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<b>REV</b> <b>06</b>				
<b>TITLE:</b> TYVAK-0085 Orbital Debris Assessment Report (ODAR) / End of Mission Plan (EOMP)				
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All future revisions to this document shall be approved by the controlling organization prior to release.



**TABLE OF CONTENTS**

**ORBITAL DEBRIS SELF-ASSESSMENT: TYVAK-0085/-0086/-0087 MISSION .....6**

**1.0 PROGRAM MANAGEMENT AND MISSION OVERVIEW .....7**

1.1 Program Management.....7

1.2 Mission Overview.....7

1.2.1 Mission Design and Development Milestones .....7

1.2.2 Mission Overview.....7

**2.0 SPACECRAFT DESCRIPTION.....9**

2.1 Physical Description of Spacecraft.....9

2.1.1 Description of Propulsion Systems.....10

2.1.2 Description of attitude control system.....10

2.1.3 Description of normal attitude of the spacecraft with respect to the velocity vector  
.....10

2.1.4 Description of any range safety or other pyrotechnic devices.....11

2.1.5 Description of the electrical generation and storage system.....11

**3.0 ASSESSMENT OF SPACECRAFT DEBRIS RELEASED DURING NORMAL  
OPERATIONS .....12**

**4.0 ASSESSMENT OF SPACECRAFT POTENTIAL FOR EXPLOSIONS AND  
INTENTIONAL BREAKUPS .....13**

4.1 Potential causes of spacecraft breakup during deployment and mission operations .....13

4.2 Summary of failure modes and effects analysis of all credible failure modes .....13

4.3 Detailed plan for any designed spacecraft breakup .....13

4.4 List of components which shall be passivated at End of Mission (EOM).....13

4.5 Rationale for all items which are required to be passivated, but cannot be due to their  
design.....13

4.6 Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4.....13

**5.0 ASSESSMENT OF SPACECRAFT POTENTIAL FOR ON-ORBIT COLLISIONS 16**

5.1 Assessment of spacecraft compliance with Requirements 4.5-1 and 4.5-2:.....16

**6.0 ASSESSMENT OF SPACECRAFT POSTMISSION DISPOSAL PLANS AND  
PROCEDURES.....17**

6.1 Description of spacecraft disposal option selected.....17

6.2 Plan for any spacecraft maneuvers required to accomplish postmission disposal: .....17

6.3 Calculation of area-to-mass ratio after postmission disposal: .....17

6.4 Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5: .....17

6.5 Detailed plan for passivating (depleting all energy sources) of the spacecraft: .....20

**7.0 ASSESSMENT OF SPACECRAFT REENTRY HAZARDS.....21**

7.1 Assessment of spacecraft compliance with Requirement 4.7-1: .....21

**8.0 ASSESSMENT FOR TETHER MISSIONS .....22**

**APPENDIX A – FMEA DETAILS AND SUPPORTING RATIONALE .....23**

Battery Explosion Failure: .....23

**APPENDIX B - REQUIREMENT 4.5-1 DAS 2.0.1 LOG.....26**

**APPENDIX C - REQUIREMENT 4.6 DAS 2.0.1 LOG .....28**

**APPENDIX D - REQUIREMENT 4.7-1 DAS 2.0.1 LOG.....31**

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## List of Figures

**Figure 2-1: Spacecraft Vehicle Layout ..... 10**  
**Figure 6-1: TYVAK-0085 Deorbit Lifetime .....Error! Bookmark not defined.**

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## List of Tables

<b>Table 1-1: Summary of Program Management Personnel .....</b>	<b>7</b>
Table 1-2: Summary of TYVAK-0085 Mission Parameters .....	8
Table 1-3: Summary of TYVAK-0086 Mission Parameters .....	8
Table 1-4: Summary of TYVAK-0087 Mission Parameters .....	8
Table 2-1: Summary of Spacecraft Parameters .....	10
Table 3-1: Summary of Spacecraft Debris Released During Normal Operations .....	12

**ORBITAL DEBRIS SELF-ASSESSMENT: TYVAK-0085/-0086/-0087 MISSION**

Requirement	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant	Not Compliant	Incomplete	
4.3-1.a			X		X			No debris released in LEO
4.3-1.b			X		X			No debris released in LEO
4.3-2			X		X			No debris released in GEO
4.4-1			X		X			Less than 0.001 probability
4.4-2			X		X			Design to electrical power system and reaction wheels
4.4-3			X		X			No planned breakups
4.4-4			X		X			No planned breakups
4.5-1			X		X			Probability 0.00000 (requirement < 0.001)
4.5-2			X		X			Probability 0.00000 (requirement < 0.01)
4.6-1(a)			X		X			Predicted orbital lifetime 3.565 years
4.6-1(b)			X		X			N/A – using atmospheric entry
4.6-1(c)			X		X			N/A – using atmospheric entry
4.6-2			X		X			N/A – Not GEO
4.6-3			X		X			N/A – Not between LEO and GEO
4.6-4			X		X			Expected probability < 0.001
4.7-1			X		X			No pieces survive reentry
4.8-1					X			No tethers used

TYVAK-0085, TYVAK-0086 and TYVAK-0087 are currently manifested to fly as a secondary “rideshare” payload. Compliance with requirements levied by NASA-STD 9719.14A on the launch vehicle are not applicable to this document and the responsibility of the launch provider.

## 1.0 PROGRAM MANAGEMENT AND MISSION OVERVIEW

### 1.1 Program Management

Parameter	Value
Mission Directorate	N/A
Program Executive	Tom Yunck (GeoOptics) / Marco Villa (Tyvak)
Program/project Manager	Marco Villa (Tyvak)
Senior Scientist	Tom Yunck (GeoOptics)
Senior Management	N/A
Foreign government or space agency participation	N/A
Summary of NASA's responsibility under the governing agreement(s)	N/A

*Table 1-1: Summary of Program Management Personnel*

### 1.2 Mission Overview

#### 1.2.1 Mission Design and Development Milestones

The schedule of mission design and development milestones is provided in Table 1.2.

TYVAK-0085 Launch	January 12, 2018
TYVAK-0086 Launch	November 11, 2018
TYVAK-0087 Launch	November 26, 2018

*Table 1.2 – Summary of Mission Design and Development Milestones*

#### 1.2.2 Mission Overview

The goal of the TYVAK-0085/-0086/-0087 Missions are to perform GPS Radio Occultation (RO) measurement demonstration utilizing a single 6U CubeSat. The collection of RO data will be used to validate the TYVAK-0085/-0086/-0087 system and quality of data collected.

Parameter	Value
Launch vehicle and launch site	Sriharikota, India
Launch date	Q1 2018
Mission duration	2+ year
Launch and deployment profile	The PSLV launch vehicle will launch the primary mission satellite. After which, it will deploy the TYVAK-0085 satellite into their final mission orbit (504km apogee, circular, sun-synchronous orbit 97.56° inclination). There is no parking or transfer orbit.

	The TYVAK-0085 satellite will decay naturally for debris mitigation and will re-enter within 25 years after completion of mission.
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*Table 1-2: Summary of TYVAK-0085 Mission Parameters*

Parameter	Value
Launch vehicle and launch site	Mahia, New Zealand
Launch date	November 2018
Mission duration	2+ year
Launch and deployment profile	<p>The Electron launch vehicle will launch and deploy the TYVAK-0086 satellite into its final mission orbit (500km, circular orbit, 85° inclination). There is no parking or transfer orbit.</p> <p>The TYVAK-0086 satellite will decay naturally for debris mitigation and will re-enter within 25 years after completion of mission.</p>

*Table 1-3: Summary of TYVAK-0086 Mission Parameters*

Parameter	Value
Launch vehicle and launch site	Sriharikota, India
Launch date	November 2018
Mission duration	2+ year
Launch and deployment profile	<p>The PSLV launch vehicle will launch the primary mission satellite. After which, it will deploy the TYVAK-0087 satellite into their final mission orbit (505km, circular, sun-synchronous orbit 98.0° inclination). There is no parking or transfer orbit.</p> <p>The TYVAK-0087 satellite will decay naturally for debris mitigation and will re-enter within 25 years after completion of mission.</p>

*Table 1-4: Summary of TYVAK-0087 Mission Parameters*



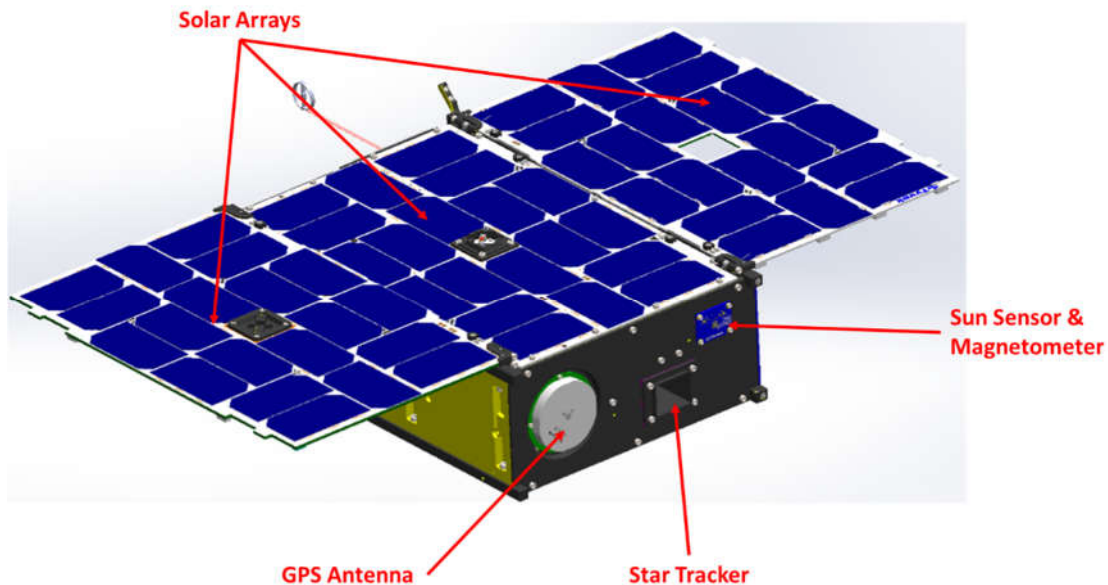
## 2.0 SPACECRAFT DESCRIPTION

### 2.1 Physical Description of Spacecraft

The TYVAK-0085/-0086/-0087 vehicles have been designed to support a 2+ year mission in LEO, and it is compatible with the P-POD launch environments and designed to the requirements in the CubeSat Design Specification (CDS). The TYVAK-0085/-0086/-0087 vehicles are 6U CubeSats with the vehicles being 30cm x 20cm x 10cm with a mass of 10.226 kg.

The TYVAK-0085/-0086/-0087 vehicle design uses subsystem modules built from printed circuit boards (PCB) or miniature enclosures mounted to the open frame primary structure. The open structure permits the vehicle to be built incrementally with open access for securing interconnects. The body mounted side panels attach directly to the primary structure and are used for thermal management and can be easily removed to get access to the interior of the vehicle. The vehicle is primarily constructed out of aluminum and PCB materials.

The TYVAK-0085/-0086/-0087 payload utilizes a GPS array antenna mounted to the Minus-Y panel to receive GPS RO signals. The signals are then captured by the CION Payload board which outputs the data files to the TYVAK-0085/-0086/-0087 CDH for storage and later transmission to the ground via X-Band or UHF transmission.



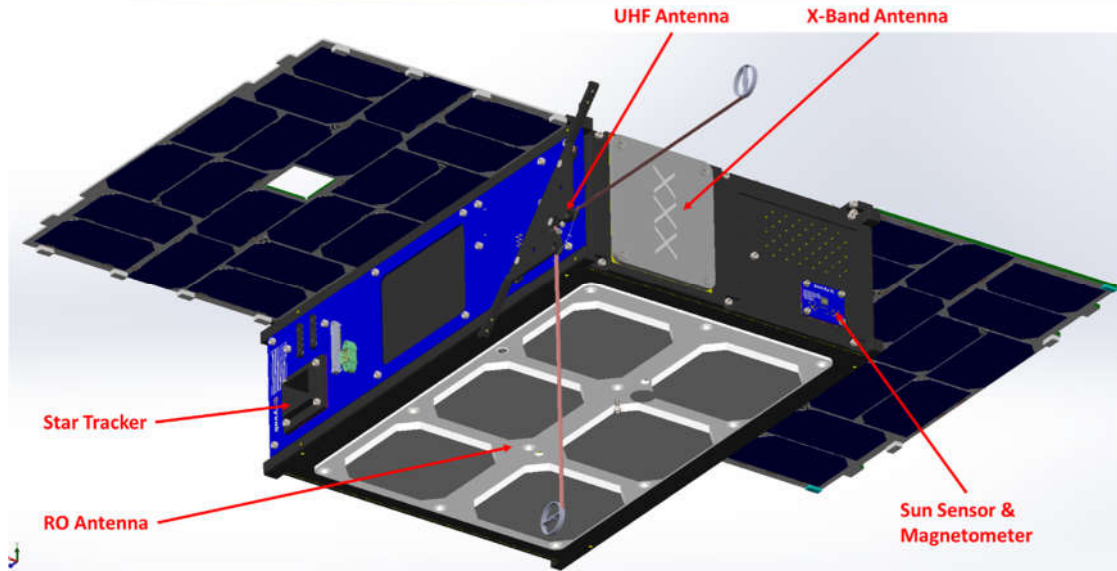


Figure 2-1: Spacecraft Vehicle Layout

Parameter	Value
Total satellite mass at launch, including all propellants and fluids	10.226 kg
Dry Mass of satellite at launch, excluding solid rocket motor propellants	10.226 kg
Identification, including mass and pressure, of all fluids	NONE. TYVAK-0085/-0086/-0087 have no propulsion
Fluids in Pressurized batteries	NONE. TYVAK-0085/-0086/-0087 use unpressurized standard COTS Li-ion battery cells
Identification of any other sources of stored energy	NONE
Identification of any radioactive materials on board	NONE

Table 2-1: Summary of Spacecraft Parameters

### 2.1.1 Description of Propulsion Systems

None.

### 2.1.2 Description of attitude control system

The TYVAK-0085/-0086/-0087 attitude determination and control system consists of a processor, Inertial Reference Module (IRM), nano-Reaction Wheel Array (nRWA), GPS receiver, Sun sensors, magnetometers, and integrated torque coils.

### 2.1.3 Description of normal attitude of the spacecraft with respect to the velocity vector

The nominal attitude of the TYVAK-0085/-0086/-0087 vehicles are in an LVLH orientation with the long axis (z-axis) facing Nadir towards the Earth and the Y-axis aligned with the velocity vector. The vehicles will rotate about the x-axis for pointing the boresight of the vehicle GPS array at the Earth limb during RO collections and will slew for sun-pointing periodically.

#### **2.1.4 Description of any range safety or other pyrotechnic devices**

None.

#### **2.1.5 Description of the electrical generation and storage system**

Energy generation is accomplished using the primary solar panels. Energy storage is accomplished using standard COTS Li-ion battery cells. The cells are recharged by the solar cells mounted on the deployable and body panels. The power management and distribution is provided by the electrical power system and battery protection circuitry.

### 3.0 ASSESSMENT OF SPACECRAFT DEBRIS RELEASED DURING NORMAL OPERATIONS

No intentional release of any object > 1mm is expected.

Parameter	Value
Identification of any object (>1mm) expected to be released from the spacecraft at any time after launch	None
Rationale/necessity for release of 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 of each object after release	N/A
Calculated orbital lifetime of each object	N/A
Compliance 4.3-1 Mission related debris passing through GEO	COMPLIANT
Compliance 4.3-2 Mission related debris passing through LEO	COMPLIANT

*Table 3-1: Summary of Spacecraft Debris Released During Normal Operations*

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## **4.0 ASSESSMENT OF SPACECRAFT POTENTIAL FOR EXPLOSIONS AND INTENTIONAL BREAKUPS**

### **4.1 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.

### **4.2 Summary of failure modes and effects analysis of all credible failure modes**

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 (Appendix A, see requirement 4.4-1) describe the combined faults that must occur for any of seven (7) independent, mutually exclusive failure modes to lead to explosion.

### **4.3 Detailed plan for any designed spacecraft breakup**

There are no planned breakups.

### **4.4 List of components which shall be passivated at End of Mission (EOM)**

The nRWA will be passivated at EOM through a series of commands to reduce wheel momentum to a minimum level and then to transition the vehicle to free drift mode.

The batteries will be passivated by discharging the cells to a minimum state and then disconnecting them from the solar panels and charging circuitry.

### **4.5 Rational for all items which are required to be passivated, but cannot be due to their design**

None.

### **4.6 Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4**

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**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 COMPLIANT

---

**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:

The batteries will be passivated by discharging the cells to a minimum state and then disconnecting them from the solar panels and charging circuit. In the unlikely event that a battery cell does explosively rupture, the small size, mass, and potential energy of these batteries is such that while the spacecraft could be expected to vent gases, most debris from the battery rupture would be contained within the vehicle due to lack of penetration energy and also because the cells are housed in a substantial aluminum bracket.

The nRWA will be passivated at EOM through a series of commands to reduce wheel momentum to a minimum level and then to transition the vehicle to free drift mode.

---

**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.

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## 5.0 ASSESSMENT OF SPACECRAFT POTENTIAL FOR ON-ORBIT COLLISIONS

### 5.1 Assessment of spacecraft compliance with Requirements 4.5-1 and 4.5-2:

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***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).*

---

Compliance statement: (Large Object Impact and Debris Generation Probability)

Required Probability: 0.001

Expected 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).*

---

Compliance statement: (Small Object Impact and Debris Generation Probability)

Required Probability: 0.01

Expected probability: 0.00000 COMPLIANT



## 6.0 ASSESSMENT OF SPACECRAFT POSTMISSION DISPOSAL PLANS AND PROCEDURES

### 6.1 Description of spacecraft disposal option selected

The satellite will de-orbit naturally by atmospheric re-entry.

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

None.

### 6.3 Calculation of area-to-mass ratio after postmission disposal:

Spacecraft Mass: ~10.226 kg (dry mass)

Cross-sectional Area: 0.117516 m<sup>2</sup>

Area to mass ratio:  $(0.117516 \text{ m}^2)/(10.226\text{kg}) = 0.01149 \text{ m}^2/\text{kg}$

### 6.4 Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5:

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**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*

---

Compliance statement:

The orbit used for disposal of structure analysis is 504 km (TYVAK-0085), 500km (TYVAK-0086) and 505km (TYVAK-0087). The worst-case orbital lifetime is predicted to be 3.565 years;  
COMPLIANT

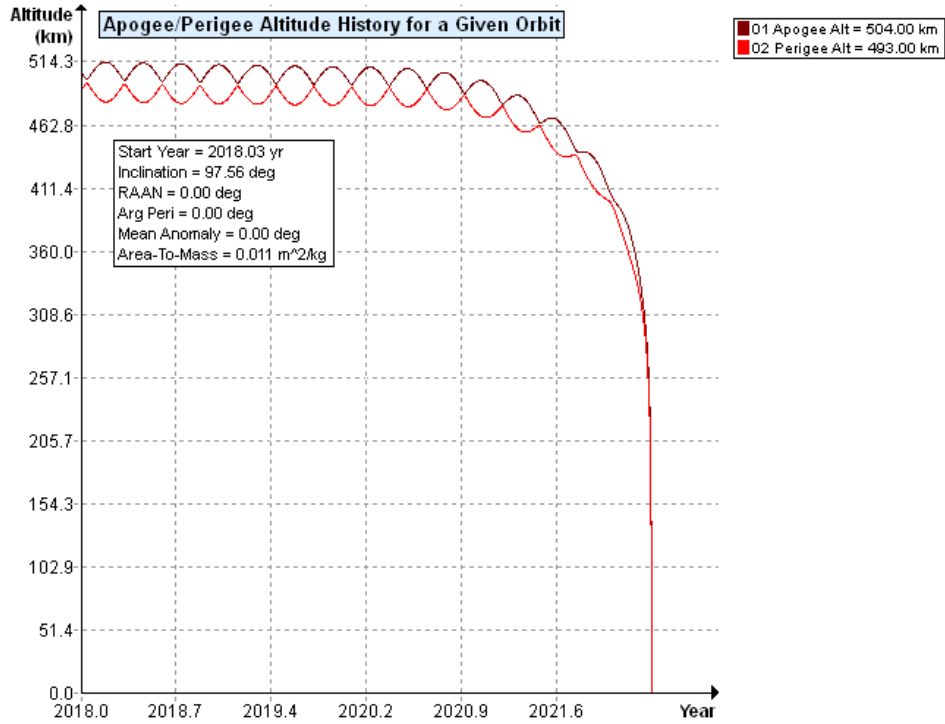


Figure 6-1: TYVAK-0085 Deorbit Lifetime

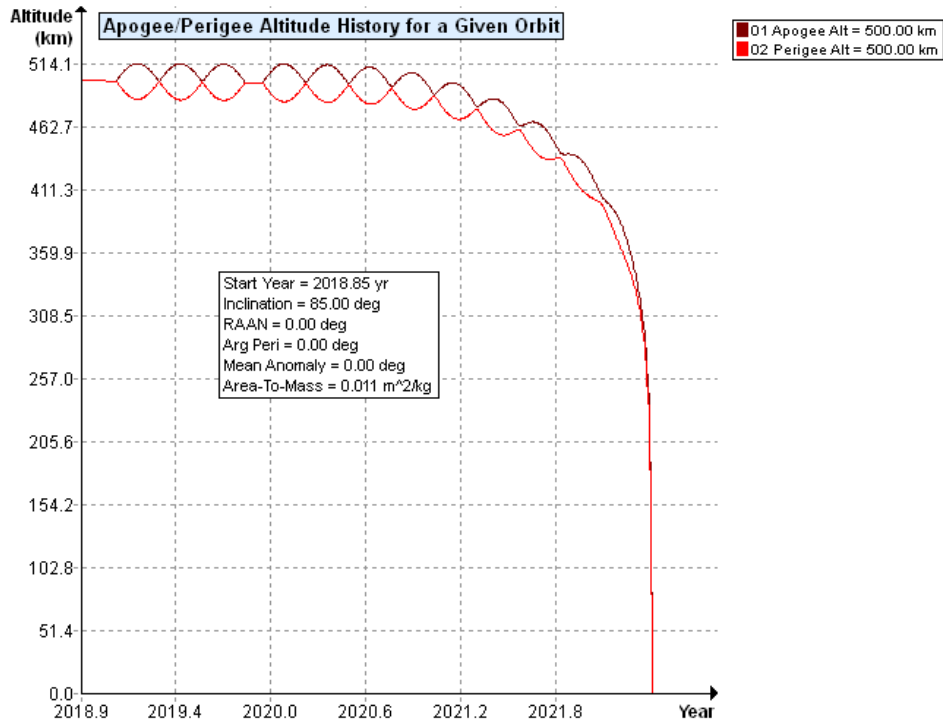


Figure 6-2: TYVAK-0086 Deorbit Lifetime

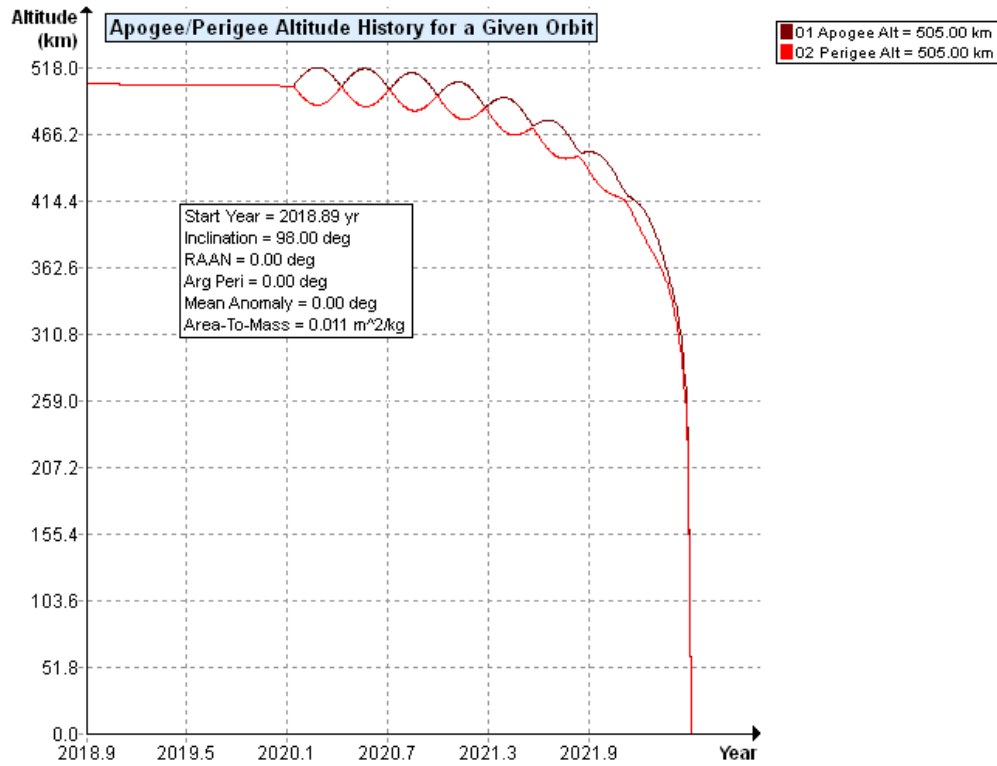


Figure 6-3: TYVAK-0087 Deorbit Lifetime

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

Compliance statement:

Not applicable. TYVAK-0085/-0086/-0087 mission orbit is LEO.

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

Compliance statement:

Not applicable. TYVAK-0085/-0086/-0087 mission orbit is LEO.

**Requirement 4.6-4. Reliability of Postmission Disposal Operations**

Compliance statement:

Not applicable. The satellite will reenter passively without the need for post mission disposal operations within the allowable timeframe.

**6.5 Detailed plan for passivating (depleting all energy sources) of the spacecraft:**

The nRWA will be passivated at EOM through a series of commands to reduce wheel momentum to a minimum level and then to transition the vehicle to free drift mode. The free drift mode does not utilize any attitude control actuators, specifically the nRWA. The power service to the nRWA will also be deactivated so that no inadvertent switch to another attitude control mode can actuate the nRWA.

The batteries will be passivated by permanently disconnecting solar array power from the battery module and discharging the cells to a minimum state under load of the spacecraft bus.

---

## 7.0 ASSESSMENT OF SPACECRAFT REENTRY HAZARDS

### 7.1 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).*

---

Compliance statement:

DAS v2.0.2 reports that TYVAK-0085/-0086/-0087 is COMPLIANT with the requirement. The vehicle is primarily composed of Aluminum and PCB (Fiberglass) material and none of the components is expected to survive re-entry. The predicted Total Debris Casualty Area is 0.00. Appendix D located in the back of this report contains the DAS 2.0.2 modeling input and results.

---

**Requirement 4.7-1., b)** *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).*

---

Compliance statement:

Not applicable. No controlled reentry planned.

---

**Requirement 4.7-1., c)** *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).*

---

Compliance statement:

Not applicable. No controlled reentry planned.

## **8.0 ASSESSMENT FOR TETHER MISSIONS**

Not applicable. There are no tethers in the TYVAK-0085/-0086/-0087 missions.

## APPENDIX A – FMEA DETAILS AND SUPPORTING RATIONALE

### Battery Explosion Failure:

**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. The battery is housed within a substantial aluminum bracket.

**Probability:** Very Low. 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).

#### **Failure mode 1:** Battery Internal short circuit.

*Mitigation 1:* Qualification and acceptance tests include vibration, thermal cycling, and vacuum tests followed by maximum system rate-limited charge and discharge to prove that no internal short circuit sensitivity exists.

*Mitigation 2:* Over/under voltage cell protection circuitry guards against stress conditions that can cause the development of internal shorts.

*Combined faults required for realized failure:* Environmental testing **AND** functional charge/discharge tests must both be ineffective in discovery of infant mortality failure rate (IMFR) related faults **OR** protection circuitry malfunctions and fails to protect cells from stress conditions.

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

*Mitigation 3:* Each cell includes an internal positive temperature coefficient (PTC) variable resistance device that reduces discharge current as cell temperature increases to prevent thermal runaway.

*Mitigation 4:* External under-voltage lockout circuitry disconnects battery when battery discharge voltage droop crosses a predefined threshold.

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

#### **Failure Mode 3:** Overcharging and excessive charge rate.

*Mitigation 5:* The satellite bus battery charging circuit design eliminates the possibility of the batteries being overcharged if circuits function nominally. This circuit will be extensively bench-tested and be proto-qualified for survival in vibration, and thermal-vacuum environments. The charge circuit disconnects the incoming current when cell voltage indicates normal full charge at 4.2V and limits charge current within battery specification. If this circuit fails to operate, continuing or excessive charge current can cause gas generation. The batteries

include overpressure release vents that allow gas to escape, virtually eliminating any explosion hazard.

*Combined faults required for realized failure:*

- 1) For overcharging: The charge control circuit must fail to limit charge voltage **AND** the PTC device must fail (or temperatures generated must be insufficient to cause the PTC device to modulate) **AND** the overpressure relief device must be inadequate to vent generated gasses at acceptable rates to avoid explosion.
- 2) For excessive charge rate: The charge control circuitry must fail to limit charge current **AND** the PTC device must fail (or temperatures generated must be insufficient to cause the PTC device to modulate) **AND** the overpressure relief device must be inadequate to vent generated gasses at acceptable rates to avoid explosion.

**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 6:* This failure mode is negated by a) proto-qualification tested short circuit protection on each external circuit, b) design of battery packs and insulators such that no contact with nearby board traces or structure 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:* 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 7:* Battery vents are not inhibited by the battery holder design or the spacecraft.

*Combined effects required for realized failure:* The spacecraft design inhibits cell venting, or cell venting clearance is sensitive to environmental stress.

**Failure Mode 6:** Crushing.

*Mitigation 8:* This mode is negated by spacecraft design. There are no moving parts in the proximity of the batteries. Qualification and acceptance tests including vibration, thermal cycling, and vacuum tests will demonstrate cell venting clearance insensitivity to environmental stress.

*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:** Excess temperatures due to orbital environment and high discharge combined.

*Mitigation 9:* The spacecraft thermal design will negate this possibility. Thermal rise will be analyzed in combination with space environment temperatures showing that batteries do not exceed normal allowable operating temperatures which are well below temperatures of concern for explosions.

*Combined faults required for realized failure:* Thermal analysis **AND** thermal design **AND** mission simulations in thermal-vacuum chamber testing **AND** the PTC device must fail **AND** over-current monitoring and control must all fail for this failure mode to occur.

**Failure Mode 8:** Polarity Reversal Due to Over-Discharge

*Mitigation 10:* The spacecraft battery chemistry (Li-ion) is not susceptible to polarity reversal due to over-discharge.

*Combined faults required for realized failure:* Spacecraft battery module assembled with incorrect cell chemistry **AND** failure of cell protection circuitry



## APPENDIX B - REQUIREMENT 4.5-1 DAS 2.0.1 LOG

09 26 2018; 14:24:12PM Processing Requirement 4.5-1: Return Status : Passed

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

\*\*INPUT\*\*

Space Structure Name = TYVAK-0085  
Space Structure Type = Payload  
Perigee Altitude = 493.000000 (km)  
Apogee Altitude = 504.000000 (km)  
Inclination = 97.560000 (deg)  
RAAN = 0.000000 (deg)  
Argument of Perigee = 0.000000 (deg)  
Mean Anomaly = 0.000000 (deg)  
Final Area-To-Mass Ratio = 0.011490 (m<sup>2</sup>/kg)  
Start Year = 2018.000000 (yr)  
Initial Mass = 10.226000 (kg)  
Final Mass = 10.226000 (kg)  
Duration = 25.000000 (yr)  
Station-Kept = False  
Abandoned = True  
PMD Perigee Altitude = -1.000000 (km)  
PMD Apogee Altitude = -1.000000 (km)  
PMD Inclination = 0.000000 (deg)  
PMD RAAN = 0.000000 (deg)  
PMD Argument of Perigee = 0.000000 (deg)  
PMD Mean Anomaly = 0.000000 (deg)

\*\*OUTPUT\*\*

Collision Probability = 0.000001  
Returned Error Message: Normal Processing  
Date Range Error Message: Normal Date Range  
Status = Pass

=====

=====  
=====  
End of Requirement 4.5-1  
=====

10 22 2018; 18:26:12PM Processing Requirement 4.5-1: Return Status : Passed

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

\*\*INPUT\*\*

Space Structure Name = TYVAK-0086  
Space Structure Type = Payload  
Perigee Altitude = 500.000000 (km)  
Apogee Altitude = 500.000000 (km)  
Inclination = 85.000000 (deg)  
RAAN = 0.000000 (deg)  
Argument of Perigee = 0.000000 (deg)  
Mean Anomaly = 0.000000 (deg)  
Final Area-To-Mass Ratio = 0.011490 (m<sup>2</sup>/kg)  
Start Year = 2018.000000 (yr)  
Initial Mass = 10.226000 (kg)  
Final Mass = 10.226000 (kg)

Duration = 25.000000 (yr)  
Station-Kept = False  
Abandoned = True  
PMD Perigee Altitude = -1.000000 (km)  
PMD Apogee Altitude = -1.000000 (km)  
PMD Inclination = 0.000000 (deg)  
PMD RAAN = 0.000000 (deg)  
PMD Argument of Perigee = 0.000000 (deg)  
PMD Mean Anomaly = 0.000000 (deg)

\*\*OUTPUT\*\*

Collision Probability = 0.000001  
Returned Error Message: Normal Processing  
Date Range Error Message: Normal Date Range  
Status = Pass

=====

===== End of Requirement 4.5-1 =====

10 22 2018; 18:28:52PM Processing Requirement 4.5-1: Return Status : Passed

=====

Run Data

=====

\*\*INPUT\*\*

Space Structure Name = TYVAK-0087  
Space Structure Type = Payload  
Perigee Altitude = 505.000000 (km)  
Apogee Altitude = 505.000000 (km)  
Inclination = 98.000000 (deg)  
RAAN = 0.000000 (deg)  
Argument of Perigee = 0.000000 (deg)  
Mean Anomaly = 0.000000 (deg)  
Final Area-To-Mass Ratio = 0.011490 (m<sup>2</sup>/kg)  
Start Year = 2018.000000 (yr)  
Initial Mass = 10.226000 (kg)  
Final Mass = 10.226000 (kg)  
Duration = 25.000000 (yr)  
Station-Kept = False  
Abandoned = True  
PMD Perigee Altitude = -1.000000 (km)  
PMD Apogee Altitude = -1.000000 (km)  
PMD Inclination = 0.000000 (deg)  
PMD RAAN = 0.000000 (deg)  
PMD Argument of Perigee = 0.000000 (deg)  
PMD Mean Anomaly = 0.000000 (deg)

\*\*OUTPUT\*\*

Collision Probability = 0.000001  
Returned Error Message: Normal Processing  
Date Range Error Message: Normal Date Range  
Status = Pass

=====

===== End of Requirement 4.5-1 =====



## APPENDIX C - REQUIREMENT 4.6 DAS 2.0.1 LOG

09 26 2018; 14:29:43PM Processing Requirement 4.6 Return Status : Passed

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

\*\*INPUT\*\*

Space Structure Name = TYVAK-0085  
Space Structure Type = Payload  
  
Perigee Altitude = 493.000000 (km)  
Apogee Altitude = 504.000000 (km)  
Inclination = 97.560000 (deg)  
RAAN = 0.000000 (deg)  
Argument of Perigee = 0.000000 (deg)  
Mean Anomaly = 0.000000 (deg)  
Area-To-Mass Ratio = 0.011490 (m<sup>2</sup>/kg)  
Start Year = 2018.000000 (yr)  
Initial Mass = 10.226000 (kg)  
Final Mass = 10.226000 (kg)  
Duration = 25.000000 (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\*\*

Suggested Perigee Altitude = 493.000000 (km)  
Suggested Apogee Altitude = 504.000000 (km)  
Returned Error Message = Reentry during mission (no PMD req.).  
  
Released Year = 2022 (yr)  
Requirement = 61  
Compliance Status = Pass

=====

=====  
End of Requirement 4.6 =====

10 22 2018; 18:41:46PM Processing Requirement 4.6 Return Status : Passed

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

\*\*INPUT\*\*

Space Structure Name = TYVAK-0086  
Space Structure Type = Payload  
  
Perigee Altitude = 500.000000 (km)  
Apogee Altitude = 500.000000 (km)  
Inclination = 85.000000 (deg)  
RAAN = 0.000000 (deg)  
Argument of Perigee = 0.000000 (deg)

Mean Anomaly = 0.000000 (deg)  
 Area-To-Mass Ratio = 0.011490 (m<sup>2</sup>/kg)  
 Start Year = 2018.000000 (yr)  
 Initial Mass = 10.226000 (kg)  
 Final Mass = 10.226000 (kg)  
 Duration = 25.000000 (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\*\*

Suggested Perigee Altitude = 500.000000 (km)  
 Suggested Apogee Altitude = 500.000000 (km)  
 Returned Error Message = Reentry during mission (no PMD req.).

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

=====

===== End of Requirement 4.6 =====

10 22 2018; 18:31:37PM Processing Requirement 4.6 Return Status : Passed

=====

Project Data

=====

\*\*INPUT\*\*

Space Structure Name = TYVAK-0087  
 Space Structure Type = Payload  
  
 Perigee Altitude = 505.000000 (km)  
 Apogee Altitude = 505.000000 (km)  
 Inclination = 98.000000 (deg)  
 RAAN = 0.000000 (deg)  
 Argument of Perigee = 0.000000 (deg)  
 Mean Anomaly = 0.000000 (deg)  
 Area-To-Mass Ratio = 0.011490 (m<sup>2</sup>/kg)  
 Start Year = 2018.000000 (yr)  
 Initial Mass = 10.226000 (kg)  
 Final Mass = 10.226000 (kg)  
 Duration = 25.000000 (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\*\*

Suggested Perigee Altitude = 505.000000 (km)



---

Suggested Apogee Altitude = 505.000000 (km)  
Returned Error Message = Reentry during mission (no PMD req.).

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

=====

===== End of Requirement 4.6 =====



---

## APPENDIX D - REQUIREMENT 4.7-1 DAS 2.0.1 LOG

Note: Only worst-case TYVAK-0085 case shown. TYVAK-0086/-0087 results at higher altitudes with lower casualty risk from reentry debris.

09 26 2018; 14:34:17PM \*\*\*\*\*Processing Requirement 4.7-1

Return Status : Passed

\*\*\*\*\*INPUT\*\*\*\*

Item Number = 1

name = TYVAK-0085

quantity = 1

parent = 0

materialID = 9

type = Box

Aero Mass = 10.226000

Thermal Mass = 10.226000

Diameter/Width = 0.366000

Length = 0.678000

Height = 0.100000

name = PX Panel

quantity = 1

parent = 1

materialID = 9

type = Box

Aero Mass = 0.362000

Thermal Mass = 0.362000

Diameter/Width = 0.082000

Length = 0.335000

Height = 0.010000

name = MX Panel

quantity = 1

parent = 1

materialID = 9

type = Box

Aero Mass = 0.700000

Thermal Mass = 0.700000

Diameter/Width = 0.082000

Length = 0.335000

Height = 0.011500

name = PZ Panel

quantity = 1

parent = 1

materialID = 9

type = Box

Aero Mass = 0.272000

Thermal Mass = 0.272000

Diameter/Width = 0.100000

Length = 0.209000

Height = 0.020000

name = MZ Panel

quantity = 1

parent = 1

materialID = 9

type = Box

Aero Mass = 0.248000

Thermal Mass = 0.248000

Diameter/Width = 0.082000

Length = 0.205000

Height = 0.020000

name = PY Panel

quantity = 1

parent = 1

materialID = 9

type = Box

Aero Mass = 1.800000

Thermal Mass = 1.800000

Diameter/Width = 0.226000

Length = 0.330000

Height = 0.011500

name = MY Panel

quantity = 1

parent = 1

materialID = 9



type = Box

Aero Mass = 2.100000

Thermal Mass = 2.100000

Diameter/Width = 0.226000

Length = 0.330000

Height = 0.011500

name = IRM

quantity = 1

parent = 1

materialID = 23

type = Box

Aero Mass = 0.225000

Thermal Mass = 0.125000

Diameter/Width = 0.100000

Length = 0.100000

Height = 0.050000

name = IMU

quantity = 1

parent = 8

materialID = 9

type = Box

Aero Mass = 0.018000

Thermal Mass = 0.018000

Diameter/Width = 0.024500

Length = 0.038000

Height = 0.011100

name = Star Camera

quantity = 2

parent = 8

materialID = 9

type = Cylinder

Aero Mass = 0.041000

Thermal Mass = 0.041000

Diameter/Width = 0.030000

Length = 0.047000

name = RWA\_Motor\_Flywheel

quantity = 3  
parent = 1  
materialID = 9  
type = Cylinder  
Aero Mass = 0.040000  
Thermal Mass = 0.020000  
Diameter/Width = 0.040000  
Length = 0.013000

name = RWA\_Motor  
quantity = 3  
parent = 11  
materialID = 9  
type = Cylinder  
Aero Mass = 0.010000  
Thermal Mass = 0.010000  
Diameter/Width = 0.040000  
Length = 0.013000

name = RWA\_Brackets  
quantity = 3  
parent = 11  
materialID = 9  
type = Box  
Aero Mass = 0.010000  
Thermal Mass = 0.010000  
Diameter/Width = 0.040000  
Length = 0.040000  
Height = 0.013000

name = Battery Module\_1  
quantity = 2  
parent = 1  
materialID = 9  
type = Box  
Aero Mass = 0.493000  
Thermal Mass = 0.352000  
Diameter/Width = 0.042000  
Length = 0.086000  
Height = 0.042000

name = Batteries  
quantity = 6  
parent = 14  
materialID = 54  
type = Cylinder  
Aero Mass = 0.047000  
Thermal Mass = 0.047000  
Diameter/Width = 0.018000  
Length = 0.065000

name = POD Antenna  
quantity = 1  
parent = 1  
materialID = 9  
type = Cylinder  
Aero Mass = 0.075000  
Thermal Mass = 0.075000  
Diameter/Width = 0.060000  
Length = 0.030000

name = CION Payload  
quantity = 1  
parent = 1  
materialID = 23  
type = Box  
Aero Mass = 0.700000  
Thermal Mass = 0.100000  
Diameter/Width = 0.200000  
Length = 0.300000  
Height = 0.005000

name = CION Cover  
quantity = 1  
parent = 17  
materialID = 9  
type = Box  
Aero Mass = 0.600000  
Thermal Mass = 0.600000  
Diameter/Width = 0.200000

Length = 0.300000

Height = 0.005000

name = KL\_BPF

quantity = 1

parent = 1

materialID = 9

type = Box

Aero Mass = 0.010000

Thermal Mass = 0.010000

Diameter/Width = 0.015000

Length = 0.030000

Height = 0.010000

name = Miteq\_LNA

quantity = 1

parent = 1

materialID = 9

type = Box

Aero Mass = 0.010000

Thermal Mass = 0.010000

Diameter/Width = 0.015000

Length = 0.030000

Height = 0.010000

name = Backplane

quantity = 1

parent = 1

materialID = 23

type = Box

Aero Mass = 0.200000

Thermal Mass = 0.200000

Diameter/Width = 0.200000

Length = 0.300000

Height = 0.004000

name = UHF\_assembly

quantity = 1

parent = 1

materialID = 23

type = Box

Aero Mass = 0.070000

Thermal Mass = 0.040000

Diameter/Width = 0.050000

Length = 0.100000

Height = 0.050000

name = UHF\_radio

quantity = 1

parent = 22

materialID = 9

type = Box

Aero Mass = 0.030000

Thermal Mass = 0.030000

Diameter/Width = 0.036000

Length = 0.083000

Height = 0.007000

name = OEM628

quantity = 1

parent = 1

materialID = 23

type = Box

Aero Mass = 0.537000

Thermal Mass = 0.037000

Diameter/Width = 0.060000

Length = 0.100000

Height = 0.009000

name = GPS Housing

quantity = 1

parent = 24

materialID = 9

type = Box

Aero Mass = 0.500000

Thermal Mass = 0.500000

Diameter/Width = 0.060000

Length = 0.150000

Height = 0.030000

\*\*\*\*\*OUTPUT\*\*\*\*\*

Item Number = 1

name = TYVAK-0085

Demise Altitude = 77.999543

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = PX Panel

Demise Altitude = 74.253027

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = MX Panel

Demise Altitude = 71.191738

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = PZ Panel

Demise Altitude = 74.929558

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = MZ Panel

Demise Altitude = 74.869714

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = PY Panel

Demise Altitude = 68.447316

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = MY Panel

Demise Altitude = 67.023792  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = IRM  
Demise Altitude = 76.521191  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = IMU  
Demise Altitude = 74.379300  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = Star Camera  
Demise Altitude = 73.346589  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = RWA\_Motor\_Flywheel  
Demise Altitude = 75.771191  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = RWA\_Motor  
Demise Altitude = 74.585988  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = RWA\_Brackets  
Demise Altitude = 74.927160  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = Battery Module\_1  
Demise Altitude = 70.537644  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = Batteries  
Demise Altitude = 65.407839  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = POD Antenna  
Demise Altitude = 74.320652  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = CION Payload  
Demise Altitude = 77.563715  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = CION Cover  
Demise Altitude = 73.338964  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = KL\_BPF  
Demise Altitude = 76.137347  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = Miteq\_LNA  
Demise Altitude = 76.137347  
Debris Casualty Area = 0.000000



Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = Backplane  
Demise Altitude = 76.976152  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = UHF\_assembly  
Demise Altitude = 77.428566  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = UHF\_radio  
Demise Altitude = 75.732074  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = OEM628  
Demise Altitude = 77.179410  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

name = GPS Housing  
Demise Altitude = 69.849331  
Debris Casualty Area = 0.000000  
Impact Kinetic Energy = 0.000000

\*\*\*\*\*

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