Astro Digital US, Inc.
3171 Jay St
Santa Clara, CA 95054

30 September 2019

Marlene H. Dortch
Secretary
Office of the Secretary
Federal Communications Commission
445 Twelfth Street, S.W.
Washington, D.C. 20554

Subject: ELS File No. 0330-EX-CN-2019
Ref. No. 50747

Dear Ms. Dortch,

Astro Digital US, Inc. ("Astro Digital") hereby submits a revised environmental assessment ("Revised EA"),[1] replacing the company's originally submitted environmental assessment requested by the Federal Communications Commission ("FCC") in the above-referenced proceeding.[2] The Revised EA includes additional information regarding the potential impact of solar radiation pressure, other matter in the upper atmosphere, and the Earth's magnetic field.[3] The Revised EA demonstrates that the proposed Ignis mission would have no significant environmental impact, and accordingly, Astro Digital requests that the FCC complete its processing and expeditiously grant the experimental application.

Additionally, although Astro Digital has provided the Revised EA to facilitate the FCC's processing of the application, Astro Digital asks the FCC to consider more closely whether it has authority to request an environmental assessment with respect to the environmental impact of satellite operations.[4] Indeed, to Astro Digital's knowledge, it is not aware that the FCC has ever requested such information from other satellite operators despite the hazardous nature of hydrazine mono-propellant and bi-propellant systems, as well as other propulsion systems.[5]

Sincerely,

/s/

Chris Biddy

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[1] Astro Digital does not seek confidential treatment of the Revised EA.
[2] *See* Letter to Marlene H. Dortch, FCC, from Chris Biddy, Astro Digital, ELS File No. 0330-EX-CN-2019 (September 27, 2019); Email to Jan A. King, Astro Digital, from Nimesh Sangani, FCC, File No. 0330-EX-CN-2019, Ref No. 50747 (September 16, 2019).
[3] There are no other substantive changes to the prior filing.
[4] *See* 47 C.F.R. §§ 1.1301 *et seq*.; *see also*, *e.g.*, *Dep't of Transportation v. Public Citizen*, 541 U.S. 752, 770 (2004) ("We hold that where an agency has no ability to prevent a certain effect due to its limited statutory authority over the relevant actions, the agency cannot be considered a legally relevant 'cause' of the effect.");
[5] *See*, *e.g.*, *Melody Music, Inc. v. FCC*, 345 F.2d 730, 731-32 (D.C. Cir. 1965).

Enclosure

CC: (w/enclosure)
Jose Albuquerque
Karl Kensinger
Nimesh Sangani

FCC Environmental Assessment: Ignis Mission

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Abbreviations and Glossary

ACE	Apollo Constellation Engine
AFI	Apollo Fusion, Inc.
CONOPS	Concept of Operations
EA	Environmental Assessment
FCC	Federal Communications Commission
Isp	Specific Impulse
LEO	Low Earth Orbit
NEPA	National Environmental Policy Act
OSHA	Occupational Safety and Health Administration
TRL	Technology Readiness Level

Introduction

The National Environmental Policy Act (NEPA) of 1969[1] requires federal agencies to provide descriptive information to evaluate environmental consequences associated with the proposed action on the human environment.

Pursuant to 47 CFR §1.1307(a)[2], the Federal Communications Commission (FCC) implements NEPA by requiring licensees to examine actions which may have a significant environmental effect on:

- Wilderness areas
- Wildlife preserves
- Threatened or Endangered (T&E) species or designated Critical Habitat Areas
- Section 106 historic properties or Native religious sites
- Floodplains
- Significant changes in surface features (wetland fill, deforestation, or water diversion)
- Antenna towers and/or supporting structures equipped with high intensity white lights in residential areas
- Human exposure to radiofrequency radiation

Under the FCC's NEPA regulations, an Environmental Assessment (EA) is required for activities which may have a significant environmental effect on the resources listed above. If the activities do not fall within the eight conditions for an EA set forth in 47 CFR § 1.1307(a), then they are presumed to be categorically excluded from environmental processing. Moreover, an EA need not be submitted to the FCC if another federal agency has assumed responsibility for determining whether of the facilities in question will have a significant effect on the quality of the human environment and, if the facilities will, for invoking the environmental impact statement process.[3] However, the FCC may require an EA if it determines, in response to a petition or on its own motion, that the action may nonetheless have a significant environmental impact.[4]

The FCC has informed Astro Digital US, Inc. (Astro Digital) that it must submit an EA under Section 1.1307(d) because it proposes to use mercury as a propellant in the thrusters that will be tested on its proposed satellite. Although the FCC recognizes that an EA has been completed by another agency for handling and processing of mercury during ground preparations, at the launch site, and during launch, it does not appear that this previously completed EA addressed the possible settling of mercury back into the atmosphere after the mercury is ejected from the spacecraft in orbit. Accordingly, this EA evaluates the potential environmental effects of mercury used by the proposed Astro Digital spacecraft after it has achieved orbit.

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1 National Environmental Policy Act of 1969, Pub. L. No. 91-190, § 102, 83 Stat. 852 (1970); 42 U.S.C. § 4321 *et seq*.

2 47 C.F.R. § 1.1307(a).

3 47 C.F.R. § 1.1311(e).

4 *See* 47. C.F.R. §§ 1.1307 (c), (d).

Purpose and Need

Astro Digital is a private U.S. satellite company headquartered in Santa Clara, California, that designs, constructs, and operates small satellites. The company is authorized by the FCC and NOAA to operate an Earth-imaging satellite system (Landmapper).[5] The company has also received Part 5 spectrum licenses for satellite technology demonstration missions in the past.

Apollo Fusion, Inc. (AFI) is an electric propulsion company that manufactures the Apollo Constellation Engine (ACE), which consists of a Hall Effect Thruster, power propulsion unit (PPU), and non-pressurized propellant storage and management system. ACE uses mercury propellant.

Astro Digital proposes to complete a flight technology demonstration of AFI's ACE propulsion system. Ignis is an electric propulsion technology demonstration mission intended to measure performance of a system with the ACE 400 W Hall-effect thruster built by AFI. Scheduled for a Q1 2020 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 will demonstrate the reliability, longevity, performance, and utility of the ACE propulsion system. ACE is cost-effective and more importantly power, volume, and mass efficient. It 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 in LEO missions, collision avoidance, missions beyond LEO, and smallsat deorbiting. This technology could also be used effectively for deorbiting some larger spacecraft.

The flight demonstration would increase the availability of US-designed and manufactured electric propulsion systems for commercial and government use. H.R. 2500—FY20 National Defense Authorization Bill, Subcommittee On Strategic Forces[6] is investigating U.S Reliance on Foreign In-Space Propulsion System: "The committee directs the Secretary of Defense to provide a report to the congressional defense committees not later than November 1, 2019, on foreign in-space propulsion systems, including electric propulsion, Hall thrusters, and chemical apogee engines, which are used for transferring a satellite to its final orbital location, in-orbit maneuvering, and transferring to a graveyard orbit at the end of the life of the satellite. The report should address which national security programs use these systems; whether there are risks from relying on foreign in-space propulsion; the impacts of a change in policy that would require U.S.-made propulsion systems, including impacts on the Department of Defense's ability to use hosted payloads or acquire commercial services; cost estimates associated with a change in policy; what research and development projects would be necessary to contribute to the development technology readiness level (TRL) and testing of U.S.-designed and -manufactured in-space propulsion systems for current and future military satellites in space; and associated costs of these development and acquisition costs." The Proposed Action would

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5 *See* Application for Orbital Deployment and Operating Authority for Astro Digital U.S., IBFS File No. SAT-LOA-20170508-00071 (granted in part and deferred in part, August 1, 2018).

6 SUBCOMMITTEE ON STRATEGIC FORCES, Markup of National Defense Authorization Act for Fiscal Year 2020, H.R. 2500, 116th Cong. at 82 (2019) docs.house.gov/meetings/AS/AS20190604/109546/BILLS-116HR2500ih-SubcommitteeonStrategicForces.pdf.

specifically increase the availability of flight-demonstrated TRL 9 US-designed and -manufactured in-space propulsion systems for current and future military satellites in space.

The propellant requirements for this mission are 1.1 kg of elemental mercury.

No Action Alternative

The no action alternative would be to cancel the flight demonstration, which would reduce the availability of flight-demonstrated TRL 9 US-designed and -manufactured in-space propulsion systems for current and future military and commercial satellites in space.

Site Information

Injection Orbit

Ignis will be deployed into a circular, medium inclination low Earth orbit at an altitude of 500 km.

Final Orbit

The Ignis demonstration mission will assess the operation of the ACE thruster as it performs multiple burns with each burn equal to approximately 90 seconds duration. Astro Digital will use the ACE thruster only to lower perigee by up to 300 km from initial spacecraft orbital injection values. Thus, at the end of the propulsive phase of the mission, the spacecraft will be left in an elliptical orbit with a perigee somewhere between 200 km and 500 km. At the conclusion of these maneuvers, approximately 0.5% of the propellant will remain in experimental chambers behind the thruster. At this point, the thruster will be decommissioned and relieved of any residual pressurized consumables, and the spacecraft will be transitioned into an end of life mode.

Table 1. Site Descriptions

Region of Interest	Description	Emissions
Injection Orbit	**Nominal Orbit Altitude**: 500 km circular	Mercury emitted during thruster use between injection and final orbit.
Final Orbit	**Nominal Orbit Altitude**: 500 km x 200 km (target)	

Review of FCC Environmental Criteria

In accordance with Section 1.1307 of the FCC's rules, the following criteria were assessed for environmental impact. Because the site of operations of interest for the Ignis satellite during which its thruster will emit mercury is located in outer space, many of the criteria are inapplicable on their face. For example, there are no officially designated wilderness areas or wildlife preserves in space,[7] nor would in-orbit operations change surface features on Earth or involve antenna towers or supporting structures. Operation of the ACE thruster also does not result in any radiofrequency radiation.

CRITERIA	YES	NO
Facilities that are to be located in an officially designated wilderness area.		X
Facilities that are to be located in an officially designated wildlife preserve.		X
Facilities that may affect listed or threatened or endangered species, or designated critical habitats, or are likely to jeopardize the continued existence of any proposed endangered or threatened species, or likely to result in the destruction or adverse modifications of proposed critical habitats.		X
Facilities that may affect districts, sites, buildings, structures or object, significant in American history, architecture, archaeology, engineering, or culture, that are listed, or are eligible for listing, in the National Register of Historic Places.		X
Facilities that may affect Indian religious sites.		X
Facilities that are to be located in a floodplain.		X
Facilities whose construction will involve significant changes in surface features, including wetland fill, deforestation, or water diversion.		X
Antenna towers or supporting structures that are to be equipped with high intensity shite lights which are to be located in residential neighborhoods, as defined by applicable zoning law.		X
Facilities causing human exposure to levels of radiofrequency radiation in excess of limits in Sections 1.1310 and 2.1093 of the FCC's rules.		X

The Ignis mission concept of operations (CONOPS) is to launch the Ignis satellite to its initial circular orbit and reduce its perigee. This will be achieved by firing the Hall thruster in the opposite direction of motion of the satellite at its apogee. Thrusting in the opposite direction of motion of the satellite means that the propellant will exit the thruster and the propellant will travel in the direction of motion of the satellite. Therefore, the thruster ion velocity will be the sum of the satellite velocity (which is the orbital velocity) and the propellant exit velocity (Equation 1):

$$v_T = v_E + v_s$$

where:

$$v_T = total\ ion\ velocity$$
$$v_E = propellant\ exit\ velocity$$
$$v_s = satellite\ velocity = orbital\ velocity$$

7 *See, e.g.,* NATIONAL WILDERNESS PRESERVATION SYSTEM, www.wilderness.net; NATIONAL WILDLIFE REFUGE SYSTEM, www.fws.gov/refuges.

The propellant exit velocity is calculated via Equation 2[8]:

$$v_E = g_0 I_{sp}$$

where:

$$v_E = propellant\ exit\ velocity$$
$$g_0 = gravitational\ acceleration = 9.8\ m/s^2$$
$$I_{sp} = specific\ impulse\ of\ the\ ACE\ thruster = 1{,}250\ s$$ [9]

Therefore, the propellant exit velocity of the ACE thruster is approximately:

$$v_E = 9.8\ m/s^2 \times 1250\ s = 12{,}250\ m/s$$

The orbital velocities for injection and final orbits are listed in Table 2.

Table 2. Orbital Velocity

Region of Interest	**Description**	**Orbital Velocity**[10]
Injection Orbit	**Nominal Orbit Altitude**: 500 km circular	7620 m/s
Final Orbit	**Nominal Orbit Altitude**: 500 km x 250 km (target)	7790 m/s

The total ion velocity is summarized in Table 3.

Table 3. Total Ion Velocity

Region of Interest	**Description**	**Total Ion Velocity**
Injection Orbit	**Nominal Orbit Altitude**: 500 km circular	19,780 m/s
Final Orbit	**Nominal Orbit Altitude**: 500 km x 200 km (target)	20,040 m/s

8 Glenn Research Center, *Specific Impulse*, NASA (May 5, 2015), https://www.grc.nasa.gov/WWW/K-12/airplane/specimp.html.

9 T.S. Matlock (December 11, 2017). *Ace Thruster Performance Verification*. *ACE Thruster Performance Verification*. Aerospace Corporation.

10 *Orbital Parameters: Low Earth Circular Orbits*, AUSTRALIAN SPACE ACADEMY (August 1, 2019) https://www.spaceacademy.net.au/watch/track/leopars.html.

The velocity required to escape Earth's atmosphere is 11,190 m/s.[11] At all points during the mission, the total ion velocity of mercury emitted by the ACE thruster will be greater than the Earth's escape velocity. Accordingly, the mercury used during the mission can be expected to leave the Earth's atmosphere rather than remaining in the atmosphere or returning to Earth.[12]

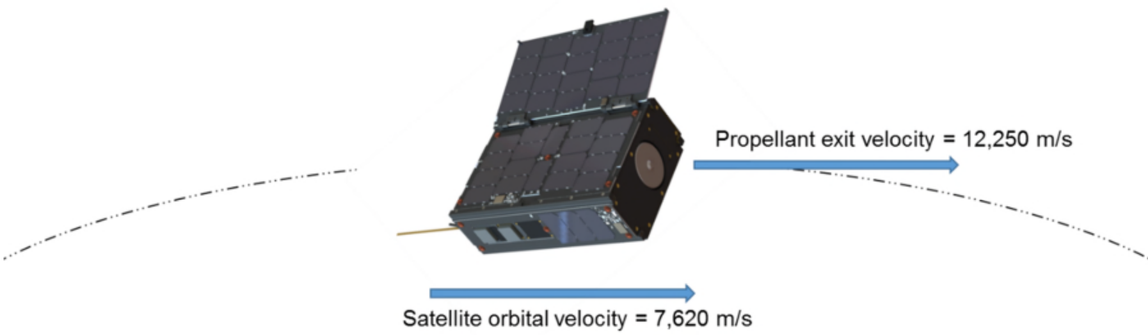

Figure 1. Diagram of satellite velocity and propellant exit velocity at the nominal injection orbit altitude. (Note that satellite velocity is higher for the final orbit parameters.)

The protons or electrons from the solar wind (or photons from the solar radiation pressure) do not have a meaningful collision or charge exchange cross section with the Hg ions, so there is little way to impart a net momentum to the velocity stream of Hg ions. Also, at 500 km altitude, the atmospheric density is between 10E-13 kg-m^3 and 5x10E-11 kg-m^3.[13] This is too low a density to significantly impact the ejected ion flow.

The earth's magnetic field will also have a negligible effect on an ejected ion's path:

- At 500 km, the gyroradius of the mercury ion traveling in the earth's magnetic field is 90 meters. The ion's gyroradius is calculated by the following Equation 3.[14]

  Gyroradius (km) = 1.02E-3*AMU^.5*(Ion temp)^.5/(Magnetic Field strength)

  Where

  AMU = 200 for Hg
  Ion temp = 10 eV for Hg
  Magnetic Field strength = 0.5 Gauss

- Taking the two bounding cases for firing the thruster with respect to the earth's magnetic field (parallel to the magnetic field and perpendicular to the magnetic field):

[11] Jet Propulsion Laboratory, California Institute of Technology, *Planets and Pluto: Physical Characteristics*, NASA (Mar. 28, 2018) https://ssd.jpl.nasa.gov/?planet_phys_par.

[12] As noted above, approximately 0.05% of the mercury propellant will remain in the satellite at the end of the Ignis mission. For the reasons discussed below with respect to the potential impact of 1.1 kg of mercury, this 0.0055 kg of mercury will not have any significant effect on the environment.

[13] https://www.spaceacademy.net.au/watch/debris/atmosmod.htm.

[14] NRL Formulary (at page 28), *available at* https://library.psfc.mit.edu/catalog/online_pubs/NRL_FORMULARY_13.pdf.

- If the Ignis satellite was in a polar orbit and fired its thruster over the equator, the ion velocity would be in approximately the same direction as the earth's magnetic field. So the ion would travel in a corkscrew trajectory (with a 90m gyroradius) around the velocity vector which is racing away tangentially from the earth. Assuming minimal gravitational deceleration, after 2,500 seconds (42 minutes), at nearly 20 km/s the ion would be 50,000 km from the earth. At that altitude, the earth's magnetic field strength has dropped from 0.5 Gauss to .001 Gauss and is negligible.
- On the other end of the spectrum, if the Ignis satellite was in a polar orbit and fired at the magnetic north pole, the ion velocity would be approximately normal to (90 degrees away from) the earth's magnetic field. So the ion's motion would be a superposition of its exit velocity vector (12.5 km/sec tangential to the earth) plus a circular motion whose gyroradius was 90m and whose axis of revolution was 90 degrees from the velocity vector. Again, assuming minimal gravitational deceleration, after 2,500 seconds (42 minutes), at nearly 20 km/s the ion would be 50,000 km from the earth. At that altitude, the earth's magnetic field strength has dropped from 0.5 Gauss to .001 Gauss and is negligible.

As previously discussed, the propellant for the mission will be traveling at a higher velocity than Earth's escape velocity. However, even if this were not the case and some propellant re-entered the Earth's atmosphere, the proposed mission would not have any meaningful environmental consequences. The total propellant load for the mission is 1.1 kg. This quantity compares to 48,080 kg (53 tons[15]) of mercury released into the atmosphere from U.S. coal power plants annually. Even if the Ignis mission did lead to all 1.1 kg of mercury planned for the mission returning to Earth (which is not the case), the amount returning would be 0.003% of the emissions from US coal power plants. Furthermore, globally wildfires emit around 1,000 metric tons of mercury every year.[16] The full load of mercury from nearly 1 million Ignis missions would be required to equal the annual emissions from wildfires alone.

Finally, if any mercury did not escape Earth's atmosphere, its impact on the environment and human health would be negligible. The current density of mercury in the atmosphere[17] is 1 - 2 ng m^{-3}. This is 50 billion times more than the increase in mercury density that would occur if all 1.1 kg of the Ignis mission propellant returned and was dispersed globally throughout the Earth's atmosphere.

[15] UNITED STATES ENVIRONMENTAL PROTECTION AGENCY: MERCURY AND AIR TOXICS STANDARDS: CLEANER POWER PLANTS (2011) https://www.epa.gov/mats/cleaner-power-plants.

[16] NATIONAL SCIENCE FOUNDATION, *Scientists Estimate Mercury Emissions from U.S. Forest Fires*, (Oct. 17, 2007) https://www.nsf.gov/news/news_summ.jsp?cntn_id=110320.

[17] D. Galloway, et. Al, *Geologic Studies of Mercury by the US Geological Survey*, U.S. Geological Survey Circular 1248, at 2 (2003).

Recommendation

The proposed Ignis mission has no impact on the following environmental assessment criteria:

- Officially Designated Wilderness Areas
- Officially Designated Wildlife Preserves
- Listed, Proposed, Threatened or Endangered Species and Critical Habitat
- Historical Properties, Cultural Resources, and Native Religious Sites
- Water Resources
- Tower Lighting and Radiofrequency Radiation

The proposed Ignis mission would not result in significant impacts on the human or natural environment. Accordingly, Astro Digital and AFI recommend a Finding of No Significant Impact.