Electric Propulsion Research and Development at NASA

George Schmidt, David Jacobson and Michael Patterson
NASA Glenn Research Center

Gani Ganapathi, John Brophy and Richard Hoffer
NASA Jet Propulsion Laboratory
Outline

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

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 commercially available Space Systems Loral (SSL) bus.

Double Asteroid Redirection Test (DART)
- Demonstrate kinetic effects of crashing an impactor spacecraft into an asteroid to significantly deflect its trajectory for planetary defense.
- Direct-funded mission to Applied Physics Laboratory (APL) which will demonstrate a kinetic impact on 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.

Lunar Orbital Platform - Gateway (LOP-G)

- International partnership to develop crew-tended cis-lunar space station. Used in conjunction with Orion spacecraft 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 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 have been offered as Government Furnished Equipment (GFE) for recent Discovery program solicitation. Now one string being utilized 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.
- Delivery date to NASA in May 2019 for DART mission.
13.3-kW class Hall thruster/PPU string developed for PPE, 40-kW SEP vehicles and eventually interplanetary cargo missions. Formerly baselined for use on ARRM.

Based on technology development at JPL and GRC on magnetically-shielded Hall thrusters.

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

- NASA is working with Busek under a Space Technology Announcement of Collaborative Opportunity (ACO) to perform life testing of Busek 600 W Hall system.
  - BHT-600 thruster
  - BHC-2500 cathode
  - PPU
- GRC is providing test facilities and test support for 5,000-hour qualification life test between June 2018 and June 2019.
- Testing will reduce cost for future customers.

- For 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 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 Hall Thruster Technology
- Sub-kilowatt EP for small spacecraft (wet mass 100-500 kg).
  - Two parallel technology activities at JPL and GRC:
    - Magnetically Shielded Miniature (MaSMI) Hall thruster (JPL internal funding)
    - Sub-Kilowatt Electric Propulsion (SKEP) technology (NASA STMD funding)
- Both activities seek to develop long-life, high-performance thruster/PPU strings with power levels from 200 to 800 W.

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
- NASA STMD’s Advanced In-Space Propulsion (AISP) project is supporting technology development of 600-W iodine compatible thruster, cathode, PPU, and propellant storage and feed system.
- Efforts so far have resulted in successful 1,174-hour durability test (limited by depletion of iodine propellant load).
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.
• 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
• All three efforts have accomplished significant testing. AR completed thruster/facility risk reduction test at GRC and 10-kW thruster/PPU/feed system test at Univ of Michigan
• Schedule for completion of final 100-hour, 100-kW steady state tests:
  - VASIMR: November 2018 at Ad Astra facility
  - ELF-250: November 2018 at MSNW facility
  - Aerojet Rocketdyne: August 2018 at GRC
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 $I_{sp} \sim 50,000$ 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