National Aeronautics and Space Administration

FY23 Topic Areas Research and Technology Development (TRTD)

A Deep-Throttling, High Specific Impulse Hall Thruster Enabling the Next Generation of Space Exploration

Principal Investigator: Richard Hofer (353); **Co-Investigators:** Jacob Simmonds (353), Dan Goebel (353), Joel Steinkraus (355)

Strategic Focus Area: Electric propulsion

Objectives

A new Hall thruster capable of high specific impulse operation over large power throttling ratios was developed for next generation deep-space mission concepts. The H10 is a high specific impulse, magnetically shielded, conducting wall, 10 kW Hall thruster with performance objectives that radically increase capabilities relative to the state-of-the-art by:

1) operating at up to 3,000 s specific impulse over a 2:1 power ratio,
2) achieving efficiencies of 50-70% over a 10:1 power ratio, and
3) realizing a total power throttling ratio of 50:1.

The specific impulse itself represents a 50% increase relative to flight Hall thrusters. Maintaining the specific impulse over a wide range of power is the key challenge and requires operation at power densities two times higher than the state-of-the-art .

Background

Electric propulsion enabled NASA's Dawn mission with the use of the NSTAR Ion thruster. NSTAR operated at high specific impulse (3100 s), but was expensive to implement. Electric propulsion is also enabling NASA's Psyche mission, which will use SPT-140 Hall thrusters. The SPT-140 operates at lower specific impulse (1800 s) than NSTAR, but the system is significantly less expensive than equivalent Ion thruster systems. For the most-demanding future mission concepts across the solar system such as Comet sample return, Ceres sample return, Centaur orbiter and lander, Mars orbiter, or Uranus orbiter and probe, what is needed is a system that can realize the cost efficiencies of Hall thrusters, but provide the high specific impulse of an Ion thruster. Currently, no such system exists.

Approach and Results

In the second year of this task, the H10 design was completed using JPL's plasma-magnetic-thermal thruster design tools. The mechanical design was then completed, and fabrication drawings were released. Fabrication was completed several months later, and the thruster was assembled (Figure 1, left). The thruster was installed in JPL's Owens vacuum chamber for performance, stability, and thermal characterization (Figure 1, right).

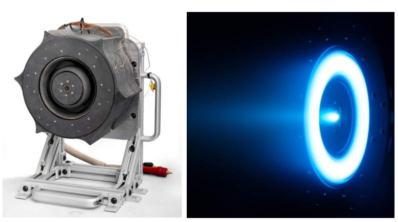

Figure 1. JPL's H10 Hall thruster implements an innovative two-zone, passive thermal management system to achieve steady-state power densities 300% higher than the SOTA. Left: H10 after final assembly. Right: Thermal steady-state operation of H10 at 15 kW.

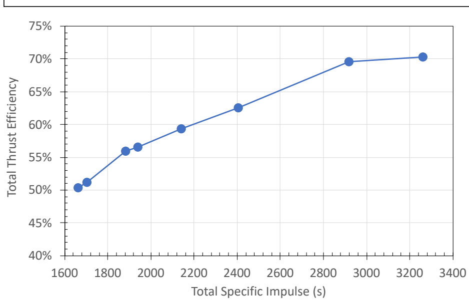

Figure 2. Total thrust efficiency versus total specific impulse of the H10 Hall thruster.

Thruster testing demonstrated that the thruster was stable over its power range and that high-performance and thermal steady-state operation was achieved. Notable metrics include:

- At 800 V, 10 kW: Thrust = 441 mN, Isp = 3240 s, and Efficiency = 70% (Figure 2).
- Constant voltage power throttling from 5-10 kW demonstrated at 600, 700, and 800 V.
- Figure 3 shows thermal steady-state operation with runs of 6-8 h at 800 V, 10 kW, 600 V, 12 kW, and 600 V, 15 kW. The latter condition exceeded the design goal by 50% and is equivalent to 300% power density improvement over the SOTA. The thermal performance was achieved through an innovative two-zone, passive thermal management system that selectively cools critical regions of the thruster to maintain temperatures within material limits. Operation up to 20 kW was demonstrated for firings of a few minutes. Test data imply that the design is likely capable of at least 20 kW thermal steady state.
- Total efficiencies of greater than 50% were measured at >1.9 kW.
- A minimum operating power of 0.2 kW was demonstrated, providing a power throttling ratio of 50:1 relative to 10 kW and 75:1 relative to 15 kW.
- Operation on krypton propellant over 300-800 V (12 kW max)
- The mass of the thruster is 20 kg, or 2 kg/kW at 10 kW.

Significance/Benefits to JPL and NASA

A comparison of various state-of-the-art Hall and Ion thrusters is tabulated in Figure 4. Flight Hall thrusters operate at no more than 2,000-s specific impulse, which limits their use on high delta-V (>10 km/s) missions. Gridded ion thrusters typically operate at the >3,000-s specific impulse necessary to efficiently perform these missions, but the high-cost of these systems significantly limit their use. By combining the specific impulse of Ion thrusters with the cost efficiencies of Hall thrusters, this task aims to provide a propulsive capability to science missions not available by any other EP technology.

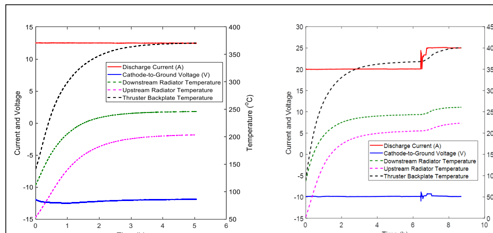

Figure 3. Thermal steady-state firings at 800 V, 10 kW (left) and 600 V, 12 and 15 kW (right).

System	Max Power (kW)	Max Specific Impulse (s)	Deep-space Technology Readiness Level	Planned Deep-space flights
Ion Thrusters				
NEXT (NASA/Aerojet)	7	4100	7	DART - 2022
RIT-2X (Ariane Group)	7.5	3500	5	MSR - 2028
Hall Thrusters				
XR-5 (Aerojet)	3	2000	8	None
SPT-140 (Maxar/Fakel)	4.5	1800	8	Psyche - 2022
BHT-6000 (Maxar/Busek)	5	1900	6	PPE - 2025
PPE-AEPS (Maxar/Aerojet)	12.5	2800	6	PPE - 2025

Figure 4. Comparison of state-of-the-art Hall and Ion thruster systems. The 10-kW, 3000 s I_{sp} H10 thruster will realize the cost efficiencies of Hall thrusters, but provide the high-I_{sp} of an Ion thruster.

Publications:

[A] Hofer, R. R., Lobbia, R., and Arestie, S., "Performance of a Conducting Wall, Magnetically Shielded Hall Thruster at 3000-s Specific Impulse," Presented at the 37th International Electric Propulsion Conference, IEPC-2022-401, Cambridge, MA, June 19-23, 2022.

[B] Hofer, R. R., Simmonds, J.B., Goebel, D.M., Polk, J.E., Arestie, S., and Lobbia, R., "High-Power Density, Magnetically-Shielded Hall Thrusters," AIAA-2024-XXX, AIAA SciTech Conference, January 2024.

PI/Task Mgr. Contact Information:

Email: Richard.R.Hofer@jpl.nasa.gov

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

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