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Electric Propulsion Research and Development at NASA

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Outline

• Current and Recent Missions
• Future Potential Missions
• Flight System Development Projects
• Research and Technology Activities
Current and Recent Missions

Dawn
- Orbital exploration of Vesta and Ceres.
- Three NSTAR gridded ion thruster strings.
- ΔV of 11 km/s and distance of 3.5x10^9 miles travelled.
- Planning ~3 months Extended Mission 2. Life ultimately limited by amount of remaining hydrazine propellant for RCS.

LISA Pathfinder
- ESA-led technology demonstrator for Laser Interferometer Space Antenna (LISA) planned for 2034.
- Launched in December 2015 and completed scientific phase by Summer of 2017.
- Colloid Micronewton Thrusters in Space Technology 7 (ST-7) Disturbance Reduction System (DRS).
- Based on work started by Busek in 1998 under Phase I SBIR with JPL.
- Challenge now is demonstrating sufficient lifetime. Focus of JPL, Busek and UCLA through 2022.
Psyche
• Exploration of largest metal asteroid, comprised almost entirely of Fe-Ni.
• NASA Discovery mission awarded to JPL in 2017, currently in Phase B (preliminary design).
• Planned for launch in 2022, arriving at Psyche in 2026 with Mars gravity assist in 2023.
• Utilizes SPT-140 Hall thruster system integrated into a commercial Space Systems Loral (SSL) bus.

Double Asteroid Redirection Test (DART)
• First demonstration of the kinetic impact technique to change the motion of an asteroid in space.
• Direct-funded Applied Physics Laboratory (APL) mission will deliberately crash DART spacecraft into the small binary asteroid/NEO Didymos.
• Primary propulsion provided by single NEXT-C gridded ion thruster string.
• PDR held in April 2018 with a planned launch readiness date in 2022.
Comet Astrobiology Exploration Sample Return (CAESAR)

- One of two New Frontiers mission finalists selected in December 2017. Both currently undergoing Phase A studies with downselect to one mission in July 2019.
- Launch in 2024-2025 to comet 67P/Churyumov-Gerasimenko with return of capsule to Earth in 2038.
- Managed by NASA Goddard Space Flight Center.
- Employs three (2 + 1) NEXT-C thruster strings.

NASA Gateway

- U.S. led development of a cis-lunar crew-tended spacecraft, used in conjunction with SLS and Orion to support exploration activities on the Moon and eventually deep space.
- Modular design features a Power and Propulsion Element (PPE) which would be launched and deployed first into lunar orbit in 2022.
- PPE under development by NASA GRC.
- Employs four Advanced Electric Propulsion System (AEPS) Hall thruster strings under development by Aerojet-Rocketdyne, NASA GRC and JPL.
Flight System Development

NEXT-Commercial (NEXT-C)

- 7-kW class gridded ion thruster and PPU suitable for broad range of NASA science missions and commercial applications.
- Development of two flight qualified thruster/PPU strings utilizing knowledge gained from NEXT technology project held from 2002 to 2012.
- Aerojet Rocketdyne (AR) is prime contractor with ZIN technologies as subcontractor for PPU development.
- Thruster/PPU strings were offered as Government Furnished Equipment (GFE) for the last Discovery program solicitation. One string now baselined for DART mission.
- NEXT-C designed for Solar Electric Propulsion (SEP) applications that must accommodate variable input power from changes in solar range over the mission:
  - Power: 0.5 to 6.9 kW
  - Thrust: 25 to 235 mN
  - Isp: 1,400 to 4,220 s
- Preliminary Design Review (PDR) held in February 2016.
- Critical Design Review (CDR) completed in April 2018.
- Delivery date to NASA in May 2019 for DART mission.
Flight System Development

Advanced Electric Propulsion System (AEPS)

• 13.3-kW class Hall thruster/PPU string developed for 40-kW SEP vehicles (PPE) and eventually interplanetary cargo missions. Formerly baselined for use on ARRM.

• Utilizes magnetic-shielding previously demonstrated by NASA to achieve long required thruster lifetimes.

• Aerojet Rocketdyne is prime contractor with ZIN technologies as subcontractor for PPU development.
  - Base period up to February 2019: Develop, test and deliver one Engineering Development Unit (EDU) string.
  - Option period up to December 2019: Deliver five flight strings.

• AEPS designed for SEP applications requiring higher thrust orbital and interplanetary transfer.
  - Power: 12.5 kW
  - Propellant Throughput: 1,700 kg
  - Maximum Isp: 2,600 s

• Preliminary Design Review (PDR) held in August 2017.

• Engineering Development Units (EDU) being fabricated for test campaign at GRC in late 2018.
Flight System Development

Multipurpose Hall 4.5 kW PPU

- GRC, in partnership with JPL, managing Phase III SBIR contract with Colorado Power Engineering (CPE) to develop and test TRL 6 prototype Hall 4.5-kW PPU capable of operating with:
  - NASA-developed HiVHAc Hall thruster
  - SPT-140 thruster
  - Aerojet XR-5 thruster
- GRC will conduct integrated system testing with HiVHAc thruster after delivery of prototype.
- PPU CDR completed in September 2017 with authority to proceed with fabrication given in January 2018.
- Testing of prototype PPU will take place in late 2018 with plan to enable development of flight hardware in separate follow-on contract.
Flight System Development

Other Flight Development Activities

Space Technology Announcement of Collaborative Opportunity (ACO)
- NASA is working with Busek under an ACO to perform life testing of Busek 600 W Hall system.
- GRC is providing test facilities, infrastructure and test support for 5,000-hour qualification life test between September 2018 and September 2019.
- Testing focused on moving BHT-600 system closer to flight readiness.

Lunar IceCube and LunaH-Map missions
- NASA supporting Busek to qualify its BIT-3 RF ion thruster for use with iodine propellant.
- Currently designed to operate at 60 W, and to produce thrust of 1.4 mN and Isp of 3,500 s with xenon propellant.
- Under Phase II SBIR extension, Busek will conduct up to 4,000 hours of wear and integration testing starting in May 2018.
- Iodine-compatible BIT-3 hardware is scheduled for delivery in summer of 2018.
Research and Technology

500-W Class Hall Thruster Technology
- Sub-kilowatt EP for small spacecraft (180-500 kg). On-going technology activities at JPL and GRC:
  - Magnetically Shielded Miniature (MaSMI) Hall thruster (JPL internal funding)
  - Sub-Kilowatt Electric Propulsion (SKEP) system development (NASA STMD funding)

Electrospray Thruster Technology
- Several activities over last few years focused on Microfluidic Electrospray Propulsion (MEP)
- JPL-developed MEP thruster demonstrated excellent stability and controllability with a thrust of 100 µN and Isp > 3,200 s.

Iodine EP System Technology
- AISP demonstration of a 600 W iodine Hall thruster system comprised of Busek BHT-600i, modular Busek PPU and iodine feed system with iSAT heritage.
- Thruster level test conducted with lab power console and GRC-developed feed system.
- Completed 1,174-hour test of iodine thruster operating with xenon cathode (limited by depletion of iodine load).
Research and Technology
100-kW Thruster Technology

- Advanced propulsion subsystems being developed under HEOMD’s Advanced Exploration Systems (AES) program:
  - Ad Astra: VASIMR (Variable Specific Impulse Magnetoplasma Rocket)
  - MSNW: ELF-250 (Electrodeless Lorentz Force)
  - Aerojet-Rocketdyne (AR): AR-100 Nested Hall Thruster
- Primary goal of each 3-year effort is to demonstrate 100-hour of continuous, steady-state operation at 100-kW. Subsystem includes thruster, PPU and feed system.
- Key performance goals include Isp range of 2,000 to 5,000 s, total subsystem efficiency > 60%, operational life > 10,000 hrs, total subsystem specific mass < 5kg/kw, and scalability to MW levels
- **Ad Astra Status**: Demonstrated 100 hours cumulative duration of pulsed operations in 6.5-minute intervals at power levels of 100 kW. Final test in November 2018.
- **MSNW Status**: Not able to achieve performance goals. Will not attempt final system level test.
- **AR Status**: X3 risk reduction test completed and GRC and integrated system testing at 10 kW at Univ of Michigan. Final test in October 2018.
EP for Planetary Defense
- JPL evaluating use of EP ion beam to impart a velocity/trajectory change to threatening planetary objects
- Beam that imparts momentum balanced by an equivalent opposing ion thruster
- Approach has several potential advantages compared to other proposed deflection techniques for asteroids in the size range of 10 to 150 km
- Key technology challenge is development of ion optics that produce beams with divergence angles less than 4 degrees

Ultra-High Specific Impulse Technology
- JPL continuing technology work on lithium-based gridded ion thruster technology with goal of \( I_{sp} \approx 50,000 \) s
- Technology applicable to missions requiring \( \Delta V \) of 100 to 200 km/s, such as an interstellar precursor mission
- Potential candidate is a mission to 550 Astronomical Units (AU) in less than 15 yrs. Allows utilization of gravity lens effect around Sun to enable viewing of exoplanets.
- High velocities possible with concurrent reduction in onboard power system mass by using Earth orbital-based laser and onboard tuned photovoltaics – current NIAC study
AISP seeks to advance iodine electric-propulsion technology across a wide range of component and system level topics toward risk reduction for future iodine missions.