & NASA/TP-2016-218600

Revision control

Product	Part number
01-04578 - Top Level Assembly SeaHawk PFM	01-04578

Contents

Figures

Tables

Self-assessment of the ODAR using template in [RD-1]

A self-assessment is provided below in accordance with the assessment format provided in Appendix A.2 of [RD-1].

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

Note: This launch has multiple spacecraft manifested and the Seahawk spacecraft is not the primary payload.

Assessment Report Format

This ODAR follows the format recommended in Appendix A.1 of [RD-1] and includes the content indicated at a minimum in each section 2 through 8 below for the Seahawk satellite. Sections 9 through 14 apply to the launch vehicle ODAR and are not covered in this document.

DAS Software [RD-2] used in this analysis

DAS Software v2.1.1

ODAR section 1: Program Management and Mission Overview

Program Management

Mission Directorate: UNCW

Physics and Physical Oceanography Center for Marine Science
University of North Carolina Wilmington

Program Executive: John M. Morrison

Senior Scientist: Gene Feldman

Mission overview

The University of North Carolina Wilmington SOCON (aka Seahawk) program consists in two identical 3U spacecraft, “Seahawk-1” and “Seahawk-2”. Those spacecraft carry an Earth Observation payload. The instrument is a multispectral high resolution camera designed for ocean colour imaging.

With an estimate 120 meter resolution, the SeaHawk instrument is designed to complement NASA SeaWiFS and Modis Instruments currently in service. These systems were designed to measure global ocean color, but the image resolution made difficult the measurements of lakes, rivers, estuaries, and coastal zones.

Mission development schedule

FRR (Seahawk-1):	November 2017
Launch (Seahawk-1):	No earlier than February 2018
FRR (Seahawk-2):	March 2018 (TBC)
Launch (Seahawk-2):	No earlier than January 2019

Mission duration

Intended operational lifetime: 18 month

Post-operation orbit lifetime: 3.4 years until re-entry via atmospheric orbital decay

Cumulated orbit lifetime: 4.9 years, as calculated with [RD-2]

Launch and deployment summary

Launch vehicle and site: SpaceX Falcon 9 – Vandenberg Air Force Base; This launch is a multi-payload launch provided by Spaceflight, with mini/micro and nano satellites.

Proposed launch date: No earlier than February 2018

Target injection orbit: SSO (LTDN 10:30) @ 575 x 575 km (used as worst case)

Deployment: ISIS DuoPack 3U deployer. The actual deployment sequence and direction is managed by the launch provider.

Orbit transfer: no orbit change (no propulsion onboard)

ODAR summary

- No debris released in normal operations
- No credible scenario for explosion
- Collision probability is compliant with NASA standards
- No disposal plan that could be compromised
- Estimated orbital lifetime until uncontrolled re-entry (with no residual material) is under 25 years

Important note:

All values and simulations are given for Seahawk-1. Seahawk-2 is planned for launch in Q1-Q2 2019 on the same launch vehicle but on a lower orbit: SSO (LTDN 10:30) @ 500 x 525 km. For this reason, Seahawk-2 compliancy could be inherited from the present ODAR, as Seahawk-1 constitutes the worst-case scenario.

ODAR section 2: Spacecraft Description

Physical description

Seahawk spacecraft is a 3U CubeSat, compliant with the standard 3U envelope of 340.5mm x 113mm x 113mm (L x W x H) in launch configuration.

Spacecraft components:

Seahawk spacecraft structure hosts a 1U / 1kg payload (described in the previous section), a GPS receiver with its body-mounted antenna, a X-band radio with its body-mounted patch antenna, a UHF/VHU radio with its dipole antennas and standard avionics (OBC, EPS, BAT, ADCS sensors and actuators…).

Spacecraft mass: 4.7kg as designed (there are neither propellants nor fluids)

Spacecraft average cross-sectional area: 0.132m^2, as per [RD-1] guidelines.

Note: nadir-pointing cross-sectional area is 0.103m^2.

Calculated Area-to-mass ratio: 0.028m^2/kg

Deployable appendages include the following (refer to Figure 1 for illustration):

- 4 solar panels, all deployed from the Z+ face
- 4 monopole whip antennas, deployed from the edges of the Z- face.

Main component locations are also illustrated in the Figure 1. Note that the payload apertures (on the X- face) are covered by a deployable solar panel during the launch.

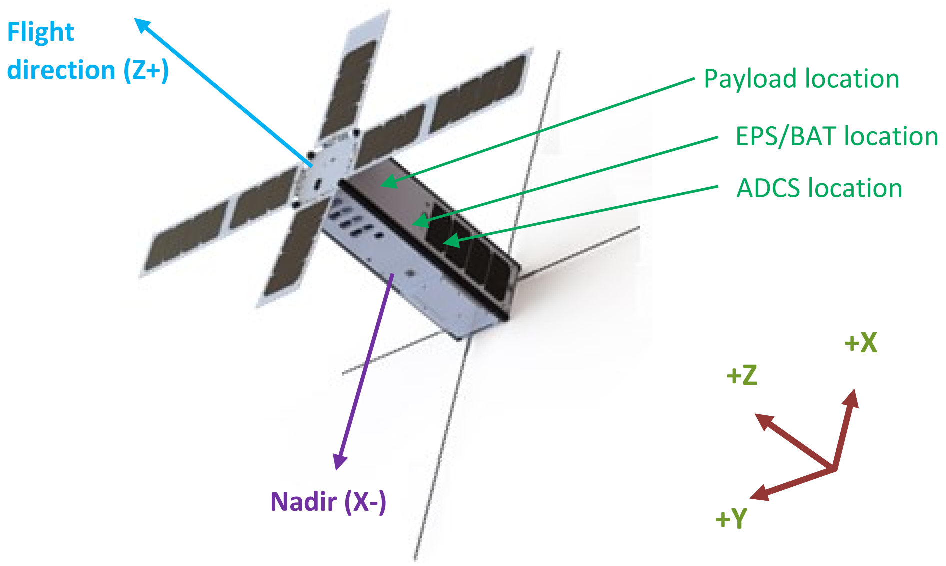

Figure 1 - Seahawk spacecraft deployable illustration

Overall dimensions in flight configuration:

Appendages in deployed configuration are shown in Figure 2. The 83mm wide solar panels are deployed in the Z+ face plane. The antennas are deployed in the Z- face plan. The overall envelop is then: 970mm (X) x 760mm (Y) x 340mm (Z).

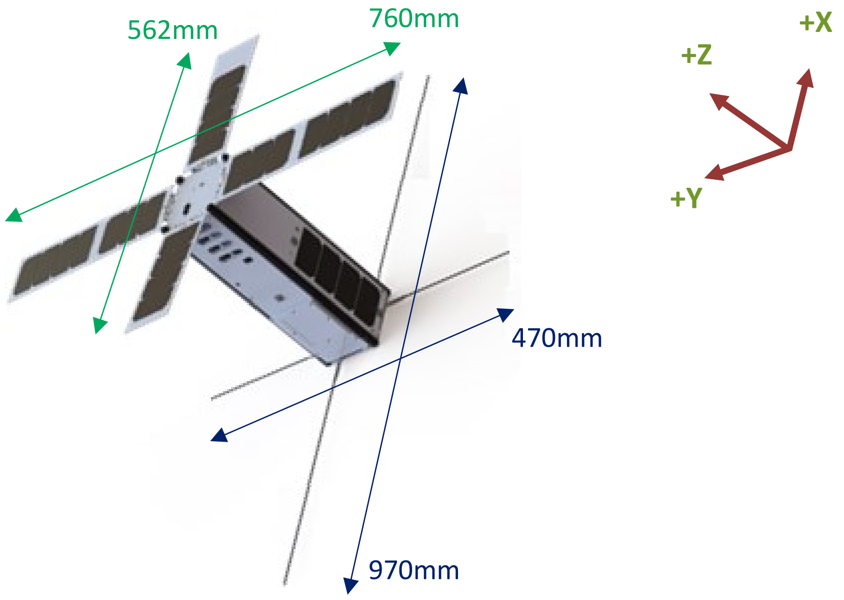

Figure 2 - Seahawk spacecraft overall envelop in flight configuration

Mechanisms

The payload consists of a multispectral push-broom camera, with an electro-mechanical shutter (refer to Figure 3). The shutter has 2 redundant solenoids that are always OFF except when actuated for a short period of time (dark frame imaging for calibration purpose). Traction springs counteract the solenoids and are always in lower energy position (about 35 grams force combined), except when the shutter is ON.

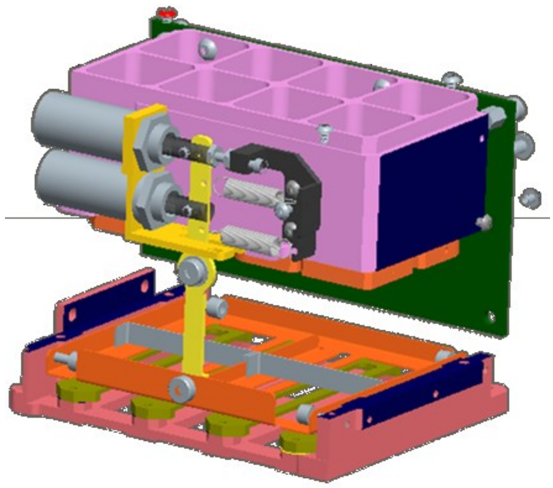

Figure 3 - Seahawk payload shutter mechanism

Deployable solar panels make use of hold-on mechanisms consisting in a piece of nylon wire tied against a burn resistor. Similar mechanisms are used to hold down each of the antennas. The deployment is achieved by small torque springs (mechanical energy is negligible after deployment, and not strong enough to cause panels to break in any folded configuration).

Attitude control system

Primarily based on fine sun-sensors attitude determination, the ADCS achieve a 1degree pointing accuracy using the following actuators:

- 5x magnetorquers, integrated in body panels
- 3x Reaction Wheels, stacked in the core avionics

Nominal mission attitude is nadir pointing, as described in the Figure 1 above.

A detumble mode is available in case the rotation rate is too high (in particular after initial deployment). In that mode, only the magneto-torquers are used.

Power generation and storage system

There are 3 body solar panels and 4 deployable solar panels (with cells on both faces) on the spacecraft. Generated power is managed by a set of battery charge regulators, which architecture is designed to handle the extremum power configurations.

A 40Whr Li-Ion Polymer battery is used, featured with a cell protection circuit to manage charging / discharging and a heater to keep the cells in operating temp. range.

Note that the electrical system architecture is designed such as it is not possible to cut power lines between the solar panels and the battery - this is to improve the overall reliability of the platform. Consequently, batteries will continue to charge whenever the panels are sunlit and cannot be passivated. This is addressed as a risk in the section 4 of this ODAR.

Propulsion and fluid systems

None. Note that batteries are unpressurized.

Other sources of stored energy

None. Neither radioactive materials nor pyrotechnic devices are used.

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

There are no intentional releases whatever the flight phase.

Note that X+ deployable solar panel also serves as payload aperture cover for the first days of flight.

Assessment of spacecraft compliance

Requirement ID	Compliancy status
Requirement 4.3-1a (debris released in LEO)	Compliant
Requirement 4.3-1b (all debris released in LEO)	Compliant
Requirement 4.3-2 (debris released in GEO)	Compliant

ODAR section 4: Assessment of Spacecraft Intentional Breakups & 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. All bolts are suitably torqued and head locked and all risk components are staked.

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 below describe the combined faults that must occur for any of nine, independent, mutually exclusive failure modes that could lead to a battery explosion.

Supporting rationales

Battery explosion impact: All failure modes below might result in battery explosion with the possibility of orbital debris generation. However, in the unlikely event that a battery cell does explosively rupture, the small size, mass, and potential energy, of these small batteries is such that while the spacecraft could be expected to vent gases, most debris from the battery rupture should be contained within the vessel due to the lack of penetration energy.

The batteries consist of lithium polymer pouch cells with a flexible casing; as has a much lower burst pressure than equivalent lithium ion can cells with metal casings there is no credible opportunity for a high pressure explosion to occur.

If a failure mode occurs that results in the accumulation of gas within a cell, the pouch cells will rupture however no shrapnel will be generated due to the polymer casing.

Probability: Very Low. Though it is not easily quantifiable, it is believed to be less than 0.1% given that multiple independent (not common mode) faults must occur for each failure mode to cause the ultimate effect (explosion).

Supporting FMEA details

Failure mode 1: Battery internal short circuit.

Mitigation 1: Complete qualification tests of the cell design and battery design through NASA EP-WI-032 testing.

Combined faults required for realized failure: Environmental testing (inclusive of Thermal cycling and thermal vacuum testing) AND functional charge/discharge tests AND ESA qualified inspection at board level must all be ineffective in discovery of the failure mode.

Failure Mode 2: Internal thermal rise due to high load discharge rate.

Mitigation 2: The power system consists of overcurrent protection at power bus level, overcurrent protection at a cell level, and overcurrent protection at a string level consisting of a positive temperature coefficient (PTC) variable resistance device to inhibit charge or discharge rates beyond acceptable levels.

Combined faults required for realized failure: The PTC must fail AND spacecraft thermal design must be incorrect AND external over current detection and protection must fail for this failure mode to occur.

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 vibration and thermal-vacuum environments and has extensive heritage on other spacecraft. The charge circuit disconnects the incoming current when battery voltage indicates normal full charge at 8.27 V. If this circuit fails to operate, continuing charge can cause gas generation.

Combined faults required for realized failure:

a) For overcharging: The charge control circuit must fail to function.

b) For excessive charge rate: The peak power generation from the solar arrays at any given time is 22W, which corresponds to approximately 2.8A potential charge current to the battery. The maximum charge rate the battery can accept is 4A. The battery is a proto-qualified Clyde Space 40Whr via NASA EP-WI-032 and has 8 LPP503759DL cells. The battery itself has two parallel strings of 2 cells connected in series and 4 strings in parallel, and thus having 8 cells. 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 only a single string from the battery was accepting charge. For this failure mode to become active one string must fail to accept a charge AND the charge control circuit on the remaining string fails.

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) proto-qualification tested short circuit protection on each external circuit previously discussed for Failure Mode 2,

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 (vibration, thermal cycling, and thermal-vacuum tests).

Combined faults required for realized failure: The PTC must fail AND an external load must fail/short-circuit AND external over-current detection and disconnect function must fail to enable this failure mode.

Failure Mode 5: Inoperable vents.

Mitigation 5: The lithium polymer pouch cells used within this design do not feature safety vent; they are hermetically sealed units. The casing is not rigid enough to allow sufficient pressure to build before the cell vents and therefore cause a hazard that might be induced by vent failure.

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 nonconductive 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: Numerous CubeSat past experiences tend to demonstrate that given the compacity of the satellite, there is not significant overall thermal rise due to the space environment in LEO and batteries do not exceed normal allowable operating temperatures which are well below temperatures of concern for explosions. The satellite thermal design is passive, with only a battery heater switched on at low temperatures. Standard satellite thermal design includes temperature monitoring and protection: should a critical temperature be monitored in a subsystem (radio, payload, battery…) then the platform automatically transitioned into safe mode, powering off its switchable power busses.

Combined faults required for realized failure: Thermal analysis AND thermal design AND mission simulations 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: The spacecraft EPS design negates this mode because the processor will stop when voltage drops too low. 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 a specific acceptable threshold. When the satellite restarts, it boots into safe mode where only core avionics are connected. By definition, this safe mode is very low power consumption and allow the system to charge again.

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:

In summary, no particular operation is required to dispose of the spacecraft.

As per the spacecraft description in ODAR section 2, the stored energy sources and the passivation methods are detailed in the table below.

Table 1 – Energy sources and passivation method

Energy sources	Assessment details	Passivation method	Required operation at EOM
Spring-based mechanisms, used for deployment of appendages and payload operation (shutter return in position of rest)	Appendage hinge residual forces are insignificant. Payload shutter spring residual force is negligible (35gr) and springs are well encapsulated in the payload casing.	None	None
Reaction wheels, spinning in standby & mission modes only	RWS are powered-off by design when platform transitions into Safe mode.	Transition out of the Mission mode is performed by: on-board schedule, command, or in case of system reset / failure	None
Battery energy storage	Battery could be discharged but platform is designed to recover from discharged state	The design is not compatible with a battery passivation	None, but risk addressed in ODAR section 4
Solar panel energy generation chain	Battery is always linked to the EPS and solar panels, no possible cut-off.	The design is not compatible with a solar panel passivation	None, but risk addressed in ODAR section 4

In case of forced EOM, transition out of Mission mode will be commanded. Otherwise the spacecraft will do so at the end of its on-board schedule (less than 1 week after last ground contact), and anytime it experiences a reset of a system failure.

Power system architecture is designed for high reliability link, excluding any EOM passivation operation. The inherent risk is addressed in the following paragraphs.

For information only (not part of this ODAR), TMTC radio is beaconing status every few minutes but could be permanently silenced by telecommand. X-band radio is always off outside Mission mode.

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

Even if battery and power generation chain couldn't be passivated by design, the Failure mode analysis detailed above demonstrates that there is no credible scenario that could lead to debris creation.

Assessment of spacecraft compliance

Requirement ID	Compliancy status
Requirement 4.4-1 (risk of accidental explosion)	Compliant
Requirement 4.4-2 (design for passivation)	Compliant
Requirement 4.4-3 (long-term risk involved by intentional break-ups)	Compliant
Requirement 4.4-4 (short-term risk involved by intentional break-ups)	Compliant

ODAR section 5: Assessment of Spacecraft Potential for On-Orbit Collisions

Inputs for DAS-2.1:

- Orbit as described in Section 1 (575km circular SSO)
- Mission lifetime as described in ODAR Section 1 (1.5year)
- Satellite characteristics as described in ODAR Section 2 (4.7kg; 0.028m^2/kg)
- No critical parts for disposal operations as per ODAR Section 6

For information only, a simulation of OBC board damage by small debris was performed. Since it is protected by a number of other boards stacked on both sides, overall damage probability is extremely low (0.000002), which is reassuring for the nominal mission operations.

Platform collision probability with large objects during orbital lifetime:

DAS-2.1 simulation outputs: 0.00000

Critical parts collision probability with small objects during mission operations:

DAS-2.1 simulation outputs: 0.00000

Assessment of spacecraft compliance

Requirement ID	Compliancy status
Requirement 4.5-1 (risk of large object collision inferior to 0.001)	Compliant
Requirement 4.5-2 (risk of small object collision inferior to 0.01)	Compliant

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

Description of spacecraft disposal option selected:

Seahawk spacecraft will be disposed by natural atmospheric re-entry (option A). As soon as injected in orbit, the spacecraft altitude will start to decay due to the residual atmospheric drag. A simulation using [RD-2] and the data below gives an orbital lifetime of 4.9years, compliant with the 25' year requirement.

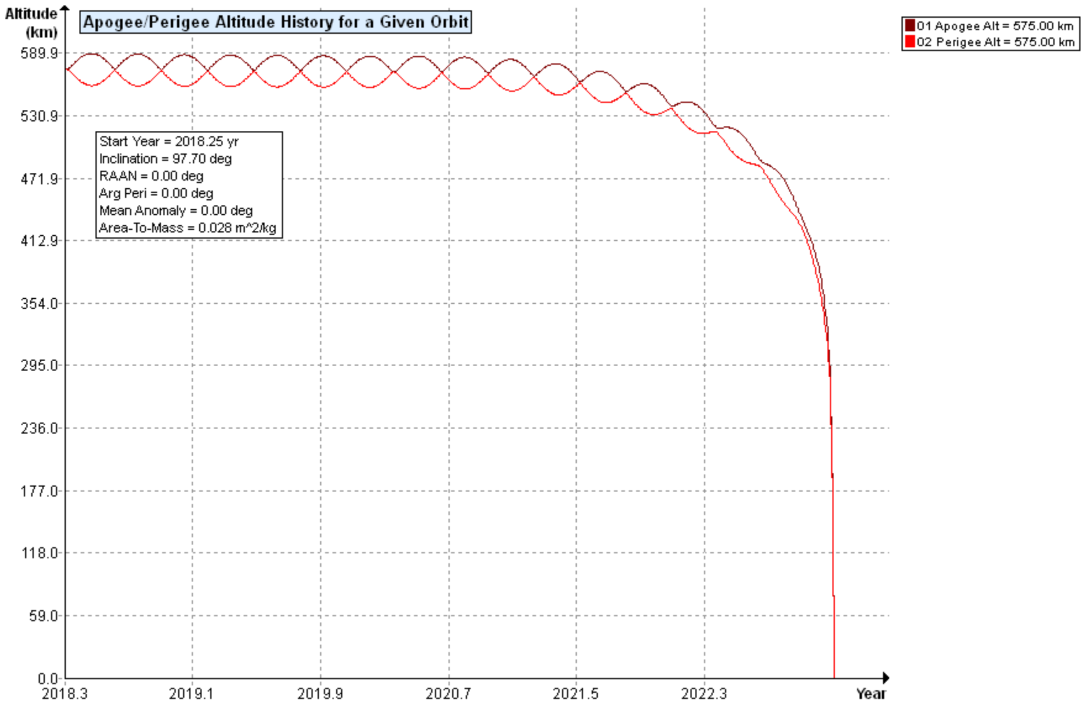

Figure 4 - Seahawk orbit natural decay plot using [RD-2]

Identification of all systems or components required to accomplish any post mission disposal operation, including passivation and manoeuvring:

As per the energy sources listed in Table 1 (ODAR section 4) and the operations identified to be performed at EOM, no particular operation is required to dispose the spacecraft (no active passivation nor manoeuvring are required).

Consequently, there are no critical parts for disposal operations.

Plan for any spacecraft manoeuvres required to accomplish post mission disposal:

There is no propulsion system and no plan to perform any orbital manoeuvre.

There is no controlled re-entry either so no need for attitude control.

Calculation of area-to-mass ratio after post mission disposal, if the controlled re-entry option is not selected

Spacecraft Mass: 4.7 kg

Cross-sectional Area: 0.132 m^2 as per [RD-1] guidelines.

Area to mass ratio: 0.132/4.7 = 0.028 m^2/kg

Assessment of spacecraft compliance

Requirement ID	Compliancy status
Requirement 4.6-1 (disposal in LEO)	Compliant
Requirement 4.6-2 (disposal in GEO)	Compliant
Requirement 4.6-3 (disposal between GEO & LEO)	Compliant
Requirement 4.6-4 (disposal operation reliability)	Compliant

ODAR section 7: Assessment of Spacecraft Reentry Hazards

Detailed description of spacecraft components by size, mass, material, shape and original location on the space vehicle

Table 2 – Spacecraft material list

Row #	Name	Parent	Qty	Main Material type for [RD-2]	Shape	Mass (kg)	Diameter/ Width (m)	Length (m)	Height (m)
1	Cubesat root element	0	1	Aluminum 6082 T6	Box	4.7	0.1	0.34	0.1
2	Body Solar Panels (Copper, Fibreglass…)	1	1	Copper Alloy	Box	0.78	0.1	0.34	0.1
3	CubeSat Structure (incl. all aluminum items)	2	1	Aluminum 6082 T6	Box	0.35	0.1	0.34	0.1
4	Platform electronic boards (FR4, copper, silicon, ceramic)	3	11	Fiberglass	FlatPlate	0.07	0.095	0.095	
5	Radio housing	3	2	Aluminum (generic)	Box	0.15	0.09	0.09	0.01
6	Fasteners (max M3x5)	3	70	Stainless Steel	Cylinder	0.001	0.006	0.005	
7	Stack rods	3	4	Titanium (6 Al-4 V)	Cylinder	0.006	0.003	0.21	
8	Thermal heat shunt	3	4	Copper Alloy	Box	0.01	0.02	0.02	0.005
9	Reaction Wheels &motors	3	3	Stainless Steel	Cylinder	0.06	0.03	0.015	

10	Harnesses	3	25	Copper Alloy	Cylinder	0.018	0.005	0.15	
11	Payload housing	3	1	Aluminum 6061 T6	Box	0.45	0.097	0.102	0.097
12	Payload boards (FR4, copper, silicon, ceramic)	11	5	Fiberglass	FlatPlate	0.045	0.085	0.095	
13	Payload solenoids	11	2	Stainless Steel	Cylinder	0.023	0.013	0.043	
14	Payload mechanical parts	11	9	Stainless Steel	Cylinder	0.012	0.013	0.017	
15	Deployable Solar Panels (Copper, Fibreglass…)	1	4	Copper Alloy	FlatPlate	0.15	0.083	0.33	
16	Patch Antenna (composite housing)	1	2	Fiberglass	Box	0.015	0.03	0.03	0.01
17	Patch Antenna (copper)	17	2	Copper Alloy	FlatPlate	0.065	0.08	0.08	
18	VHF/UHF Antenna	1	4	Nitinol (NiTi)	FlatPlate	0.008	0.005	0.5	

The table above details the main materials used for the spacecraft, in a format compatible with [RD-2]. Note that electronics components, glues and other low melting temperature material were not detailed (e.g. optical glass, silicon).

Summary of objects expected to survive an uncontrolled re-entry, using [RD-2]

No components are expected to survive the re-entry, as per DAS-2.1 simulation. The largest stainless steel pieces will demise at a 65km altitude.

Calculation of probability of human casualty for the expected uncontrolled re-entry

As per [RD-2] simulation, and using the inputs above, DAS-2.1 calculates the following probability: 1:100000000

Hazardous material summary

Because the battery cells are not considered as hazardous articles by regulations, there is no detailed information on the chemical content except that they don't contain heavy metals. By products of the battery could be released during re-entry as the aluminium container will break, however no hazardous material is expected to survive the re-entry, due to the very light container type and the type and quantity of chemical involved.

No other hazardous materials are present on the spacecraft.

Assessment of spacecraft compliance

Requirement ID	Compliancy status
Requirement 4.7-1 (risk of human casualty inferior to 0.0001, evaluated for an uncontrolled re-entry as mentioned in ODAR section 6)	Compliant

ODAR section 8: Assessment for Tether Missions

Not applicable as there are no tethers in the Seahawk mission.

Assessment of spacecraft compliance

Requirement ID	Compliancy status
Requirement 4.8-1 (risk involved by tether)	Compliant

Simulation logs of DAS-2.1 [RD-2]

```
06 13 2017; 08:58:09AM    Activity Log Started
06 13 2017; 08:59:01AM    Processing Requirement 4.3-1:    Return
Status :  Not Run

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

=============== End of Requirement 4.3-1 ===============
06 13 2017; 08:59:03AM    Processing Requirement 4.3-2: Return Status
: Passed

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

=============== End of Requirement 4.3-2 ===============
06 13 2017; 08:59:05AM    Requirement 4.4-3:  Compliant

=============== End of Requirement 4.4-3 ===============
06 13 2017; 09:10:30AM    Processing Requirement 4.5-1:    Return
Status :  Passed

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

**INPUT**

      Space Structure Name = Seahawk
      Space Structure Type = Payload
      Perigee Altitude = 575.000000 (km)
      Apogee Altitude = 575.000000 (km)
      Inclination = 97.700000 (deg)
      RAAN = 0.000000 (deg)
      Argument of Perigee = 0.000000 (deg)
      Mean Anomaly = 0.000000 (deg)
      Final Area-To-Mass Ratio = 0.028000 (m^2/kg)
      Start Year = 2018.250000 (yr)
      Initial Mass = 4.700000 (kg)
      Final Mass = 4.700000 (kg)
      Duration = 1.500000 (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 = 0.000002
      Returned Error Message: Normal Processing
      Date Range Error Message: Normal Date Range
```

```
        Status = Pass

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

=============== End of Requirement 4.5-1 ===============
06 13 2017; 09:19:59AM     Requirement 4.5-2:  Compliant

==================================================
Spacecraft = Seahawk
Critical Surface = OBC board
==================================================

**INPUT**

        Apogee Altitude = 575.000000 (km)
        Perigee Altitude = 575.000000 (km)
        Orbital Inclination = 97.700000 (deg)
        RAAN = 0.000000 (deg)
        Argument of Perigee = 0.000000 (deg)
        Mean Anomaly = 0.000000 (deg)
        Final Area-To-Mass = 0.028000 (m^2/kg)
        Initial Mass = 4.700000 (kg)
        Final Mass = 4.700000 (kg)
        Station Kept = No
        Start Year = 2018.250000 (yr)
        Duration = 1.500000 (yr)
        Orientation = Fixed Oriented
        CS Areal Density = 0.760000 (g/cm^2)
        CS Surface Area = 0.008800 (m^2)
        Vector = (0.000000 (u), 1.000000 (v), 0.000000 (w))
        CS Pressurized = No
        Outer Wall 1   Density: 0.570000 (g/cm^2)  Separation: 5.000000
(cm)
        Outer Wall 2   Density: 5.000000 (g/cm^2)  Separation: 1.000000
(cm)

**OUTPUT**

        Probabilty of Penetration = 0.000002 (0.000002)
        Returned Error Message: Normal Processing
        Date Range Error Message: Normal Date Range


06 13 2017; 09:24:20AM     Processing Requirement 4.6 Return  Status  :
Passed

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

**INPUT**

        Space Structure Name = Seahawk
        Space Structure Type = Payload

        Perigee Altitude = 575.000000 (km)
        Apogee Altitude = 575.000000 (km)
        Inclination = 97.700000 (deg)
        RAAN = 0.000000 (deg)
        Argument of Perigee = 0.000000 (deg)
        Mean Anomaly = 0.000000 (deg)
```

```
        Area-To-Mass Ratio = 0.028000 (m^2/kg)
        Start Year = 2018.250000 (yr)
        Initial Mass = 4.700000 (kg)
        Final Mass = 4.700000 (kg)
        Duration = 1.500000 (yr)
        Station Kept = False
        Abandoned = True
        PMD Perigee Altitude = 571.502813 (km)
        PMD Apogee Altitude = 574.729298 (km)
        PMD Inclination = 97.673435 (deg)
        PMD RAAN = 178.153898 (deg)
        PMD Argument of Perigee = 355.332978 (deg)
        PMD Mean Anomaly = 0.000000 (deg)

**OUTPUT**

        Suggested Perigee Altitude = 571.502813 (km)
        Suggested Apogee Altitude = 574.729298 (km)
        Returned Error Message = Passes LEO reentry orbit criteria.

        Released Year = 2023 (yr)
        Requirement = 61
        Compliance Status = Pass

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

=============== End of Requirement 4.6 ===============
06 13 2017; 09:25:22AM     *********Processing Requirement 4.7-1
        Return Status :  Passed

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

name = Seahawk
quantity = 1
parent = 0
materialID = -1
type = Box
Aero Mass = 4.700000
Thermal Mass = 4.700000
Diameter/Width = 0.100000
Length = 0.340000
Height = 0.100000

name = Body panels
quantity = 1
parent = 1
materialID = 19
type = Box
Aero Mass = 3.793000
Thermal Mass = 0.780000
Diameter/Width = 0.100000
Length = 0.340000
Height = 0.100000

name = Structure
quantity = 1
parent = 2
materialID = -1
type = Box
Aero Mass = 3.013000
```

```
Thermal Mass = 0.350000
Diameter/Width = 0.100000
Length = 0.340000
Height = 0.100000

name = Platform boards
quantity = 11
parent = 3
materialID = 23
type = Flat Plate
Aero Mass = 0.070000
Thermal Mass = 0.070000
Diameter/Width = 0.095000
Length = 0.095000

name = Radio housing
quantity = 2
parent = 3
materialID = 5
type = Box
Aero Mass = 0.150000
Thermal Mass = 0.150000
Diameter/Width = 0.090000
Length = 0.090000
Height = 0.010000

name = Fasteners (max size M3x5)
quantity = 70
parent = 3
materialID = 54
type = Cylinder
Aero Mass = 0.001000
Thermal Mass = 0.001000
Diameter/Width = 0.006000
Length = 0.005000

name = Stack rods
quantity = 4
parent = 3
materialID = 65
type = Cylinder
Aero Mass = 0.006000
Thermal Mass = 0.006000
Diameter/Width = 0.003000
Length = 0.210000

name = Thermal heat shunt
quantity = 4
parent = 3
materialID = 19
type = Box
Aero Mass = 0.010000
Thermal Mass = 0.010000
Diameter/Width = 0.020000
Length = 0.020000
Height = 0.005000

name = Reaction wheels gimbal+motor
quantity = 3
parent = 3
materialID = 54
```

```
type = Cylinder
Aero Mass = 0.060000
Thermal Mass = 0.060000
Diameter/Width = 0.030000
Length = 0.015000

name = Harnesses
quantity = 25
parent = 3
materialID = 19
type = Cylinder
Aero Mass = 0.018000
Thermal Mass = 0.018000
Diameter/Width = 0.005000
Length = 0.150000

name = Payload housing
quantity = 1
parent = 3
materialID = 8
type = Box
Aero Mass = 0.829000
Thermal Mass = 0.450000
Diameter/Width = 0.097000
Length = 0.102000
Height = 0.097000

name = Payload boards
quantity = 5
parent = 11
materialID = 23
type = Flat Plate
Aero Mass = 0.045000
Thermal Mass = 0.045000
Diameter/Width = 0.085000
Length = 0.095000

name = Payload solenoids
quantity = 2
parent = 11
materialID = 54
type = Cylinder
Aero Mass = 0.023000
Thermal Mass = 0.023000
Diameter/Width = 0.013000
Length = 0.043000

name = Payload mechanical parts
quantity = 9
parent = 11
materialID = 54
type = Cylinder
Aero Mass = 0.012000
Thermal Mass = 0.012000
Diameter/Width = 0.013000
Length = 0.017000

name = Deployable Panels
quantity = 4
parent = 1
materialID = 19
```

```
type = Flat Plate
Aero Mass = 0.150000
Thermal Mass = 0.150000
Diameter/Width = 0.083000
Length = 0.330000

name = Patch antenna (composite housing)
quantity = 2
parent = 1
materialID = 23
type = Box
Aero Mass = 0.080000
Thermal Mass = 0.015000
Diameter/Width = 0.030000
Length = 0.030000
Height = 0.010000

name = Patch antenna radiative element
quantity = 2
parent = 16
materialID = 19
type = Flat Plate
Aero Mass = 0.065000
Thermal Mass = 0.065000
Diameter/Width = 0.080000
Length = 0.080000

name = Deployable VHF/UHF antenna
quantity = 4
parent = 1
materialID = -2
type = Flat Plate
Aero Mass = 0.008000
Thermal Mass = 0.008000
Diameter/Width = 0.005000
Length = 0.500000

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

name = Seahawk
Demise Altitude = 77.994385
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Body panels
Demise Altitude = 76.114410
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Structure
Demise Altitude = 75.163429
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Platform boards
Demise Altitude = 74.164711
Debris Casualty Area = 0.000000
```

```
Impact Kinetic Energy = 0.000000

*************************************
name = Radio housing
Demise Altitude = 71.871292
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Fasteners (max size M3x5)
Demise Altitude = 73.777084
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Stack rods
Demise Altitude = 74.302017
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Thermal heat shunt
Demise Altitude = 73.847328
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Reaction wheels gimbal+motor
Demise Altitude = 67.508415
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Harnesses
Demise Altitude = 74.394104
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Payload housing
Demise Altitude = 71.812996
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Payload boards
Demise Altitude = 71.049004
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Payload solenoids
Demise Altitude = 67.826508
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Payload mechanical parts
Demise Altitude = 67.813400
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000
```

```
************************************
name = Deployable Panels
Demise Altitude = 76.873795
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Patch antenna (composite housing)
Demise Altitude = 77.033310
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Patch antenna radiative element
Demise Altitude = 75.641121
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Deployable VHF/UHF antenna
Demise Altitude = 77.878220
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

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

=============== End of Requirement 4.7-1 ===============
06 13 2017; 09:26:52AM     Project Data Saved To File
```

END of ODAR for Seahawk