PREPARED BY Kelly Cheng Systems Engineer	CAGE CODE 6J8J8	NUMBER	
APPROVALS		**TYPE** Analysis Procedure	
Approved By: Richard Prasad Lead Systems Engineer		**DATE** **Final release date**	
Concurrence: Austin Williams CTO		**SUPERSEDES SPEC DATED** **NA**	
		REV **01**	

TITLE: TYVAK-0129 Orbital Debris Assessment Report (ODAR) / End of Mission Plan (EOMP)

Warnings and Disclaimers:

REVISION SUMMARY

REV NO.	RELEASE DATE	BRIEF DESCRIPTION/REASON FOR CHANGE	EFFECTIVE PAGES
01	10/25/18	Initial draft for review	All

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ORBITAL DEBRIS SELF-ASSESSMENT: TYVAK-0129 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 passivate propulsion, 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 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-0129 is 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	Marco Villa (Tyvak)
Program/project Manager	Austin Williams (Tyvak)
Senior Scientist	Austin Williams (Tyvak)
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-0129 Launch	February 26, 2019

Table 1.2 – Summary of Mission Design and Development Milestones

1.2.2 Mission Overview

The goal of the TYVAK-0129 mission is to perform bus risk-reduction via the maiden flight of the next generation 6U Tyvak Nanosat bus platform and perform on-orbit experimental performance demonstration of both a low-thrust electric propulsion payload and an RF receiver payload system. The collection of vehicle data will be used to validate the TYVAK-0129 bus and payload systems.

Parameter	Value
Launch vehicle and launch site	Sriharikota, India
Launch date	Q1 2019
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-0129 satellite into its final mission orbit (500km, circular, sun-synchronous orbit 98° inclination). There is no parking or transfer orbit. The TYVAK-0129 satellite will decay naturally for debris mitigation and will re-enter within 25 years after completion of mission.

Table 1-2: Summary of TYVAK-0129 Mission Parameters

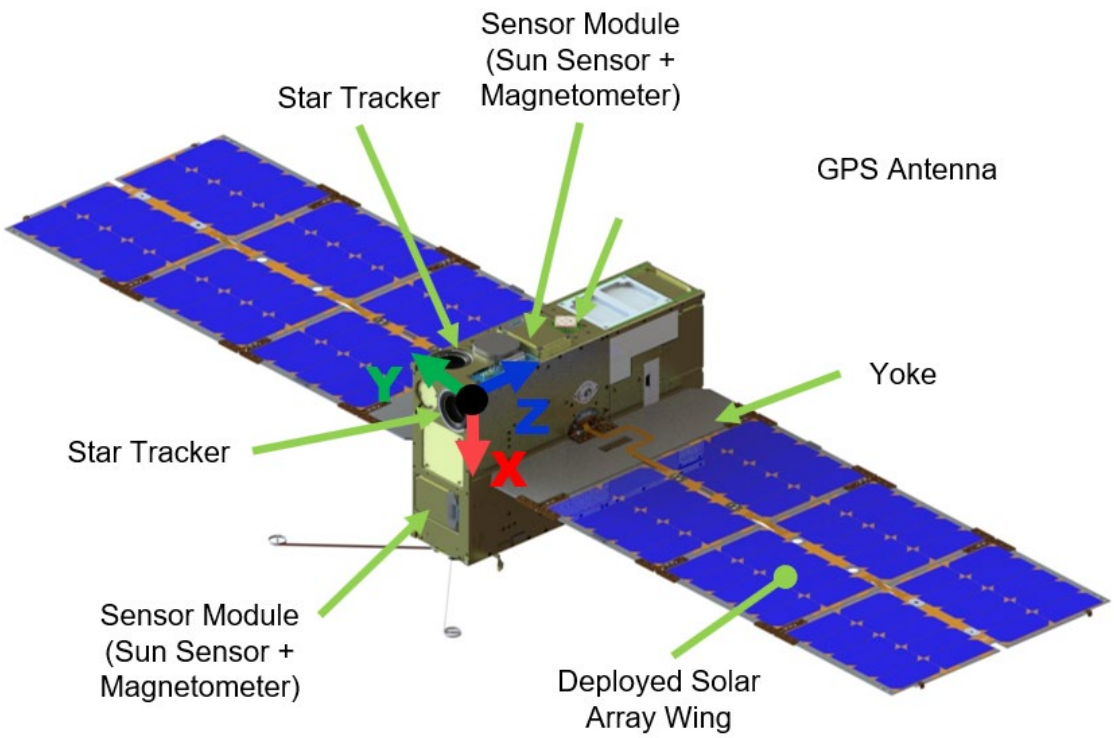
2.0 SPACECRAFT DESCRIPTION

2.1 Physical Description of Spacecraft

The TYVAK-0129 vehicle has 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-0129 vehicle is a 6U CubeSat with the vehicle being 30cm x 20cm x 10cm with a mass of 12.2 kg.

The TYVAK-0129 vehicle design uses subsystem modules built from printed circuit boards (PCB) or miniature enclosures secured to a primary structure consisting of panels and rails. The panel and railed open structure permits the vehicle to be built incrementally with access for integrating subsystem modules and securing interconnect harnessing. The subsystems are placed within the vehicle to optimize mass properties, radiation protection, thermal heat rejection, power handling, vehicle orientation, and cabling length. The deployable solar arrays attach to the primary structure via a one-axis gimballed solar array. Two of the bus side-panels are dedicated as radiators 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 first TYVAK-0129 payload utilizes a Hemispherical antenna mounted in the pre-designated payload volume on the Minus-X panel to receive ground emitter signals. The signals are then captured by the payload electronics assembly which sends processed data to the TYVAK-0129 CDH for storage and later transmission to the ground via S-Band transmission.



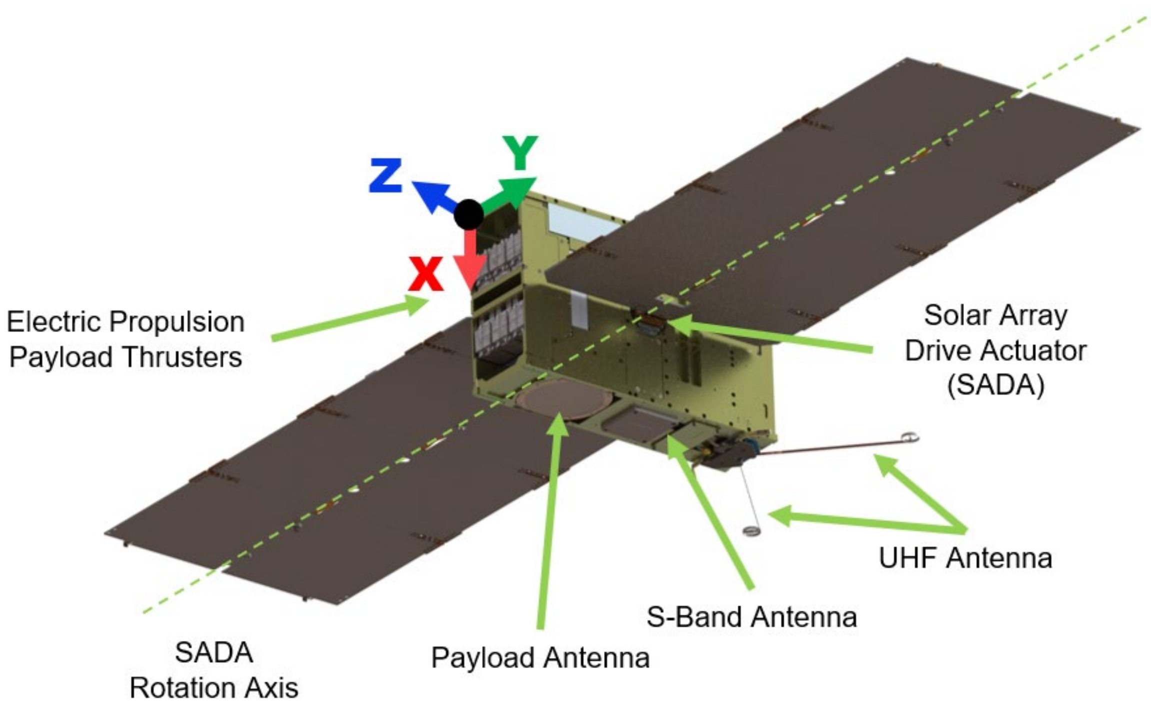


Figure 2-1: Spacecraft Vehicle Layout

Parameter	**Value**
Total satellite mass at launch, including all propellants and fluids	12 kg
Dry Mass of satellite at launch, excluding solid rocket motor propellants	11.99 kg
Identification, including mass and pressure, of all fluids	TYVAK-0129 contains an electric propulsion system that utilizes an ionic liquid propellant. The propellant has a mass of 12.7 grams and is at ambient pressure. The propellant is stored such that the internal pressure equilibrates with ambient pressure.
Fluids in Pressurized batteries	NONE. TYVAK-0129 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

The TYVAK-0129 payload consists of an electric propulsion system. The thrusters consist of a self-contained tank filled with ionic liquid-propellant. The maximum operating thrust for all payload thrusters is approximately 400mN. The payload cannot be operated in ambient conditions on the ground.

2.1.2 Description of attitude control system

The TYVAK-0129 attitude determination and control system consists of the flight computer, imu, reaction wheels, GPS receiver, sun sensors, magnetometers, and torque rods.

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

The nominal attitude of the TYVAK-0129 vehicle is in an LVLH orientation with the long axis (Z-axis) facing along the velocity vector and the X-axis aligned towards nadir (earth). The vehicles will rotate about the Z-axis for minimizing Star Tracker sun/earth occlusions, maximizing solar charging and orienting the boresight of the S-band patch antenna towards ground asset(s).

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 two deployable solar array wings. Energy storage is accomplished using standard COTS Li-ion battery cells. The cells are recharged by the solar cells mounted on the deployable solar arrays. The power management and distribution is provided by the electrical power system and battery protection circuitry. A single-axis rotating gimbal interfaces with both solar array wings to increase the total solar charging output.

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

4.0 ASESSMENT 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.

The potential energy of the electric propulsion payload propellant is too low or inaccessible to be worth quantifying. The Thruster Head Subsystem is not a pressurized container, and is designed to maintain no pressure differential with ambient, so it does not store mechanical potential energy. Chemical potential energy in the propellant is stored very stably, so except in cases of extreme external temperature (see below) or deliberate power-on and command of off-nominal operation, the energy should not be possible to release. If the propellant is destabilized, the energy is released in a benign manner. There is a minimal gravitational potential energy due to the weight of the liquid. There is no storage of electrical potential energy; high-impedance bleed resistors are employed to prevent build-up between otherwise-isolated electrodes.

The electric propulsion payload subsystems do not contain any volatile compounds. Combustion is infeasible. When heated, the propellant will decay, without burning, at >400°C, but before this, the plastic of the propellant supply system will have melted at >340°C. The payload is incapable of generating these temperatures on its own, so an external failure would be required to cause these events.

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 reaction wheels will be passivated at end-of-mission 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.

The electric propulsion payload subsystem will be left in an unpowered state during passivation.

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

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 reaction wheels will be passivated at end-of-mission 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.

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:

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. The payload propulsion system is not used for 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: ~12.0 kg (dry mass)

Cross-sectional Area: 0.221 m^2

Area to mass ratio: (0.221 m^2)/(12.0kg) = 0.0184 m^2/kg

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

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 550 km. This is to provide worst-case margin against launch vehicle insertion errors above the nominal 500km altitude. The worst-case orbital lifetime is predicted to be 3.641 years; COMPLIANT

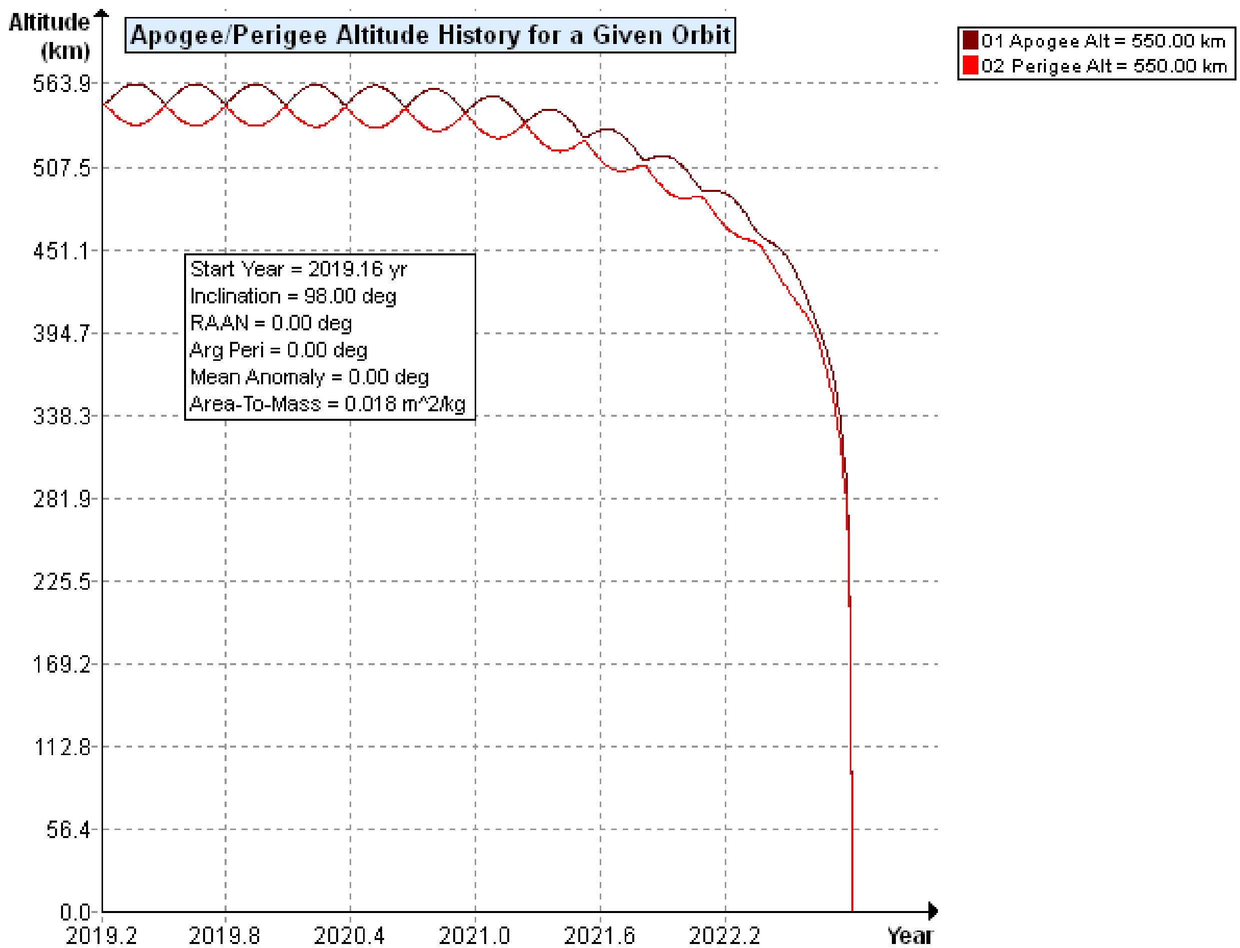


Figure 6-1: TYVAK-0129 Deorbit Lifetime

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

Compliance statement:

Not applicable. TYVAK-0129 mission orbit is LEO.

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

Compliance statement:

Not applicable. TYVAK-0129 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 reaction wheels will be passivated at end-of-mission 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 reaction wheels. The power service to the reaction wheels will also be deactivated so that no inadvertent switch to another attitude control mode can actuate the reaction wheels.

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-0129 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 $1.80m^2$ and the risk of Human Casualty is 1:49,700 below the required 1:10,000 limit. 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-0129 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

```
10 26 2018; 16:26:07PM  Processing Requirement 4.5-1:     Return Status :  Passed

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

**INPUT**

    Space Structure Name = TYVAK-0129
    Space Structure Type = Payload
    Perigee Altitude = 500.000000 (km)
    Apogee Altitude = 500.000000 (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 = 0.018400 (m^2/kg)
    Start Year = 2019.000000 (yr)
    Initial Mass = 12.000000 (kg)
    Final Mass = 12.000000 (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

```
10 26 2018; 16:35:57PM  Processing Requirement 4.6 Return Status :   Passed

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

**INPUT**

    Space Structure Name = TYVAK-0129
    Space Structure Type = Payload

    Perigee Altitude = 500.000000 (km)
    Apogee Altitude = 500.000000 (km)
    Inclination = 98.000000 (deg)
    RAAN = 0.000000 (deg)
    Argument of Perigee = 0.000000 (deg)
    Mean Anomaly = 0.000000 (deg)
    Area-To-Mass Ratio = 0.018400 (m^2/kg)
    Start Year = 2019.160000 (yr)
    Initial Mass = 12.000000 (kg)
    Final Mass = 12.000000 (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 = 2021 (yr)
    Requirement = 61
    Compliance Status = Pass

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

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

APPENDIX D - REQUIREMENT 4.7-1 DAS 2.0.1 LOG

```
10 26 2018; 16:33:41PM *********Processing Requirement 4.7-1
   Return Status :  Passed

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

name = TYVAK-0129
quantity = 1
parent = 0
materialID = 9
type = Box
Aero Mass = 12.000000
Thermal Mass = 12.000000
Diameter/Width = 0.366000
Length = 1.523000
Height = 0.229000

name = PX Panel
quantity = 1
parent = 1
materialID = 9
type = Flat Plate
Aero Mass = 0.142000
Thermal Mass = 0.142000
Diameter/Width = 0.098000
Length = 0.226000

name = MZ Panel
quantity = 1
parent = 1
materialID = 9
type = Flat Plate
Aero Mass = 0.624000
Thermal Mass = 0.624000
Diameter/Width = 0.225000
Length = 0.365000

name = PZ Panel
```

```
quantity = 1
parent = 1
materialID = 9
type = Flat Plate
Aero Mass = 0.481000
Thermal Mass = 0.481000
Diameter/Width = 0.225000
Length = 0.365000

name = PY Panel
quantity = 1
parent = 1
materialID = 9
type = Flat Plate
Aero Mass = 0.213000
Thermal Mass = 0.213000
Diameter/Width = 0.214000
Length = 0.830000

name = MY Panel
quantity = 1
parent = 1
materialID = 9
type = Flat Plate
Aero Mass = 0.229000
Thermal Mass = 0.229000
Diameter/Width = 0.216000
Length = 0.830000

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

```
name = Backplane
quantity = 1
parent = 1
materialID = 23
type = Flat Plate
Aero Mass = 0.223000
Thermal Mass = 0.223000
Diameter/Width = 0.208000
Length = 0.218000

name = UHF Antenna
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.033000
Thermal Mass = 0.033000
Diameter/Width = 0.050000
Length = 0.080000
Height = 0.007000

name = GPS Assembly
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.142000
Thermal Mass = 0.071000
Diameter/Width = 0.059000
Length = 0.083000
Height = 0.014000

name = OEM719
quantity = 1
parent = 10
materialID = 23
type = Box
Aero Mass = 0.031000
Thermal Mass = 0.031000
Diameter/Width = 0.046000
```

```
Length = 0.071000
Height = 0.011000

name = GPS Cover
quantity = 1
parent = 10
materialID = 9
type = Box
Aero Mass = 0.040000
Thermal Mass = 0.040000
Diameter/Width = 0.059000
Length = 0.083000
Height = 0.014000

name = Globalstar Modem
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.060000
Thermal Mass = 0.060000
Diameter/Width = 0.065000
Length = 0.119000
Height = 0.015000

name = Globalstar Antenna
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.060000
Thermal Mass = 0.060000
Diameter/Width = 0.048000
Length = 0.048000
Height = 0.010000

name = Payload_MaxEnv
quantity = 1
parent = 1
materialID = 9
```

```
type = Box
Aero Mass = 3.000000
Thermal Mass = 3.000000
Diameter/Width = 0.145000
Length = 0.226000
Height = 0.094000

name = Solar Array Wing
quantity = 2
parent = 1
materialID = 16
type = Box
Aero Mass = 0.997000
Thermal Mass = 0.892000
Diameter/Width = 0.340000
Length = 0.706000
Height = 0.003000

name = Solar Cells
quantity = 60
parent = 16
materialID = 25
type = Flat Plate
Aero Mass = 0.003500
Thermal Mass = 0.003500
Diameter/Width = 0.037000
Length = 0.076000

name = S-Band_Antenna
quantity = 1
parent = 1
materialID = 5
type = Box
Aero Mass = 0.049000
Thermal Mass = 0.049000
Diameter/Width = 0.065000
Length = 0.065000
Height = 0.005000

name = Star Tracker Module
```

```
quantity = 2
parent = 1
materialID = 9
type = Box
Aero Mass = 0.321000
Thermal Mass = 0.209000
Diameter/Width = 0.073000
Length = 0.124000
Height = 0.046000

name = Baffle
quantity = 2
parent = 19
materialID = 9
type = Cylinder
Aero Mass = 0.112000
Thermal Mass = 0.112000
Diameter/Width = 0.045000
Length = 0.100000

name = Coarse Sensor Module
quantity = 2
parent = 1
materialID = 23
type = Box
Aero Mass = 0.011000
Thermal Mass = 0.011000
Diameter/Width = 0.052000
Length = 0.075000
Height = 0.002000

name = SADA
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.360000
Thermal Mass = 0.360000
Diameter/Width = 0.040000
Length = 0.090000
```

```
Height = 0.040000

name = GPS Antenna
quantity = 1
parent = 1
materialID = 8
type = Box
Aero Mass = 0.026000
Thermal Mass = 0.026000
Diameter/Width = 0.035000
Length = 0.035000
Height = 0.008000

name = Torque Rod
quantity = 3
parent = 1
materialID = 19
type = Cylinder
Aero Mass = 0.104000
Thermal Mass = 0.104000
Diameter/Width = 0.015000
Length = 0.075000

name = Reaction Wheel
quantity = 3
parent = 1
materialID = -1
type = Cylinder
Aero Mass = 0.380000
Thermal Mass = 0.380000
Diameter/Width = 0.044000
Length = 0.027000

name = Load Controller
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.066000
Thermal Mass = 0.066000
```

```
Diameter/Width = 0.070000
Length = 0.075000
Height = 0.018000

name = LDRR
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.202000
Thermal Mass = 0.202000
Diameter/Width = 0.058000
Length = 0.083000
Height = 0.030000

name = IMU
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.072000
Thermal Mass = 0.072000
Diameter/Width = 0.044000
Length = 0.047000
Height = 0.034000

name = Flight Computer
quantity = 1
parent = 1
materialID = 23
type = Box
Aero Mass = 0.369000
Thermal Mass = 0.369000
Diameter/Width = 0.090000
Length = 0.137000
Height = 0.030000

name = Umbilical Board
quantity = 1
parent = 1
```

materialID = 23

type = Box

Aero Mass = 0.012000

Thermal Mass = 0.012000

Diameter/Width = 0.023000

Length = 0.095000

Height = 0.012000

name = HDRM

quantity = 4

parent = 1

materialID = 54

type = Cylinder

Aero Mass = 0.015000

Thermal Mass = 0.015000

Diameter/Width = 0.025000

Length = 0.016000

name = PIB

quantity = 1

parent = 1

materialID = 23

type = Box

Aero Mass = 0.053000

Thermal Mass = 0.053000

Diameter/Width = 0.078000

Length = 0.147000

Height = 0.020000

*************OUTPUT****

Item Number = 1

name = TYVAK-0129

Demise Altitude = 77.997371

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = PX Panel

Demise Altitude = 75.192340

```
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = MZ Panel
Demise Altitude = 72.976394
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = PZ Panel
Demise Altitude = 74.073613
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = PY Panel
Demise Altitude = 76.919418
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = MY Panel
Demise Altitude = 76.855496
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Battery Module
Demise Altitude = 67.653909
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
name = Backplane
Demise Altitude = 75.630269
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

************************************
```

name = UHF Antenna

Demise Altitude = 76.384051

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = GPS Assembly

Demise Altitude = 75.494941

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = OEM719

Demise Altitude = 73.923761

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = GPS Cover

Demise Altitude = 73.460832

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Globalstar Modem

Demise Altitude = 76.420558

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Globalstar Antenna

Demise Altitude = 71.964238

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Payload_MaxEnv

Demise Altitude = 59.093878

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

```
***********************************
name = Solar Array Wing
Demise Altitude = 0.000000
Debris Casualty Area = 1.797272
Impact Kinetic Energy = 92.440338

***********************************
name = Solar Cells
Demise Altitude = 0.000000
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

***********************************
name = S-Band_Antenna
Demise Altitude = 73.920527
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

***********************************
name = Star Tracker Module
Demise Altitude = 73.764699
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

***********************************
name = Baffle
Demise Altitude = 69.276550
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

***********************************
name = Coarse Sensor Module
Demise Altitude = 77.364926
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

***********************************
name = SADA
Demise Altitude = 66.873394
```

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = GPS Antenna

Demise Altitude = 73.536605

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Torque Rod

Demise Altitude = 69.795706

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Reaction Wheel

Demise Altitude = 51.907206

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = Load Controller

Demise Altitude = 75.587238

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = LDRR

Demise Altitude = 72.518652

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

name = IMU

Demise Altitude = 74.444785

Debris Casualty Area = 0.000000

Impact Kinetic Energy = 0.000000

****

```
name = Flight Computer
Demise Altitude = 72.379933
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = Umbilical Board
Demise Altitude = 77.270566
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = HDRM
Demise Altitude = 70.772214
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

*************************************
name = PIB
Demise Altitude = 76.990082
Debris Casualty Area = 0.000000
Impact Kinetic Energy = 0.000000

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

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