National Aeronautics and Space Administration

Ultra-high Specific Impulse Lithium-fueled Ion Thruster for Interstellar Precursor Missions

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Program: Topical R&TD

Project Objective:

Demonstrate the feasibility of a gridded ion thruster operating at a specific impulse of 40,000 s. This ultra-high specific impulse is an order of magnitude greater than the current state of the art for ion thrusters. The objective of this activity is to experimentally demonstrate operation of a lithium-fueled gridded ion thruster at an input power of up to 50 kW with a specific impulse of 40,000 s.

FY18/19 Results:

Modeling, design, and fabrication of a lithium-fueled, gridded ion thruster was completed. A lithium propellant feed system was modeled, designed, fabricated and calibrated with water. A complete set of computer-controlled, high- and low-voltage power supplies was assembled and tested on resistive load. The vacuum test facility was refurbished and readied for testing with lithium.

Tests using argon without beam extraction indicated good discharge chamber performance.The thruster demonstrated the ability to sustain applied voltages of up to 7.5 kW in vacuum without arcing (6 kV is required to produce a specific impulse of 40,000 s with lithium). However, electron-backstreaming through some yet-to-be-identified leak path prevented thruster operation on argon at applied beam voltages of greater than 1 kV. Despite weeks of trouble shooting, the electron-backstreaming leak path has yet to be identified at the time of this writing. The inability to stand off more than ~1 kV with the discharge plasma on is woefully unacceptable and unexpected. This behavior has prevented testing of the thruster with lithium propellant.

Benefits to NASA and JPL (or significance of results):

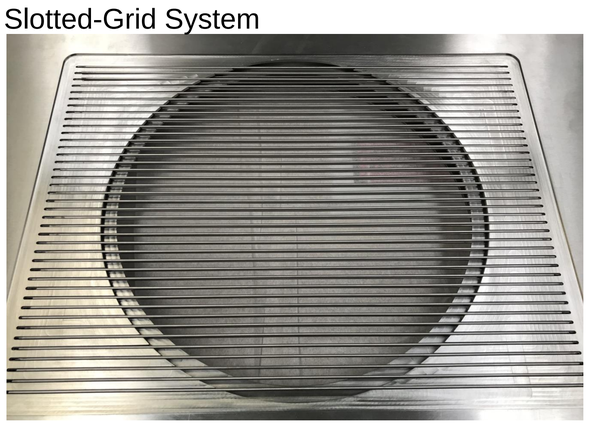
Successful demonstration in FY'19 of the lithium-fueled ion thruster at a specific impulse of 40,000 s would be a major step toward developing the capability to perform missions with characteristic velocities in the 100-200 km/s range (10x better than the Dawn mission). Examples of ultra-high delta-V missions are given in the table below.

Thruster modeling indicates that the unique characteristics of a lithium plasma discharge can be exploited to enable operation at extremely high propellant efficiencies (~98%) that are needed for long thruster life. The very high propellant efficiency would result in an order of magnitude lower production rate of charge-exchange ions that are responsible for the primary wear-out failure mode for ultra-high specific impulse ion thrusters. In addition, the significantly lower production rate of charge-exchange ions is expected to minimize the interaction of the charge-exchange plasma with the high-voltage photovoltaic array assumed to be the power source for the propulsion system.

This R&TD spawned four related activities, two NASA Innovative Advanced Concept (NIAC) awards (Phase I and Phase II), a Topical R&TD for the development of a lithium-compatible hollow cathode, and a SURP for the investigation of lithium-discharge plasmas with Princeton University.

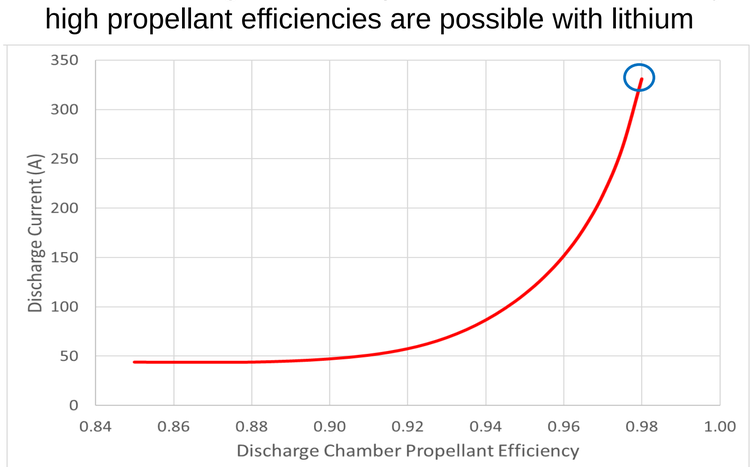
Lithium-fueled, Gridded Ion thruster for Operation at a Isp = 40,000 s

Slotted-Grid System



Complete Lithium-Ion Thruster

Modeled discharge chamber performance indicates very high propellant efficiencies are possible with lithium



Lithium-Ion thruster operating on argon at 1 kV and 1A

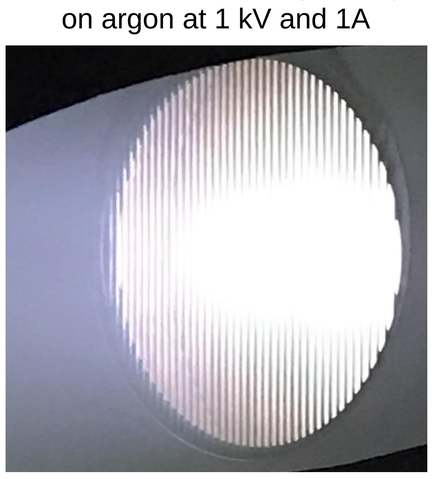
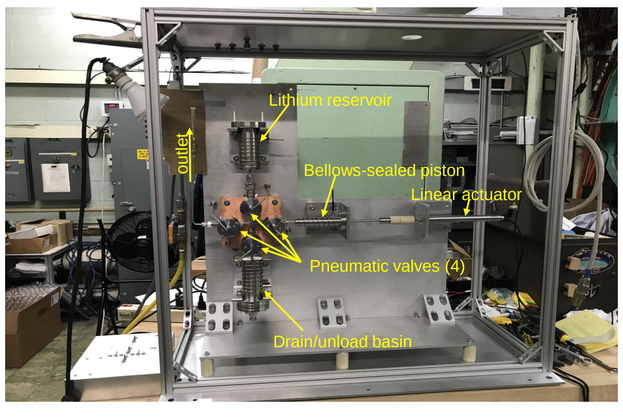


Table 1. Examples of very high ΔV missions and projected performance for a laser-electric propulsion system based on a 50,000-s lithium-fueled gridded ion thruster.

Mission	Total Time of Flight (years)	Payload Mass* (kg)	Max. EP Sysetm Power Level (MW)	ΔV (km/s)
Uranus Rendezvous	1.7	600	10	179
Neptune Rendezvous	3.0	600	10	180
Pluto Rendezvous	4.1	600	10	185
Solar Gravity Lens Focus at 550 au	13	600	10	191
Round Trip to Jupiter (with 180-day stay at Jupiter)	2.8	53,000	50	122
Round Trip to Saturn (with 180-day stay at Saturn)	4.0	59,000	50	147

Lithium Propellant Feed System



Publications:

John Brophy, James Polk, and Dan Goebel, "Development of a 50,000-s Lithium-fueled, Gridded Ion Thruster, IEPC-2017-042, Presented at the 35th International Electric Propulsion Conference, Georgia Institute of Technology, Atlanta, Georgia, October 8 – 12, 2017.

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