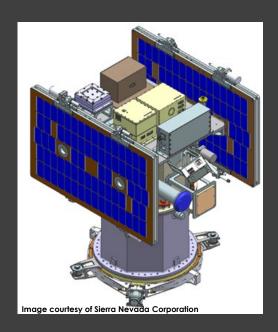


DEVELOPMENT AND OPERATION OF THE STPSAT-5 SMALL SATELLITE POWER SUBSYSTEM

Space Power Workshop – Torrance, CA April 1, 2019

- LINDA ETTLING DOD SPACE TEST PROGRAM -ALBUQUERQUE, NM
- Pat Remias, John Eterno, Clyde O'Quinn –
 Sierra Nevada Corporation Louisville, CO
- CLIFFORD GRAHAM, MARK BARRERA THE AEROSPACE CORPORATION – ALBUQUERQUE, NM AND EL SEGUNDO, CA

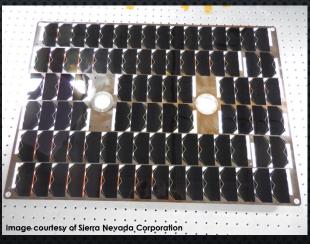




STPSAT-5 POWER SUBSYSTEM DEVELOPMENT AND OPERATION

- MISSION OVERVIEW
- DRIVING POWER REQUIREMENTS
- SPACECRAFT OVERVIEW
- POWER SUBSYSTEM OVERVIEW
- Power Subsystem Development and Analysis
- Mission status
- POWER SUBSYSTEM PERFORMANCE ON ORBIT
- LESSONS LEARNED



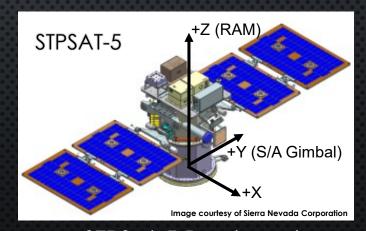


STPSAT-5 MISSION OVERVIEW

- HOSTING 5 DOD SPACE EXPERIMENTS
 - RADIATION-HARDENED ELECTRONIC MEMORY EXPERIMENT (RHEME)
 - High-bandwidth Anti-jam Laser Optical NETwork (HALO-NET) — Laser communications experiment
 - RAM ANGLE MAGNETIC FIELD SENSOR (RAMS)
 - STRONTIUM IODIDE RADIATION INSTRUMENTATION (SIRI) GAMMA RADIATION SENSOR
 - Integrated Miniaturized Electrostatic Analyzer-Reflight (IMESA-R) — Space Weather sensor
- ONE YEAR MISSION LIFE
- GOAL TO UTILIZE CUBESAT-CLASS HARDWARE WHERE
 PRACTICAL TO ADVANCE MATURITY AND REDUCE COST
- 450 km x 550 km, 97.8 deg inclined orbit, ~10:30
 AM descending node
- Launch Mass: ~ 115 kg
- LAUNCHED ON SSO-A (SMALLSAT EXPRESS) FALCON 9
 RIDESHARE: DECEMBER 3, 2018 AT 10:34 AM PST



STPSat-5 Orbit



STPSat-5 Deployed Configuration

STPSAT-5 DRIVING REQUIREMENTS FOR POWER SUBSYSTEM

- MINIMUM DESIGN LIFE: 1 YEAR
- Mission modes
 - Mode A: Spacecraft velocity oriented with sun-constrained roll
 - Mode B: HALO-Net Boresight Ground tracking Short Duration (< 10 min)
 - SAFE SUN TRACK
- PROVIDE POWER FOR PAYLOAD AND SPACECRAFT BUS
 - Payload power 30 W orbit average (Mode A & B)
 - SPACECRAFT BUS POWER 75 W ORBIT AVERAGE
- BUS VOLTAGE: 22 34 VDC
- Battery depth of discharge: < 30% (State of charge > 70%)

STPSAT-5 SPACE VEHICLE OVERVIEW



HALO-Net RS-422 UART PPS 28 VDC

RAMS

RS-422 UART PPS & Temp 8 VDC

iMESA RS-422 UART 28 VDC

RS-422 UART 28 VDC

RHEME

SIRI RS-422, Temp PPS, Analogs, Discretes, 5 VDC







Solar Array Wings (2) SNC Mechanisms

Solar Array Gimbal (2) SNC 1-axis Drives Slip-Ring Transfers

AZUR Space Cells



Mechanisms (4)

Motorized LightBand

Structures

Solar Array TiNi E500

Hold Down & Release



Primary Structure Machined Aluminum

Secondary Structure Machined Aluminum

C&DH



PIE#1 1 HALO-Net Interface

RAMS Interface

PIE #2

SIRI Interface RHEME Interface iMESA Interface



SCAB

Voltage Reduction Level Translation Battery Protection

SwRI SC-3U cPCI Avionics

Centaur SBC

Leon3FT Dual Core Processor 8 GB Science Data Storage TTC I/F w/CCSDS Formatter VC0 Functions

LVPS

Provides Low Voltage Power +12V 5V and 3.3V EMI/EMC Filtering

Stepper Motor Driver

Solar Array Gimbal Control (2) 2-Phase Stepper Motor Control

EPSC

Bus Power Control Solar Array Switching Battery Charge Control EOM Arm & Fire Switches

HPD

Heater Controllers 30 AD590/16 T/C Inputs PIE Power Outputs **HDRM Outputs**

TLVD

Thruster Drivers Latch Valve Drivers Catbed Heater Switches

GN2 Fill/Drain



BCT RWp500 Reaction Wheels

Torque Rods

(3)

(3)

Magnetometer



BCT Flexcore GNC Processor

SNC ADCS Software Functions Attitude Determination (Kalman Filter) Star Tracker Processing Star Catalog Attitude Command & Control Orbit Propagator

MEMS IRU

NovAtel GPS Receiver



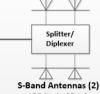
ADCS

Telecom



Innoflight SCR-101 USB Transceiver

GNOME Type 1 Encryption 2 Msps Software Defined Radio



ADC Stacked Patch 4π Coverage



Latch Valve Prop Fill/Drain Valve Filter

ECAPS 1N **Propulsion** Thrusters x4

Valve

Pressure

Transducer

Kapton Heaters 12 Heater Circuits

Temperature Sensors 30 AD 590 Circuits 10 Type-K Thermocouples



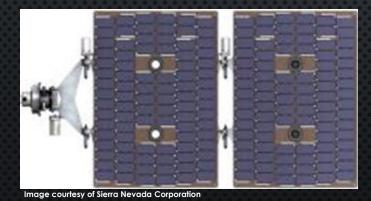
MLI Blankets Paints & Finishes

Thermal

STPSAT-5 ELECTRICAL POWER SUBSYSTEM

- SOLAR ARRAY
 - AZUR SPACE MULTI-JUNCTION SOLAR CELLS (29.3% EFFICIENCY)
 - 2 WINGS OF 2 PANELS EACH
 - 20 solar cell strings, each producing up to 0.5A
 - SINGLE-AXIS SOLAR ARRAY DRIVE
 - New solar array design developed under internal research and development at Sierra Nevada Corporation
- Power Control and Distribution
 - FLIGHT SOFTWARE CHARGE CONTROLLER CONFIGURES STRING SWITCH STATE TO GET BETWEEN 5 – 20 ACTIVE STRINGS
 - SWITCH STATE IS ADJUSTED TO MAINTAIN BATTERY CHARGE WITHIN VOLTAGE AND CURRENT LIMITS

- BATTERY
 - SAFT LITHIUM ION CELLS
 - 17.4 A-HR BATTERY CAPACITY
 - 32 V NOMINAL AT FULL CHARGE
 - HERITAGE BATTERY FROM OG-2 MISSION



Solar Array Wing



Image courtesy of Sierra Nevada Corporation

Single-Axis Gimbal



Image courtesy of Sierra Nevada Corporation

Battery

SOLAR ARRAY DEVELOPMENT

- SOLAR ARRAY PROCESS
 DEVELOPMENT INCLUDED
 TESTING OF 10x19" AND
 16x19" COUPON
 PANELS
 - LAPSS TESTING
 - THERMAL VACUUM
 - AMBIENT THERMAL CYCLING
- FLIGHT-LIKE STPSAT-5
 PANEL WAS TESTED FOR
 QUALIFICATION
 - LAPSS TESTING
 - VIBRATION
 - THERMAL VACUUM



Image courtesy of Sierra Nevada Corporation

Solar Array Coupon



Image courtesy of Sierra Nevada Corporation

Thermal Cycling

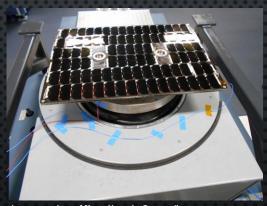


Image courtesy of Sierra Nevada Corporation

Vibration Test



Image courtesy of Sierra Nevada Corporation

Thermal Vacuum

BATTERY DEVELOPMENT

- ORIGINAL PLAN WAS TO USE A NEW DEVELOPMENT BATTERY, HOWEVER, ISSUES WERE EXPERIENCED DURING QUALIFICATION
- New plan was to use existing surplus battery from OG-2 program and repurpose for STPSat-5
 - ONE OG-2 BATTERY YIELDED 2
 BATTERIES FOR STPSAT-5 (1 FOR TEST AND 1 FOR FLIGHT)
- MINOR MECHANICAL MOUNTING MODIFICATIONS WERE REQUIRED TO PROVIDE ADEQUATE CLEARANCE BETWEEN BATTERY AND DEPLOYABLE SOLAR ARRAY



OG-2 Battery (2 modules)

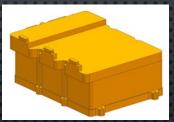


Image courtesy of Sierra Nevada Corporation

STPSat-5 Battery (1 module)

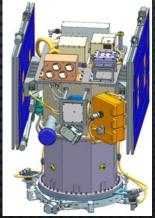


Image courtesy of Sierra Nevada Corporation

STPSat-5 Stowed Configuration (Battery in orange)

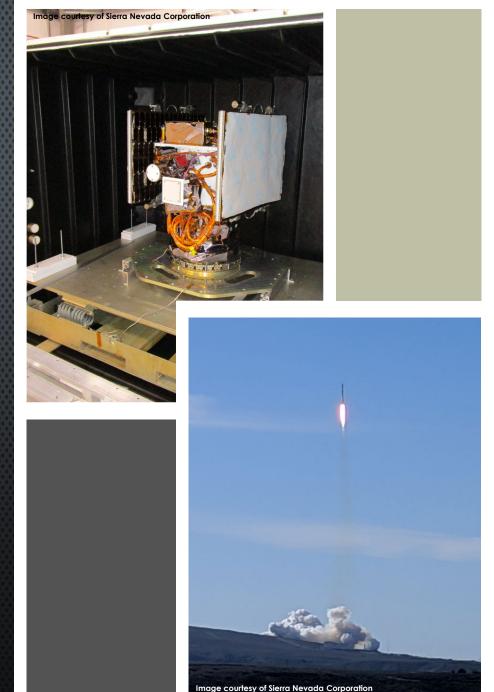
POWER ANALYSIS

Mission Mode	Payload Orbit Average Power (W)	Bus Orbit Average Power (W)	Battery SOC (%)	Satellite Pointing	Array Gimbal
Mode A	20	95	> 70%	Velocity oriented, solar constraine d	Gimballed solar arrays (single- axis)
Safe	0	100	> 70%	Sun tracking	Fixed

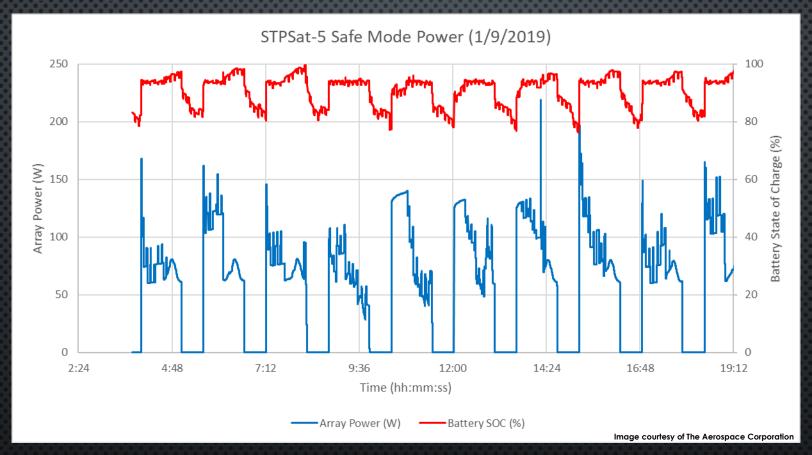
MAXIMUM SOLAR ARRAY POWER ~ 320 W

MISSION STATUS

- LAUNCH: DECEMBER 3, 2018
 FROM VANDENBERG AFB, CA
- EXPERIMENT DATA COLLECTION IN PROGRESS

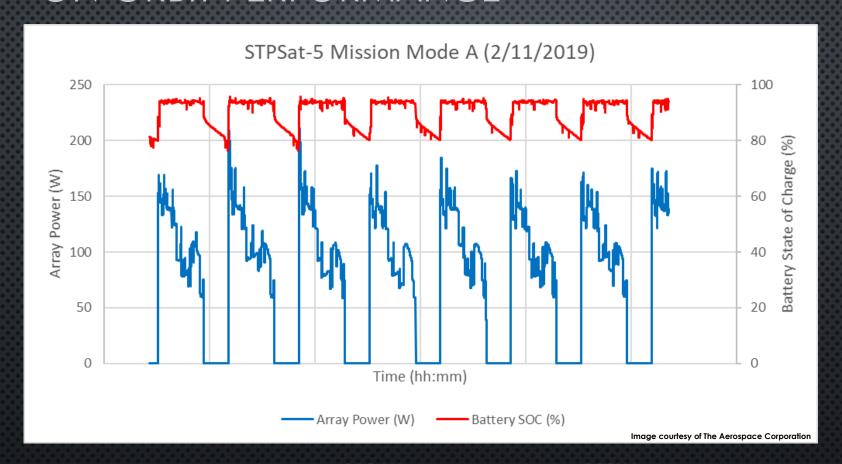


SAFE SUN-TRACK ON-ORBIT PERFORMANCE



- Array sunlit average power $\sim 75\text{-}95~\text{W}$ max capability of 320 W limited by flight software switching
- TYPICALLY < 10 OUT OF 20 CIRCUITS TOTAL NEEDED TO BE SWITCHED ON TO MAINTAIN BATTERY WITHIN LIMITS
- MINIMUM BATTERY STATE OF CHARGE > 76%

MISSION MODE A ON-ORBIT PERFORMANCE



- Array sunlit average power $\sim 110~W$ max capability of 320W limited by flight software switching
- TYPICALLY < 12 OUT OF 20 CIRCUITS TOTAL NEEDED TO BE SWITCHED ON TO MAINTAIN BATTERY WITHIN LIMITS
- MINIMUM BATTERY STATE OF CHARGE > 76%

LESSONS LEARNED

- GIMBALLED SOLAR ARRAYS ON MICROSAT-CLASS VEHICLES ARE A PRACTICAL MEANS TO ACHIEVE MORE CAPABLE SYSTEMS, HOWEVER ...
 - ALWAYS LOOK FOR LOW-COST ALTERNATIVES WHERE POSSIBLE
 - Have an "off-ramp" for New Development Items

- A ROBUST POWER SUBSYSTEM PROVIDES CRITICAL RESOURCES TO ...
 - ADDRESS ON-ORBIT ISSUES/ANOMALIES
 - Exceed mission expectations