ASTRAEUS: Ascendant Sub-kW Transcelestial Electric Propulsion System

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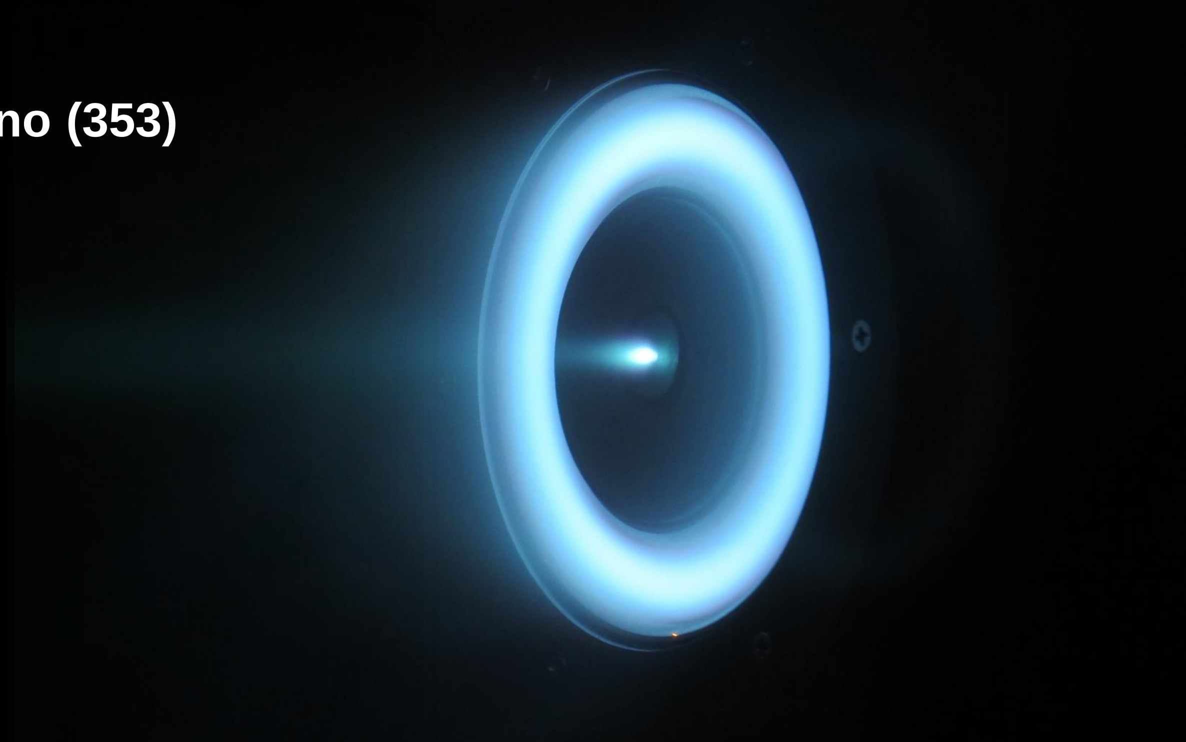
4X Strategic Initiative

Presentation # 48



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Abstract

The ASTRAEUS (Ascendant Sub-kW Trancelestial Electric propulsion System) program aims to deliver a low-power long-life electric propulsion (EP) system (i.e. an integrated thruster, power processing unit [PPU], and xenon flow controller [XFC]) for deep-space missions that has achieved the following:

(1) Demonstrated in relevant dynamic & thermal environments and has undergone experimental/analytical lifetime validation (i.e. achieve TRL 6);

(2) Throttling range of 150 – 900 W with a peak total efficiency of >40% and a peak Isp of >1,500 s;

(3) Capability of >100 kg Xe throughput (~10 kh operational lifetime);

(4) Total system dry mass of <10 kg (not including the Xe tank);

(5) Can be credibly proposed on Discovery and New Frontiers mission proposals (i.e. TRL-6) within 3 years.

Successful completion of this initiative will enable >5 km/s ΔV sub-300 kg spacecraft science missions that improve science-per-$ return by a factor of ~2 compared to the current state-of-the-art through the development of low-power, long-life, high-performance, and low-mass electric propulsion technologies that are not viable commercially.

The ASTRAEUS Thruster (MaSMi-EM)

Problem Description

Context: The 4X Directorate aims to improve the return-on-investment (ROI) of interplanetary science missions by enabling low-mass small spacecraft (i.e. smallsats), which may reduce total mission costs by up to 50% and provide 4X a significant advantage in competed mission calls. ASTRAEUS, which features world-leading efficiency, sub-kW operation, and >150-200 kg Xe throughput, is critical to meeting these goals by enabling interplanetary smallsats.

SOA: There are no commercial flight-qualified or proposable (TRL-6) sub-kW EP ***system*** options providing sufficient performance and Xe throughput for deep-space smallsats available in the U.S.

- Primary challenge is the development of a compact high-performance PPU
  - Only flight-qualified low-power U.S. unit is the Busek 1 kW PPU, which has flight heritage (total on-orbit ops time ~100 h)
  - Busek unit is heavy (~8 kg) with a large volume (~14 L) and low volumetric power density (~71 W/L)
- Magnetic shielding is the current SOA for Hall thrusters as it virtually eliminates the leading life-limiting mechanism
  - Busek BHT-600 represents the commercial SOA – has no flight heritage, is ***not*** magnetically shielded, and had demonstrated ~65 kg Xe throughput with significant wear of the thruster due to plasma erosion

Relevance to NASA: ASTRAEUS would exceed the applicable NASA/JPL Technology Roadmap desires for performance and ΔV (see Roadmaps 2.2.1.7 and 2.2.1.2). By using EP-equipped smallsats, NASA would see a dramatic increase in science ROI through a combination of reduced cost per mission (lower spacecraft mass = lower total cost) and more proposal opportunities (SIMPLEx, "Half-Discovery," etc.). Furthermore, conventionally sized (~500 - 1,000 kg) spacecraft using radioisotope thermoelectric generators (RTGs) with the proposed EP system will be capable of rendezvous and orbit-capture at outer solar system planets and celestial objects, enabling previously infeasible/prohibitively expensive missions.

Methodology

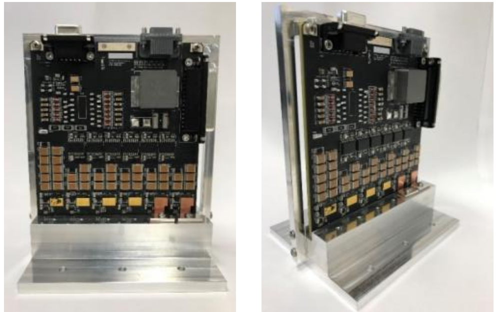
PPU Technical Approach
- The PPU is comprised of 4 converters: discharge, magnet, keeper, & housekeeping
- All PPU converters use GaN FET technology, leveraged from Europa Clipper
- Combination of Flying Capacitor Multi-Level (FCML) and buck/boost architectures
- PPU converters advanced from a breadboard level to a form-fit-function prototype

Thruster Technical Approach
- Start long-duration wear test (LDWT) targeting >50 kg Xe throughput by end of FY21
- Component-level qualification of magnet and cathode to be continued from FY19
- Dynamic environmental testing (shock and random vibration) was to be performed

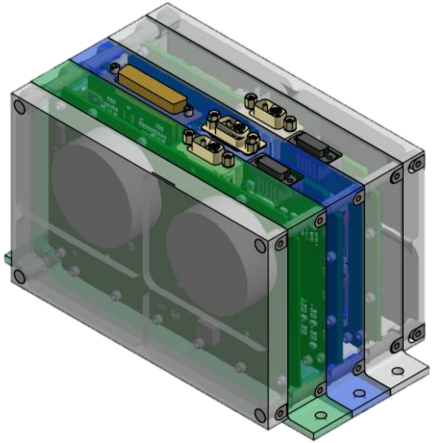
XFC Technical Approach
- Originally planned to partner with a commercial company to provide an XFC
- Target was a functional prototype to be used for integrated thruster & PPU testing

Innovative Features

The development and qualification of an ultra-compact sub-kW PPU, followed by the qualification of the MaSMi Hall thruster. A PPU meeting the proposed performance and size targets has never been developed in the commercial sector, and MaSMi represents the highest performing sub-kW Hall thruster in the world.



PPU discharge converter slice



ASTRAEUS packaged PPU prototype CAD

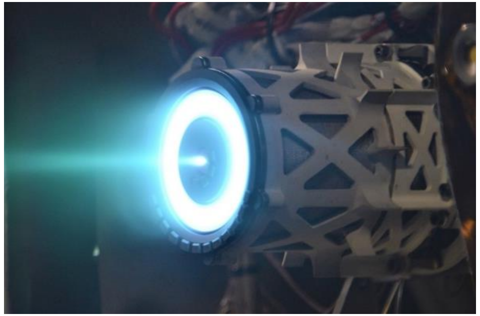
Results

PPU Achievements
- Successfully demonstrated breadboards of each converter
- Advanced the designs to a form-fit-function prototype w/ a3D-printed chassis
- >90% total efficiency power conversion over 150 – 1000 W, representing the highest-efficiency & most-compact 1 kW PPU in the world
- Prototype to be used in integrated testing with the thruster and XFC

Thruster Achievements
- LDWT started & processed ~20 kg Xe in FY20; testing ongoing
- Completed magnet & cathode component qualification; testing ongoing
- Dynamic testing postponed to FY21 due to COVID-related delays

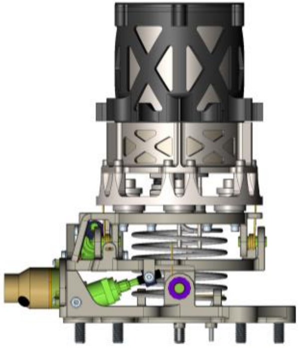
XFC Achievements
- Partnered with CU Aerospace to develop prototype XFC, delivered in August
- Prototype XFC passed cleanliness testing and is awaiting thruster testing
- EM version expected to be delivered mid-FY21

System-Level Achievements
- Established collaboration with NASA MSFC to develop thruster gimbal
- Gimbal design nearly complete; structural & thermal analysis in early FY21
- Fabrication of gimbal expected in mid-FY21



MaSMi-EM operating at 300 V – 1000 W during the long-duration wear test

Prototype CUA XFC



MaSMi-EM mounted on in-development gimbal assembly

Publications

Conversano, *et. al.*, “Performance characterization of a low-power magnetically shielded Hall thruster with an internally-mounted hollow cathode,” *Plasma Sources, Science, & Technology*, Vol. 28, No. 10 (2020).

Becatti, *et. al.*, “Demonstration of 25,000 Ignitions on a Proto-Flight Compact Heaterless Lanthanum Hexaboride Hollow Cathode,” *Acta Astronautica* (Accepted, 2020).

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Barba, *et. al.*, “High Science Value Return of Small Spacecraft at Mars,” *NASA Decadal Survey*, 2020.