Electric propulsion

Several significant advancements in electric propulsion (EP) systems and related technologies occurred this year.

Flight programs

ESA's SMART-1 (Small Missions for Advanced Research in Technology) spacecraft, equipped with a PPS(r)-1350-G Hall-effect thruster (HET) built by the Snecma Safran Group, completed a successful mission to the Moon. The HET accumulated nearly 5,000 hr of operation. Because of the above-nominal performance of the solar arrays and propulsion system, propellant was available to reboost the spacecraft, enabling a one-year mission extension. Extensive analyses and correlations of flight data on the EP system performance and spacecraft parameters allowed validation of theories and computer models related to the operation of on-orbit EP systems.

A bismuth Hall thruster undergoes performance tests at Busek.

Lockheed Martin Commercial Space Systems continues to use Aerojet MR-510 arcjets (600-s I_{sp}) as the primary north/south stationkeeping (NSSK) thruster for its A2100 spacecraft. The A2100 fleet of on-orbit spacecraft includes 26 vehicles with 112 arcjets on board, which combined have accumulated approximately 15,000 hr of failure-free arcjet operation—this is in addition to the over 80 vehicle-years of NSSK provided by first-generation (MR-508/509) arcjets.

The Aerojet EO-1 pulsed plasma thrusters (PPTs) continue to see additional on-orbit activity, with the total number of firing pulses in excess of 233,000 shots over 64 hr of on-orbit operation. The PPTs provide limited attitude control.

Ion thrusters

Wright State University (WSU) developed computer models of the plasma in the discharge chamber of an ion engine. In addition, WSU altered PRIMA, a computer code that tracks primary electrons throughout the discharge and includes the effects of magnetic fields on the primary electrons. PRIMA is used to optimize the magnetic circuit design for primary electron confinement.

NASA Glenn and JPL are leading a government technology program to design, develop, and validate the Herakles thruster for NASA's Prometheus Project, specifically for the JIMO (Jupiter Icy Moons Orbiter) mission. A 2,000-hr, 21-kW wear test of the NASA Glenn HiPEP (high-power electric propulsion) thruster was completed, and a wear test of the JPL NEXIS thruster is continuing toward its 2,000-hr goal. Results from these tests are expected to provide input into the optics materials selection for the Herakles thruster. Aerojet supported the 20-kW NEXIS program with the design of the 65-cm development model thruster (DMT) and environmental testing. The company also supported the HiPEP 25-kW program with the design of the DMT and fabrication of the pyrolytic graphite grids. The pyrolytic graphite ion optics passed vibration testing, which validates the material selection and rectilinear concept for large-area ion thrusters. Fabrication of the first laboratory-model Herakles thruster has started at NASA Glenn.

Aerojet supports the NEXT (NASA evolutionary xenon thruster) 40-cm ion system and leads the design, build, and delivery of the prototype model EP thruster, the xenon propellant management system (PMS), and the digital control interface unit (DCIU) simulator. Aerojet completed the design of all three of these elements, as well as fabrication of the PMS and DCIU simulator hardware.

Hall thrusters

Michigan Technological University (MTU) is part of a university/industry collaboration with Aerophysics and Aerojet to develop a 20-kW bismuth Hall thruster. The Isp Lab at MTU demonstrated the first successful test firing of a bismuth HET outside of the former Soviet Union. The MTU-designed thruster operates between 2 and 6 kW and is intended as a pathfinder for future high-power bismuth thruster development.

Busek delivered the flight-qualified BHT-200 HET to the Air Force Research Laboratory (AFRL) for integration onto the TacSat-2 (RoadRunner) spacecraft. The 2006 launch of the BHT-200 will be the first U.S.-designed and built HET to fly in space. Busek is also the first U.S. agency to achieve controlled operation of a bismuth-fueled HET.

NASA Glenn and Aerojet completed the design, fabrication, and performance evaluation of the 3-kW high-voltage Hall accelerator, which has the characteristics needed for Discovery-class NASA science mission applications. The evaluation included input powers from 0.2 to 2.9 kW, demonstrating a 14:1 throttle range.

NASA Glenn leads an Exploration Systems Mission Directorate-sponsored project to design and demonstrate HET technology at power lev-

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els up to 150 kW. Preliminary thruster and hollow cathode designs are completed, and fabrication will occur next year. A 600-kW high-thrust Hall system, which utilizes the design, is under development through a complementary effort led by Aerojet. The program will complete the design and then fabricate and test a full-scale engineering model Hall system, including a multithruster system integration test. The NASA-sponsored Direct Drive Demonstrator program at Aerojet will complete an end-to-end ground demonstration of a subscale direct-drive Hall system, including high-voltage arrays fully illuminated in the test facility chamber with the HET firing.

Development of Aerojet's 4.5-kW Hall thruster propulsion system for use on Lockheed Martin commercial and military spacecraft is nearly complete. In August, the power processing unit was flight qualified and the 5,600-hr thruster qualification life test was more than 85% complete. The Lockheed Martin Mississippi Space and Technology Center focused on the qualification of the xenon feed system components. The xenon flow controller is flight qualified, and production hardware is in work.

Lockheed Martin, in collaboration with AFRL, performed high-fidelity experiments to characterize the interaction of the HET plume with energized solar arrays. In addition, a series of tests was run to evaluate the amount of leakage current experienced by solar arrays immersed into ionized plasma created by HETs. A fully operational and qualified system of HETs is expected to be available for flight applications in early 2006.

Advanced HET technology investigations at Alta include extended characterization of two different dual-stage demonstrators developed by an Alta-Alcatel/Alenia partnership and Snecma and a Snecma-developed thruster with magnetic thrust steering capability. The 100-200-W HET progressed from the development to the engineering phase, with full characterization performed on various HT-100 units, and preliminary design complete for the key subsystem assemblies.

Micropropulsion

The Illinois Observing Nanosatellite, which was scheduled to launch in November, will test microvacuum arc thrusters from Alameda Applied Sciences for attitude control. These thrusters have a sandwich electrode/insulator geometry producing ion velocities of up to 30 km/s and a thrust/power ratio of 10 µN/W.

Busek will deliver four three-axis micro-PPTs for propulsive attitude control on the Air Force Academy FalconSat-3 satellite. Busek will also deliver two µNewton colloid thruster modules for the JPL/NASA New Millennium satellite ST-7. The colloid thrusters provide extremely fine thrust resolution and low noise to allow detection of gravitational waves in space.

Alta continued flight qualification of field emission electric propulsion (FEEP) technology. An engineering model of the Alta FEEP-150 microthruster underwent a validation firing test for the Microscope, LISA Pathfinder, and Gaia missions. During the 1,600-hr test, the thruster unit demonstrated more than 500 Ns of total impulse, with controlled thrust between 0.1 and 220 µN, and a response bandwidth in excess of 200 Hz. This is the maximum total impulse ever recorded by a single microthruster.

Other EP devices

Princeton University leads a NASA-funded effort to develop ALFA^2, a high-power lithium-fed magnetoplasmadynamic (MPD) thruster that can operate at 250 kW with an I_{sp} of 6,000 sec and thrust efficiency above 60%. The team consists of members from JPL, NASA Marshall, NASA Glenn, Aerojet, University of Michigan, and Worcester Polytechnic Institute. A six-month study resulted in a detailed design of the thruster, lunar and Mars cargo mission and system analyses, and particle-in-cell simulations showing that contamination of spacecraft surfaces from lithium is eliminated with a simple plume shield.

A HiPEP thruster undergoes wear testing at NASA Glenn.

Tethers Unlimited and the Georgia Institute of Technology collaborated under funding from a NASA Glenn Phase-I Small Business Innovation Research contract to investigate use of innovative magnetic nozzle designs to improve the performance of MPD and Lorentz force accelerator thrusters. The effort used simulation and analysis to identify a magnetic nozzle concept that appears to have strong potential for improving current flow uniformity and reducing anode fall inefficiencies in megawatt-class thrusters.