Application of Solar Electric Propulsion to the Low Thrust Lunar Transit of the Gateway Power and Propulsion Element

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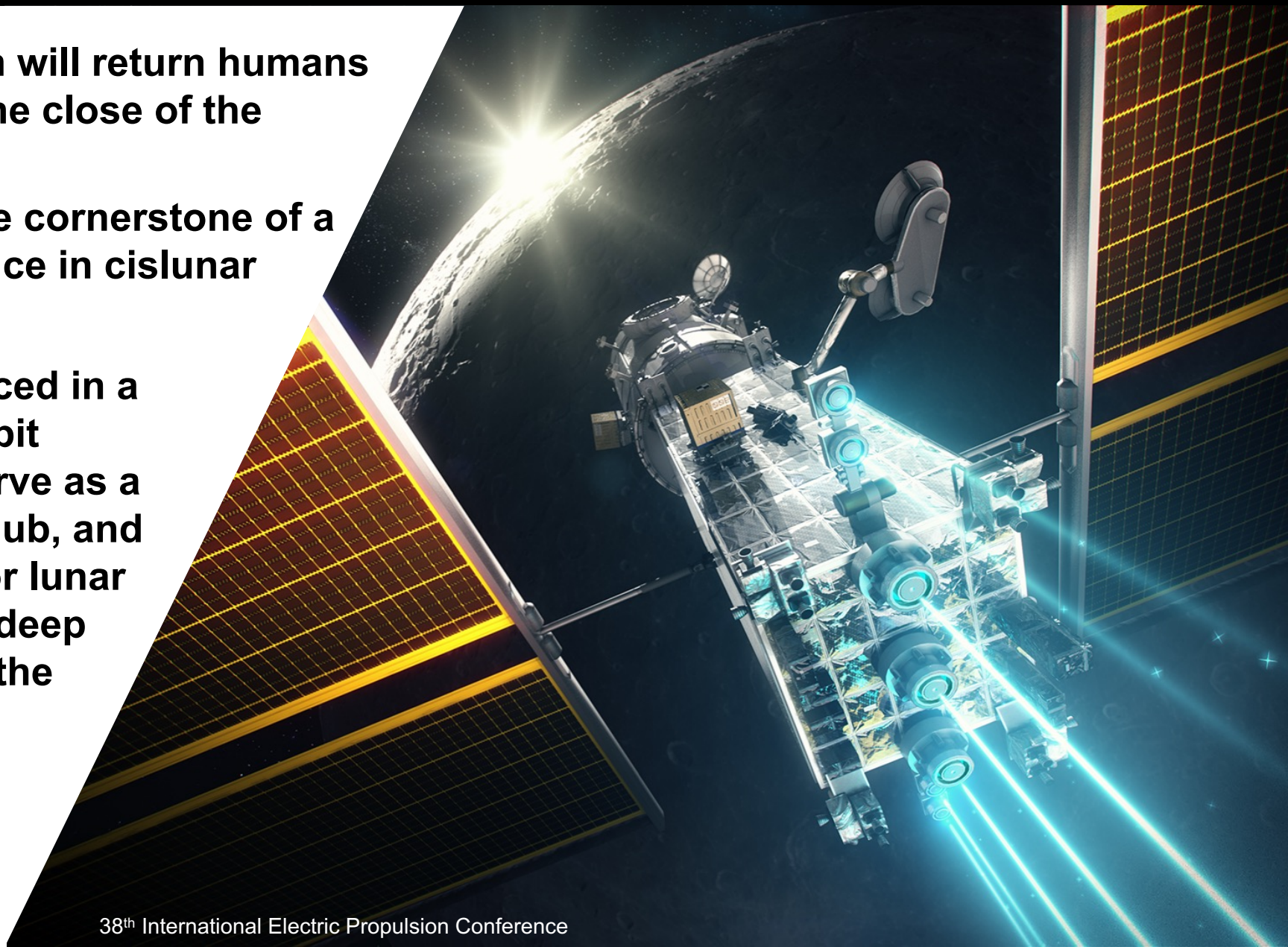
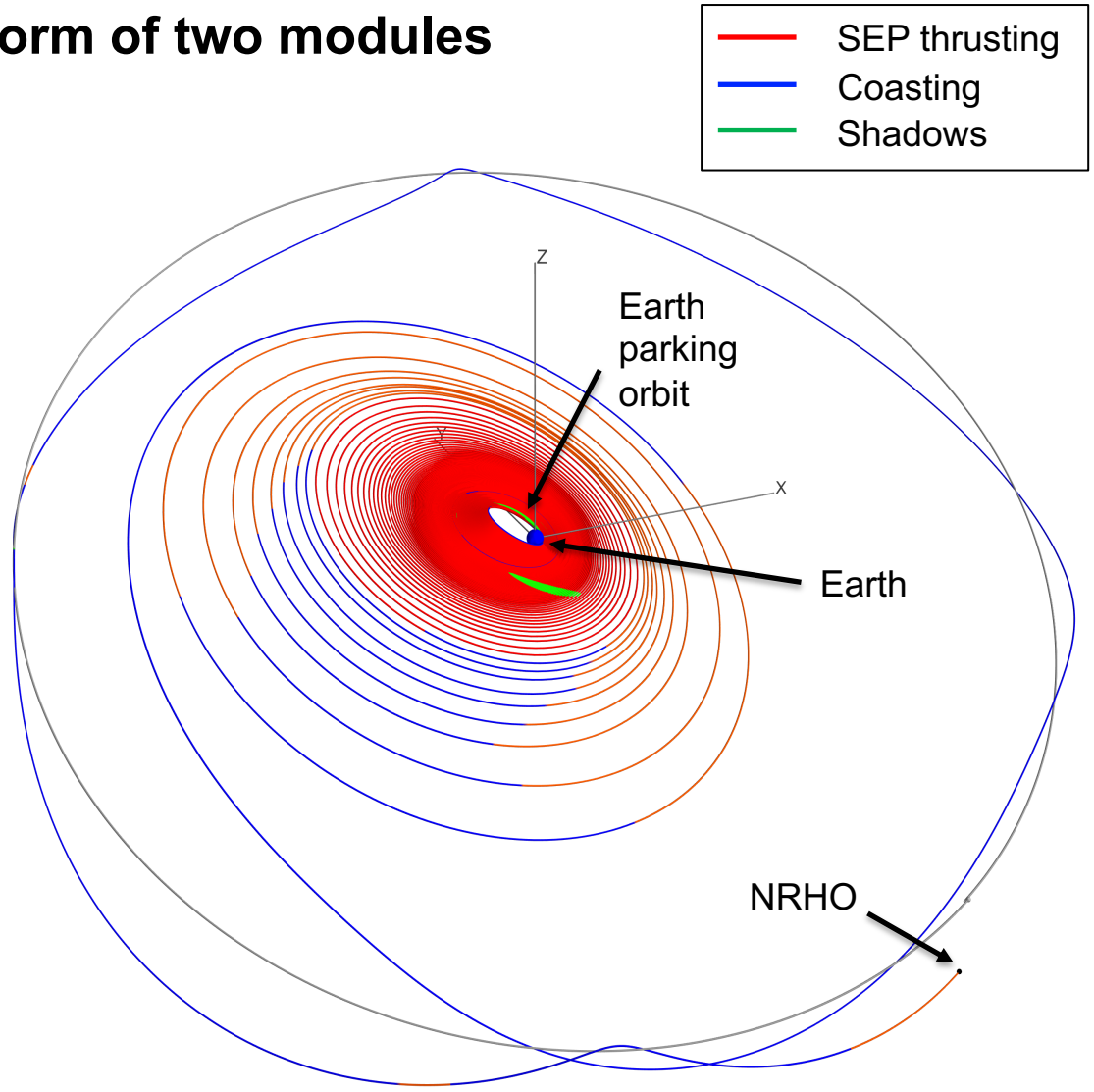
Background

- NASA's Artemis program will return humans to the lunar surface by the close of the decade
- Gateway will serve as the cornerstone of a sustained human presence in cislunar space
- As a crewed outpost placed in a Near Rectilinear Halo Orbit (NRHO), Gateway will serve as a staging point, logistics hub, and communications relay for lunar surface exploration and deep space missions beyond the Earth-Moon system



Gateway Lunar Transit

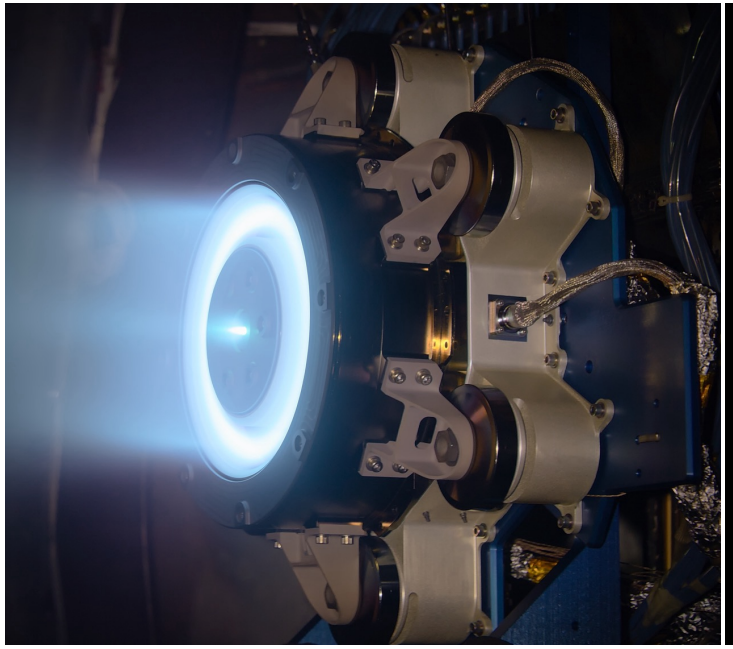
- **The initial capability of Gateway will come in the form of two modules**
  - Power and Propulsion Element (PPE)
  - Habitation and Logistics Outpost (HALO)
- **These two will be integrated into a single spacecraft on the ground and will launch and transit to the NRHO together as one vehicle[1]**
- **Gateway will be inserted into a highly elliptic Earth parking orbit by a Falcon Heavy commercial launch vehicle (CLV)**
- **The PPE Solar Electric Propulsion (SEP) system will then be used to complete a low-thrust spiral transfer trajectory to the target NRHO**
  - Demonstration of high-powered SEP
- **Visually similar to ESA's SMART-1 trajectory**



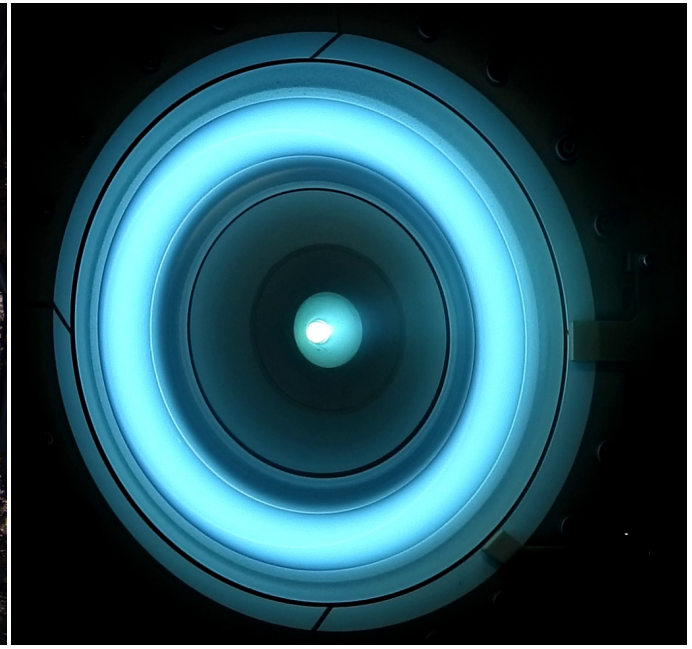
Lunar Transit Design Reference Mission 5
(Earth J2000 Reference Frame)

PPE SEP System

- **PPE will carry a 50kW SEP capability**
  - Most powerful EP system ever flown
  - Driven by 2x 35kW solar arrays[2]
- **7 individual thruster strings of two types**
  - 3x 12kW Advanced Electric Propulsion System (AEPS)
  - 4x 6kW Busek Hall Thruster 6000 (BHT-6000)[3]
- **2.3N total thrust capability at 2,600s Isp[4, 5]**



AEPS (image credit: NASA)

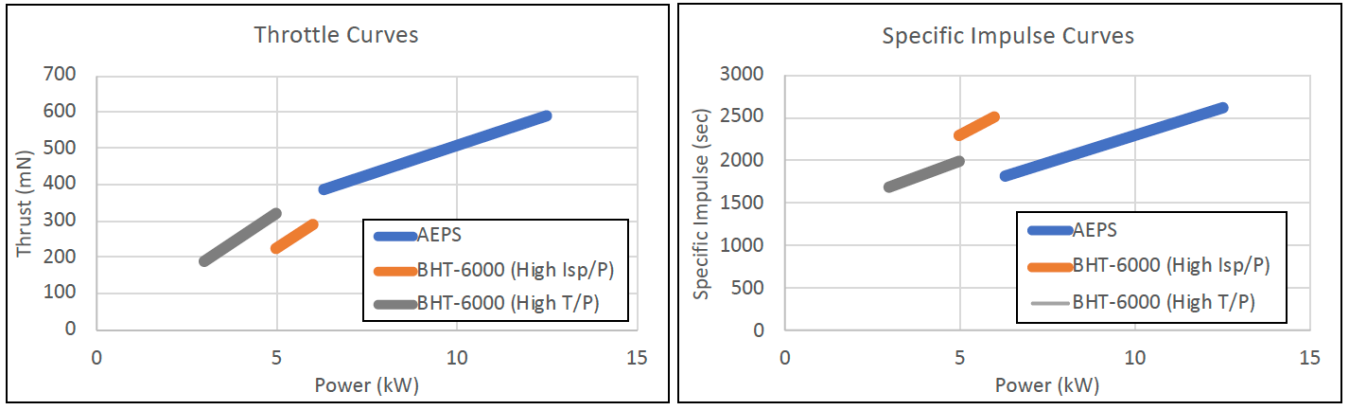


BHT-6000 (image credit: Maxar)

- **To transit Gateway from ~GTO to NRHO, PPE will produce more than 3,000m/s Δv[6]**
- **SEP system will consume >2,000kg[6] of Xenon propellant**
- **Lunar Transit will take in excess of 365 days of total transit time[1]**
- **Spiraling out of Earth's gravity well will consist of >300 days of nearly continuous thrusting[2]**
  - SEP will not be operated while the vehicle is in shadow or during critical vehicle activities such as communications system calibration

SEP Performance Assumptions

- **Mission Design assumes the SEP system to perform in one of two operating modes**
  - High Thrust[3]
    - BHT-6000's operate at 300V
  - High Isp[3]
    - BHT-6000's operate at 600V
- **Thruster performance is assumed to be linear with current input at a fixed potential within accepted ranges**
- **Individual strings can be throttled to match in-situ power generation capabilities of PPE solar arrays**



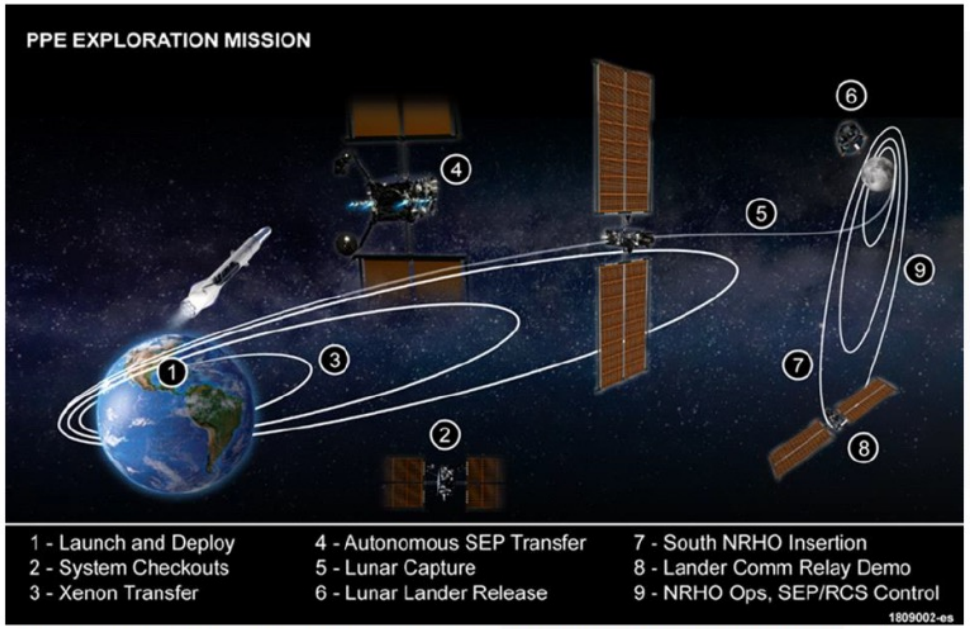
IPS Throttle and Performance Ranges[6]

Mode	Thruster Power (kW)	Thrust (N)	Isp (s)
High Thrust	46	2.36	2,458
High Isp	48	2.33	2,670

- **Lunar Transit is designed to take advantage of high thrust setting to more rapidly escape damaging Van Allen belts, then use high isp operating mode to complete the trajectory while minimizing propellant consumption**

Co-Manifesting Gateway's First Two Elements

- **Under the original CONOPS, the PPE was to transit alone to the NRHO**
  - HALO would transit separately on a more traditional high-thrust trajectory
- **In 2020, the co-manifesting of PPE and HALO was implemented to simplify the Gateway architecture**
  - Single launch architecture and delivery of an initial habitable capability via SEP
- **Addition of a complete second spacecraft significantly increased performance needs**



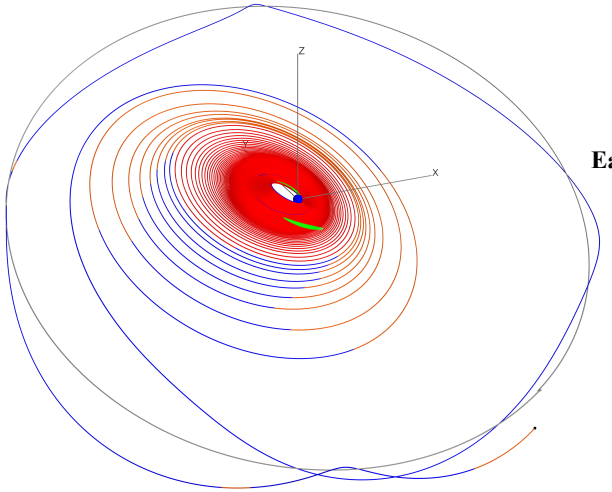
Gates M. et al. (2019). An Update on the Power and Propulsion Element: First Gateway Element Launch in 2022, 70th International Astronautical Congress (IAC), Washington D.C. United States, 21-25 October 2019

Original solo-PPE CONOPS

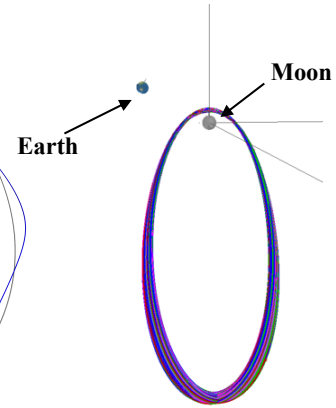
	Solo-PPE Transit[7]	PPE+HALO Transit
Transit Time	~180 days	>365 days[1]
Δv	~2,000 m/s	>3,000 m/s[6]
Xenon Used	~900 kg	> 2,000 kg[6]
SEP Impulse	~24 MNs	>50 MNs

IPS Impulse Requirements

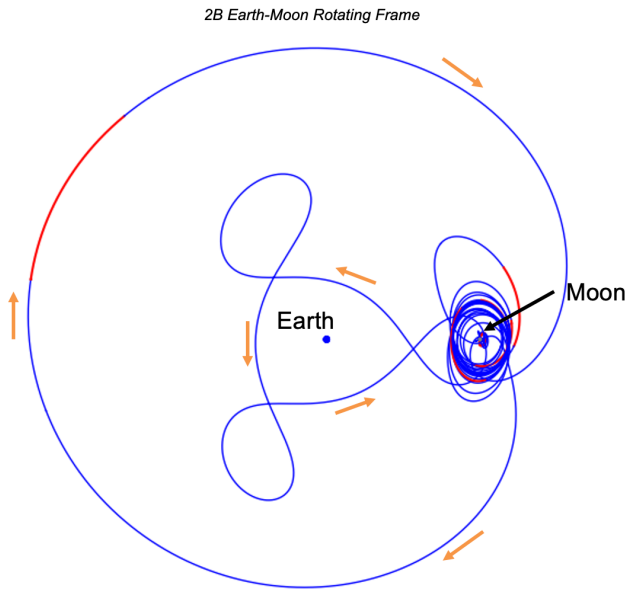
- **The PPE IPS is required to support the entire Gateway 15-year mission including:**
  1. Transit of PPE+HALO to the NRHO
  2. Station-keeping in the NRHO for 15 years
  3. Round trip uncrewed transit from NRHO to DRO and back to NRHO
  4. End of Life disposal of Gateway to a 70,000km DRO
- **Assumed configuration of thruster strings must have enough thruster lifetime to cover all 4 mission phases with positive margin**
- **All thrusters are not expected to last the entire 15-year Gateway mission**
  - Magnetically shielded AEPS are assumed to be available from BOL to EOL



Lunar Transit



9:2 L2S NRHO

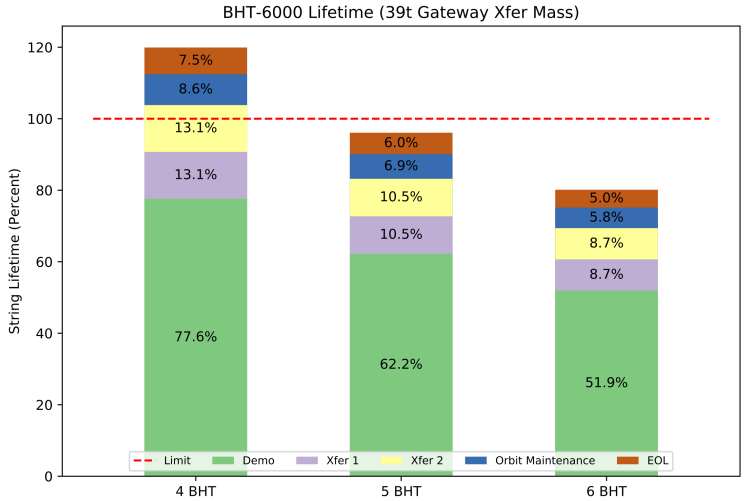


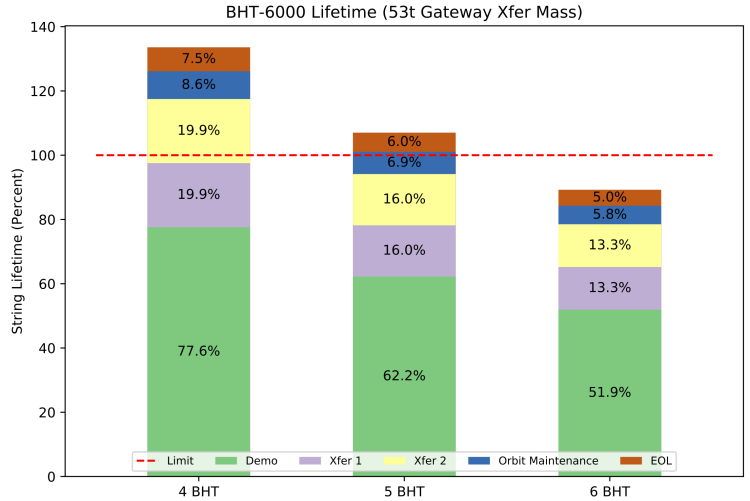
Gateway DRO Disposal

Thruster Configuration Trade Studies

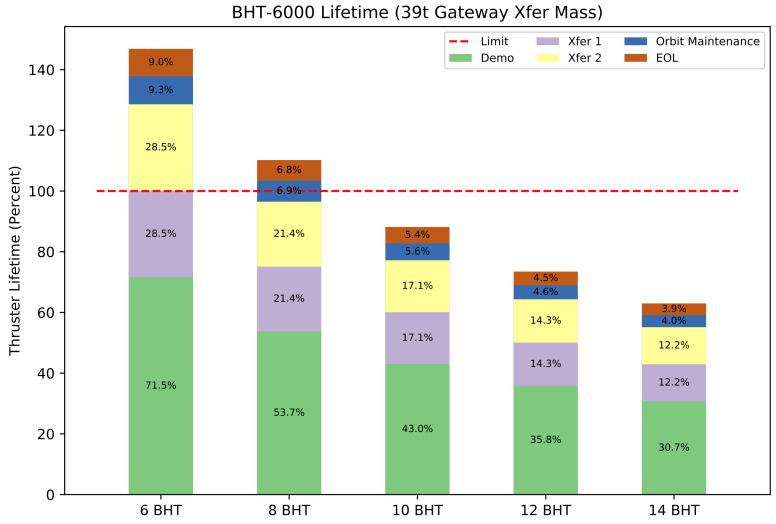
- **Early analysis assessed ability to complete Gateway mission assuming only BHT-6000 strings were available**
  - Zero AEPS strings onboard
- **Gateway stack mass may vary throughout mission lifetime**
  - NRHO-DRO transfers assumed to occur either at 39t or 53t
- **6 BHT-6000's held enough lifetime to cover Gateway mission prior to PPE+HALO co-manifest**
- **After PPE+HALO co-manifest, increased transit mass required at least 12 BHT's to cover Gateway lifetime**
  - Further motivated the inclusion of AEPS/HERMeS thruster

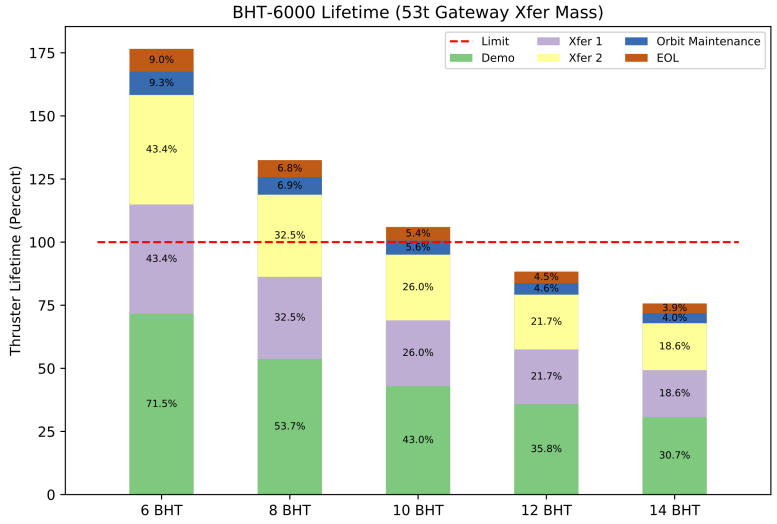
Solo-PPE Transit + Gateway Mission





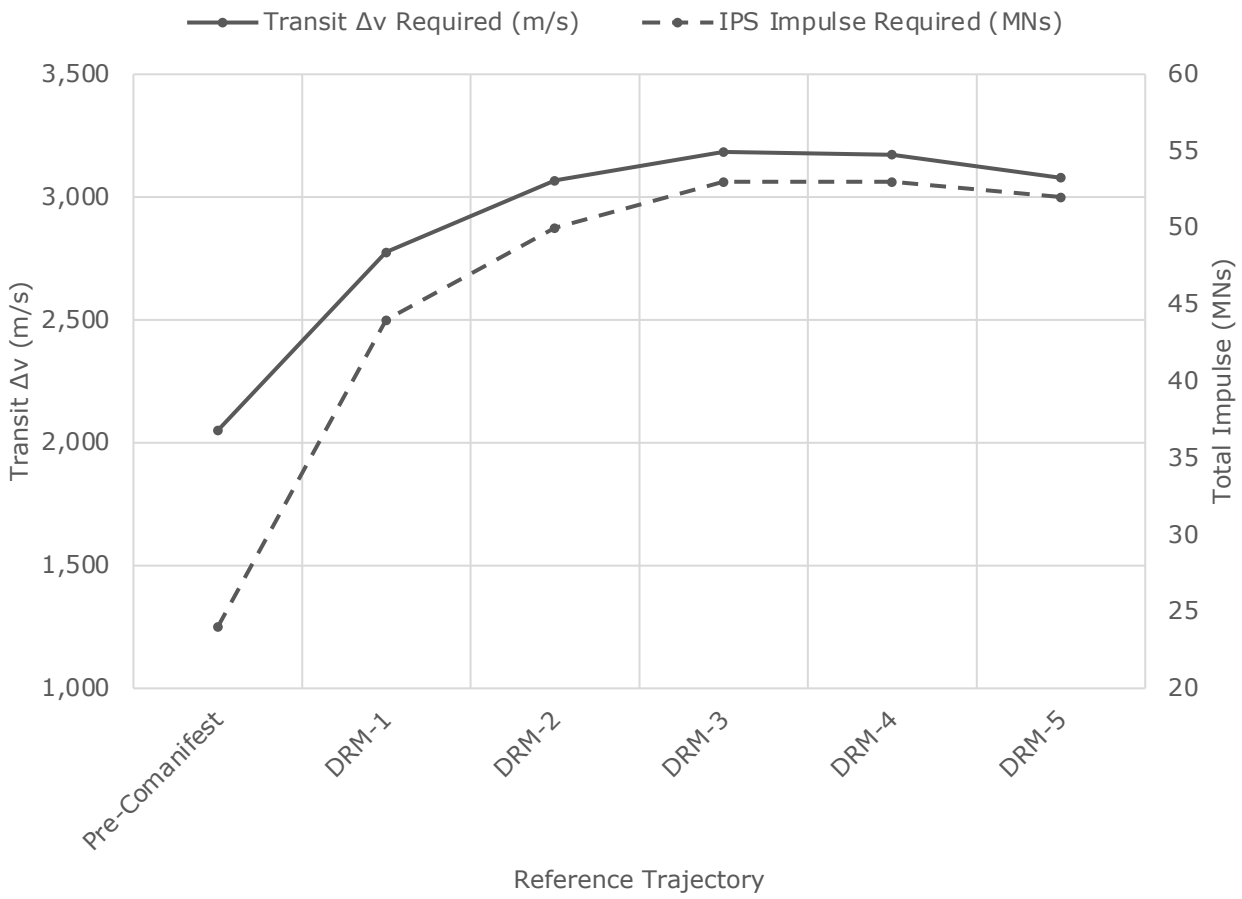
PPE+HALO Transit + Gateway Mission





Thruster Utilization History

- **The design of the Lunar Transit has matured over time along with the design of the PPE/HALO vehicles and their relevant subsystems**
- **The decision to co-manifest the PPE/HALO spacecrafts significantly increased propulsion needs**
  - ~2,000 m/s and 24 MNs solo-PPE
  - >3,000 m/s and ~53 MNs PPE+HALO
- **Addition of HALO to Lunar Transit CONOPS required 700 m/s more Δv and ~120% increase in SEP impulse**
- **The PPE IPS has absorbed this performance creep with minimal changes to vehicle architecture**



Conclusions

- **The PPE represents an order of magnitude step forward in on-orbit electric propulsion capabilities**
- **PPE's 50kW SEP system will power the delivery of Gateway's initial capability and is the foundation of NASA's sustained human presence in cislunar space**
- **The PPE+HALO low-thrust Lunar Transit is a true transportation application of EP**
  - Delivery of a massive crewed spacecraft to a dynamically sensitive destination, the NRHO
  - Unprecedented combination of spacecraft mass and Δv output
- **Flight demonstration of the Lunar Transit is the first step towards future EP transportation architectures**
  - Crew and cargo Mars vehicles
  - Robotic outer planets missions
- **SEP will support the entire 15-year Gateway mission with life to spare**
- **Gateway will support first crewed operations and visiting vehicles in future Artemis missions**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References

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5. W. Huang, J. Gilland, D. Herman, et al, "A Facility Effect Characterization Test of the BHT-6000 Hall Thruster," in *SciTech*, Orlando, 2024.
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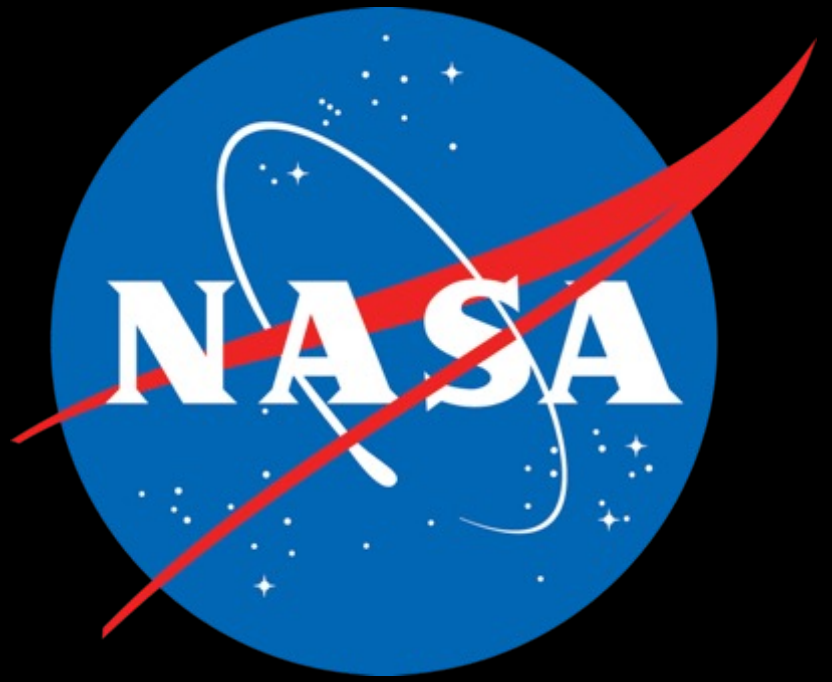
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