Updated Performance Measurements of the Phase Four RF Thruster

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Small Satellite Market Driving Rapid Innovation

In 10 years, 10x satellites in Earth orbit

Need: mass-manufacturable propulsion system to move from launch orbit to value-generating orbit.
Traditional Electric Propulsion Systems

Advantages:
• Gridded Ion Engines (GIEs) and Hall Effect Thrusters (HETs) create thrust with very high fuel efficiency
• GIEs and HETs have been developed for decades, have flight heritage, and are trusted technologies

Disadvantages:
• Require an anode and cathode, which erode over time
• High voltage, complex power electronics
• Precision designs can be difficult to manufacture
• Subsystems are traditionally large, available in low volume

Problem: traditional electric propulsion systems are complex and difficult to build
RF Electric Propulsion Systems

Advantages:
• Technology does not require an anode or cathode
• System does not require high voltage electronics
• Thruster geometry and subcomponents are simply manufactured

Disadvantages:
• New technology without flight heritage
• No compelling performance ever demonstrated

Problem: RF thrusters are promising but have so far have only been unproven concepts.
The Phase Four RF Thruster

Differentiating Approach:

- Leverage small scale DC-RF electronics miniaturization
- Miniaturize the plasma volume to maximize heating
- Full R&D cycle in house at P4 - design/mfg/test
- Simple design - most complex fabrication involves 3 axis CNC mill

Enables:

- RF thrusters to scale from CubeSat applications to large satellite applications
- Reduced thruster costs, manufacturable at scale
- High performance, electrodeless, low cost, low mass electric satellite thruster
Testing The Phase Four RF Thruster

- Torsional pendulum thrust stand at The Aerospace Corporation
- Pendulum deflects when thruster fires
- Pendulum displacement calibrated to known force, revealing thruster output
## Previously Tested RFT-0 Validates Concept

<table>
<thead>
<tr>
<th>Metric</th>
<th>Phase Four RFT-0(^1)</th>
<th>Takahashi 2011(^2)</th>
<th>Shabshelowitz 2013(^3)</th>
<th>Williams 2013(^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrust [mN]</td>
<td>3.5 to 5</td>
<td>2.7</td>
<td>4.9</td>
<td>6</td>
</tr>
<tr>
<td>Specific Impulse [s]</td>
<td>120 to 170</td>
<td>459</td>
<td>120</td>
<td>350</td>
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<tr>
<td>Power [W]</td>
<td>102 to 121</td>
<td>700</td>
<td>961</td>
<td>840</td>
</tr>
<tr>
<td>Mass [kg]</td>
<td>2.8</td>
<td>&gt;50</td>
<td>&gt;50</td>
<td>&gt;50</td>
</tr>
<tr>
<td>Size</td>
<td>3U CubeSat</td>
<td>Table Top</td>
<td>Table Top</td>
<td>Table Top</td>
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</tbody>
</table>

Miniaturized RFT-0 achieves same performance as tested RF thrusters at fraction of size, power, & mass

Problem: RFT still not close to meeting performance of existing HETs and GIEs

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\(^1\) Presented at International Electric Propulsion Conference, 2017 (Siddiqui et al., IEPC-2017-431)

\(^2\) Takahashi et al., APL, 98, 141503, 2011

\(^3\) Shabshelowitz et al., JPP, 29, 3, 2013

\(^4\) Williams et al., JPP, 29, 3, 2013
RFT-2 Demonstrates First RF Thruster Scaling

(a) Thrust

(b) Specific Impulse

Power [W]

[mN]

Power [W]

[sec]
Comparison to Previous Generation

- Isp scaling: 3.5 to 6.5 seconds per Watt
- 4x to 6.5x improvement at 120 W compared to RFT-0
- Meets or exceeds every RF thruster ever directly tested, at < 10% mass and < 20% power input

RFT-2 is the highest performance (Isp/Power) electrodeless RF thruster demonstrated.
Comparison to Existing State of the Art

- Isp scaling: 3.5 to 6.5 seconds per Watt
- Comparable Isp scaling to small HET and GIE thrusters
- RFT-2 entering high power test regime to measure performance scaling & long duration testing up to 400 W
- Results to be presented at AIAA P&E Forum, 7/2018

RFT-2 testing is about to enter regime dominated by small HET and GIE thrusters

[1] Frieman et al., JPC, AIAA-2016-4833
Summary

- Phase Four RFT uses miniaturization of electronics and thruster to achieve high performance, electrodeless RF thruster

- Results demonstrate Isp/Power scaling in CubeSat power regime comparable to small HET/GIE scaling

- Upcoming measurements to demonstrate performance and long duration results this summer

**RFT-2 represents true electrodeless, low cost, mass manufacturable thruster with performance scaling comparable to SoA**