National Aeronautics and Space Administration

Low-Power Electric Propulsion System Enabling High-ΔV Smallsats

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Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Propulsion Systems for Small Satellites**

Objectives

The objective of this task is to deliver a low-power long-life electric propulsion (EP) system (i.e. an integrated thruster, power processing unit [PPU], and propellant feed system) that has

1) demonstrated a throttling range of 150 – 900 W with a peak total efficiency of >40% and a peak Isp of >1,500 s
2) demonstrated the capability of >100 kg Xe throughput (~10 kh operational lifetime);
3) demonstrated survival through relevant dynamic & thermal environments and has undergone experimental/analytical lifetime validation (i.e. achieve TRL 6);
4) a total system dry mass of <10 kg (not including the Xe tank);
5) sufficient technical development to be credibly proposed on Discovery and New Frontiers mission proposals.

Approach & Results

PPU Development – A JPL-spec PPU, comprising of three power converter units (discharge, cathode keeper, and magnet) has been under development over the past 3 years. The PPU was intended to accept 26 – 100 V input and employ Gallium Nitride (GaN) based electrics which are undergoing qualification for Europa Clipper. Unfortunately, schedule and workforce conflicts due to flight program demands on Section 346 prevented fabrication & test of the prototype PPU during this program; a paper design was completed. Nevertheless, JPL's commercial partner ExoTerra, who hold a license for various elements of ASTRAEUS, successfully developed a commercialized variant of an ASTRAEUS-compatible PPU. The prototype ExoTerra PPU was successfully validated in an end-to-end subsystem demonstration including a JPL-built thruster and ExoTerra-provided PPU & XFC.

Thruster Development – The ASTRAEUS thruster (MaSMi) has successfully completed a 10-year development effort, including an FY19-21 Strategic Initiative program, an FY17-18 Topical R&TD program, and an FY16 Spontaneous Concept effort. Previously, the thruster has undergone several characterization test campaigns, short-duration wear testing, laser induced fluorescence (LIF) testing, an experimentally validated numerical analysis to support the projected Xe throughput of >125-500 kg Xe, and structural and thermal analysis. To date, the thruster has demonstrated >100 kg Xe throughput with no change in performance over >7200 h of operation in a long-duration wear test. An independent cathode long-duration wear test successfully demonstrated >13,200 h of operation, with post-test destructive analysis suggesting significantly longer lifetime was possible had the test not been voluntarily terminated. The thruster was exposed to and survived dynamic environment (random vibration & shock) testing to qualification levels. An electromagnet qualification campaign saw a set of three engineering model magnet coils survive random vibration, shock, and 3064 deep thermal cycles (-125oC to +500oC) for a ground-support equipment (GSE) failure caused the TVAC test to end.

XFC Development – The primary ASTRAEUS XFC, which is compatible with Discovery-Class mission redundancy requirements, has been developed by commercial partner CU Aerospace. A prototype XFC was successfully validated in benchtop testing. The engineering model XFC was functionally validated at CU Aerospace before being delivered to JPL for dynamic environment testing, through which it successfully survived. The ASTRAEUS team is awaiting post-dynamics functional test results from CU Aerospace. In parallel, commercial partner ExoTerra also developed a commercially applicable ASTRAEUS-compatible XFC. While it does not meet Discovery-Class requirements, it is baselined on numerous upcoming flights of ExoTerra hardware and was used in the end-to-end ASTRAEUS subsystem demonstration.

TGA Development – The development of a thruster gimbal assembly (TGA) was requested of the ASTRAEUS team late in FY20. While funding prevented fabrication of a prototype, a paper design of the TGA was completed by the end of FY21. This design, developed in collaboration with Marshall Space Flight Center, met all kinematic requirements of JPL's mechatronics group and was passed through structural and thermal analysis, which suggested a high probability of survival. The engineering drawing set for all elements of the TGA were uploaded and released through EPDM.

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Background

The Ascendant Sub-kW Transcelestial Electric Propulsion System (ASTRAEUS) is a low-power long-life electric propulsion (EP) system that will enable the 4X Directorate to credibly propose deep-space high-ΔV smallsats in response to agency-wide solicitations. Total mission costs may be reduced by up to 50% without significant sacrifice of science return,making "Half-Discovery" proposals tractable & proposable while offering 4X a significant advantage in competed mission concept calls. This is due to the high efficiency of EP combined with the long-life low-power features of the proposed system which lowers launch mass. In the 2017-2018 Team-X study for the sub-300 kg VAMOS (Venus Airglow Measurements and Orbiter for Seismicity) mission, the use of the proposed sub-kW EP system enabled VAMOS to achieve its science objectives for an estimated total project cost (including launch and ops) of <$300 M. A separate 4X-funded A-Team study investigating missions enabled or enhanced by a low-power long-life EP system generated more than 100 mission concepts using either SEP (solar electric propulsion) or more advanced REP (radioisotope thermoelectric generator [RTG] powered electric propulsion) for outer solar system missions with 12 selected for more detailed investigation and all working from or adding to the 4X Discovery and New Frontiers mission pools.

Significance/Benefits to JPL & NASA

This is the first program in JPL's history to develop, demonstrate, and validate all elements of a completely JPL-managed Hall-thruster based electric propulsion system. With the exception of component-level TVAC testing, all technical objectives for the task were successfully completed. Most notably, an end-to-end ASTRAEUS subsystem validation test was performed to demonstrate the readiness of the system for future JPL/NASA missions. The thruster has broken numerous world records for lowpower EP devices, including most demonstrated throughput (>100 kg Xe) and highest performance (>1900 s total Isp, >50% total efficiency); it has proven to have truly enabling capabilities for interplanetary smallsat missions. The technologies developed throughout the 3-year task have been successfully transferred to commercial partners for future JPL and commercial needs. Additionally, the program has generated 7patents with >20 technical publications.

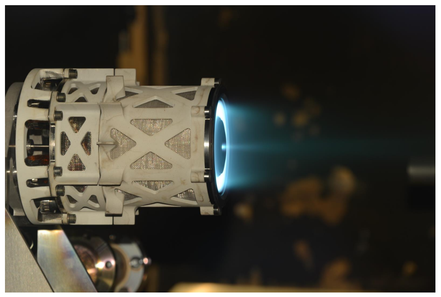
FY21 Noteworthy Publications

Barba, N., Austin, A., Banfield, D., Chmielewski, A., Clark, P., Coogan, W., Conversano, R., Cormarkovic,V., Diniega, S., Edwards, C., French, R., Fuller, J., Gallagher, M., Giersch, L., Komarek, T., Lillis, R., Loghry, C., Matousek, S., Montabon, L., Mischna, M., Niles, P., Norton, C., Shihabi, M., Stamenkovic, V., Swann, C., Tan, F., and Woolley, R., "High Science Value Return of Small Spacecraft at Mars," NASA Decadal Survey, 2020.

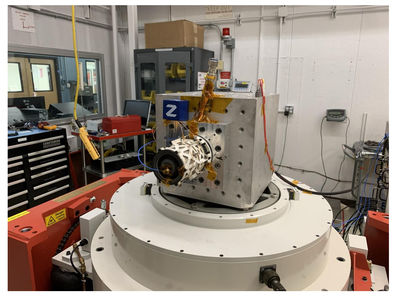
Conversano, R. W., Lobbia, R. B., Lopez-Ortega, A., Chaplin, V. H., Reilly, S. W., Arestie, S. M., and Goebel, D. M., "Long-Duration Wear Testing of the ASTRAEUS Hall Thruster, Phase I: 50 kg Xe Total Throughput," Space Propulsion 2020+1 Conference, SP2020-005, Virtual Event: 2021.

Becatti, G., Conversano, R. W., and Goebel, D. M., "Demonstration of 25,000 Ignitions on a Proto-Flight Compact Heaterless LaB6 Hollow Cathode," Plasma Sources Science and Technology, vol. 178 (2021).

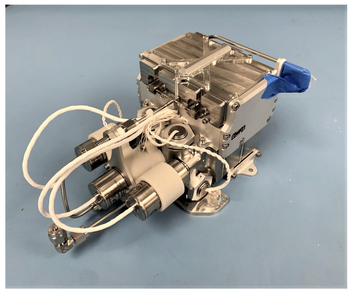
Conversano, R. W., Arestie, S. M., Lobbia, R. B., Lopez-Ortega, A., Chaplin, V. H., Reilly, S. W., and Goebel, D. M., "Long-Duration Wear Testing of the ASTRAEUS Hall Thruster, Phases II & III: 72 kg Xe Throughput & 1.2 MN-s Total Impulse," *AIAA-2021-3443*, AIAA Propulsion and Energy Forum, Virtual Event, 2021



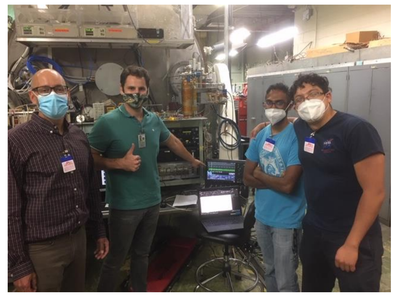
ASTRAEUS thruster operating at 300 V – 1000 W.



ASTRAEUS thruster at JPL's Environmental Test Lab for dynamic environments testing.



Discovery Class mission compliant XFC delivered by CU Aerospace



Dr. Conversano with ExoTerra PPU team during successful ASTRAEUS subsystem demonstration of JPL thruster and ExoTerra PPU & XFC, with proof of thruster operation shown on the oscilloscope .

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