NASA’s NextSTEP Advanced Electric Propulsion Activities

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NextSTEP BAA: Advanced Electric Propulsion Background

• Developing propulsion technology systems in the 50- to 300-kW per thruster range to meet the needs of a variety of long duration, deep-space mission applications beyond capabilities being developed for 40-kW SEP Tech Demo Mission.

• NASA Board Area Announcement (BAA) was released in 2014.

• 3 proposals were selected to develop and demonstrate NextSTEP advanced electric propulsion (EP) subsystems.
  • Ad Astra - VASIMR (Variable Specific Impulse Magnetoplasma Rocket)
  • MSNW - ELF-250 (Electrodeless Lorentz Force)
  • Aerojet Rocketdyne - Nested Hall Thruster

• Primary goal is, during the third year, to demonstrate 100-hour of continuous, steady-state operation of propulsion subsystem at 100-kW in a relevant TRL 5 environment.
  • Subsystem includes thruster, power processing unit, feed system, and other key components.

• A 50% cost-sharing requirement was stipulated in BAA.
NextSTEP BAA: Advanced Electric Propulsion Background

- Key performance goals include Isp range of 2,000 to 5,000s, total system efficiency > 60%, operational life > 10,000 hrs, total system specific mass < 5kg/kw, and scalable to MW levels.


- With similar development costs/schedules/risk, could jump directly to higher power EP flight development and obtain more advanced EP systems sooner.

- Offers the potential for use of alternate propellants (hydrogen, oxygen, water, carbon dioxide, methane, etc.), including those ISRU derived.

![Propellants Image]
Ad Astra’s Variable Specific Impulse Magnetoplasma Rocket (VASIMR®)

Objectives & Technical Approach:
- Demonstrate a TRL-5 single core VASIMR® thruster with PPU’s, the VX-200SS, in thermal steady-state for at least 100 continuous hours at 100 kW
- Leverage Ad Astra’s privately funded superconducting magnet, propellant management system, power processing units, and unique vacuum capabilities to test the steady-state performance of its integrated thermal design

Team:
- Dr. F.R. Chang Díaz, Ad Astra, CEO, Strategic Guidance, Private Investment Leveraging
- Key team members, organization, and role
- Dr. M.D. Carter, Ad Astra, Engineering Development and Principal Investigator
- Dr. J.P. Squire, Ad Astra, Experimental Implementation and Measurement, co-Principal Investigator
- Mr. L. Dean, Ad Astra, Director of Manufacturing
- Ms. Yamaris Lopez-Nieves, Ad Astra, Contracts Manager

Schedule/Objectives

<table>
<thead>
<tr>
<th>Milestones</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Design Mfg &amp; Assembly</td>
<td></td>
<td></td>
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<tr>
<td>1st Stage, 2nd Stage pulsed Low-T plasma tests</td>
<td></td>
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<tr>
<td>2nd Stage &amp; Plasma Dump Preparation Complete</td>
<td></td>
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<tr>
<td>1st &amp; 2nd Stage Integrated Low-T plasma tests</td>
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<tr>
<td>VX-200SS Integrated Duration High-T plasma tests</td>
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</tbody>
</table>

10:00 AM, 10:30 AM, 3:30 PM, 4:00 PM, 4:30 PM, 5:00 PM, 5:30 PM
Objectives & Technical Approach:

- Demonstrate performance capabilities to TRL 5 with 100 kW input power for 100 h at thermal steady-state
- Implement the X3, Nested Hall thruster
- Demonstrate the XR-100, 100 kW system extensible to MW class systems

<table>
<thead>
<tr>
<th>Metric</th>
<th>XR-100 Objective</th>
</tr>
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<tbody>
<tr>
<td>Specific Impulse</td>
<td>~2,000 to ~5,000 s</td>
</tr>
<tr>
<td>In-space lifetime capability</td>
<td>&gt;50,000 h</td>
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<tr>
<td>Operational lifetime capability</td>
<td>&gt;10,000 h</td>
</tr>
<tr>
<td>System efficiency</td>
<td>&gt;60%</td>
</tr>
<tr>
<td>Power per thruster</td>
<td>250 kW</td>
</tr>
<tr>
<td>System kg/kW</td>
<td>&lt;5 kg/kW</td>
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</tbody>
</table>

Team:

- Propulsion System Development: Aerojet Rocketdyne
- Propulsion System Testing: NASA GRC (VF-5)
- Feed System: Aerojet Rocketdyne
- PPU Engineering: Aerojet Rocketdyne
- Thruster Development:
  - Aerojet Rocketdyne
  - University of Michigan
  - Jet Propulsion Laboratory

Schedule/Objectives

- Year 1: Component demonstration testing
- Year 2: TRL 4 System Demonstration Test
- Year 3: TRL 5 System Demonstration Test

Aerojet-Rocketdyne and U Michigan presentations:
Session EP-1: 11:00 AM, 11:30 AM
100 Joule Electrodeless Lorentz Force Thruster

- Lightweight, highly variable, highly scalable EP thruster
- One Thruster, 250 mm diameter
  - 1,500-8,000 s Isp
  - 100-1000 kW input power
- ELF-250 electromagnetically forms, accelerates and ejects a high-density magnetized plasmoid – no electrodes
- Operation on Water, Argon, Xenon, and other propellants
- Science & Technology demonstrated in the laboratory
  - Multi-Pulse and complex propellants demonstrated
  - 0.1-2K Joule, 100 W -2 MW discharges demonstrated

Team:

MSNW LLC
- Design high power thruster geometry
- Design and qualify PPU
- Thermal design and modeling
University of Washington
- Provides testbed extension and facility support
- Operate ELF-250 at 100 kW for 100 hrs
Helion Energy Inc.
- Design and implement advanced, lightweight PPU systems

Schedule/Objectives:

- 6 months – Thruster Assembly
- 12 Months – Pulsed operation 100 kW thruster and PPU
- 15 months – Full thermal engineering model
- 24 months – Steady thermo-vac thruster and PPU operations
- 27 months – Pulsed High power facility upgrades completed
- 36 months – 100 hr, 100-200 kW integrated test

MSNW and ELF/FRC presentations: None
• **MSNW Space Propulsion Lab**
  – 3 Vacuum Chambers including Large Vacuum Facility
  – Fusion Laboratory with 2 test bays and fabrication shop
Development/Demonstration Plan

• **Year 2 (FY17)**
  – Complete full thermal engineering model
  – Complete material coating for high temperature thruster components
  – Assembly of thermally validated and vacuum rated thruster
  – Conduct steady thermo-vac thruster and PPU operations

• **Year 3 (FY18)**
  – Complete pulsed high power test facility upgrades
  – Conduct Quasi-Steady 100-200 kW integrated tests at MSNW facility
  – Prepare for steady thruster testing
  – Conduct 100 hour, 100-200 kW integrated test
  – Complete data analysis and submit Final Report and Estimate for optional further development
NextSTEP Advanced Propulsion
Technical Challenges and Status

• Major technical challenges include:
  - Thermal management
  - Performance characterization and direct thrust measurements
    - Each vendor is addressing this with varying approaches.
  - Design, preparation, and execution of the high power, long-duration tests
    - Facilities capable of long duration testing of high power systems are a challenge.
    - May require investment for advancing the state of the art.

• Milestone test status:

<table>
<thead>
<tr>
<th>Year 3: 100-hr, 100-kW System Demonstration Test</th>
<th>Anticipated Completion Date</th>
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</thead>
<tbody>
<tr>
<td>Ad Astra Variable Specific Impulse Magnetoplasma Rocket</td>
<td>8/30/18 (existing RF PPUs) 11/30/18 (new RF PPUs)</td>
</tr>
<tr>
<td>Aerojet Rocketdyne Nested Hall Thruster</td>
<td>11/30/18</td>
</tr>
<tr>
<td>MSNW Electrodeless Lorentz Force thruster</td>
<td>Not Applicable</td>
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</tbody>
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