Space Vehicle (SV)
Space Debris Assessment Report/
End-of-Life Plan (SDAR/EOLP)

STPSat-4

23 April 2018

Version 0

Space and Missile Systems Center (SMC)
Advanced Systems & Development Directorate (SMC/AD)

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SDAR/EOLP History Page

Version	Date	Description of Changes/ OCR(s)
0	6 Apr 2018	Initial Draft

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Preface

Air Force Instruction (AFI) 91-217, Space Safety and Mishap Prevention Program, requires the SV Program Manager (PM) to prepare and deliver a Space Debris Assessment Report/

End-of-Life Plan (SDAR/EOLP) per the format, content, and schedule described in Attachment 3. AFI 91-217 also directs the Program Manager to assess space debris policy compliance described in Department of Defense Instruction (DoDI) 3100.12, and Space Support and Strategic Command Instruction (SI) 505-4 Satellite Disposal Procedures during all mission phases. An informational copy of this SDAR/EOLP shall be submitted to Joint Force Space Component Command (JFSCC).

Failure to meet debris mitigation requirements described in AFI 91-217 shall be documented in this SDAR/EOLP and submitted for review by the Center (or equivalent) Chief Engineer with a copy of the formal risk acceptance for any non-compliance. The Space and Missile Systems Center Commander (or designated approving official) is the final approving authority for the SDAR/EOLP.

Compliance Summary

The STPSat-4 space vehicle will launch in 4Q FY2019 into a Low-Earth Orbit (LEO) of 400 km and in a circular orbit of 51.6 degrees inclination. The mission length is one year; however, the science objectives are expected to be achieved by six months. STPSat-4 orbit disposal will be by uncontrolled atmospheric re-entry within 2 years of launch. The space vehicle complies with all orbital debris mitigation requirements of DoDI 3100.12 and AFI 91-217

Exception to National Space Policy (EtP) Status

This space vehicle is compliant with the U.S. Government Orbital Debris Mitigation Standard Practices (USG ODMSP).

1 PROGRAM MANAGEMENT AND MISSION OVERVIEW

1.1 Identification of the Program Sponsoring the Mission and the Program Manager

The Department of Defense Space Test Program (STP) is the sponsor for the STPSat-4 mission. SMC/ADST has program execution responsibility. The Mission Manager is Capt Justin Bruh, justin.bruh@us.af.mil, 281-244-1928.

1.2 Identification of Any Mission Partners' Participation and a Summary of the Air Force's Responsibility under the Governing Agreements

STPSat-4 includes a partnership with the organizations listed in Table 1.2-1. The Air Force's responsibility under Government Agreements is described in AFI 10-1202 (I); AR 70-43; OPNAVINST 3913.1A STP Management. AFI 10-1202 describes the STP responsibility to provide "access to space" for military science and technology (S&T) experiments.

A signed Memorandum of Agreement (MOA) with each payload organization provides a detailed description of specific responsibilities. A summary of Air Force responsibilities includes manifest, payload integration, mission assurance, orbital safety and on-orbit operations for one year.

Table 1.2-1 STPSat-4 Mission Partners

Experiment	Organization	Principle Investigator
Modular Solar Array (MATRS):	Air Force Research Lab (AFRL)	Mr. Bernie Carpenter
Integrated Miniaturized Electrostatic Analyzer – Reflight (iMESA-R)	United States Air Force Academy (USAFA)	Dr. Matthew McHarg
Navy Interferometric Star Tracker Experiment (NISTEx):	Naval Observatory (NAVOBSY)	Dr. Rachel Dulik
Modular Radio Frequency Tiles (MRFT)	Air Force Research Lab (AFRL)	Mr. Christopher Lesniak
Nanosatellite Tracking Experiment (NTE)	Space and Naval Warfare Systems Center (SPAWARSYSCEN)	Mr. Terry Albert

The STPSat-4 spacecraft is being designed, developed and integrated by MEI Technologies (MEIT) using the DoD Human Exploration Payloads (DHEP) contract. STP provides contract funding. NASA provides launch on an International Space Station (ISS) re-supply mission at no cost to the Air Force or STP.

1.3 Schedule of Mission Design and Development Milestones through Proposed Launch Date

Table 1.3-1 Design/Development Milestones

Milestone	Date
Preliminary Design Review (PDR)	8 July 2014 *
Critical Design Review (CDR)	14 Sept 2016
Space Vehicle Integration and Test (I&T)	7 Sept 2017
Initial Launch Capability (ILC) *	15 Oct 2019*

* Note: 1. The program experienced a long pause between PDR and CDR – funding was moved to support higher priority STP projects.

2. For ISS Re-supply missions, the ILC is defined as delivery to NASA ("turn over" date). Typically, NASA will manifest the SV to the launch vehicle closest to the turn over date. Aug 2019 is the planned turn over date.

1.4 Mission Operational Milestones from Launch through End-of-Life (EOL)

Table 1.4-1 Mission Operational Milestones

Milestone	Date
Deployment	Nov 2019
Last Ops Readiness Review (ORR)	Oct 2018
Operations	1 year*

* Note: STP funding for space experiments ends at one (1) year of on-orbit operations. Science objectives are expected to be met within six months of deployment. When science objectives are met or at the end of one year, STP might transition to another sponsor to extend operations for additional data collection.

1.5 Summary Table Indicating Compliance or Noncompliance with each Debris Mitigation Requirement of DoDI 3100.12 and AFI 91-217

Table 1.5-1 summarizes mission compliance with requirements in AFI 91-217 and DoDI 3100.12.

Table 1.5-1 Compliance Summary

SDAR/ EOLP Section	Requirement Description	DoDI 3100.12	DoDI Compliance	AFI 91-217	AFI Compliance	Comments/Justification (required if non-compliance noted)
3	Debris Released On Orbit	6.3.1	**Compliant**	5.4.5	**Compliant**	STPSat-4 is not planning or intending to release debris on orbit.
4	Debris Generated by Explosions and Intentional Breakups	6.3.2.1	**Compliant**	5.4.6.1	**Compliant**	- No propulsion system - FMEA examined the integrated probability of explosion for battery and reaction wheel failure modes - Lithium Ion batteries tested to NASA standard "Certification and Acceptance of COTS Li-Ion Batteries" (JSC 66548) (Reference #3) - Testing and certification to this standard meets NASA requirements for manned space flight (Reference #4 & #5) - Reaction wheels are space-qualified hardware designed for longer on-orbit missions than the intended STPSat-4 duration - Based on FMEA the probability of explosion < 1×10^{-3}
				5.4.7	**N/A**	No planned intentional breakup.
5	On-orbit Collisions	6.3.3	**Compliant**	5.4.8	**Compliant**	- STPSat-4 does not perform post-mission disposal maneuvers - Based on orbit insertion altitude, the STPSat-4 will de-orbit in less than two years (Reference #7) - No collision would prevent post-mission disposal
				5.6	**Compliant**	- NASA ISS Trajectory Operations Planning Office (TOPO) will perform STPSat-4 jettison analysis responsible for protecting

SDAR/ EOLP Section	Requirement Description	DoDI 3100.12	DoDI Compliance	AFI 91-217	AFI Compliance	Comments/Justification (required if non-compliance noted)
						manned and active spacecraft following separation from ISS through reentry. - Aerospace analysis (Reference #6) indicates that the STPSat-4 probability of collision with large objects will not exceed requirements - See Figures 5.1-1, 5.1-2, and 5.1-3. NASA will perform additional analysis prior to separation from ISS to confirm.
6	End-of-Life Plans and Procedures	6.3.2.2	**Compliant**	5.4.6.2	**Compliant**	No propulsion system or fluids on STPSat-4. At the time of spacecraft re-entry, the battery capacity is expected to be depleted. Battery life expectancy based on planned power demand is approximately 15 months. The reaction wheels will stop working when battery is depleted.
		6.4.1	**Compliant**	5.7.2.1	**Compliant**	Probability of successful disposal is 100% - atmospheric re-entry less than 2 years. (Reference #7)
				5.7.3.1.1	**Compliant**	Conservative projections for solar activity, atmospheric drag indicate atmospheric re-entry less than 2 years. (Reference #7)
		6.4.2	**N/A**	5.7.3.2	**N/A**	Disposal orbit is not planned or intended
		6.4.3	**N/A**	5.7.3.3	**N/A**	Direct retrieval is not planned or intended
				5.7.4	**Compliant**	Both battery and reaction wheel passivation occurs simultaneous with battery depletion or deorbit.

SDAR/ EOLP Section	Requirement Description	DoDI 3100.12	DoDI Compliance	AFI 91-217	AFI Compliance	Comments/Justification (required if non-compliance noted)
7	Spacecraft Reentry Hazards	6.4.1	**Compliant**	5.7.2.2	**N/A**	STPSat-4 is not planning or intending a controlled deorbit.
				5.7.3.1	**Compliant**	- At end of mission, the STPSat-4 will naturally decay leading to atmospheric reentry within 2 years of deployment from the ISS. (Reference #7) - The STPSat-4 risk to general public due to uncontrolled atmospheric reentry is zero. (Reference #7) This value is less than the expectation of casualty (Ec) of 100 x 10-6 (one hundred in one million) cited in AFI 91-217.
8	Tether Missions	6.3.3	**N/A**			There are no tether elements associated with this mission.

1.6 Brief Description of the Mission

The purpose of the STPSat-4 mission is to economically provide access to space for multiple DoD space experiments.

The following are the STPSat-4 experiment objectives:

- iMESA: Measure the low-energy component of the plasma energy spectrum to improve space situational awareness.
- MATRS: Characterize the ability of MOSAIC modular solar array technology to provide flexible and reliable solar array performance in a relevant environment
- MRFT: Demonstrate the space worthiness of the tile architecture, materials, and components in the combined effects environment of LEO
- NISTEx: Test the astrometric accuracy, celestial navigation proficiency and space situational awareness tracking capability
- NTE: Test passive retro-reflectors for better tracking and identification of Nanosats/Cubesats

1.7 Description of Operational Orbits

The STPSat-4 program consists of a spacecraft bus and a suite of five experimental payloads deployed from the ISS. STPSat-4 is capable of launching on any ISS resupply mission in a soft-stowed configuration. STPSat-4 will be temporarily stored in the ISS internal volume until being jettisioned via the Cyclops deployer through the Japanese Experiment Module (JEM) airlock. Once deployed, the operation is planned for one year. STPSat-4's orbit is circular @ 400 km and 51.6 degree of inclination. Orbit duration variance is based on ISS orbit altitude variance of 330 - 435 km. The initial ISS separation altitude will determine STPSat-4 orbit duration.

1.8 Chronology of Management Reviews

Not Applicable: Since STPSat-4 is only sponsored by STP for one year on orbit, a review is planned 90 days before end of one year to determine if there is remaining spacecraft life and a sponsor to continue on-orbit operations.

Table 1.8-1 Management Reviews

Date	OCR(s)	Comments
Aug 2020	SMC/ADST	• This review will be conducted 90 calendar days before end of operation

1.9 Identification of the Anticipated Launch Vehicle and Launch Site

STPSat-4 may be launched on any ISS resupply mission. NASA's Payload Integration Manager (PIM) will manifest STPSat-4 on a launch vehicle approximately six months before delivery to NASA. It is expected that the re-supply mission will be flown on a SpaceX Falcon 9 from Cape Canaveral.

1.10 Identification of the Proposed Launch Date and Mission Duration

The expected launch date to the ISS is October 2019. The spacecraft ILC is 14 Aug 2019. Once the STPSat-4 arrives at the ISS it may not be immediately deployed. As described in Section 1.7, the STPSat-4 must be scheduled for deployment through the Japanese Experiment Module (JEM) airlock. STP will sponsor STPSat-4 for one year on-orbit.

1.11 Identification of Released Objects

There is no planned or anticipated release of objects during the STPSat-4 mission.

1.12 Identification of any Interaction or Potential Physical Interference with Other Operational Spacecraft

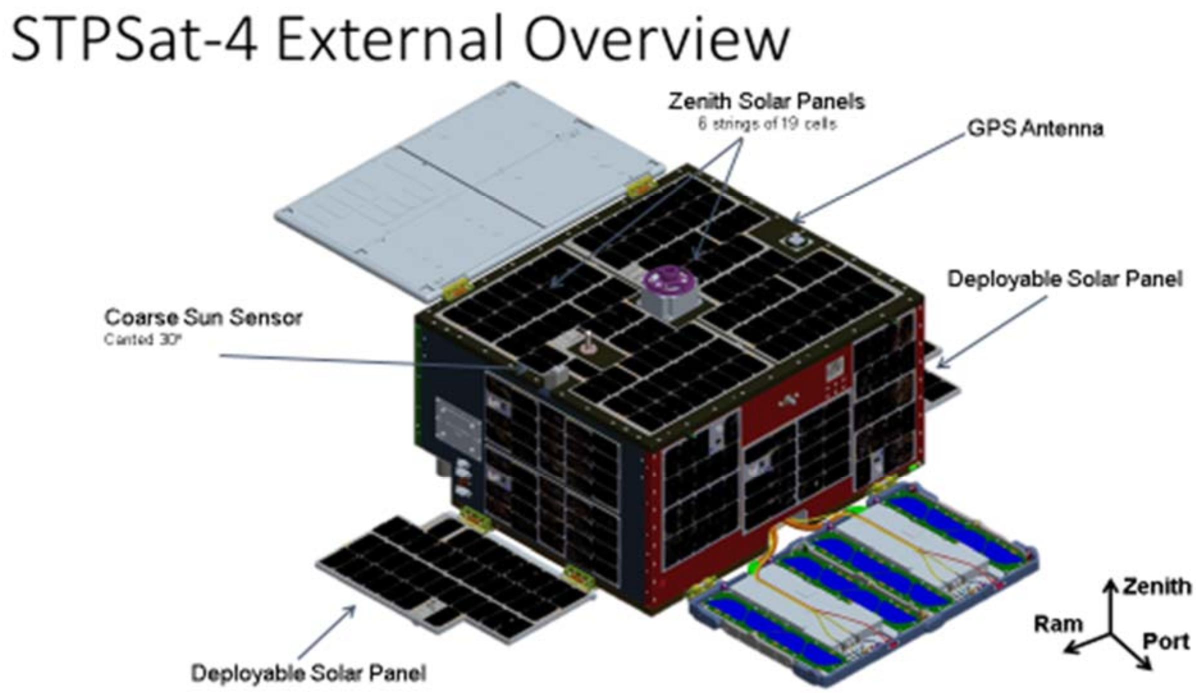
There is no planned or anticipated interaction with other spacecraft. There is no known potential for physical interference with other operational spacecraft. NASA will conduct conjunction analysis before STPSat-4 deployment from the ISS.

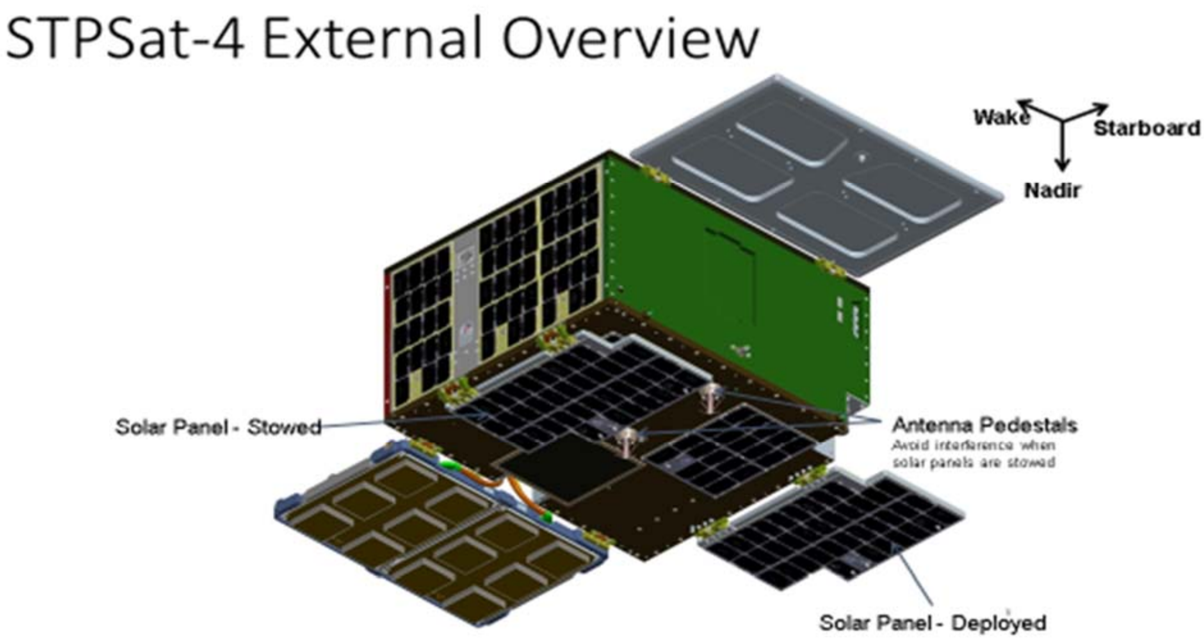
2 SPACECRAFT DESCRIPTION

2.1 Physical Description of Spacecraft

STPSat-4 is a small ESPA-class satellite weighing at 105 kg. The bus is a rectangular aluminum structure. The satellite has two deployable solar panels. The remaining solar arrays are body mounted. The satellite has no propulsion module. The bus hosts five small experiments, each weighing between 1 and 6 kg. The other two deployable panels contain two experiments, one for the solar array experiment (MATRS) and the other for the RF Tile experiment (MRFT).

2.2 Detailed Illustration of the Spacecraft





2.3 Total Spacecraft Mass at Launch

Nominal Spacecraft mass 105 kg

2.4 Dry Mass of Spacecraft at Launch

Dry mass: 105 kg

2.5 Total Mass of Post-Passivation Spacecraft

105 Kg

2.6 Propulsion System Description

Not Applicable: STPSat-4 Spacecraft does not contain propulsion

2.7 On-Board Fluids

Not Applicable: No propulsion

2.8 Fluid System Description

Not Applicable: No propulsion

2.9 Attitude Determination and Control Subsystem (ADCS)

The ADCS is a three-axis stabilized altitude control system based on the Blue Canyon Technologies (BCT) XACT Nano-Satellite Attitude Control. It consists of four 1.2 Nms reaction wheels arranged in a pyramid arrangement that can spin at +/- 6000 RPM. The system also contains three orthogonal torque rods. The ADCS control unit (Flexcore) contains an FPGA LEON3FT Processor that provides attitude determination, attitude control algorithms, orbit propagation, orbit adjust, momentum management, time management and command and telemetry. The ADCS also contains a coarse sun sensor with four diodes in a pyramid arrangement to cover 45-54 degree haft cone FOV. Lastly, the system contains two nano star trackers. One on wake and one on port. The star trackers can track stars at angular rates up to 3 degrees/second. The STPSat-4 ADCS system is a legacy system and procured from Blue Canyon Technology.

STPSat-4 has 3 nominal orientations. The first is Local Vertical Local Horizon (LVLH) where the spacecraft face indicated to be in the ram direction in section 2.2 is perpendicular to the velocity vector. The LVLH attitude will be maintained for approximately 25% of the spacecraft's life. The other attitudes are Sun Point, where the face indicated to be in the zenith direction in section 2.2 will be pointed in the direction of the Sun, and Ground Track, where the face indicated to be in the nadir direction in section 2.2 is pointed towards the location of the Earth station to be communicated with. In these two attitudes, the angle of any particular point or face on the spacecraft with respect to the velocity vector will be constantly changing so as to maintain the spacecraft's orientation to either the Sun or the Earth station.

2.10 Range Safety Device Description

Not Applicable: STPSat-4 does not have range safety or other pyrotechnic devices

2.11 Electrical Power Subsystem (EPS) Description

The STPSat-4 EPS uses Direct Energy Transfer to control and manage solar array power. The battery sets the array voltage because they are directly connected to each other. String switching is used to regulate the amount of current that is allowed to go into the battery. The EPS consists of two Power Control Electronic (PCE) box, a Lithium-Ion (Li-Ion) rechargeable battery pack with Voltage Monitoring Board, a DC-DC regulator, the inhibit board, and solar panels. The PCE connects and controls solar cells strings to charge the satellite Li-Ion batteries and distributes power to satellite subsystems and experiments.

The solar system will include twelve body-mounted panels attached to five different sides of the satellite and two deployable panels, which contain four solar strings facing Zenith and four solar strings facing Nadir. The body mounted solar panels and the deployable solar panels use EMCORE/SOLAERO ZTJ (29.5 % efficiency) solar cells arranged in parallel strings of 19 cells connected in series. The STPSat-4 battery assembly consists of two re-chargeable Li-Ion battery packs, to supply 28 VDC, via converter, to the satellite subsystems and experiments. Each battery pack has a nominal voltage of 32.4 VDC (3.6 VDC per cell) and a capacity of 9 Ah. Each battery pack has the same cell layout of Panasonic cells (P/N: NCR 18650A). The EPS will be able to supply 88.9 watts continuous and peak at 155 watts. The battery was fully qualified to NASA's safety requirements including thermal runaway.

2.12 Other Stored Energy Sources

None

2.13 Radioactive Materials

None

2.14 Table of Stored Energy Sources

There are no stored energy sources other than the batteries and the reaction wheels described in paragraphs 2.9 and 2.10

2.15 List of Changes in Propulsion System and Energy Systems (i.e., Other Stored Energy Sources) since Launch

Data to be added during operations.

Table 2.15-1 Changes since Launch

Date	Description of Change

2.16 Status of the Major Systems On Board the Spacecraft, Including any Changes in Redundancy

The STPSat-4 is a single-string, science and technology spacecraft. Sub-systems like the ADCS are space-qualified hardware expected to exceed the on-orbit service life required by STPSat-4. We do not anticipate changes to the redundancy.

3 ASSESSMENT OF SPACECRAFT DEBRIS RELEASED ON ORBIT

Not Applicable: There is no planned release of objects or debris during STPSat-4 mission life.

3.1 Identification of Any Object (>5mm) Expected to be Released from the Spacecraft any Time after Launch (Including Dimensions, Mass and Material)

Not Applicable

3.2 Rationale/Necessity for Release of Each Object

Not Applicable

3.3 Time of Release of Each Object

Not Applicable

3.4 Release Velocity of Each Object with Respect to Spacecraft

Not Applicable

3.5 Expected Orbital Parameters (Apogee, Perigee and Inclination) of each Object after Release

Not Applicable

3.6 Calculated Orbital Lifetime of each Object, Including Time Spent in Low Earth Orbit (LEO)

Not Applicable: The calculated orbital lifetime for the entire spacecraft is less than 2 years

3.7 Compliance Assessment

DoDI 3100.12, Paragraph 6.3.1 states the following:

6.3.1: Release of debris during normal operations shall be controlled in all operational orbit regimes. Spacecraft and upper stages shall be designed to eliminate or minimize debris released during normal operations. Each instance of planned release of debris larger than five millimeters in any dimension that remains on orbit for more than 25 years shall be evaluated and justified on the basis of cost effectiveness and mission requirements.

Assessment:

Section 3. DoDI 3100.12 Compliance Assessment Table		
Para	**Compliance**	**Comments**
6.3.1.	Compliant	STPSat-4 is not planning or intending to release debris on orbit.

Justification for Non-Compliance: N/A

AFI 91-217, Section 5.4.5 states the following:

5.4.5. Assessment of Debris Released During Normal Operations. PMs shall design space systems to eliminate or minimize the creation of any operational or mission-related debris. If the release of debris is unavoidable, programs shall obtain appropriate exceptions to policy and *minimize the number, size, and orbital lifetime of any debris released. This requirement applies to all space systems in Earth orbit. Note: Operational or mission-related debris includes debris released during normal space operations (e.g., sensor covers, tie-down straps, explosive bolt fragments). It does not include slag ejected during the burning of a solid rocket motor or liquids dispersed from a spacecraft.*

5.4.5.1. Debris passing through Low-Earth Orbit (LEO). For missions leaving debris in orbits passing through LEO, released debris with diameters of 5 mm or larger shall have maximum orbital lifetimes of 25 years from date of release. The total object-time product shall not exceed 100 object-years per mission. The object-time product is the sum over all debris of the total time spent below 2000 km altitude during the orbital lifetime of each object. Reference NASA-STD-8719.14A.

5.4.5.2. Debris passing near Geosynchronous Orbit (GEO). For missions leaving debris in orbits with the potential of traversing GEO (GEO altitude +/- 200 km and +/- 15 degree latitude), released debris with diameters of 5 cm or greater shall be left in orbits which will ensure that within 25 years after release the apogees will no longer exceed GEO – 200 km. Reference NASA-STD-8719.14.

Assessment:

Section 3. AFI 91-217 Compliance Assessment Table		
Para	**Compliance**	**Comments**
5.4.5	Compliant	STPSat-4 is not planning or intending to release debris on orbit.
5.4.5.1.	Compliant	STPSat-4 is flying in LEO. STPSat-4 is not planning or intending to release debris on orbit.
5.4.5.2.	Compliant	STPSat-4 is not passing near GEO.

Justification for Non-Compliance: N/A

4 ASSESSMENT OF SPACECRAFT POTENTIAL FOR EXPLOSIONS AND INTENTIONAL BREAKUPS

4.1 Identification of all Potential Causes of Spacecraft Breakup

*Note: The spacecraft does not have a pressure system. The battery capacity will completely drain by time the spacecraft re-enters atmosphere.

There are two potential sources of spacecraft breakup: Accidental battery explosion and atmospheric re-entry. Section 4.2 covers accidental explosion. Atmospheric reentry will result in disintegration of the spacecraft. The Reentry Risk Assessment for STPSat-4, 20 September 2017 (Reference #7) identifies and describes that no STPSat-4 items are expected to survive reentry.

Summary of Failure Modes and Effects Analyses (or Equivalent Analyses) of all Credible Failure Modes That May Lead to an Accidental Explosion:

Analysis indicates that there is only one possible failure mode for accidental explosions. The Lithium ion battery array and circuit protections were designed with NASA manned spacecraft in mind. Design and testing was accomplished according to the NASA Requirements for Flight Certification and Acceptance of Commercial-off-the-Shelf (COTS) Lithium Ion (LI-ION) Batteries (JSC 66548) (Reference #3). Based on battery system design and testing, the probability of explosion is low (Reference #5)

4.2 Summary of Failure Modes and Effects Analyses (or Equivalent Analyses) of all Credible Failure Modes That May Lead to an Accidental Explosion

The Failure Modes and Effects Analyses (FMEA) of all credible failure modes that may lead to an accidental explosion was performed by MEIT (Reference #4). The sub-systems that offer the potential for an explosive release of energy are: 1) lithium ion batteries that pose the known possibility of destructive failure if not managed and conditioned properly, and 2) reaction wheel catastrophic failure. Other subsystems that offer accidental explosion potential are not incorporated into the STPSat-4 design.

4.2.1 Lithium-ion (LI-ION) Batteries

STPSat-4 will utilize one battery box, which consists of two re-chargeable Li-Ion battery packs to supply 28 VDC to satellite subsystems and experiments (***Figure 4-1***). The battery packs are charged using a commercial-off-the-shelf (COTS) Battery Charge Regulator (BCR). The BCR uses the Constant Current/Constant Voltage (CC/CV) charge control method to independently charge and monitor each battery. Each battery pack has the same cell layout of Panasonic cells (P/N: NCR 18650A). Each battery pack (Flight and EDU) consists of three cells in parallel and nine in series (3P9S) (***Figure 4-2***). The cells have a nominal voltage of 3.6 V and a current capacity of 3 Ah. Each battery pack has a nominal voltage of 32.4 VDC and a capacity of 9 Ah.

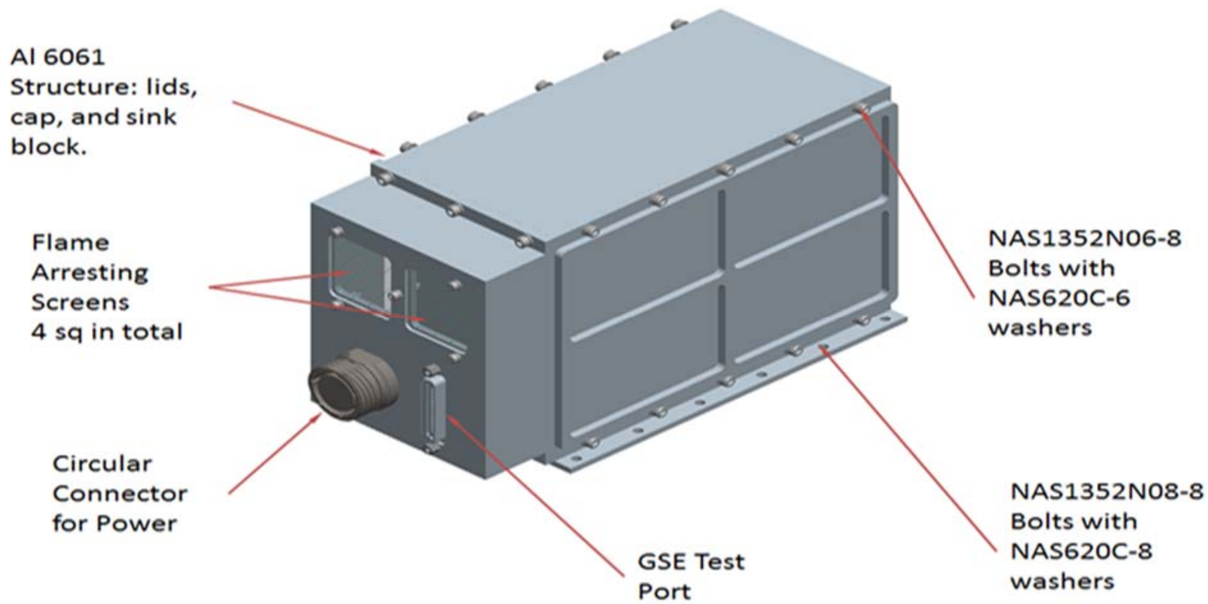


Figure 4.2-1. STPSat-4 Battery Box configuration and ports

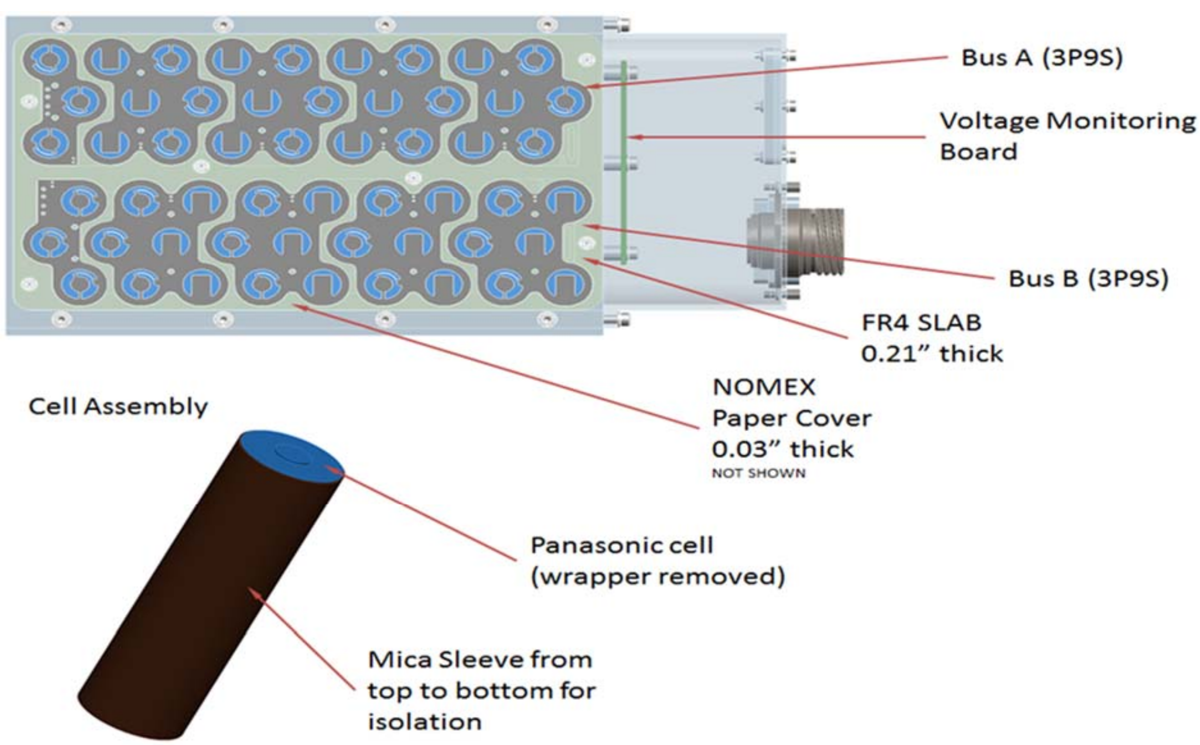


Figure 4.2-2. STPSat-4 two-bus cell array

The STPSat-4 battery employs the following safety features to prevent hazards associated with Li-Ion batteries:

- Cells are mounted on an aluminum block to dissipate and radiate heat energy, provide cell sidewall support, and provide adequate cell-to-cell separation.

- Cells are inserted in a mica sleeve facilitating visual inspection for bulges or cracks. Mica provides good thermal conduction and is an electrical insulator.
- One FR4 slab is used on the top-and-bottom of the aluminum cell block. Nomex paper on top of FR4 is used to absorb possible ejecta.
- A series of NI-201 bus plates with integral fusible links are used to connect the cells by spot welds. To prevent circulating currents within parallel cells, a seven (7) Amp fuse link connects the negative leg of each cell termination before connecting to other cells in parallel. A nine (9) Amp fusible link will protect each battery pack to the PWR + line.
- The battery box is anodized, to minimize the possibility of a short.
- Cells are oriented in alternate fashion to reduce wiring and associated resistance.
- A vent (four sq in) with a flame-arresting screen is added to eliminate sparks and fire.
- The Voltage Monitor Board monitors voltage of each virtual cell (3P) to signal the PCE of an unbalance condition. It also monitors for an overvoltage condition. Two metal-oxide-semiconductor field-effect transistors (MOSFETs) connected in series open if an overvoltage condition is detected.
- A scoop proof D38999 series 3, size 17 circular female connector for power.
- Dsub HD44 connector for ground support equipment.
- Teflon coated wire rated to 200 Deg C was selected in accordance with TA-92-03.

4.2.2 Johnson Space Center Lithium-ion (LI-ION) Batteries Flight Certification And Acceptance Standard (Reference #3)

As part of their manned space flight safety program, the NASA Johnson Space Center (JSC) defines requirements for flight certification and acceptance of COTS Li-Ion Batteries (JSC 66548) (Reference #3). This standard was produced by the JSC Engineering Directorate, Energy Systems Division.

This document provides the details of the tests required to carry out engineering evaluation of the battery and the cells contained in the battery; the qualification tests required to qualify the battery design to the flight environments and the flight acceptance testing of 100 % of the flight batteries.

As detailed in JWI 8705.3, the first step should be to carry out the engineering evaluation tests before the qualification tests are carried out to confirm that the battery design is safe for space use. The qualification test confirms that the batteries pass the environmental tests and the flight acceptance tests shall be carried out after qualification tests have been completed.

4.2.3 STPSat-4 Lithium-ion (LI-ION) Batteries Testing

The STPSat-4 project office developed a Statement of Work (SOW) describing STPSat-4 battery testing based on the JSC 66548 standard. The battery testing SOW was coordinated and approved by the JSC Energy Systems Division. In response to this SOW, the developer (MEIT) created and executed a battery Test Plan that included a battery-level test set and a cell-level test set consistent with JSC 66548. (Reference #4)

4.2.3.1 Battery Level Testing (1 battery/2 cells) (Reference #4)

Battery level testing was performed with a flight-like protective circuit board installed, including mechanical cell restraints. The flight-like test circuit board was evaluated for safety controls and trip levels measured during card electrical testing prior to battery safety test commencement.

4.2.3.2 Battery Overcharge Testing (1 battery per lot)

A fully-charged battery pack (1 battery per lot) with flight-like protective circuit board was overcharged using a 10 V limit up to a 0.3C (1 amp max) charge current. The voltage at which the overvoltage (OV) protection MOSFET switch activates was recorded. The battery was discharged using a 0.5C current to determine the voltage at which the OV MOSFET resets itself. The pack underwent one charge/discharge cycle following overcharge to determine the functional capability of the pack and its capacity. Testing demonstrated nominal behavior confirming system performance and safety.

4.2.3.3 Battery Overdischarge Testing (1 battery per lot)

The battery packs with flight-like protective circuit board were over-discharged with a 0.5C current towards 0 V. The safety under-voltage (UV) protection MOSFET switches are designed to activated at this test condition protecting the circuit. The voltage at which the safety UV MOSFET switches activates was recorded. (Note: The circuit board should prevent the battery pack from going into a reversal condition.)

The battery was charged up to 0.3C current to determine the voltage at which the UV MOSFET switches reset. The pack underwent one discharge after this to determine the functional capability of the pack and its capacity. Testing demonstrated nominal behavior confirming system performance and safety.

4.2.3.4 Battery External Short Testing (1 battery per lot)

The battery pack was externally short circuited using a 50-100 mΩ load and the short was held for three hours or until the UV MOSFET switches activated. A 1 kHz data collection rate was used for the first three seconds. The current at which the safety MOSFET activated was noted. (Note: The circuit board prevents the battery pack from experiencing the short circuit condition.)

The battery was charged using a 0.3C current to determine the voltage at which the UV MOSFET switches reset. The pack underwent one charge/discharge cycle to determine the functional capability of the pack and its capacity. Testing demonstrated nominal behavior confirming system performance and safety.

4.2.3.5 Cell Level Testing (6 cells) (Reference #4)

Cell level testing was performed on bare cells with mechanical cell restraints installed, however the protection control board was not used.

4.2.3.6 Cell Overcharge Testing (minimum 2 cells)

A minimum of two fully charged cells were overcharged independently with a C/2 current with a 10 V limit until an occurrence or for six hours. Current, voltage, and temperature were recorded. Testing demonstrated nominal behavior confirming system performance and safety.

4.2.3.7 Cell Over-Discharge Testing (minimum 2 cells)

Two fully charged cells were over-discharged with a C/2 current to 0 V then cells were reversed. An additional 150% of capacity was removed after reaching 0 V. Current, voltage, and temperature were recorded. Testing demonstrated nominal behavior confirming system performance and safety.

4.2.3.8 Cell External Short Testing (minimum 2 cells)

A minimum of two fully-charged cells were externally short circuited independently, using a 10-20 mΩ load and holding the short for two hours. A 1 kHz data collection rate was used for the first 3 seconds. Testing demonstrated nominal behavior confirming system performance and safety.

4.2.3.9 Thermal Runaway Testing

Battery level testing was performed using a flight like structure with a generic FR4 board in place of the voltage monitoring board (VMB), 57 flight like LI-ION cells, one LI-ION cell specially designed to short and create the thermal runaway condition, and all cells connected using flight like nickel bus plates with fusible links. Testing showed that thermal runaway did not propagate to adjacent cells and that the structure is effective at dissipating the additional heat.

The only event of concern was some a small gap created between the side and back plates of the box structure. This appears to have been caused by pressure build-up inside of the box. It was noted that the mesh between the VMB board and the cell banks was clogged with debris causing the pressure build-up. As a result, this mesh was removed. The mesh at the external front face of the structure was left to prevent the escape of debris.

See reference 9 for results.

4.2.4 Reaction wheel

Reaction wheels are space-qualified hardware designed and tested for on-orbit durations well in excess of STPSat-4 one-year on orbit. Reaction wheels are not a credible source for a debris-forming event.

4.3 Plan for Designed Spacecraft Breakup

Not Applicable: There is no plan for designed spacecraft breakup.

4.4 List of Components Identified for Passivation at EOL

Not applicable: There is no plan for active passivation. Passivation will be at battery failure or atmospheric re-entry. At the time of spacecraft re-entry, the battery capacity is expected to be depleted. Battery life expectancy based on planned power demand is approximately 15 months. The reaction wheels will stop working when the battery is depleted.

4.5 Rationale for all Items Identified for Passivation but Not Designed to be Passivated

Not applicable.

4.6 Compliance Assessment

DoDI 3100.12, Paragraph 6.3.2.1 states the following:

6.3.2.1. The development of the design of spacecraft or upper stages shall seek to demonstrate that there is no credible failure mode for accidental explosion. If credible failure modes exist, the probability of the occurrence of such failure modes shall be limited through design or operational procedures.

Assessment:

Section 4. DoDI 3100.12 Compliance Assessment Table		
Para	**Compliance**	**Comments**
6.3.2.1.	Compliant	- No propulsion system - Lithium Ion batteries tested to NASA standard “Certification and Acceptance of COTS Li-Ion Batteries” (JSC 66548)

		- Testing and certification to this standard meets NASA requirements for manned space flight - Reaction wheels are space-qualified hardware designed for longer on-orbit missions than the intended STPSat-4 duration

Justification for Non-Compliance: N/A

AFI 91-217, Sections 5.4.6.1 and 5.4.7 state the following:

5.4.6.1. The PM for each spacecraft or launch vehicle shall:

5.4.6.1.1. Demonstrate via failure mode and effects analyses (or equivalent) that the integrated probability of explosion for all failure modes (excluding collisions) of each separate spacecraft and launch vehicle orbital stage is less than 1 x 10^{-3} (one in one thousand). Reference NASA-STD-8719.14.

5.4.6.1.2. Ensure the design of all spacecraft and launch vehicle components include the ability to deplete onboard sources of stored energy and disconnect energy generation sources when no longer required for mission operations or post-mission disposal or control.

5.4.7. Assessment of Debris Generated by Intentional Breakups. Programs shall assess and limit the effect of intentional breakups of spacecraft and launch vehicle orbital stages on other users of space. Consistent with cost effectiveness and mission objectives, organizations conducting intentional breakups and/or collisions shall ensure that:

5.4.7.1. Planned explosions or intentional collisions shall occur at altitudes such that, for orbital debris fragments larger than 10 cm, the object-time product does not exceed 100 object-years. No debris larger than 1 mm shall remain in Earth orbit longer than one year. Reference NASA-STD-8719.14A.

5.4.7.2. Immediately before a planned explosion or intentional collision, the probability of related debris larger than 1 mm colliding with any active satellite within 24 hours of the breakup shall not exceed 1 x 10^{-6} (one in a million). Reference NASA-STD-8719.14A.

Assessment:

Section 4. AFI 91-217 Compliance Assessment Table		
Para	**Compliance**	**Comments**
5.4.6.1.1.	Compliant	- No propulsion system - FMEA examined the integrated probability of explosion for battery and reaction wheel failure modes - Lithium Ion batteries tested to NASA standard “Certification and Acceptance of COTS Li-Ion Batteries” (JSC 66548) - Testing and certification to this standard meets NASA requirements for manned space flight - Reaction wheels are space-qualified hardware designed for longer on-orbit missions than the intended STPSat-4 duration - Based on FMEA the probability of explosion $< 1\times10^{-3}$
5.4.6.1.2.	Compliant	- The plan to deplete onboard sources of stored energy include battery depletion at approximately 15 months or de-orbit. The reaction wheels will stop working when the battery is depleted or the spacecraft de-orbits. - There is no plan to disconnect energy generation sources. The batteries are expected to fail or the spacecraft will de-orbit.

5.4.7.	N/A	STPSat-4 is not planning an intentional breakup.
5.4.7.1.	N/A	STPSat-4 is not planning an intentional explosion or collision.
5.4.7.2.	N/A	STPSat-4 is not planning an intentional explosion or collision.

Justification for Non-Compliance: N/A

5 ASSESSMENT OF SPACECRAFT POTENTIAL FOR ON-ORBIT COLLISIONS

5.1 Calculation of Spacecraft Probability of Collision with Known Space Objects Larger than 10 cm in Diameter during the Orbital Lifetime of the Spacecraft

As shown in Reference #6, Aerospace performed analysis for two cases describing different spacecraft attitudes affecting the drag coefficient used in analysis:

Case 1: Attitude is fixed in the Local Vertical Local Horizon (LVLH) frame for a one-year operational life, then the spacecraft tumbles (random orientation) until re-entry

- The LVLH ballistic coefficient was used for the first year of propagation, then the tumbling ballistic coefficient was used for the remaining propagation to re-entry
- Minimum ballistic area projected into velocity direction during the first year, hence minimum drag coefficient

Case 2: Spacecraft is in a random orientation until re-entry

- Spacecraft will change between LVLH and Sun Pointing attitude several times per day during the one-year operational life, thereby causing a variety of ballistic areas to be projected into the velocity vector
- Used the tumbling ballistic area (random orientation) for the entire propagation

Case 1 represents a worst-case scenario; Case 2 is the expected flight profile.

Aerospace analysis included three predictive Marshall Space Flight Center (MSFC) solar flux profiles: 5th 50th and 95$^{th.}$ Information provided in this section is a synopsis of Aerospace analysis. For a complete description of Aerospace analysis, see Reference #6.

5.1.1 Collision with Manned Objects

AFI 91-217 paragraph 5.6.2 limits the probability of collision with manned spacecraft to not exceed 1 x 10^{-6} (one in one million). The Aerospace analysis assumed that STPSat-4 would be safely separated from the ISS and focused their manned space object collision analysis on the Tiangong-2 (TG-2) Chinese Space Station located in a 369 km × 378 km, 42.8° orbit. ***Figure 5.1-1*** shows the results of the Aerospace analysis indicating that in the worst case scenario Case 1 at the 5th and 50th percentile atmospheres slightly exceed the threshold probability of collision with manned spacecraft criterion.

Background Population	Atmospheric Percentile		
	5th	50th	95th
Manned Objects (Case 1)	1.02E-06	1.50E-06	8.32E-07
Manned Objects (Case 2)	3.84E-07	3.75E-07	3.16E-07

Figure 5.1-1 Manned Objects Collision Probability Summary

However, further analysis in the report shows that these probabilities fall below the 1 x 10^{-6} threshold if STPSat-4 maintains an LVLH attitude less than 28.8 weeks (or 55%) of the first year of operation. Nevertheless, maintaining this attitude for more than 55% of the year is an unrealistic scenario because STPSat-4 does not possess the power margins to achieve this. The satellite would deplete its batteries and enter into a tumble well before this threshold. Therefore, the analysis indicates that STPSat-4 does comply with AFI 91-217 paragraph 5.6.2. in this regard.

NASA has successfully deployed approximately 100 objects from the ISS. Most deployments are satellites, some are re-supply capsules filled with ISS waste and separated for atmospheric burn in.

NASA policies and practices govern jettison of SVs from the ISS. NASA has evaluated the initial deployment and subsequent separation from the ISS in accordance with ISS Partner Program Directive (PPD) 1011 Rev B. Both nominal and contingency situations are examined, similar to the previously identified Case 1 and Case 2 scenarios, in the analysis performed by the NASA Vehicle Integrated Performance and Environmental Resources (VIPER) office. All situations assume a worst case ballistic number (BN) for the ISS. The results for the nominal case show that under no conditions does STPSat-4 return to the vicinity of the ISS within the 30-day window defined in ISS PPD 1011 Rev B (reference #8). Within any given 30 day period the ISS will nominally perform at least one reboost maneuver meaning that under these conditions the probability of re-contact with the ISS post-deployment is zero.

Under contingency conditions STPSat-4 is assumed to be in the worst case LVLH attitude and per ISS PPD 1011 Rev B must remain outside the vicinity of the ISS for 10 days following deployment to allow for the program office to determine the appropriate avoidance strategy. With solar flux at the 95th percentile, a violation occurs as STPSat-4 would re-enter the vicinity of the ISS in 7 days. However, this is again an unrealistic scenario as the spacecraft would deplete its batteries well before 7 days if it remained in the LVLH attitude. With the batteries depleted the ADCS would cease to function and STPSat-4 would enter a tumble mode and revert to a trajectory similar to the nominal profile. Again, this makes the probability of re-contact with the ISS zero.

5.1.2 Collision with Active Satellites

As shown in Figure 5.1-2, Aerospace analysis indicates that the STPSat-4 probability of collision with active satellites will not exceed 10 x 10-6 (ten in one million) IAW AFI 91-217 5.6.3.

Background Population	Atmospheric Percentile		
	5th	50th	95th
Operational (Active) Satellites (Case 1)	3.69E-06	3.39E-06	3.56E-06
Operational (Active) Satellites (Case 2)	7.08E-06	2.82E-06	2.75E-06

Figure 5.1-2 Active Satellite Collision Probability Summary

5.1.3 Collision with Large Space Objects

As shown in Figure 5.1-3, Aerospace analysis indicates that the STPSat-4 probability of accidental collision with space objects larger than 10 cm in diameter is less than 1 x 10-3 (one in a thousand) IAW AFI 91-217 5.4.8.1. To calculate this probability, Aerospace calculated the probability of collision with large inactive objects and then calculated the total collision probability.

Background Population	Atmospheric Percentile		
	5th	50th	95th
Probability of Total Collisions (Case 1)	1.33E-05	1.47E-05	1.19E-05
Probability of Total Collisions (Case 2)	1.21E-05	6.82E-06	6.06E-06

Figure 5.1-3 Large Objects Collision Probability Summary

5.2 Identification of All Systems or Components Required to Accomplish any Post-Mission Disposal Operations, Including Passivation and Maneuvering

Not applicable. There is no planned post - mission disposal operations. Disposal will be through atmospheric re-entry.

5.3 Calculation of Spacecraft Probability of Collision with Space Objects, Including Orbital Debris and Meteoroids, of Sufficient Size to Prevent Post-Mission Disposal

The STPSat-4 disposal plan is uncontrolled de-orbit in less than 2 years, therefore no STPSat-4 system activation or operation is required for post-mission disposal and collision with space objects, including orbital debris and meteoroids, as it will have no effect on disposal.

5.4 Compliance Assessment.

DoDI 3100.12, Paragraph 6.3.3 states the following:

6.3.3. The probability of collision with known objects during launch and orbital lifetime shall be estimated and limited in the development of the design and mission profile for spacecraft or upper stages. Designs shall consider and, consistent with cost effectiveness, limit the probability that collisions with debris smaller than one centimeter in diameter will cause loss of control and prevent post-mission disposal.

Assessment:

Section 5. DoDI 3100.12 Compliance Assessment Table		
Para	**Compliance**	**Comments**
6.3.3	Compliant	- Analysis from the Aerospace Corporation and NASA VIPER office show that STPSat-4 is compliant with all collision probability requirements. (Reference #6) - Although not expected, collisions with debris will not prevent post-mission disposal (atmospheric de-orbit).

Justification for Non-Compliance: N/A

AFI 91-217, Sections 5.4.8 and 5.6 state the following:

5.4.8. Assessment of Debris Generated by On-orbit Collisions. In developing the design and mission profile of a space system, a program will estimate and limit the probability of accidental collision with trackable space objects during the system's orbital lifetime.

5.4.8.1. Collisions with Large Objects. Programs shall demonstrate that, during the orbital lifetime of each spacecraft or launch vehicle component in or passing through LEO, the probability of accidental collision with space objects larger than 10 cm in diameter is less than 1×10^{-3} (one in a thousand). Reference NASA-STD-8719.14

5.4.8.2. Collisions with Small Objects. Programs shall demonstrate that, during the mission of the space system, the probability of accidental collision with objects (including space debris and meteoroids) sufficient to prevent post-mission disposal is less than 1×10^{-2} (one in one hundred). Reference NASA-STD-8719.14

5.6. Safe Separation to Manned and Active Spacecraft.

5.6.1. The organization with Satellite Control Authority is responsible for protecting manned spacecraft and active spacecraft following separation of the last launch vehicle component through satellite decommissioning, EOL disposal, or reentry. All orbital operations shall comply with the following risk criteria unless documented waivers exist: (T-1)

5.6.2. The probability of collision with manned spacecraft shall not exceed 1×10^{-6} (one in one million) per spacecraft.

5.6.3. The probability of collision with active satellites shall not exceed 10×10^{-6} (ten in one million) per spacecraft.

Assessment:

Section 5. AFI 91-217 Compliance Assessment Table		
Para	**Compliance**	**Comments**
5.4.8.1	Compliant	Aerospace analysis (Reference #6) indicates that the STPSat-4 probability of collision with space objects larger than 10 cm in diameter is less than 1 x 10-3 (one in a thousand) – See Figure 5.1-3.
5.4.8.2	Compliant	Although not expected, collisions with debris will not prevent post-mission disposal (atmospheric de-orbit).
5.6.1.	Complaint	Analysis by the NASA VIPER office shows that STPSat-4 is compliant with applicable jettison standards; making the probability of collision with the ISS during the lifetime of STPSat-4 zero.
5.6.2.	Compliant	Based on separation from the ISS and the low orbit altitude, Aerospace performed analysis on the Tiangong-2 (TG-2) manned station. Aerospace analysis (Reference #6) indicates that the STPSat-4 probability of collision with manned spacecraft will not exceed 1 x 10-6 (one in one million) for the expected case – See Figure 5.1-1. NASA will perform additional analysis prior to separation from ISS.
5.6.3.	Compliant	Aerospace analysis (Reference #6) indicates that the STPSat-4 probability of collision with active satellites will not exceed 10 x 10-6 (ten in one million) – See Figure 5.1-2.

Justification for Non-Compliance: N/A

6 ASSESSMENT OF SPACECRAFT POST-MISSION DISPOSAL PLANS AND PROCEDURES

6.1 Demonstration of Reliability of Post-Mission Disposal Operations

Disposal will occur via uncontrolled atmospheric re-entry. No disposal operations or maneuvers are planned or required.

6.2 Description of Spacecraft Disposal Option Selected

Atmospheric re-entry within 2 years based on initial orbit altitude (ejected from ISS) and affected by phenomena such as space weather and atmospheric drag.

6.3 Plan for any Spacecraft Maneuvers Required to Accomplish Post-Mission Disposal

Not applicable: Spacecraft maneuvers not required to accomplish STPSat-4 post-mission disposal.

6.4 Calculation of Area-to-Mass Ratio after Post-Mission Disposal, if controlled reentry option not selected

Not applicable: There is no post mission disposal except through uncontrolled re-entry.

6.5 Procedure for Executing Post-Mission Disposal Plan

No procedure for executing the post-mission disposal plan is required. The post-mission disposal plan is de-orbit within two years executing an uncontrolled re-entry

6.6 Detailed Plan for Passivation of Spacecraft

The plan for STPSat-4 passivation is battery failure contemporary with spacecraft de-orbit. Battery life is designed for 15 months.

6.6.1 Depletion of residual propellants and fluids as thoroughly as possible

Not applicable: No propellants or fluids on STPSat-4

6.6.2 Disabling charging circuits

Not applicable: No charging circuits on STPSat-4

6.6.3 De-energizing of rotational energy sources

The reaction wheels will be de-energized after battery life ends (expected at 15 months)

6.7 Compliance Assessment

DoDI 3100.12, Paragraphs 6.3.2.2, 6.4.1, 6.4.2 and 6.4.3 state the following regarding requirements for disposal and passivation:

6.3.2.2. All on-board sources of stored energy of a spacecraft or upper stage shall be depleted or safed when they are no longer required for mission operations or post-mission disposal. Depletion shall occur as soon as such an operation does not pose an unacceptable risk to the payload. Propellant depletion burns and compressed gas releases shall be designed to minimize the probability of subsequent accidental collision and to minimize the impact of a subsequent accidental explosion.

6.4.1. Atmospheric reentry. Leave the structure in an orbit in which, using conservative projections for solar activity, atmospheric drag will limit the lifetime to no longer than 25 years after completion of mission.

6.4.2. Maneuvering to a Storage Orbit. A maneuver strategy shall be used that reduces the risk of leaving a structure near an operational orbit regime. The structure may be relocated to one of the following orbit regimes:

6.4.2.1. An orbit with perigee altitude above 2,000 kilometers and apogee altitude below 19,700 kilometers.

6.4.2.2. An orbit with perigee altitude above 20,700 kilometers and apogee altitude below 35,300 kilometers.

6.4.2.3. An orbit with perigee altitude above 36,100 kilometers.

6.4.2.4. Removal from Earth orbit into heliocentric orbit.

6.4.3. Direct retrieval. Retrieve the structure and remove it from orbit as soon as practical after mission completion.

Assessment:

Section 6. DoDI 3100.12 Compliance Assessment Table		
Para	**Compliance**	**Comments**
6.3.2.2.	Compliant	No propulsion system or fluids on STPSat-4. At the time of spacecraft re-entry, the battery capacity is expected to be depleted. Battery life expectancy based on planned power demand is approximately 15 months. The reaction wheels will stop working when the battery is depleted.
6.4.1	Compliant	The STPSat-4 disposal plan is atmospheric reentry. Using conservative projections for solar activity, atmospheric drag will limit the lifetime to no longer than 2 years after completion of mission. (Reference #4)
6.4.2.	N/A	Disposal orbit is not planned or intended.
6.4.2.1.	N/A	
6.4.2.2.	N/A	
6.4.2.3.	N/A	
6.4.2.4.	N/A	
6.4.3.	N/A	Direct retrieval is not planned or intended.

Justification for Non-Compliance: N/A

AFI 91-217, Sections 5.4.6.2, 5.7.2.1, 5.7.3.1.1, 5.7.3.2, 5.7.3.3 and 5.7.4 state the following:

5.4.6.2. The operating unit shall deplete and/or safe all onboard sources of stored energy of the space system (e.g., residual propellants, batteries, high-pressure vessels, self-destructive devices, flywheels, and momentum wheels) when no longer required for mission operations. Depletion shall occur as soon as this operation does not pose an unacceptable risk to the payload. (T-3)

5.7.2.1. The probability of successful compliance with Section 5.7.3. shall be no less than 0.90 at EOL. This includes any maneuvers, deployments, or other actions required to ensure compliance with 5.7.3. This calculation builds from an initial pre-launch estimate of the ability to execute disposal, and shall undergo periodic re-assessment during the orbital operations phase. Updates to EOL planning shall occur throughout orbital operations, as required. (T-2)

5.7.3.1.1. Uncontrolled Atmospheric Reentry. Leave the spacecraft or launch vehicle component in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the end of mission.

5.7.3.2. Disposal Orbits. At EOL, relocate the structure to a storage regime consistent with the ODMSP.

5.7.3.2.1. When selecting disposal orbits, operators shall account for spacecraft area/mass ratio and the effect of future orbital drift due to gravitational perturbations and other space environmental effects. Due to fuel gauging uncertainties near the end of mission, use a maneuver strategy that has the least risk of leaving the structure near an operational orbit regime.

5.7.3.3. Direct retrieval. Direct retrieval strategies shall comply with all disposal requirements in this AFI and in the ODMSP.

5.7.4. Passivation. All spacecraft and launch vehicle components, to include research and development systems, shall undergo passivation during final disposal.

5.7.4.1. During space system design and development, the PM shall identify sources or potential sources of stored energy and shall develop and implement a plan for minimizing these sources at EOL. The PM shall include a description of the passivation procedure in the SDAR and if applicable, the EOLP. This description shall not only identify the passivation actions for all sources of stored energy but also provide a notional timeline of when the actions shall take place. This plan shall identify all passivation measures, to include:

5.7.4.1.1. Burning residual propellants to depletion.

5.7.4.1.2. Venting propellant lines and tanks.

5.7.4.1.3. Venting pressurized systems.

5.7.4.1.4. Discharging batteries (or other energy storage systems) and preventing recharging.

5.7.4.1.5. Depressurizing gas and liquid filled batteries.

5.7.4.1.6. Deactivating range safety systems.

5.7.4.1.7. De-energizing control moment gyroscopes.

5.7.4.2. Residual propellants and other fluids, such as pressurant, shall undergo depletion as thoroughly as possible, by either burns or venting, to prevent accidental break-ups by over-pressurization or chemical reaction.

5.7.4.2.1. To ensure that all disposal orbit parameters are met, the final disposal operation shall account for any induced ΔV due to depletion burns/venting.

5.7.4.2.2. Sealed heat pipes and passive nutation dampers need not undergo depressurization at EOL.

5.7.4.3. Batteries shall incorporate designs, both structurally and electrically, to prevent breakups. At the end of operations, battery charging lines shall undergo de-activation.

5.7.4.3.1. The complete discharge of batteries and their subsequent disconnection from charging circuits is preferable. If this is impractical, the batteries shall be left with a permanent electrical drain to prevent recharging. If permitted by design, pressurized batteries shall undergo depressurization at EOL.

5.7.4.4. Self-destruct systems shall incorporate designs to prevent unintentional destruction due to inadvertent commands, thermal heating, and/or radio frequency interference.

Assessment:

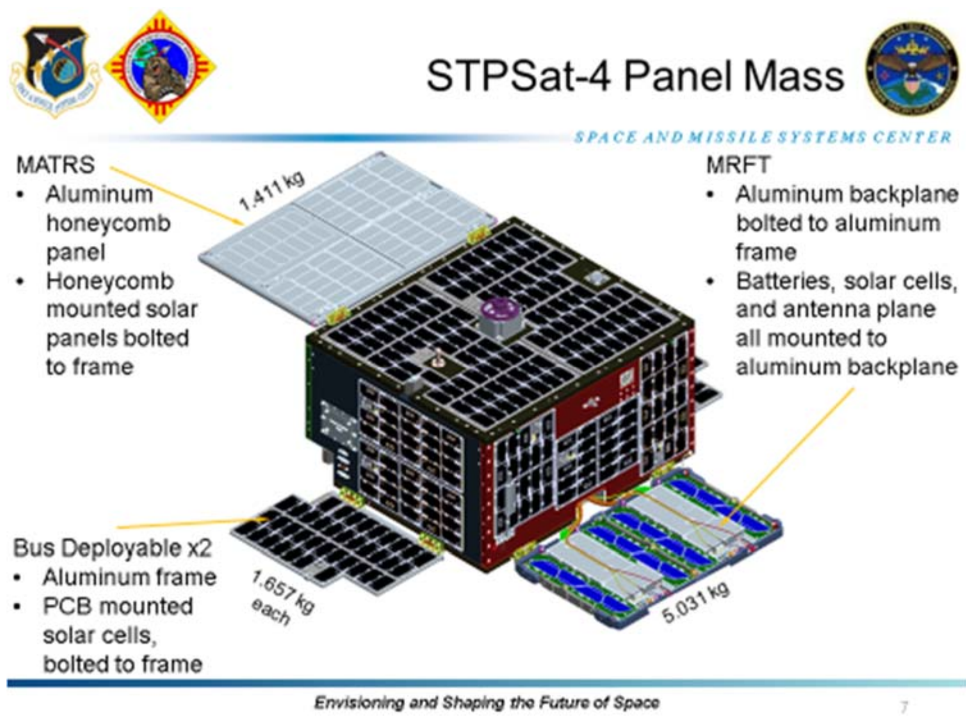
Section 6. AFI 91-217 Compliance Assessment Table		
Para	**Compliance**	**Comments**
5.4.6.2.	Compliant	No propulsion system or fluids on STPSat-4. At the time of spacecraft re-entry, the battery capacity is expected to be depleted. Battery life expectancy based on planned power demand is approximately 15 months. The reaction wheels will stop working when the battery is depleted.
5.7.2.1.	Compliant	The probability of successful disposal is 100%. The STPSat-4 initial orbit insertion altitude will result in an atmospheric re-entry in less than 2 years. (Reference #7)
5.7.3.1.1.	Compliant	The STPSat-4 disposal plan is de-orbit and atmospheric reentry. Using conservative projections for solar activity, atmospheric drag will limit the lifetime to no longer than 2 years. (Reference #7)
5.7.3.2.	N/A	Disposal orbit is not planned or intended
5.7.3.3.	N/A	Direct retrieval is not planned or intended.
5.7.4.1.1.	N/A	No propellant
5.7.4.1.2.	N/A	No propellant
5.7.4.1.3.	N/A	No propellant
5.7.4.1.4.	Compliant	Batteries will be expended by spacecraft system demand before atmospheric re-entry.
5.7.4.1.5.	Compliant	STPSat-4 lithium ion batteries are not sealed allowing venting and discharge of any gas pressure.
5.7.4.1.6.	N/A	STPSat-4 has no range safety systems.
5.7.4.1.7.	Compliant	Control moment gyroscopes (reaction wheels) will be de-energized associated with battery depletion or deorbit
5.7.4.2.	N/A	No propellant
5.7.4.2.1.	N/A	No propellant
5.7.4.2.2.	N/A	STPSat-4 has no sealed heat pipes or passive nutation dampers.
5.7.4.3.	Compliant	STPSat-4 batteries are designed, both structurally and electrically, to prevent breakups. The battery was designed IAW NASA's safety standard JSC 66548 (Reference #3) . The design has been tested and qualified. Thermal runaway was conducted and battery survived with very little damaged.
5.7.4.3.1	Compliant	Batteries will be expended by spacecraft system demand before atmospheric re-entry.
5.7.4.4.	N/A	STPSat-4 has no self-destruct systems.

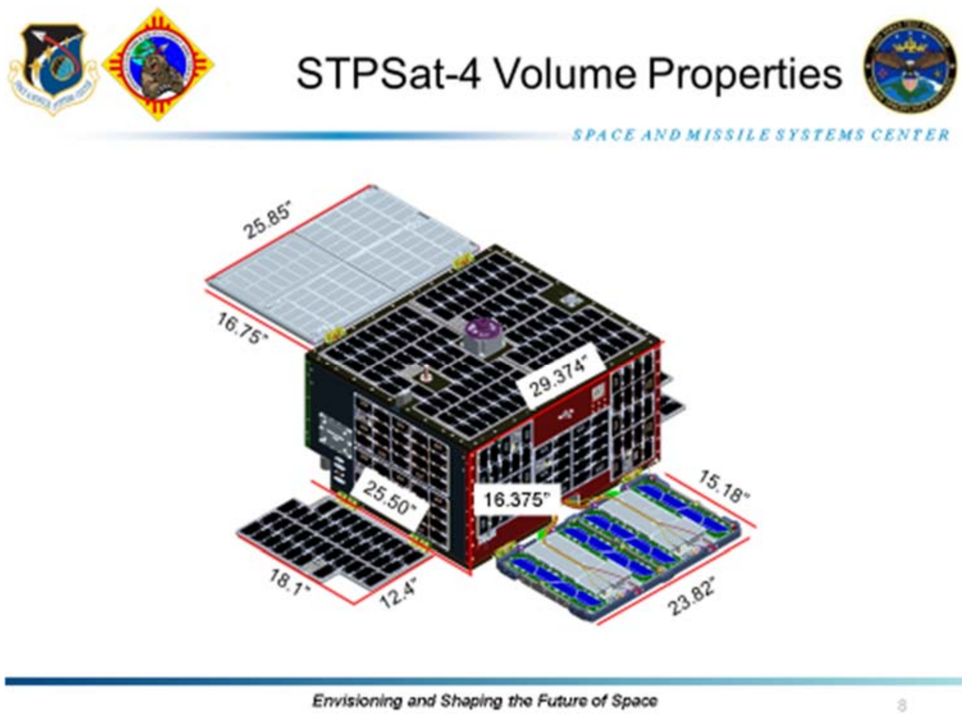
Justification for Non-Compliance: N/A

7 ASSESSMENT OF SPACECRAFT REENTRY HAZARDS

7.1 Detailed Description of Spacecraft Components by Size, Mass, Material, and Shape

Atmospheric reentry is the STPSat-4 disposal option intended and planned. ***Figure 7.1-1*** identifies the major components of STPSat-4. A Master Equipment List (MEL) that provides the requisite detail is attached (Reference #7).




STPSat-4 Volume Properties
SPACE AND MISSILE SYSTEMS CENTER
25.85"
16.75"
29.374"
25.50"
16.375"
15.18"
18.1"
12.4"
23.82"
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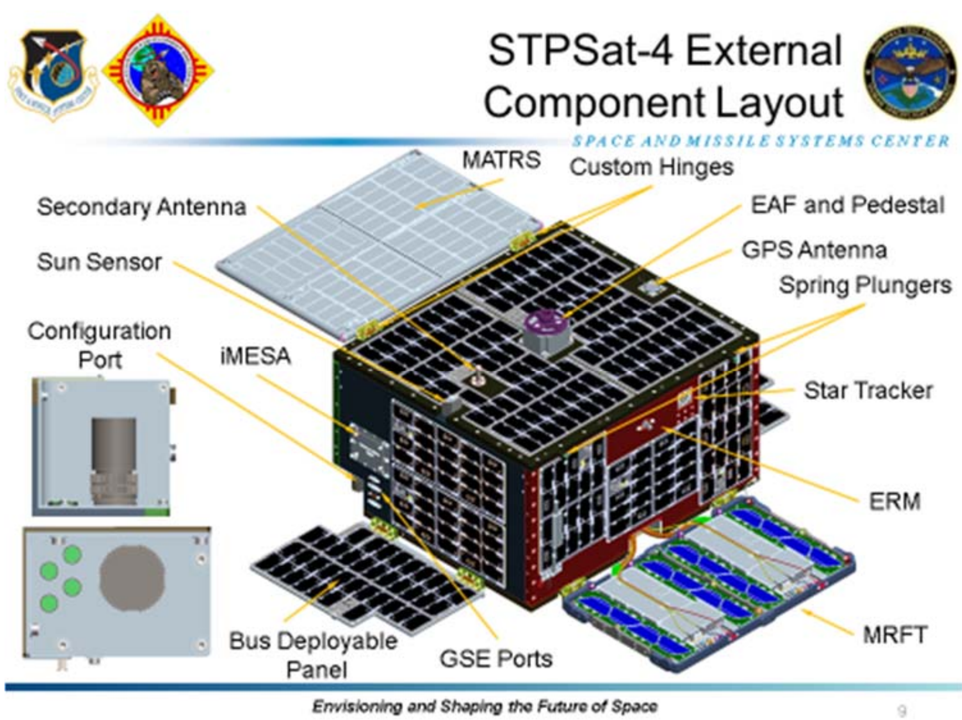
8


STPSat-4 External Component Layout
SPACE AND MISSILE SYSTEMS CENTER
MATRS
Custom Hinges
Secondary Antenna
EAF and Pedestal
GPS Antenna
Sun Sensor
Spring Plungers
Configuration Port
iMESA
Star Tracker
ERM
MRFT
Bus Deployable Panel
GSE Ports
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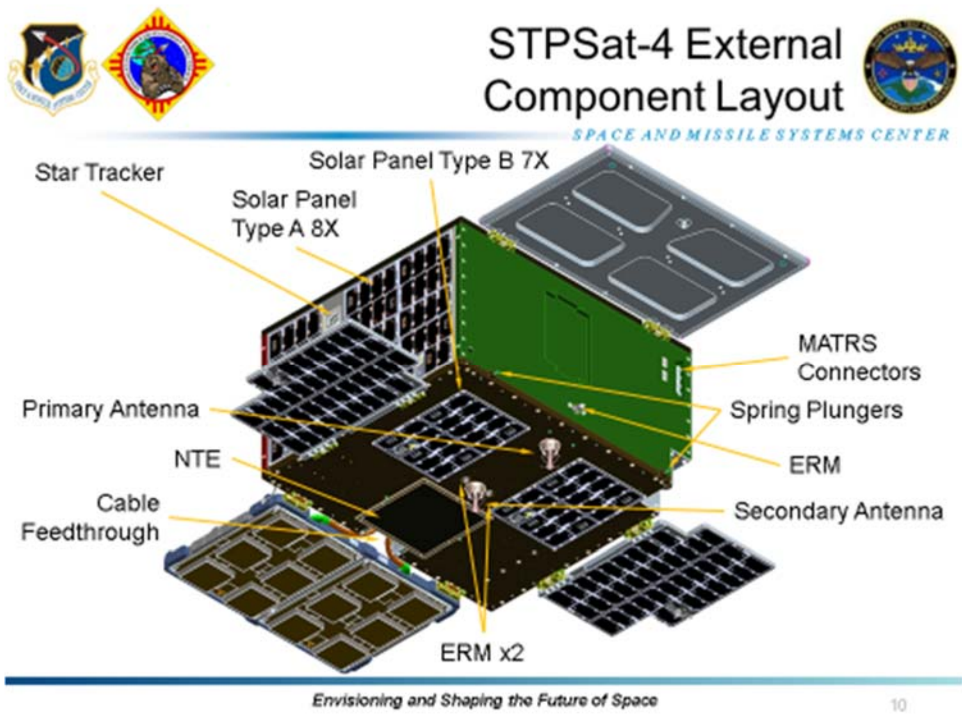
9


STPSat-4 External Component Layout
SPACE AND MISSILE SYSTEMS CENTER
Star Tracker
Solar Panel Type B 7X
Solar Panel Type A 8X
MATRS Connectors
Spring Plungers
Primary Antenna
NTE
ERM
Cable Feedthrough
Secondary Antenna
ERM x2
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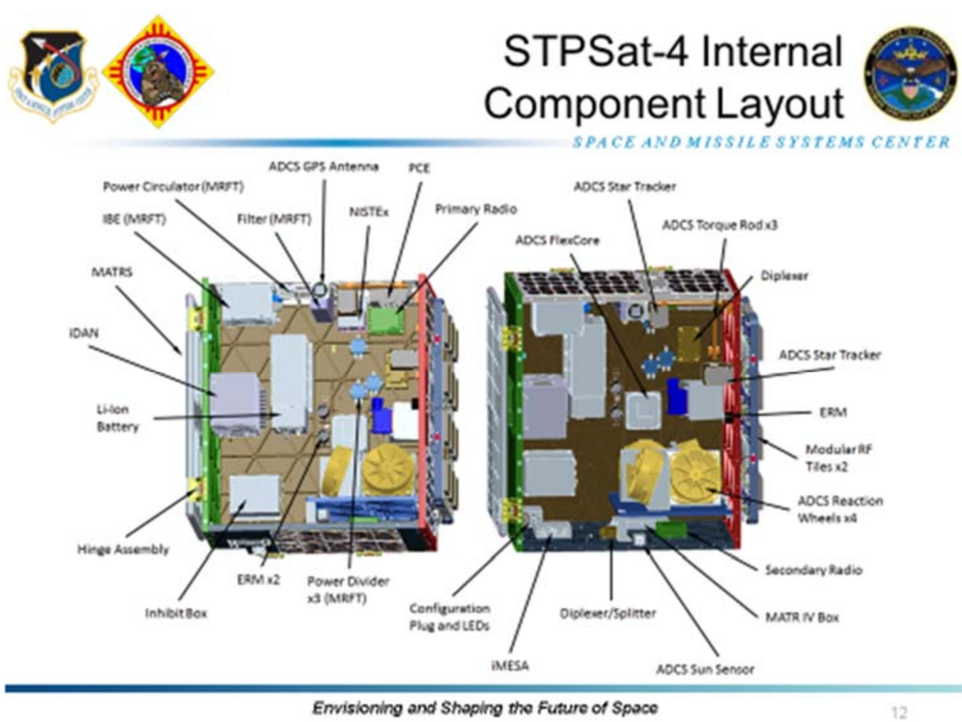
STPSat-4 Internal Component Layout
SPACE AND MISSILE SYSTEMS CENTER
ADCS GPS Antenna
PCE
Power Circulator (MRFT)
IBE (MRFT)
Filter (MRFT)
NISTEx
Primary Radio
MATRS
iDAN
Li-Ion Battery
Hinge Assembly
Inhibit Box
ERM x2
Power Divider x3 (MRFT)
ADCS Star Tracker
ADCS Torque Rod x3
ADCS FlexCore
Diplexer
ADCS Star Tracker
ERM
Modular RF Tiles x2
ADCS Reaction Wheels x4
Secondary Radio
MATR IV Box
Configuration Plug and LEDs
Diplexer/Splitter
iMESA
ADCS Sun Sensor
Envisioning and Shaping the Future of Space
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Time	Key Events	Demise	Notes	
1696 sec	77.1 km	Walls		Missing and/or estimated
1704 sec	76.0 km	RWA Brackets		Survives and poses risk
1720 sec	73.9 km	RWA Housing		Risk negligible or < 15 J KE
1754 sec	68.1 km	Battery Housing		Insufficient information to assess

Object Description	Shape	Count	Material Type	Diam/Width (m)	Length (m)	Wall/Core Thickness (m)	Face Sheet Thickness (m)	Height or Min Diam (m)	Unit Mass (kg)	Total Mass (kg)	Separation Altitude (km)	Demise Altitude (km)	Debris Area (m²)	Total Debris Area (m²)	Total Casualty Area (m²)
STRUCTURE															
Ram Wall	Plate	1	Al 7075-T7351	0.378	0.610	0.007			4.57	4.57		77.1	0.000	0.000	0.000
Starboard Wall	Plate	1	Al 7075-T7351	0.378	0.746	0.006			5.12	5.12		77.1	0.000	0.000	0.000
Wake Wall	Plate	1	Al 7075-T7351	0.378	0.610	0.008			5.00	5.00		77.1	0.000	0.000	0.000
Port Wall	Plate	1	Al 7075-T7351	0.378	0.746	0.006			4.83	4.83		77.1	0.000	0.000	0.000
Nadir Wall	Plate	1	Al 7075-T7351	0.648	0.746	0.007			9.13	9.13		77.1	0.000	0.000	0.000
Zenith Wall	Plate	1	Al 7075-T7351	0.648	0.746	0.005			7.27	7.27		77.1	0.000	0.000	0.000
Ram Rack (Holds RWA)	Plate	1	Al 7075-T7351	0.330	0.330	0.006			1.74	1.74	77.1	67.6	0.000	0.000	0.000
Solar Panel Deployable frame	Plate	2	Al 6061-T651	0.314	0.461	0.004			1.45	2.90		90.0	0.000	0.000	0.000
Feedthrough Panel	Box	1	Al 7075-T7351	0.076	0.152	0.003		0.127	0.63	0.63		88.8	0.000	0.000	0.000
EAF (Experiment Attachment Fixture)	Disk	1	CRES 15-5 PH	0.102		0.006			0.40	0.40	77.1	66.9	0.000	0.000	0.000
EXPERIMENTS															
iMESA Top Housing	Plate	1	Al 6061-T651	0.104	0.102	0.006			0.16	0.16		79.5	0.000	0.000	0.000
iMESA	Box	1	Al 6061-T651	0.104	0.102	0.007		0.045	1.01	1.01	77.1	69.1	0.000	0.000	0.000
MATRS Panel	Plate	1	Al 5052 1.6 pcf hc, M55J/CyE fs	0.404	0.635	0.002	0.0013		1.41	1.41		92.5	0.000	0.000	0.000
IV Box (MATRS)	Box	1	Al 6061-T651	0.076	0.156	0.002		0.032	1.97	1.97	77.1	75.0	0.000	0.000	0.000
MRFT Array Frame Front	Sheet	1	Al 6061-T651	0.025	0.750	0.009			0.48	0.48		82.7	0.000	0.000	0.000
MRFT Tile Support Structure	Plate	1	Al 6061-T651	0.277	0.347	0.002			0.58	0.58		90.0	0.000	0.000	0.000
MRFT Filter	Box	1	Al 6061-T6	0.049	0.238	0.010		0.076	1.50	1.50	77.1	68.3	0.000	0.000	0.000
MRFT Integrated Electronics Top Assembly	Box	1	Al 6061-T651	0.138	0.134	0.002		0.112	2.28	2.28	77.1	75.1	0.000	0.000	0.000
NISTEx	Box	1	Al 6061-T651	0.079	0.108	0.001		0.072	0.51	0.51	77.1	76.1	0.000	0.000	0.000
POWER															
Chassis, Battery	Box	1	Al 6061-T651	0.117	0.207	0.008		0.140	2.60	2.60	77.1	68.1	0.000	0.000	0.000
Connector Cap, Battery	Box	1	Al 6061-T651	0.064	0.136	0.003		0.097	0.24	0.24		68.1	0.000	0.000	0.000
Lid, Battery	Plate	2	Al 6061-T6	0.136	0.207	0.005			0.41	0.82		68.1	0.000	0.000	0.000
End Cap, Battery	Plate	2	G10 / FR4	0.120	0.204	0.006			0.10	0.20		68.1	0.000	0.000	0.000
Panasonic NCR-18650A Li-Ion Cells	Cylinder	54	SS 316	0.019	0.065	0.0008			0.05	2.57	68.1	67.3	0.000	0.000	0.000
Inhibit Box (with Lid)	Box	1	Al 6061-T651	0.075	0.168	0.002		0.149	0.79	0.79	77.1	73.7	0.000	0.000	0.000
Terminal Block	Block	1	Molded phenolic, UL 94V-1	0.017	0.170			0.006	0.05	0.05	77.1		0.000	0.000	0.000
PCE	Box	1	Al 6061-T6	0.105	0.116	0.003		0.057	0.54	0.54	77.1	72.9	0.000	0.000	0.000
ATTITUDE CONTROL															
Flexcore Housing	Box	1	Al 6061-T6	0.100	0.100	0.003		0.050	0.18	0.18	77.1	71.1	0.000	0.000	0.000
Nano Star Tracker Housing	Box	2	Al 6061-T6	0.055	0.102	0.002		0.050	0.14	0.28		90.0	0.000	0.000	0.000
Torque Rod (Blue Canyon Techologies, 13ICD0945)	Cylinder	3	Fe	0.017	0.193	0.006			0.16	0.47	77.1	66.4	0.000	0.000	0.000
Reaction Wheel Mounting Bracket (attached to RAM Rack)	Box	4	Al 6061-T6	0.064	0.152	0.001		0.150	0.42	1.67	77.1	76.0	0.000	0.000	0.000
Reaction Wheel Top Housing	Cylinder	4	Al 6061-T6	0.146	0.044	0.002			0.22	0.89	76.0	73.9	0.000	0.000	0.000
Reaction Wheel Bottom Housing	Plate	4	Al 6061-T6	0.149	0.149	0.002			0.10	0.38		73.9	0.000	0.000	0.000
Reaction Wheel Flywheel	Disk	4	416 Stainless	0.140		0.005		0.030	0.66	2.63	73.9	62.5	0.000	0.000	0.000
Reaction Wheel Magnet Carrier	Box	4	416 Stainless						0.08	0.33			0.000	0.000	0.000
Reaction Wheel Baseplate dual spiral	Box	4	Al 7075-T7531						0.23	0.93			0.000	0.000	0.000
Reaction Wheel Motor	Cylinder	4	Proprietary						0.05	0.22			0.000	0.000	0.000
TELECOMMUNICATION															
Radio Antenna	Disk	3	Al 2024	0.600		0.003			1.98	5.94		88.9	0.000	0.000	0.000
STRX-101 Radio	Box	2	Al 6061-T651	0.081	0.082	0.006		0.041	0.34	0.67	77.1	69.7	0.000	0.000	0.000
Diplexer	Box	2	Al 6061-T651	0.057	0.082	0.008		0.023	0.23	0.46	77.1	68.8	0.000	0.000	0.000
COMMAND AND DATA															
IDAN	Box	1	Al 2024	0.300	0.600	0.001		0.200	4.79	4.79	77.1	75.3	0.000	0.000	0.000
MISC															
Harnesses & Fasteners	Plate	1							10.67	10.67			0.000	0.000	0.000
Hinge Assys	Plate	1	Al 7075-T7351						0.92	0.92			0.000	0.000	0.000
Solar Panels	Plate	1							4.47	4.47			0.000	0.000	0.000
Totals		128								95.2				0.0	0.00

Figure 7.1-1 Major STPSat-4 Space Vehicle Components

7.2 Summary of Objects Expected to Survive an Uncontrolled Reentry, Specifying Software Tool(s) Used for the Analysis

STPSat-4 survivability was modeled with AHaB tool, providing:

– Sequence of events for reentry breakup

– Debris separation altitudes from parent body

– Debris demise altitudes

– Mass, debris area, and casualty area of surviving debris

Aerospace analysis indicates that: 1) No components from STPSat-4 are predicted to pose a casualty risk; and 2) Total casualty area for the STPSat-4 is 0 m2

7.3 Calculation of Expectation of Human Casualty for the Expected Year of Uncontrolled Reentry and the Spacecraft Orbital Inclination

Analysis indicates that 100% of STPSat-4 will be destroyed during an uncontrolled re-entry. Based on 51.6 orbital inclination, Aerospace (Reference #7) estimated that the expected casualty in 2020 is zero.

7.4 Preliminary Plan for Spacecraft Controlled Reentry

Not Applicable. There is no plan for controlled re-entry.

7.5 Compliance Assessment

DoDI 3100.12, Paragraph 6.4.1 states the following regarding the atmospheric disposal option:

6.4.1. Atmospheric reentry. Leave the structure in an orbit in which, using conservative projections for solar activity, atmospheric drag will limit the lifetime to no longer than 25 years after completion of mission. If this option is selected, either the risk of injury from the total debris casualty area for components and structural fragments surviving reentry shall not exceed 1 in 10,000 (based upon an evenly distributed human population density across the Earth), or it shall be confined to a broad ocean or essentially unpopulated area.

Assessment:

Section 7. DoDI 3100.12 Compliance Assessment Table		
Para	**Compliance**	**Comments**
6.4.1.	Compliant	- The STPSat-4 will be injected into an orbit from the ISS where atmospheric drag will limit the lifetime to no longer than 2 years after mission completion. - The ISS orbit is variable between 330 and 435 km - The Aerospace Corporation calculated the expected orbit lifetime for the STPSat-4 SV based on the planned orbit of 400km circular orbit at 51.6° inclination. (Reference #7)
6.4.1.	Compliant	Based on Aerospace Corporation analysis of STPSat-4 parts and ballistic coefficient the expectation of casualty for components and structural fragments surviving reentry is zero (Reference #7)

Justification for Non-Compliance: N/A

AFI 91-217, Sections 5.7.2.2 and 5.7.3.1 state the following regarding the atmospheric disposal option:

5.7.2.2. For controlled reentry, the probability of success at the time of the reentry burn shall be sufficiently high so as not to cause a violation pertaining to limiting the risk of human casualty.

5.7.3.1. Atmospheric Reentry. The preferred disposal option is atmospheric reentry when feasible.

5.7.3.1.1. Uncontrolled Atmospheric Reentry. Leave the spacecraft or launch vehicle component in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the end of mission.

5.7.3.1.1.1. The risk to the general public due to uncontrolled atmospheric reentry shall not exceed an individual probability of casualty (Pc) of 1×10^{-6} (one in one million) and the *collective risk to the general public shall not exceed a casualty expectation (Ec) of 100 x 10^{-6} (one hundred in one million).*

5.7.3.1.1.2. Any maneuvers required to place the spacecraft or launch vehicle in a compliant atmospheric reentry orbit shall comply with the requirements in Section 5.6.

5.7.3.1.2. Controlled Atmospheric Reentry. For controlled reentry of any orbiting object, the selected trajectory shall comply with the requirements in Section 4.6.

Assessment:

Section 7. AFI 91-217 Compliance Assessment Table		
Para	**Compliance**	**Comments**
5.7.2.2	N/A	STPSat-4 is not planning a controlled re-entry.
5.7.3.1	Compliant	STPSat-4 is planning an uncontrolled atmospheric reentry. (Reference #7)
5.7.3.1.1	Compliant	At end of mission, the STPSat-4 will naturally decay leading to atmospheric reentry within 2 years of deployment from the ISS. (Reference #4)
5.7.3.1.1.1	Compliant	- The STPSat-4 risk to general public due to uncontrolled atmospheric reentry is zero. - This value is less than the expectation of casualty (E_c) of 100 x 10-6 (one hundred in one million) cited in AFI 91-217. (Reference #7)
5.7.3.1.1.2	Compliant	The STPSat-4 will be deployed from the ISS into an orbit that will naturally comply with disposal requirements in Section 5.6. No maneuvers are required to achieve disposal. (Reference #4)
5.7.3.1.2	N/A	STPSat-4 is not planning or intending a controlled deorbit.

Justification for Non-Compliance: N/A

8 ASSESSMENT FOR TETHER MISSIONS

Not Applicable. There are no tethers associated with this mission.

8.1 Type of Tether

Not Applicable.

8.2 Description of Tether System

Not Applicable.

8.3 Determination of Minimum Size of Object That Will Cause Tether Severance

Not Applicable.

8.4 Tether Mission Plan, Including Duration and Post-Mission Disposal

Not Applicable.

8.5 Probability of Tether Colliding with Large Space Objects

Not Applicable.

8.6 Probability of Tether Severance During Mission or After Post-Mission Disposal

Not Applicable.

8.7 Maximum Orbital Lifetime of a Severed Tether Fragment

Not Applicable.

8.8 Compliance Assessment

DoDI 3100.12, Paragraph 6.3.3 states the following regarding tether missions:

6.3.3. The probability of collision with known objects during launch and orbital lifetime shall be estimated and limited in the development of the design and mission profile for spacecraft or upper stages. Designs shall consider and, consistent with cost effectiveness, limit the probability that collisions with debris smaller than one centimeter in diameter will cause loss of control and prevent post-mission disposal. Tether systems shall be uniquely analyzed for both intact and severed conditions.

Assessment:

Section 8. DoDI 3100.12 Compliance Assessment Table		
Para	**Compliance**	**Comments**
6.3.3	N/A	STPSat-4 does not employ a tether system to de-orbit.

Justification for Non-Compliance: N/A

9 REFERENCE LIST

1. DoDI 3100.12, Space Support, 14 September 2000
2. AFI 91-217, Space Safety and Mishap Prevention, Change 1, 25 January 2017
3. JSC 66548 - Requirements for Flight Certification and Acceptance of Commercial-off-the-Shelf (COTS) Lithium Ion (LI-ION) Batteries
4. STPSAT-4 Battery Testing Requirements Document #: DOD-STPSAT4-045
5. STPSAT-4 Battery Test Results, 25 January 2017
6. Analysis of Orbital Lifetime and Collision Probability with Large Objects for the STPSat-4 Space Vehicle, 27 October 2017
7. Reentry Risk Assessment for STPSat-4, 20 September 2017
8. STPSat-4 Re-contact Analysis
9. Battery Thermal Runaway Results

LIST OF ACRONYMS

Acronym	Meaning
AD	Advanced Systems and Development Directorate
ADCS	Attitude Determination and Control Subsystem
AFI	Air Force Instruction
AFRL	Air Force Research Lab
BCR	Battery Charge Regulator
BCT	Blue Canyon Technologies
CC/CV	Constant Current/Constant Voltage
CDR	Critical Design Review
COTS	Commercial-Off-the-Shelf
DHEP	DoD Human Exploration Payloads
DoDI	Department of Defense Instruction
DPA	destructive physical analysis
EDU	Engineering Development Unit
EELV	Evolved Expendable Launch Vehicle
EOL	End-of-Life
EOLP	End-of-Life Plan
EPS	Electrical Power Subsystem
ESPA	EELV Secondary Payload Adapter
EtP	Exception to National Space Policy
FMEA	Failure Modes and Effects Analyses
GEO	Geosynchronous Orbit
I&T	Integration and Test
ILC	Initial Launch Capability
iMESA-R	Integrated Miniaturized Electrostatic Analyzer – Reflight
ISS	International Space Station
JEM	Japanese Experiment Module
JFSCC	Joint Force Space Component Command
JSC	Johnson Space Center
LEO	Low-Earth Orbit
Li-Ion	Lithium-Ion
MATRS	Modular Solar Array
MEL	Master Equipment List
MOA	Memorandum of Agreement
MOSFET	metal-oxide-semiconductor field-effect transistor
MRFT	Modular Radio Frequency Tiles

NASA	National Aeronautics and Space Administration
NAVOBSY	Naval Observatory
NISTEx	Navy Interferometric Star Tracker Experiment
NTE	Nanosatellite Tracking Experiment
ORR	Ops Readiness Review
OV	overvoltage
PCE	Power Control Electronics
PDR	Preliminary Design Review
PIM	Payload Integration Manager
PM	Program Manager
S&T	Science and Technology
SDAR	Space Debris Assessment Report
SMC	Space and Missile Systems Center
SOW	Statement of Work
SPAWARSYSCEN	Space and Naval Warfare Systems Center
STP	Space Test Program
SV	Space Vehicle
TBD	To Be Determined
USAFA	United States Air Force Academy
USG ODMSP	U.S. Government Orbital Debris Mitigation Standard Practices
UV	under-voltage