The Ion Propulsion System for the Solar Electric Propulsion Technology Demonstration Mission

Daniel A. Herman, Walter Santiago, Hani Kamhawi
NASA Glenn Research Center, Cleveland, OH

James E. Polk, John Steven Snyder, Richard Hofer, and J. Morgan Parker
NASA Jet Propulsion Laboratory, Pasadena, CA

Presented at Joint Conference of 30th International Symposium on Space Technology and Science
34th International Electric Propulsion Conference and 6th Nano-satellite Symposium,
Hyogo-Kobe, Japan
July 4 – 10, 2015
IEPC-2015-008 /ISTS-2015-b-008

Statement A: Approved for public release; distribution is unlimited.
Outline

• SEP TDM, ARRM, and EMC Overview

• Ion Propulsion System Overview

• NASA In-House Technology Development Status
  – 12.5 kW HERMeS Thruster
  – 13.3 kW HP-120V PPU

• Engineering Development and Flight Hardware Plan

• Conclusions
• High-power SEP can be enabling for both near-term and future exploration architectures and science missions
• NASA is maturing mission design for a 50kW-Class SEP Demonstration
  – Most mature concept is the Asteroid Redirect Robotic Mission
Long-Term, Stable Asteroid Storage for Crew Access

Earth-Moon Lagrange points provide stable, crew-accessible destination while expanding exploration capability toward long-term deep-space operations

- Serve as a staging point for large cargo masses en route to Mars
High-Power SEP systems required to move large masses in interplanetary space
- Leveraged in a multi-use, evolvable space infrastructure
High-Power SEP systems required to move large masses in interplanetary space
- Leveraged in a multi-use, evolvable space infrastructure

High-Power SEP Technology Investments

- NASA is developing the requisite technologies for a 50kW-Class Solar Electric Propulsion Demonstration to enable SEP missions and applications at higher power levels.

25-kW Solar Array Structures: MegaFlex (left) and ROSA (right).

12.5kW HERMES TDU-1

HP-300V Brassboard PPU

HP-120/800V Brassboard PPU

HP-300V PPU and HERMeS TDU-1 Integration Test
Ion Propulsion System and Thruster Requirements

- **Reference Ion Propulsion System (IPS) capability**

<table>
<thead>
<tr>
<th>Capability</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total system power</td>
<td>40 kW</td>
</tr>
<tr>
<td>Maximum specific impulse</td>
<td>3000 s</td>
</tr>
<tr>
<td>Xenon throughput</td>
<td>10,000 kg</td>
</tr>
<tr>
<td>String fault tolerance</td>
<td>Single</td>
</tr>
<tr>
<td>Solar range</td>
<td>0.8 – 1.9 AU</td>
</tr>
<tr>
<td>Input voltage range</td>
<td>95 – 140 V</td>
</tr>
</tbody>
</table>

- **Attributes of a single HERMeS thruster assuming 40 kW EP Power divided by 3 active EP strings and one non-operating spare (assumes PPU efficiency is 94%)**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum input power to PPU</td>
<td>13.3 kW</td>
</tr>
<tr>
<td>Maximum discharge power</td>
<td>12.5 kW</td>
</tr>
<tr>
<td>Discharge voltage at 3000s $I_{sp}$</td>
<td>800 V</td>
</tr>
<tr>
<td>Discharge current at 3000s $I_{sp}$</td>
<td>15.6 A</td>
</tr>
<tr>
<td>Service life (unmargined)</td>
<td>50,000 h</td>
</tr>
<tr>
<td>Minimum discharge power</td>
<td>6.25 kW (50% maximum power)</td>
</tr>
</tbody>
</table>
• 3+1 EP Strings consisting of four elements
  – Flight Thrusters (FT)
  – Power Processing Unit (PPU)
  – Xenon Feed System (XFS)
  – Mechanical Integration Hardware (MIH)

• Thruster gimbal is part of spacecraft structures and mechanisms
HERMeS Thruster Development Status

• NASA GRC and JPL developed 12.5 kW Hall Effect Rocket with Magnetic Shielding (HERMeS) to demonstrate viability and address mission risks
  – Hall Thruster Lifetime Qualification
  – Ground Test Facility Effects
  – Spacecraft Accommodation

• First Technology Demonstration Unit (TDU-1) fabricated and extensively tested
  – Operating envelope (blue) spans 300-800 V, 8.9-31.3 A (3.5:1), & 6.25-12.5 kW
  – TDU-1 testing has demonstrated operating points (red) as low as 300 V, 2 A

  • Performance and plume mapping: including facility effects characterizations, magnetic field strength optimization, magnetic field symmetry assessment, cathode flow fraction characterization, and plume flux, energy, and charge state
  • Multiple thermal characterizations to quantify thermal margin
  • Wall probe measurements to verify magnetic shielding require for long-life

• Second thruster (TDU-2) being fabricated for environmental testing
TDU-1 testing to date has spanned 300-800 V, 0.6-12.5 kW

References

- Hofer, et al, JANNAF 2015
- Kamhawi, et al, JANNAF 2015
- Kamhawi, et al, IEPC 2015
- Hofer, et al, IEPC 2015
HP-120V PPU Development Status

13.3 kW HP-120V Full-Bridge Topology Power Processing Unit (PPU) developed to demonstrate viability and address mission risks

- PPU development schedule

- Brassboard unit developed and tested over operating range 2 – 14 kW, 95 – 140 V input, and 200 – 800 V output demonstrating 94.0 – 95.5% efficiency
  - Ambient functional testing
  - Vacuum performance characterization
  - HERMeS thruster compatibility testing including 12.5 kW, 3000 s thruster design point

- Pinero, et al, JPC 2015
Xenon Feed System (XFS) Single String and Single High Pressure Components

- XFS consists of four elements:
  - 8 seamless, aluminum-lined COPV tanks (60 cm diam. x 305 cm long)
  - 1 Pressure Management Assembly (PMA)
  - 4 Xenon Flow Controllers (XFC)
  - Isolation valves, service valves, tubing
IPS Transition for Flight

- Acquisition for most major IPS components has been initiated to meet the Dec. 2020 ARRM launch date
  - Draft Request for Proposals (RFP) issued for Engineering Development Unit (EDU) EP String
    - Option for Qualification Model (QM) and Flight Model (FM) Hardware
    - Includes thruster, PPU, and XFC
  - With some additional development, the NASA in-house HERMeS thruster and HP-120V PPU designs could become the basis for future flight NASA missions

<table>
<thead>
<tr>
<th>EP String Procurement Event</th>
<th>Date (Subject to Change)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft RFP Release</td>
<td>May 21, 2015</td>
</tr>
<tr>
<td>Industry Conference</td>
<td>June 10, 2015</td>
</tr>
<tr>
<td>Comments on Draft Due</td>
<td>June 22, 2015</td>
</tr>
<tr>
<td>Final RFP Release</td>
<td>July 14, 2015</td>
</tr>
<tr>
<td>Proposal Due Date</td>
<td>August 28, 2015</td>
</tr>
<tr>
<td>Contract Award</td>
<td>March 29, 2016</td>
</tr>
</tbody>
</table>

- Draft Request for Proposals (RFP) for pathfinder, prototype xenon tank pending

- Acquisition of up to 10 metric tons of xenon being carefully planned to avoid market price run-off or disruption of availability
Conclusions

- NASA is developing a high-power SEP systems required to move large masses in interplanetary space as part of a multi-use, evolvable space infrastructure
- NASA is maturing mission design for a 50kW-Class SEP Demonstration
  - Most mature concept is the Asteroid Redirect Robotic Mission
- NASA is developing the requisite technologies for the SEP TDM, including ARRM, to enable these SEP missions and applications at higher power levels
  - HERMeS is a 12.5 kW Hall thruster co-developed by GRC and JPL for operation up to 3000 s specific impulse and a 50 kh lifetime that is enabled through the use of magnetic shielding
  - HP-120V PPU is a 13.3 kW full-bridge topology PPU capable of operating the HERMeS thruster at the 12.5 kW, 3000 s operating point and demonstrated efficiencies up to 95.5%
- An Ion Propulsion System design has been developed for the Asteroid Redirect Vehicle utilizing a 3 + 1 EP string architecture based on the NASA in-house developed technologies and their demonstrated performance
- Acquisition for most major IPS components has been initiated to meet the Dec. 2020 ARRM launch date (EP strings, xenon tank, xenon propellant in planning)
The support of the joint NASA GRC and JPL development of HERMeS by NASA’s Space Technology Mission Directorate through the Solar Electric Propulsion Technology Demonstration Mission (SEP TDM) project is gratefully acknowledged.
SEP TDM supported papers at 2015 JANNAF, IEPC, & JPC


