Form 442, Technical Question 6 Response

Ignis - Spectrum Utilization Details

6a. *Description of Research Project*:

6a.1: *Introduction:*

6.a.1.i: *Applicant:* Astro Digital US, Inc. (Astro Digital) is a private U.S. satellite company headquartered in Santa Clara, California. We design, construct, and operate small satellites. The company is authorized by the FCC and NOAA to operate an Earth-imaging satellite system (Landmapper) and distribute images and many other data products derived from our imaging database, on a commercial basis.[1] The company has also received Part 5 Spectrum licenses for satellite technology demonstration missions in the past.

6a.1.ii: *Mission Summary:* Ignis is an electric propulsion technology demonstration mission, intended to measure performance of a system with a 300 watt Hall-effect thruster called the Apollo Constellation Engine (ACE) built by Apollo Fusion Inc. Scheduled for a Q3 2019 launch, the mission goal is to demonstrate the propulsion system on-orbit and verify its performance and applicability to small spacecraft in the 100-500 kg range. The mission is not a part of Astro Digital's Landmapper System, although information from the testing may support changes to future generations of that system or other Earth observation platforms designed and manufactured by Astro Digital. The mission will demonstrate the reliability, longevity, performance, and utility of the ACE propulsion system, which utilizes a proprietary high-density propellant.[2] A 300 watt Hall Effect propulsion system that is cost-effective, but more importantly power, volume and mass efficient, enables more orbital maneuverability for a small to medium class of space vehicles. Areas where this technology could be of benefit include orbital debris removal missions, collision avoidance, missions beyond-LEO, and smallsat deorbiting. In principle, this technology could also be used effectively for deorbiting some larger spacecraft.

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[1] *See* IBFS File SAT-LOA-20170508-00071 (granted in part and deferred in part, August 1, 2018).

[2] Pursuant to 5 U.S.C. § 552 and 47 C.F.R. § 0.459, Astro Digital seeks confidential treatment of the information contained in the letter submitted with this application and titled "Confidential Exhibit for the Ignis Spacecraft." This letter contains proprietary and confidential information related to the Ignis propellant system. Also submitted with this application is a letter titled "Request for Confidential Treatment," which explains that confidential treatment is needed to protect competitively sensitive information that, if subject to public disclosure, would cause significant commercial, economic, and competitive harm.

6a.2: *Satellite Physical and Orbital Characteristics:* The satellite is depicted in the following figure:

Ignis Satellite Platform

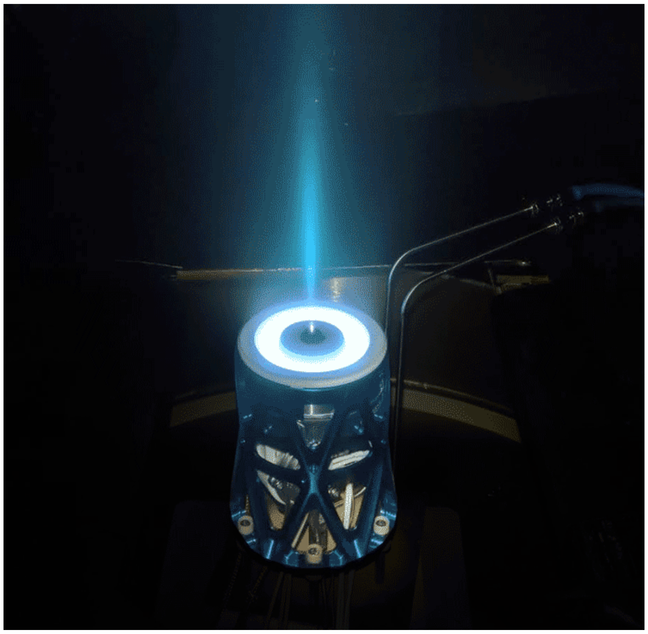
6a.2.i: *Dimensions and Mass:* The satellite is a rectangular solid shape with dimensions of 366 mm (X) x 113 mm (Y) x 239 mm (Z), which complies with the industry standard for a 6U XL cubesat. The satellite has a wet mass of 12 kg. Of this mass, 10.9 kg is spacecraft inert mass with an additional 1.1 kg of propellant.

6a.2.ii: *Overview of Propulsion System:* Ignis is an electric propulsion technology demonstration mission, intended to measure performance of a system with a 300 watt Hall-effect thruster. The spacecraft will use the thruster to reduce its orbital perigee and will determine the change in its orbital parameters using GPS to measure its position and velocity. At end-of-mission the spacecraft will be passivated, and its orbital altitude will be allowed to passively decay. The thruster uses magnetic and electric fields to ionize and accelerate the propellant. A total propellant load of 1.1 kg is planned for the mission. Expected performance is 18 mN thrust with 1,100 seconds of specific impulse.

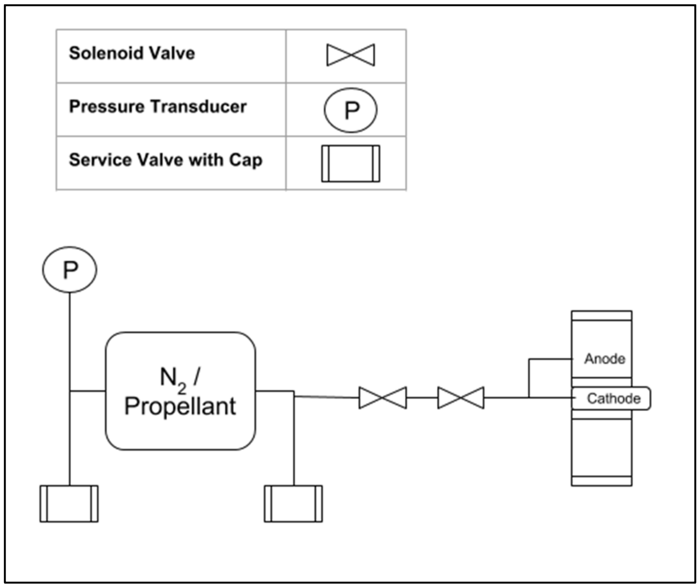
ACE will be the first known Hall thruster system in space to include these innovations:

- Center-mounted cathode (expected to improve on-orbit performance compared to ground performance relative to other Hall thrusters)
- Unpressurized 15psia tank (compared to 2700psia to 4000psia for other systems)
- Compact propellant feed system with no moving parts
- Single board PPU at >95% efficiency

At 4.5 kg dry mass, 60 mN/kW thrust, and 200 kN-s total impulse, the commercial ACE product system offers significant improvements in mass, volume, and performance relative to other propulsion systems. This enables satellites to become smaller, lighter, and more effective, making ACE a key enabling technology for the large constellations and for every satellite in LEO or MEO.



Photograph of Ignis Propulsion System



Ignis Mission ACE Propulsion System Block Diagram

6a.2.iii: *Initial (Deployment) Orbit:* The injection orbit of the Ignis Mission is anticipated to be as follows:

Orbit Altitude: 500 km circular (± 1km)
Inclination: 45.00° ± 0.50°
Local Time of Ascending Node (LTAN): TBD by launch provider at a later date

Ignis will use a secondary payload launch opportunity. Thus, it is possible that the injection orbit parameters could be different, as we could be re-assigned to fly on the launch of a different primary satellite system. AD will advise the Commission should such an event occur.

6a.2.iv: *Radio Frequency Characteristics of the ACE Propulsion System:*

The ACE propulsion system contains no RF generating sources and none are used to excite the propellant in any way. No component of the propulsion system is designed to radiate in the radio spectrum. However, a formal RF emissions test will be carried out by Astro Digital on the integrated spacecraft system to measure and record any and all RF emissions emitted by the spacecraft, including the propulsion system, while in operation. This will be carried out as an element of the satellites functional and environmental test program.

6a.3: *Mission Operations:* AD plans to use the Ignis spacecraft propulsion system in order to modify the orbital parameters of the spacecraft injection orbit. The total ΔV produced by the ACE is approximately 1,000 m/sec. The total impulse of the thruster is estimated to be 200 kN-sec. The mean I_{sp} of the thruster is expected to be 1100 sec. The Ignis demonstration mission is estimated to have a nominal duration of 9 months. The operation of the ACE thruster will be carried out in multiple burns with each burn/orbit equal to approximately 90 seconds duration. We note, in particular, that the thruster will not be used to increase the apogee of the orbit at any time. In that regard *the thruster's performance will never contribute to increasing the post mission orbital lifetime of the spacecraft.*

6a.3.i: *Planned Orbital Maneuvers:* AD only plans to use the ACE thruster to lower perigee by up to 300 km from initial spacecraft separation values. Thus, at the end of the propulsive phase of the mission the spacecraft will be left in an elliptical orbit with a perigee of approximately 200 km. Following this maneuver, the thruster will then be decommissioned and relieved of any residual pressurized consumables, and the spacecraft will be transitioned into an end of life mode.

6.a.3.ii: *Orbital Debris:* AD has provided an Orbital Debris Assessment Report (ODAR) which is attached with our Form 422 submission. We hereby summarize the findings of our ODAR document.

6a.4: *ODAR Submission:*

6a.4.i: *Human Casualty Risk:* Our debris analysis shows that, as our reentry is uncontrolled, we are compliant with ODAR Requirement 4.7-1 regarding human casualty risk using the "Atmospheric Reentry Option (a) as the probability of human casualty is less than 0.0001. DAS v2.0.2 has been used and reports that the Ignis spacecraft is COMPLIANT with the requirement.

6a.4.ii: *Propulsion System Failure vs. Orbit Altitude:* The ACE propulsion system will only be used as stated above in Section 6a.3.i. Thus, if, during the operation of the thruster it should fail to produce further thrust, the orbital lifetime will not increase beyond the lifetime of the worst case expected orbit, which will be 500 km x 500 km (worst case). The baseline orbital lifetime of our spacecraft, in accordance with our ODAR submission, is less than 5 years. AD has determined that if the satellite is dead on arrival at an injection orbit altitude of 500 km, it will have a worst-case orbital lifetime of less than 3 years.

6a.5: *Radio Frequency Characteristics*

6a.5.i: *TT&C Frequencies:* TLM and CMD data transmission from/to the spacecraft are proposed at the following frequencies:

Link Direction	Frequency Band (MHz)	Bandwidth Occupied (kHz)	Max. Data Rate (kbps)
Uplink (command)	402.88 – 402.92	40	38.4
Downlink (telemetry)	400.48 – 400.52	40	38.4

The occupied bandwidth of the radio system is 40.0 kHz (at -3 dBc) and employs a very steep skirted bandpass filter to limit its output bandwidth. GFSK modulation is employed on the downlink.

The CMD uplink utilizes EESS spectrum (Earth-to-space) in accordance with ITU Table of Frequency Allocations - within the band 402.0 to 403.0 MHz. In this application we are using this link in the category of service, Space Operations. While we do not comply with US Footnote 384 (as we are not transmitting to a US Gov. spacecraft) we have been mindful of the utilization made by the NOAA GOES DCS system and have avoided the use of those uplink frequencies, as discussed below.

6a.5.ii: _Coordination Status of UHF Frequencies:_ The government agency using the allocation between 402 and 403 MHz is NOAA. It is used for the GOES DCS system and by NOAA radiosondes operating in the *Meteorological Aids* category of service. Astro Digital has previously coordinated satellites with NOAA on precisely the same frequencies (under both Part 5 and Part 25 of the Commission's rules).[3] With this filing we will, once again, initiate coordination with NOAA regarding this additional experimental use of the same frequencies for Earth-to-space transmission. The conditions for use are essentially identical to our current operations within this band. And, as we expect to carry out and conclude the operations of this mission before June 2020 (nominal), we do not anticipate issues with this coordination process. We will, of course, keep the Commission apprised of our coordination efforts.

Regarding the TLM Downlink, we have recently coordinated with all the federal agencies regarding use of this frequency channel for the Astro Digital Landmapper system and anticipate no issues with coordinating use of this frequency for the Ignis satellite.

6a.5.iii: _Ground Station Location and Characteristics:_

There are two ground stations associated with the Ignis mission. These stations are situated in Santa Clara, California, USA and Littleton, Colorado USA. The specific

[3] *See supra* note 1.

locations are as given in our Form 442. However, for ease of review, these are repeated here:

- Santa Clara, CA Earth Station: Lat: 37.380000°, Long.: -121.961110°
  Altitude: 32.8 ft (AMSL)

- Littleton, CO Earth Station: Lat: 39.573201°, Long: -105.133683°, Altitude: 5835 ft (AMSL)

As described in our Form 442, our emissions from these ground stations are as follows:

- Command Transmitter Power Output: 50 watts
- Command Antenna Gain: 21.5 dBi
- Command System EIRP: 37.8 dBw

6b. *Specific Objectives of the Research Project*:

The research objectives of this project are:

a) To demonstrate that the ACE thruster provides a mass, power and volume efficient high delta V capability to SmallSats via orbital maneuvering. This mission will show that this particular system is mature enough to be used by the commercial and government small satellite market and can be quickly and easily integrated with smallsats as well as larger, more capable spacecraft with extremely low mass and volume allocations.

b) To demonstrate the performance increases of a center mounted cathode design, intended to increase on-orbit performance compared to heritage designs. Specific impulse and thrust will be directly measure or estimated from changing orbital parameters and satellite dynamics to verify the performance increases of this design.

c) To demonstrate that the high efficiency PPU design has sufficient maturity and that the components used in its design have been adequately tested and proven for flight. The PPU conversion efficiency and thermal data taken for the duration of the mission will show that the system is well-isolated from the rest of the spacecraft, allowing the unit to be integrated with a range of buses without further electrical or thermal design consideration from a bus provider.

d) To demonstrate the feasibility and performance of a low pressure (15 psia) propellant storage and feed system absent moving parts. Pressure and propellant throughput will be measured to show that this simple low-pressure architecture successfully mitigates the risks and concerns inherent in the high-pressure mechanized systems of heritage hall effect thrusters.

e) To show that the performance of this propulsion system is consistent across a performance window of several months; with total burn time of the system potentially exceeding 10 hours and extreme thermal cycling, the choice of materials and mechanical / thermal design will be shown to adequately withstand a space environment. By demonstrating consistent performance, mission budgets for de-orbiting can be accurately predicted; spacecraft employing this propulsion system would be able to safely de-orbit.

While the maturity of the system can be demonstrated via performance tests, thermal tests, and other key environmental criteria, there is no substitute for running a space propulsion system in a space environment. Therefore, the utilization of a Part 5 Experimental License is appropriate, and this project is in the public interest.

6c. *How will the program of experimentation demonstrate a reasonable promise of contributing to the development, expansion or utilization of the radio art, or is along a research line not already investigated?*

This propulsion system is an ideal candidate technology for placement on small (or even large) spacecraft in order to be utilized to mitigate collisions with other space objects, to maintain accurate orbital characteristics and, most importantly, it can allow semi-controlled or even controlled, timely and safe re-entry of a spacecraft upon mission completion for smallsat class systems. Given the Commission's focus on the debris of non-Federal space stations and given the public interest in this matter, we believe our demonstration is in line with the goals and objectives of the Commission's experimental licensing program.[4] Further, we note that because of the unpressurized tank subsystem we believe the reduced cost and risk of using the ACE technology is also very much in the public interest.

[4] *See Mitigation of Orbital Debris in the New Space Age*, Notice of Proposed Rulemaking and Order on Reconsideration, 33 FCC Rcd 11352 (2018).