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JPSS-1: BUILDING THE NATION'S NEXT GENERATION OPERATIONAL POLAR-ORBITING WEATHER SATELLITE

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ABSTRACT

The Joint Polar Satellite System – 1 (JPSS-1) is the Unites States' next-generation, operational, polar-orbiting weather satellite that was launched on November 18, 2017 and subsequently renamed NOAA-20. The JPSS-1 satellite is comprised of the spacecraft bus and its five instrument payloads. Ball Aerospace built the JPSS-1 spacecraft bus, the Ozone Mapping and Profiler Suite (OMPS) instrument, and was the satellite integrator. This paper provides an overview of the JPSS program, the design and construction of the satellite bus, integration of the instruments, satellite-level test program, and the launch campaign.

INTRODUCTION

A new generation of Earth-observing satellites are enabling both meteorologists to improve their forecasts and scientists to better understand long-term climate change. The Joint Polar Satellite System (JPSS) is the next generation, operational, polar-orbiting, environmental satellite system for the United States. JPSS is a collaborative program between the National Oceanic and Atmospheric Administration (NOAA) and its acquisition agent, the National Aeronautics and Space Administration (NASA).

Satellites in the JPSS constellation circle the Earth 14-times per day, traveling from pole-to-pole in a sun-synchronous orbit at an altitude of 824 km and orbital speed of 7.4 km/sec. Covering the entire globe twice per day, JPSS satellites gather global measurements of atmospheric, terrestrial and oceanic conditions, including sea surface and land surface temperatures, vegetation, clouds, rainfall, snow and ice cover, fire locations and smoke plumes, atmospheric temperature, water vapor, and ozone.[1] These satellite observations are the primary source of data used by the National Weather Service in weather forecast models. By utilizing the newly developed JPSS Common Ground System (CGS) and state-of-the-art instruments, JPSS satellites provide higher resolution data with less latency, providing more accurate and timely data for weather forecasting.

JPSS satellites also provide continuity of environmental data records from NOAA's Polar Operational Environmental Satellite (POES) spacecraft – the precursor to JPSS – and from NASA's aging Earth Observing System (EOS), a group of satellites that provide critical insights into how Earth's systems interact, including clouds, oceans, vegetation, ice, and the atmosphere. Continuing uninterrupted the long-term environmental data records gathered by these satellites is critical to understanding fluctuations in Earth's climate.

JPSS SATELLITE CONSTELLATION

Satellite	Launch / Planned Launch
Suomi National Polar-orbiting Partnership (S-NPP)	October 28, 2011
Joint Polar Satellite System – 1 (JPSS-1/NOAA-20)	November 18, 2017
Joint Polar Satellite System – 2 (JPSS-2)	2021
Joint Polar Satellite System – 3 (JPSS-3)	2026
Joint Polar Satellite System – 4 (JPSS-4)	2031

Exhibit 1. Current and Planned JPSS Satellite Constellation.

The JPSS satellite constellation is comprised of five satellites with launches spanning a period of twenty years, as shown in Exhibit 1.[2] The first satellite in the JPSS constellation, the Suomi National Polar-orbiting Partnership (S-NPP), is the bridge between NOAA's legacy POES satellites, the EOS satellites, and the JPSS constellation. Launched on October 28, 2011 with a 5-year design lifetime, S-NPP has performed well with ~99.8% mission availability since commissioning.

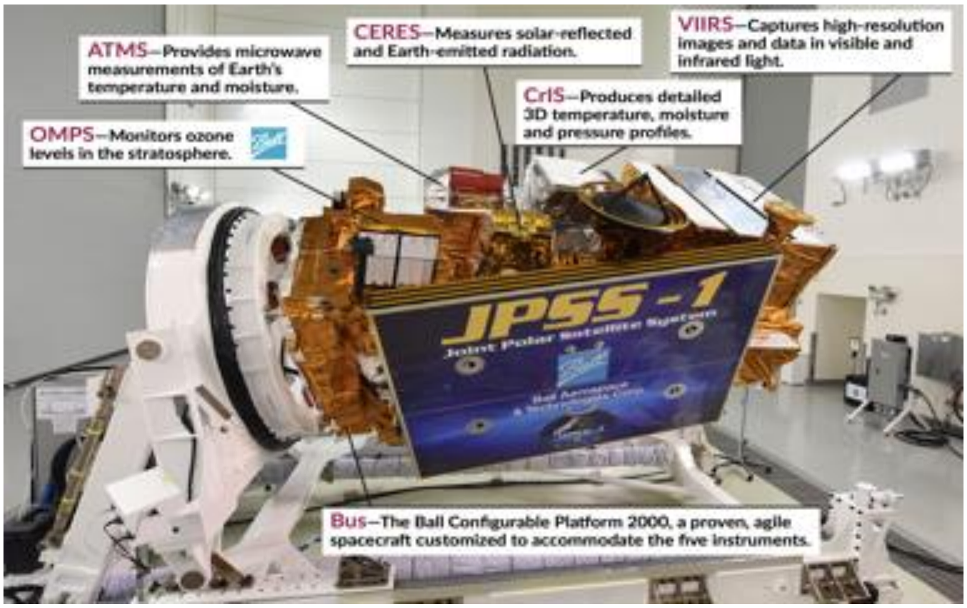


Exhibit 2. JPSS-1 Satellite.

The second satellite in the JPSS constellation, JPSS-1, began its construction in October 2010 and was launched on November 18, 2017. Shown in Exhibit 2, the JPSS-1 satellite consists of the spacecraft bus and five instrument payloads. Having each flown on S-NPP, these instruments trace their heritage to those on NASA's EOS missions, NOAA's POES satellites, and the Department of Defense's Defense Meteorological Satellite Program (DMSP). Considered the first in the operational series of JPSS satellites with a 7-year design lifetime, the JPSS-1 spacecraft bus and instruments includes upgrades in design, construction, and test commensurate with an operational program.

For both S-NPP and JPSS-1, Ball Aerospace designed and built the spacecraft bus and the OMPS instrument, integrated all five instruments, performed satellite-level testing, and provided launch and on-orbit satellite commissioning support.

JPSS-1 SPACECRAFT BUS DESCRIPTION

The JPSS-1 spacecraft "bus", based upon the proven Ball Configurable Platform (BCP) 2000 heritage architecture and S-NPP design, incorporates evolutionary design improvements and enhancements to meet JPSS operational mission requirements. The combined BCP series of spacecraft have flown more than 85 years, consistently exceeding each spacecraft's design lifetime. The BCP 2000 is a fully redundant design that provides a highly reliable platform to protect missions from spacecraft failure. It has excellent pointing, agility, and data throughput capabilities to satisfy demanding instrument needs and mission requirements.

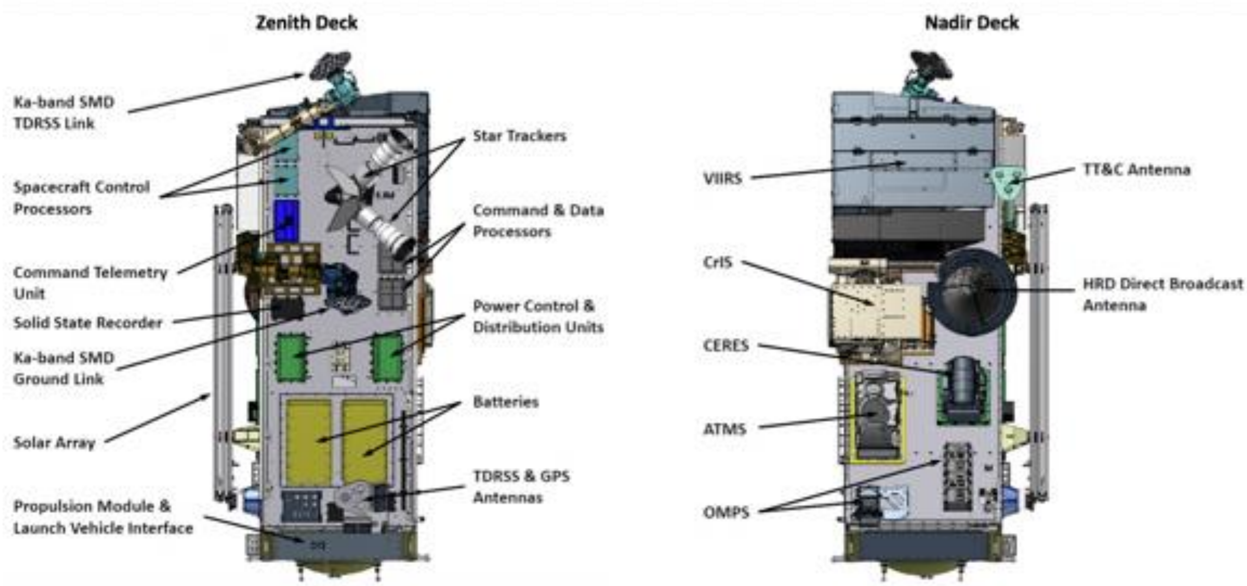


Exhibit 3. JPSS-1 Satellite General Arrangement.

The general arrangement of the JPSS-1 satellite Zenith (away from Earth) and Nadir (Earth facing) decks is shown in Exhibit 3. Excluding the deployable booms and solar array, the bus measures 1.9 x 2.6 x 4.4 meters and weighs 1,639 kg fully fueled. With the addition of 590 kg in instrument payloads, the JPSS-1 satellite has a launch mass of 2,229 kg. After on-orbit deployments of the booms and solar array are complete, the JPSS-1 satellite measures 3.2 x 3.4 x 10.4 meters. The basic layout of the spacecraft bus is the same for JPSS-1 as S-NPP. The Nadir deck provides the mounting locations for the five instruments and is designed to meet their respective interface requirements. Spacecraft bus components are mounted on the Zenith deck, side decks, and internally to the structure. The bus consists of eight subsystems as described in the following subsec- tions. Key enhancements from S-NPP are noted in each subsystem description, as applicable.

Command and Data Handling (C&DH)

The C&DH subsystem provides the capability to collect telemetry from all spacecraft systems, properly format data, and ship it to the ground for processing. The C&DH subsystem also provides an uplink path for commands sent to the spacecraft where they are received, processed, routed to the various subsystems, and executed. These functions are performed by a block redundant Spacecraft Control Processor (SCP), a block redundant Command & Data Processor (CDP), redundant Precision External Clock (PEC), internally redundant Command Telemetry Unit (CTU), and Solid State Recorder (SSR) components. The C&DH subsystem provides the capability to upload new flight software from the ground to the SCP on-orbit. The CDP provides both 1553 and SpaceWire bus controllers for spacecraft component and instrument communications. The C&DH subsystem features evolved BCP 2000 architecture and includes an enhancement from the obsolete IEEE 1394 (Firewire) bus controller on S-NPP to the SpaceWire bus controller on JPSS-1.

Telecommunications

The telecommunications subsystem provides the interface between the satellite and the JPSS CGS and field terminal users. It provides downlink of Stored Mission Data (SMD), downlink of telemetry and uplink of ground commands via Low Rate Data (LRD) links, and direct broadcast to field terminals via High Rate Data (HRD) links.

The primary SMD link is via a gimbaled Ka-band antenna providing a 300 Mbit/s downlink to the CGS receiving stations in Norway, Antarctica, Alaska, and New Mexico. A back-up SMD link is via a gimbaled Ka-band antenna providing a 300 Mbit/s downlink relayed through the NASA Tracking and Data Relay Satellite System (TDRSS). Each gimbaled antenna is mounted on a boom that deploys away from the spacecraft after launch to provide the required field of view coverage to the ground stations for gimbal range of motion. The dual Ka-band SMD capability is an enhancement from the single X-band SMD capability on S-NPP. This JPSS-1 capability will deliver data more quickly, with no more than 80 minutes from observation to end user. The TDRSS antenna also provides the ability to further reduce data latency should mission needs demand more rapid data delivery.

The LRD link receives command uplink transmissions from the CGS and forward commands from TDRSS through Nadir and Zenith S-band patch antennas coupled to redundant command receivers. The command uplink supports both 2 kbit/s and 128 kbit/s rates from the CGS and 1 kbit/s and 125 kbit/s rates from TDRSS S-band Single Access Service. This system can receive uplinked real-time and stored commands as well as software table loads from ground stations. The LRD system also provides telemetry downlink via redundant S-band telemetry transmitters at varying rates.

The HRD link broadcasts a real-time Consultative Committee for Space Data Systems (CCSDS) formatted mission data stream from a Nadir-deck mounted X-band antenna to a worldwide network of HRD users equipped with field terminals utilizing relatively small 3-meter ground station antennas. The HRD system operates at a constant 15 Mbit/s data rate. The HRD direct broadcast service has proven invaluable due to its low data latency and easier data access in remote areas.

Attitude Determination and Control

The attitude determination and control subsystem (ADCS) provides attitude knowledge of the spacecraft orientation by use of sensors. The ADCS also has a series of actuators that are used in repositioning the spacecraft into a commanded orientation using flight proven algorithms. The ADCS employs a three-axis stabilized system using reaction wheels as the primary control actuators and star trackers, a fiber-optic gyroscope, and Global Positioning System (GPS) as primary sensors. This provides 3-axis stabilized 50 arcsec control, 21 arcsec knowledge, and 75 m position accuracy. The system also employs Sun sensors and magnetometers to complement the primary systems and provide data in safe-hold modes, magnetic torque rods for backup control authority and momentum management, and propulsive thrusters for orbit attainment, maintenance, and orbital debris avoidance. The ADCS features evolved BCP 2000 architecture from that of S-NPP.

Electrical Power and Distribution

The electrical power and distribution subsystem (EPDS) provides the power generation, energy storage, power control and distribution to the instrument payloads and spacecraft components with 1650 Watts orbit-average power available at the end of life. The EPDS employs a switch regulated direct energy transfer system which transfers power generated from the sun's energy directly to the spacecraft loads at a regulated bus voltage of 28 ± 6 Vdc. The EPDS provides fault protection as well as load shedding in emergency situations to ensure mission safety. The EPDS includes a single, three-segment, ~11 m2 active area, articulated solar array, dual Li-Ion batteries to store power for use during eclipse or periods of peak demand, and two Power Control & Distribution Units (PCDU). The ADCS features evolved BCP 2000 architecture from that of S-NPP.

Thermal Control

The thermal control subsystem (TCS) maintains satellite temperature and gradient limits using passive and active heater control methods for all instruments and spacecraft components. This optimizes instrument performance and maximizes on-orbit lifetime of electronic components. Passive design techniques include multi-layer insulation (MLI), heat pipes, standard thermal control surfaces, and thermal isolation. Instruments are thermally isolated from the spacecraft with isolating mounts and MLI and employ their own radiating surfaces and/or panels. As an enhancement from S-NPP, Kevlar reinforced blankets are incorporated over critical systems for Micrometeoroids and Orbital Debris (MMOD) protection.

Flight Software (FSW)

The FSW executes the on-board ADCS, EPDS, and TCS control algorithms, provides command sequence storage and execution, and implements the fault detection and responses to ensure mission success. FSW has extensive on-orbit heritage, including high reuse from S-NPP, and runs on two 133-MHz BAE Rad750 PowerPC single-board computers with 128 MB of RAM and 12 MB of EEPROM. FSW modifications from S-NPP were driven by the evolutionary updates to the BCP 2000 architecture and enhancements on JPSS-1.

Propulsion

The propulsion subsystem provides the on-board orbit adjust capability needed to attain the mission orbit after launch vehicle separation, orbit maintenance to maintain the mission orbit repeat and local time nodal crossing accuracy, and controlled reentry of the satellite at the end of the mission. The propulsion subsystem uses a mono-propellant hydrazine system in a segregated module. The design consists of a single positive expulsion hydrazine diaphragm tank, propellant distribution feed system, eight 22 N thrusters (2 sets of 4), valves, filters, sensors, plumbing, and thermal control hardware. The propulsion subsystem is mounted on a dedicated structure and is an all-welded, modular construction that operates as a blowdown system. The thrusters are canted to provide attitude control torques in all three axes. As an enhancement from S-NPP, the propulsion system is protected from MMOD by a spun aluminum cover over the exposed end of the tank and Kevlar-reinforced blankets.

Spacecraft Structure and Mechanisms

The bus structure provides a rigid platform for mounting all instruments and spacecraft components and modules; gives clear fields-of-views (FOV) for sensors and antennas, and meets all struc- tural load requirements for launch and on-orbit environments. The bus structure is nearly identical to the S-NPP design. It incorporates a wedge shape to accommodate the large payloads within the Delta II launch vehicle fairing envelope. The mechanisms provide solar array release, deployment, and articulation as well as gimbaled antenna release, deployment, and pointing. The gimbaled an- tenna system is an enhancement resulting from the switch from X-band SMD downlink on S-NPP to Ka-band SMD downlink on JPSS-1.

JPSS-1 INSTRUMENTS

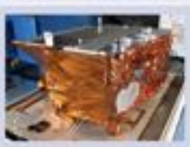
JPSS-1 Instruments		Key Specifications	Contractor
	ATMS – Advanced Technology Microwave Sounder	Coverage: 22 bands from 23 GHz to 183 GHz Nadir Resolution: 15.8 - 74.8 km Average Data Rate: 32,000 bps Average Power: 130 Watts Mass: 85 kgs	Northrop Grumman Electronic Systems
	CrIS – Cross-track Infrared Sounder	Coverage: 1305 spectral channels from 3.92 µm to 15.38 µm Nadir Resolution: FOV 14 km diameter 1 km vertical layer Average Data Rate: 1,900,000 bps Average Power: 245 Watts Mass: 175 kgs	Harris
	VIIRS – Visible Infrared Imaging Radiometer Suite	Coverage: 22 spectral bands from 412 nm to 12 µm Nadir Resolution: 400m Average Data Rate: 7,674,000 bps Average Power: 319 Watts Mass: 280 kgs	Raytheon
	OMPS-N – Ozone Mapping and Profiler Suite, Nadir	Coverage: Mapper: 0.3-0.38 µm, Profiler: 0.25-0.31 µm Nadir Resolution: Mapper: 50 km, Profiler: 250km Average Data Rate: 409,600 bps Average Power: 120 Watts Mass: 56 kgs	Ball Aerospace
	CERES – Clouds and the Earth's Radiant Energy System	Coverage: 3 Channels – 0.3 to 5 µm, 8 to 12 µm, 0.3 to > 50 µm Nadir Resolution: 20 km Average Data Rate: 10,520 bps Average Power: 55 Watts Mass: 54 kgs	Northrop Grumman Aerospace Systems

Exhibit 4. JPSS-1 Spacecraft Instruments.[1]

JPSS-1's five instruments are the Advanced Technology Microwave Sounder (ATMS), the Cross-track Infrared Sounder (CrIS), the Ozone Mapping and Profiler Suite (OMPS), the Visible Infrared Imaging Radiometer Suite (VIIRS), and Clouds and the Earth's Radiant Energy System (CERES). These instruments offer higher spatial and spectral resolution than their predecessors, which translates to greater detail on spectra and atmospheric parameters. When this higher level of detail is fed into a numerical weather prediction model, the resulting forecast has a high degree of accuracy. Photographs and key specifications for each instrument is shown in Exhibit 4. An overview of each instrument and its purpose is detailed below.

Cross-track Infrared Sounder (CrIS) / Advanced Technology Microwave Sounder (ATMS)

CrIS and ATMS work together to measure global high-resolution profiles of temperature and moisture. These two sensors provide the majority of data used as input to Numerical Weather Pre diction (NWP) models. Higher spatial, temporal, and spectral resolution and more accurate sounding data from CrIS and ATMS support continuing advances in NWP models and data assimilation systems to improve short- to medium-range weather forecasts.

CrIS is a spectrometer with 1,305 spectral channels providing the ability to measure 3-dimensional, high resolution temperature profiles with greater accuracy than previous instruments. CrIS also provides data that helps scientists understand phenomena like El Nino and La Nina, which impact global weather patterns.

ATMS operates in both clear and cloudy conditions, providing high spatial resolution microwave measurements of temperature and moisture. ATMS, a 22-channel passive microwave radiometer, has improved sampling and two more channels than previous instruments. When ATMS takes measurements inside the eye of a hurricane, it helps to provide a clearer picture of the hurricane's warm core and the intensity of its rainfall.

Visible Infrared Imaging Radiometer Suite (VIIRS)

VIIRS' 22 channels contribute to improved weather forecasting by measuring clouds and the nature of cloud content, which helps better predict rainfall. Along with its abilities to track long-term data on land vegetation and ocean surface features like sea surface temperature and sea ice concentration, VIIRS tracks fires, flooding, and drought as they happen. When combined with ATMS, and CrIS data, VIIRS data improves hurricane track and intensity forecasts.

For long-term climate monitoring, VIIRS continues critical data records of vegetation, clouds, aerosols, sea and land surface temperatures, the health of the biosphere, and changes in land cover. VIIRS extends the data records of NASA's Moderate Resolution Imaging Spectroradiometer (MODIS), which was launched aboard NASA's Terra and Aqua spacecraft in 1999 and 2002.

VIIRS day/night band also allows it to detect low levels of visible/near infrared light at night to detect and discriminate between low clouds, fog, snow, ice, and blowing dust/sand lit by moonlight and lightning. This represents a significant advance over previous instruments because it provides calibrated visible observations of clouds and other phenomena at night, which were previously not seen.

Clouds and the Earth's Radiant Energy System (CERES)

The three-channel radiometer CERES measures the balance of sunlight and the heat in the Earth's system and how it changes over time, continuing the Earth radiation budget data record of other CERES instruments on Terra, Aqua, and other satellites. CERES data can be used for evaluating the effects and climatic impact of natural disasters, such as volcanic eruptions and major floods and droughts.

Ozone Mapping and Profiler Suite – Nadir (OMPS-Nadir)

OMPS takes accurate long-term measurements of the Earth's ozone layer and builds on decades of ozone observations made by predecessor instruments on NOAA's series of Polar-Orbiting Operational Environmental Satellite (POES) spacecraft. When combined with cloud predictions, OMPS data helps create the Ultraviolet Index, a guide to safe levels of sunlight exposure.

INTEGRATION AND TEST OF THE JPSS-1 SATELLITE

Spacecraft Bus Assembly

The JPSS-1 spacecraft bus is comprised of approximately 250 major components. These components are produced by Ball Aerospace and nearly 40 major subcontractors. The time from placement of order an order to receipt or "lead time" for these components ranges from a few months to several years. Rigorous parts screening, parts qualification testing, component level qualification, proto-qualification, and/or acceptance testing all extend component lead time. Such rigorous screening and testing is required to ensure mission success for the operational JPSS-1 satellite.

Exhibit 5. Zenith Deck View of Completed JPSS-1 Spacecraft Bus.

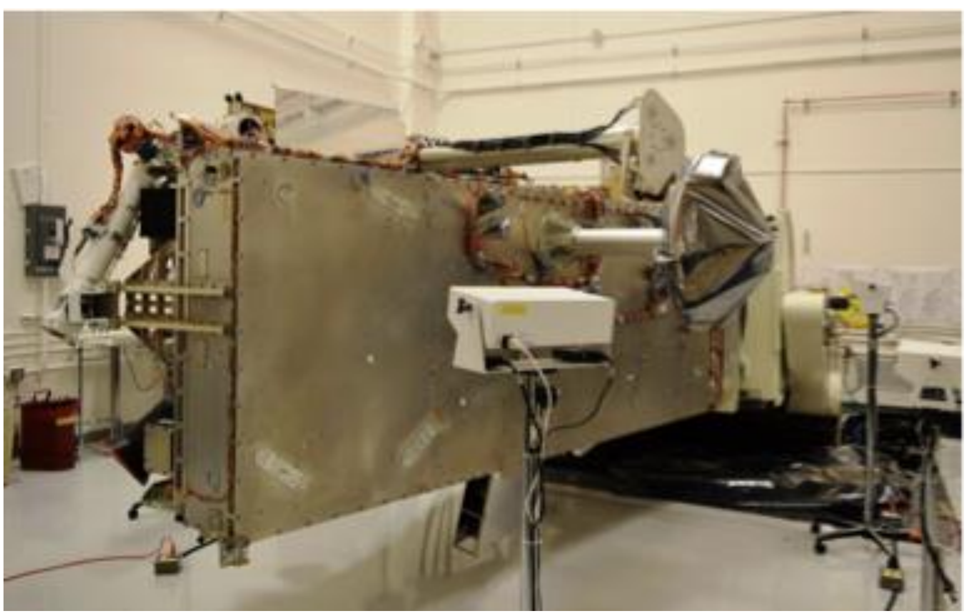


Exhibit 6. Nadir Deck View of Completed JPSS-1 Spacecraft Bus.

JPSS-1 bus procurements and fabrication efforts began in September 2011. Bus assembly, integration, and test (AI&T) began in January 2014. Bus AI&T proceeded as a series of mechanical and electrical integration activities that extended throughout calendar year 2014 as additional components were delivered. Bus AI&T was concluded on schedule in December 2014 following functional performance baseline testing, a 10-day cleanliness bake-out, and an early compatibility test with the JPSS CGS. Views of the completed spacecraft bus are shown in Exhibit 5 and Exhibit 6.

Instrument Integration

JPSS-1 satellite AI&T began with integration of the CERES instrument in December 2014, the OMPS instrument in January 2015, the VIIRS instrument in February 2015, and the CrIS instrument in March 2015. Due to setbacks in completion of the ATMS instrument, an ATMS Engineering Development Unit (EDU) was temporarily installed on the satellite in April 2015 to allow satellite-level testing to proceed. An EDU is a form, fit, and functionally equivalent instrument built without flight rigor. This EDU was ultimately replaced with the flight qualified ATMS unit in August 2017. A photograph of the fully integrated JPSS-1 satellite is shown in Exhibit 2.

Satellite-Level Testing

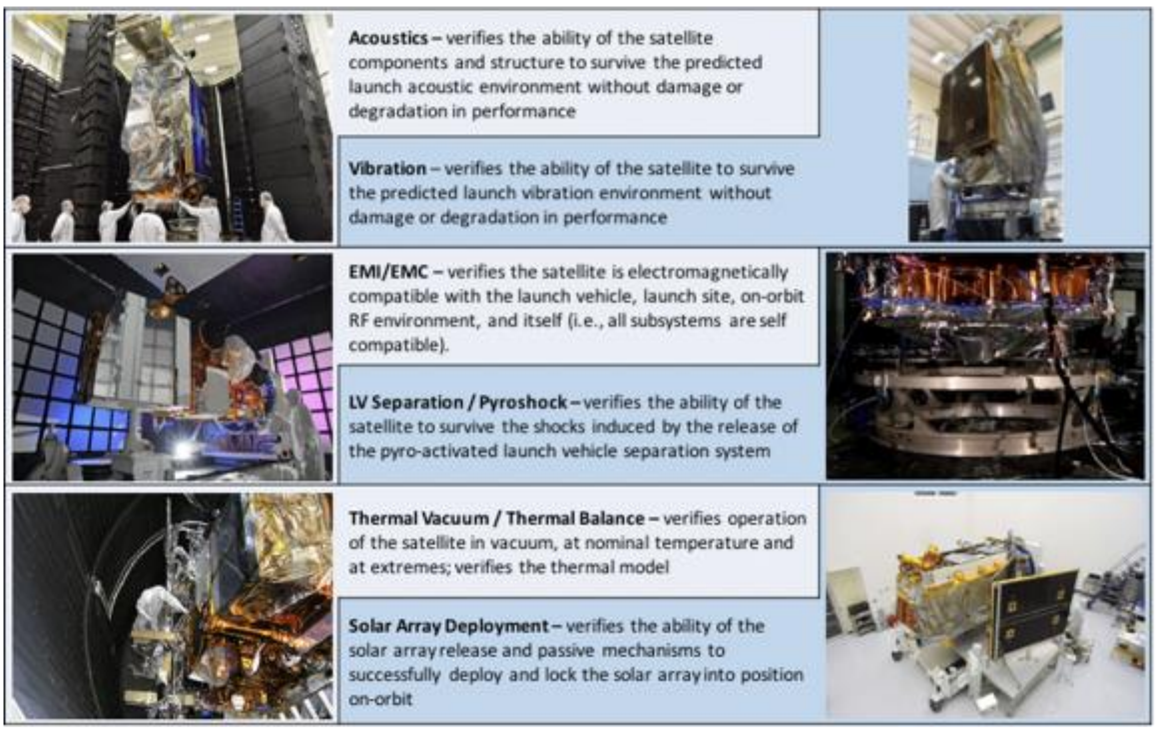


Exhibit 7. JPSS-1 Satellite Environment Test Program.

JPSS-1 satellite-level testing consisted of comprehensive performance, compatibility, and environmental tests to verify integrated performance and ensure readiness for flight. As shown in Exhibit 7, the environmental test program included direct field acoustic testing, vibration testing, LV separation/pyroshock testing, electromagnetic interference / electromagnetic compatibility (EMI/EMC) testing, thermal vacuum testing, and solar array deployment testing. Interspersed with these environmental tests were performance tests and increasingly more rigorous compatibility tests between the satellite and the CGS. Satellite-level testing spanned more than 1-year, beginning in April 2016 and concluding in July 2017. At the conclusion of satellite-level testing, JPSS-1 verification and validation was completed, a comprehensive Pre-Ship Review was conducted, and the satellite was loaded into its shipping container for shipment to the launch site.

JPSS-1 LAUNCH PREPARATION

Exhibit 8. JPSS-1 Satellite Arriving at Vandenberg AFB.[3]

The JPSS-1 launch campaign began on 30 August 2017 with over-road shipment of the JPSS-1 satellite from Ball Aerospace in Boulder, Colorado to the launch site at Vandenberg Air Force Base, California. A photograph of the satellite in its shipping container arriving at the launch base on September 1, 2017 is shown in Exhibit 8.

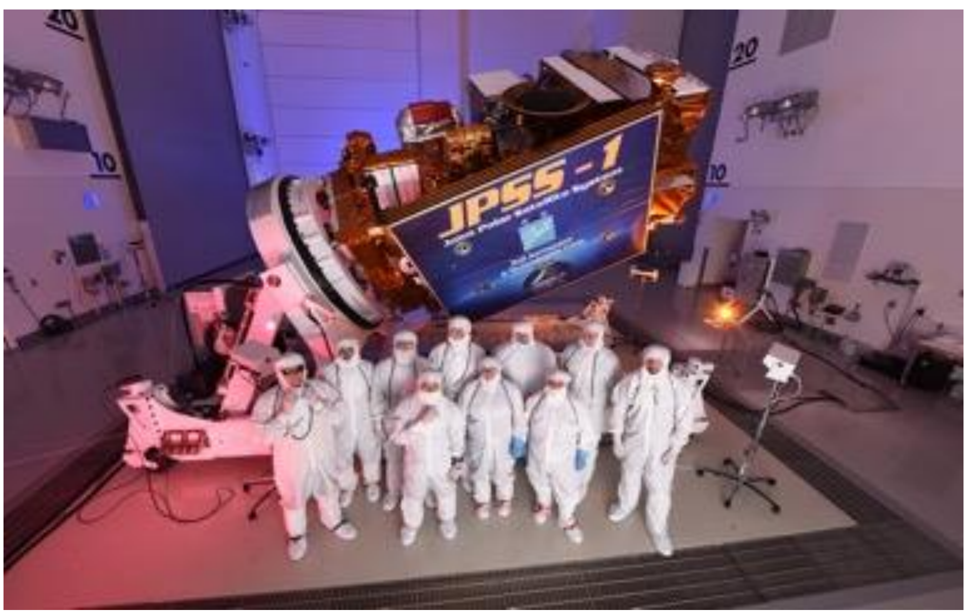


Exhibit 9. JPSS-1 Satellite at the Astrotech Payload Processing Facility.

After arriving at Vandenberg AFB, the satellite was installed in the Astrotech Payload Processing Facility (PPF) for post-shipment checks and tests to verify the health of the satellite. See Exhibit 9. After successful completion of these tests, the satellite began final preparations for integration with the launch vehicle. Final preparations included satellite cleaning and closeout of MLI, cleaning and closeout of all instruments, fueling of the satellite, installation of the Delta II payload attachment fitting, and encapsulation of the satellite in a transport "can" used to move the satellite from the PPF to Vandenberg's Space Launch Complex 2 West (SLC-2W).

Exhibit 10. Encapsulated Satellite Leaving the Payload Processing Facility for the Launch Pad.

Exhibit 11. JPSS-1 Satellite During Delta II Launch Vehicle Fairing Installation.[4]

On October 24, 2017, the satellite was moved to SLC-2W and integrated with the Delta II launch vehicle. Exhibit 10 shows the satellite leaving the PPF. Exhibit 11 shows the satellite after integration with the Delta II launch vehicle and with one half of the fairing installed. Post integration activities included lightning contingency tests, launch configuration integrated system tests, and final closeouts of the satellite and launch vehicle.

CONCLUSION: JPSS-1 LAUNCH AND COMMISSIONING

Exhibit 12. Launch of the Delta II carrying the JPSS-1 Satellite.[5]

Exhibit 13. JPSS-1 Satellite Just Prior to Separation from the Delta II Second Stage.[6]

At 1:47 a.m. Pacific Standard Time on November 18, 2017, the JPSS-1 satellite was successfully launched from Vandenberg AFB aboard a Delta II 7920 rocket. See Exhibit 12. Approximately 57.5 minutes after launch, JPSS-1 separated from the Delta II second stage over the Indian Ocean. See Exhibit 13. Approximately 63 minutes after launch the solar arrays on JPSS-1 deployed and the satellite was operating on its own power.[7] Shortly thereafter, satellite commissioning activities, which laste approximately 90-days, commenced.

ACKNOWLEDGMENTS

The author wishes to acknowledge the entire contractor and Government team for their dedication, commitment, and tireless efforts to build, test and deliver the JPSS-1 satellite on-orbit. These individuals and their families who supported them over the 7-year JPSS-1 program are a credit to themselves, their organizations, and our Nation.

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