

The NRL Precision Orbital Transfer Vehicle

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Introduction: The NRL Naval Center for Space Technology (NCST) successfully completed and operated a low-cost advanced propulsion spacecraft designed for the precision orbital transfer of small satellites. This Upper Stage (U/S) launched on a Boeing Delta II from Cape Canaveral Air Force Station (CCAFS), Florida, in June 2006 and completed the transfer and release of two experimental small satellites. NRL engineers operated the spacecraft from the NRL Blossom Point (BP) Mission Operations Center in southern Maryland.

Description of the Upper Stage: The Upper Stage is a propulsion module that also functions as a stand-alone spacecraft. It contains all hardware necessary for autonomous operations, including processing, software, RF communications, attitude determination/control, and power. The U/S provides the propulsion necessary to transfer the experimental small satellites from the Delta II–provided geosynchronous transfer orbit (GTO) to the final geosynchronous orbit. The U/S development efforts began in late 2003, with the Navy providing funding to NRL as a mission partner with DARPA and the Air Force.

Spacecraft System Testing: By September 2005, the U/S flight vehicle had undergone design, analysis, integration, and initial system test activities. System tests included mission simulations, alignments, EMI/EMC, and BP/Air Force Satellite Control Network (AFSCN) ground segment compatibility tests. Prior to shipment from NRL to the launch site, final system-level environmental tests were conducted over a seven-week period. These consisted of lateral random vibration (2-axis), axial random vibration, acoustic, pyro shock, alignment verification, thermal vacuum, small satellite separation testing, and spin balance/mass properties (Figs. 7(a)-(c)). The final flight software qualification testing was performed in parallel to the vibration testing with the assistance of a high-fidelity mission simulator, allowing successful “flying” while simulating multiple mission variables. Detailed analysis and testing of the primary structure thrust cone material was conducted, along with qualification testing of the main heat shield restraint system. Modifications of the flight heat shield restraint were implemented upon completion of the qualification testing. One of the final tests prior to ship-

ping to Florida was a fit-check with the Boeing Delta II Flight Payload Attach Fitting (PAF) (Fig. 7(d)).

Ship to the Cape, System Integration, and Fueling: The Upper Stage and supporting mechanical and electrical ground equipment shipped via NRL truck to CCAFS on December 7, 2005. There, in the Solid Motor Assembly Building (SMAB) (Fig. 8(a)), the U/S underwent electrical, propulsion, and battery functional testing, transducer calibration, alignments, BP/AFSCN compatibility, operations rehearsals, and initial electrical interface checks with the small satellites. Due to launch vehicle delays, the U/S was powered down until the launch vehicle was ready to support. Later, the U/S was transported to the Defense Satellite Communications System (DSCS) Processing Facility (DPF). NRL propulsion engineers, working with CCAFS contractor personnel, precisely loaded the mono methyl hydrazine (MMH) and nitrogen tetroxide (NTO) hypergolic propellants into the U/S fuel tanks. Following fueling, the small satellites were installed by NRL engineers and technicians on the top deck of the U/S. The integrated stack, known as the Space Vehicle (SV), was spin balanced by NRL engineers in the DPF. Following spin balance, the SV was installed on the Delta II third stage, which had been spin balanced separately. A large modular protective canister was installed around the integrated third stage and SV. Very early one morning two weeks before launch, this canister was slowly towed to Launch Complex 17A and hoisted on top of the rest of the Delta II rocket. The protective canister was removed, and final preparations of the SV were performed (Fig. 8(b)). These preparations included removing covers from sensitive surfaces, installing arming plugs, and performing pre-launch functional tests.

Launch and U/S Operations: The Upper Stage was launched into a geostationary transfer orbit on June 21, 2006, by a Boeing Delta II 7925 launch vehicle (Fig. 9). The launch was scheduled for 21:33 Z, and after two short slips into the 4-hour launch window, lifted off at 22:15 Z. The launch vehicle provided a very accurate insertion, as expected. The first contact from the U/S to the BP Mission Operations Center was made through the AFSCN Diego Garcia Remote Tracking Station (RTS).

All command and control activities for the Upper Stage were conducted from the NRL Blossom Point Tracking Facility (BPTF). NRL performed the pre-launch mission planning and the post-launch satellite orbit determination, maneuver planning/execution, and operations. Tracking data and telemetry were collected using both the AFSCN and BP assets. NRL-developed orbit determination software was used to



FIGURE 7(a)
Lateral vibration testing in acoustic chamber.



FIGURE 7(b)
Thermal vacuum chamber testing.



FIGURE 7(c)
Sensor and thruster alignment inspections.



FIGURE 7(d)
Fit-check with Boeing Delta II Flight Payload Attach Fitting (PAF).



FIGURE 8(a)
Electrical testing in the SMAB high bay at CCAFS.



FIGURE 8(b)
The Upper Stage in its flight configuration, ready for launch.

provide accurate position and velocity data for ground antenna pointing and maneuver planning. The main mission operations successfully ended in approximately four days with the Upper Stage inserting into a near geostationary orbit and successfully separating the two small satellites. All systems and subsystems performed as planned.

Mission Integration: The NCST provided significant system support to the joint program in order to ensure mission success. NRL was responsible for ensuring that the integrated Space Vehicle (U/S and small satellites) would meet all launch requirements. Detailed integrated SV analysis was performed (or managed) by NRL engineers, including integrated structural models, thermal analysis, and nutation (fluid energy dissipation) analysis. Additionally, all launch site range activities — facilities, resources, and spacecraft fueling — were managed by NRL on behalf of the program. A significant NRL presence was made at CCAFS and positive long-term relationships were established.

Evaluation of Technologies: The demonstration has resulted in an innovative propulsion system capable of a range of future missions for which large amounts of delta-V are required. Key technologies demonstrated include the following: a very low mass fraction, highly integrated structure; a novel thermal shield that minimized the height of the U/S; first flight on a U.S. satellite of platinum/rhodium bi-propellant attitude control thrusters; first flight of a high-performance coated columbium delta-V thruster; commercial off-the-shelf manual valve tested to aerospace standards; lightweight Inconel-718 composite overwrap pressure vessels; very lightweight all-titanium propellant tanks with internal propellant management devices; triple-junction solar cells; lithium-ion batteries; and the first flight of a low-cost/high-performance star tracker. This experimentation and these technologies enable such missions as autonomous maneuvering, transfer of secondary payloads, and orbit plane changes.

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FIGURE 9

Launch — June 21, 2006 (photo courtesy of USAF).