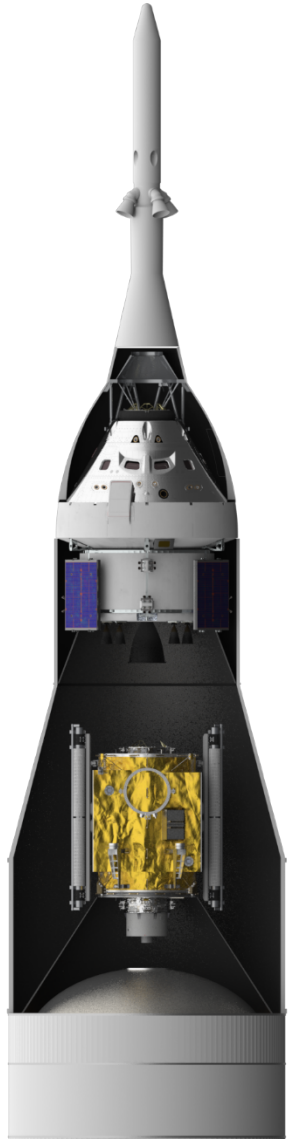
National Aeronautics and Space Administration

Power and Propulsion Element Update

Michele Gates, HEOMD November 30, 2017

What we Shared in the Last Meeting:
Power & Propulsion as a 1st Element in Gateway Concept

- Advantages of solar electric propulsion in cislunar space
  - Storable fuel
  - Translation flexibility
  - Mass savings
  - Technology advancement for deeper space applications
- A power & propulsion element (PPE) would provide key functions for the gateway including
  - Transportation and controls for lunar orbital operations
  - Power to gateway elements
  - Communications
- PPE would launch co-manifested on SLS with Orion on EM-2



Also from the Last Meeting:
Power & Propulsion Element (PPE) Near Term Events

✓ Release of PPE Request for Information and Synopsis for Studies through NextSTEP BAA Appendix C	Jul 17, 2017
✓ NASA Update to NASA Advisory Council HEO Committee	Jul 24, 2017
✓ RFI Responses Due	Jul 28, 2017
✓ STMD Electric Propulsion System Preliminary Design Review	Aug 1-3, 2017
✓ NextSTEP BAA Appendix C for PPE Industry Studies Release	Aug 2017
✓ PPE virtual industry day	Aug 17, 2017

Accomplishments against Milestones stated and since Last Meeting
Power & Propulsion Element (PPE) Related

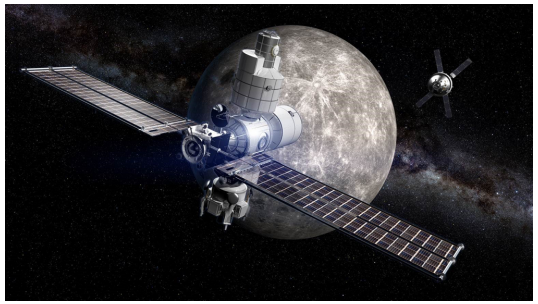
✓ Continued Kick off Interaction with NextSTEP BAA habitation contractors	July 2017
✓ Update stakeholders on ARM transition and potential strategy for SEP	July 2017
✓ NASA/European Space Agency TIM on cis-lunar concept in Houston	Jul 11-12, 2017
✓ Review of PPE Reference Requirements in NASA in Houston	Jul 12, 2017
✓ Update to HEOMD DPMC: top level reference PPE requirements	Jul 17, 2017
✓ Release of PPE Request for Information and Synopsis for Studies through NextSTEP BAA Appendix C	Jul 17, 2017
✓ NASA Update to NASA Advisory Council HEO Committee*	Jul 24, 2017
✓ NASA technical face-to-face meeting on standards and certification rqmts	Jul 26-28, 2017
✓ PPE RFI Responses Due	Jul 28, 2017
✓ NASA/ISS international partners cis-lunar concept technical iteration	Aug 1-3, 2017
✓ STMD electric propulsion system Aerojet Rocketdyne preliminary design review	Aug 1-3, 2017
✓ Release of NextSTEP BAA Appendix C for PPE Industry Studies	Aug 11, 2017
✓ PPE virtual industry day*	Aug 17, 2017
✓ Independent Review of PPE (MCR lite)	Sep 12-13, 2017
✓ HEOMD DPMC ATP for PPE	Sep 18, 2017
✓ Interactions with habitation BAA contractors 'cycle 1' *	Oct 2017
✓ Interactions with HEO and ISS international partners	Oct 2017
✓ PPE Industry Study Selection Announcement	Nov 1, 2017

Discussions with NextSTEP habitation and potential international partners are ongoing and will continue

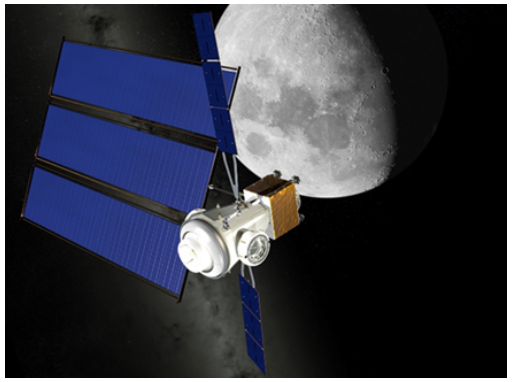
PPE Industry Study Selections

Five study contracts announced 01Nov2018.

All are under contract.



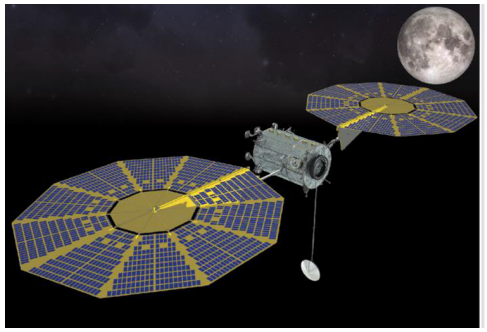
BOEING



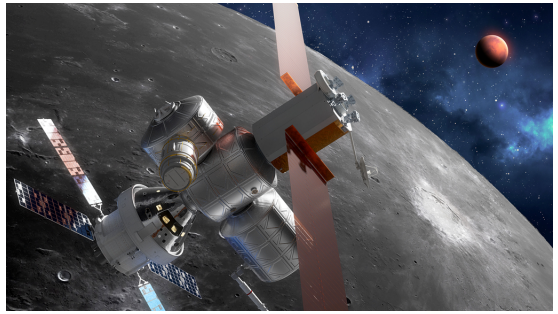
SIERRA NEVADA CORPORATION

AEROJET ROCKETDYNE

DRAPER



Orbital ATK



LOCKHEED MARTIN

SSL

DSS Deployable Space Systems

DRAPER

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Industry studies focused on examining differences between prior solar electric propulsion (SEP) mission concepts, expected industry capabilities, and potential needs supporting NASA's Deep Space Gateway concept

- **Overall objectives:**
  - **(Obj. #1): Identify and understand significant potential synergies between PPE specific capabilities and current and/or future commercially available capabilities**

    Includes identification of PPE specific capabilities that may be beyond current and/or future planned commercial capabilities. This could also include a variety of topics such as but not limited to the use of advanced solar electric propulsion, innovative ideas for partnership business models including intellectual property, asset ownership, and timing of delivery of the asset and/or services to the Government.
  - **(Obj. #2): Evaluate and understand driving technical differences and implications between prior concepts and approaches developed under the Asteroid Redirect Robotic Mission (ARRM) and the proposed concept for the PPE**

    Includes items such as implications to meeting reference technical requirements and/or drivers for validating a concept of operations.
  - **(Obj. #3): To obtain data that supports NASA's ability to define, derive, and validate the PPE requirements and a baseline mission concept**

    Includes identification of options and approaches to meeting PPE specific capabilities (as described in Attachment B of NextSTEP BAA Appendix C) and for contributing reliability and verification/validation data for a PPE approach that supports a human-rated DSG system.

Study Topics – Brief Descriptors

#1 – Approach for PPE Design and Verification

#2 – Minimize the Probability of the Occurrence of Failure Modes

#3 – Orbit Maintenance

#4 – Rendezvous and Docking of Crewed/Uncrewed Visiting Vehicles

#5 – Uncrewed Autonomous Orbit Transfer

#6 – PPE Power Generation and Power Transfer Capability

#7 – Two International Docking System Standard (IDSS) Interfaces

#8 – PPE 15-Year Lifetime

#9 – Long-Term, Autonomous Operations Approach for PPE

#10 – PPE High-Reliability Communications

#11 – Optical Communication Demonstration

#12 – Assessment of NASA Standards for a PPE in a Human-Rated DSG

#13 – PPE Extensibility to Current and Future Commercial Capabilities

#14 – Impacts of Acquiring EP Strings As Part of the Commercial Bus

#15 – PPE Accommodations for Hosting Hardware

#16 – Managing Battery Charge/Discharge During Eclipse Durations

#17 – Conceptual Layout, Potential Clearance and Blockage Issues

#18 – Crew Exercise and Implications of Extended Stay Durations

#19 – PPE Assembly, Integration and Test

#20 – PPE Extensibility to Future Exploration Support Systems

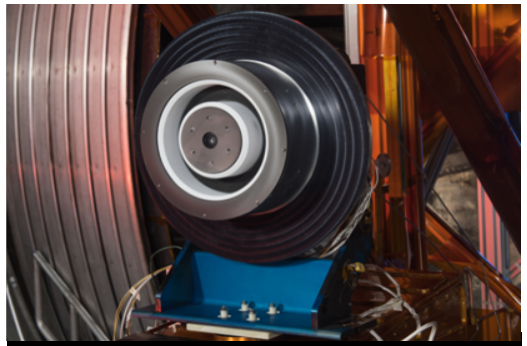
#21 – Attitude Control of the DSG Stack

#22 – Transferring Additional Power to DSG Elements

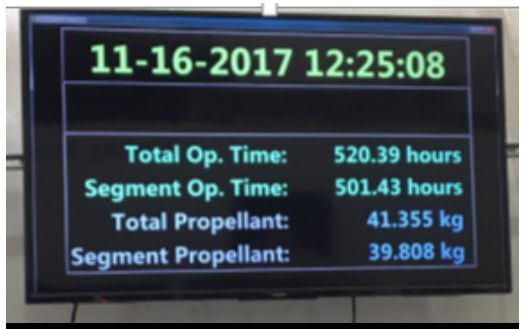
#23 – Avionics and Software

Electric Propulsion Progress
STMD Solar Electric Propulsion

Technology Demonstration Unit (TDU) life testing at Glenn Research Center and JPL environment testing.

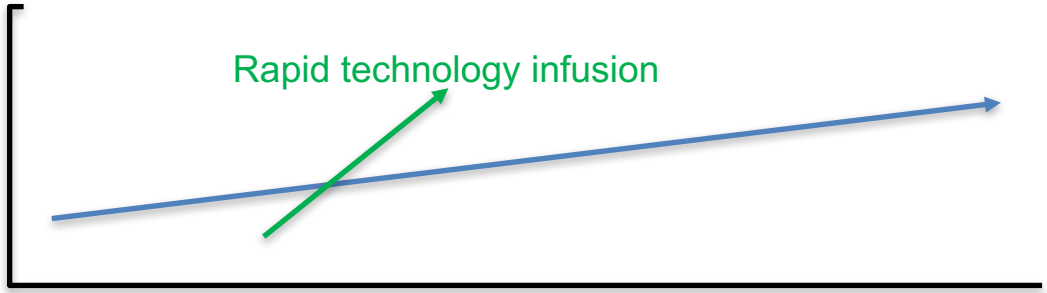


TDU-3 installed for testing

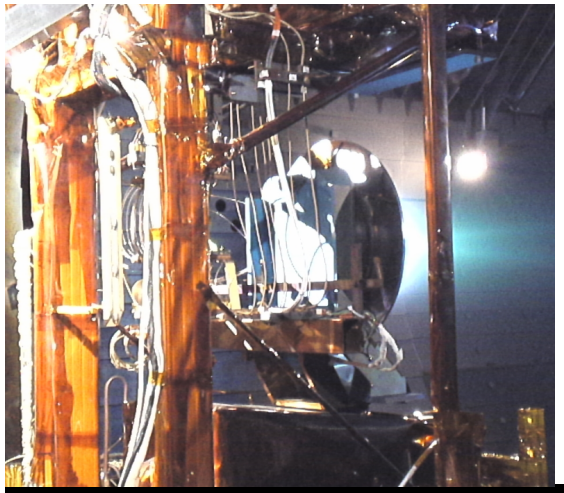


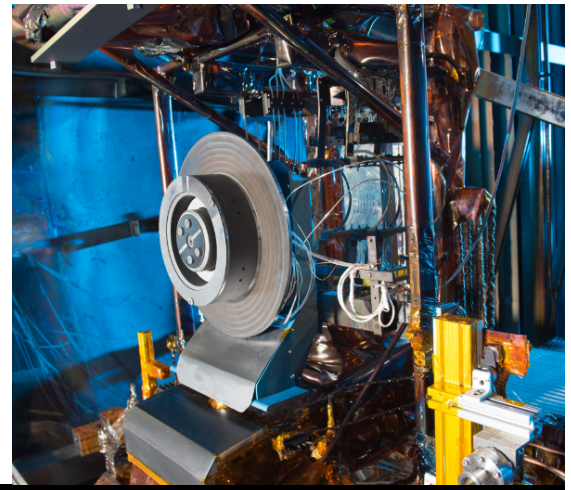
TDU-3 ongoing wear test

TDU power is 3x state-of-the-art with triple the lifetime

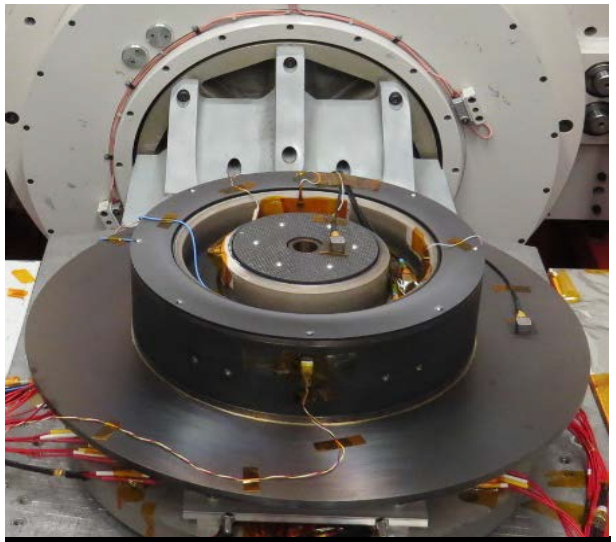


Public-private partnerships "could drastically reduce the time to market for these new EP technologies … from 10 to 15 years down to as little as 3–5 years."
Lev, et al., *New Space*, 2017

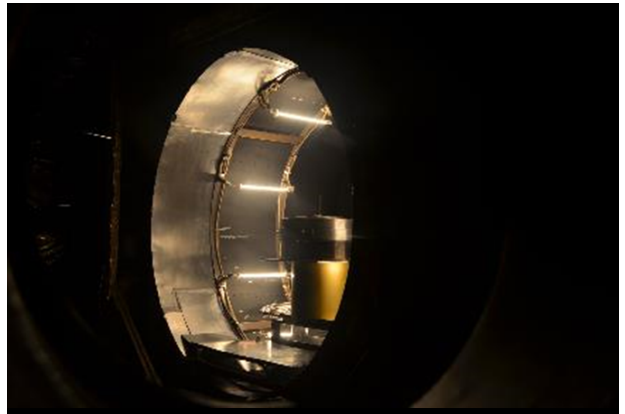




TDU-2 on the thrust stand



TDU-2 on the vibration table



TDU-2 mass model in TVAC shroud during pre-TVAC shakedown test.

PPE Near Term Milestones
as of Nov 29, 2017

✓PPE Industry Study Contracts Awarded	Nov 17, 2017
✓Kickoff Review of Interoperability Standards	Nov 17, 2017
• Orbital ATK PPE study kickoff	Nov 27, 2017
• Loral SSL PPE study kickoff	Nov 29, 2017
• Sierra Nevada Corp PPE study kickoff	Nov 30, 2017
• Boeing PPE study kickoff	Dec 4, 2017
• Lockheed Martin PPE study kickoff	Dec 5, 2017
• Industry study 45 day reports	Jan 2018

BACK UP

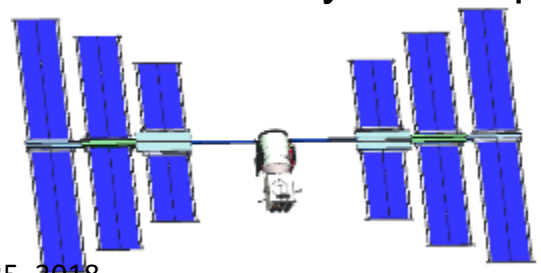
Advantages of Solar Electric Propulsion (SEP) in Cislunar Space

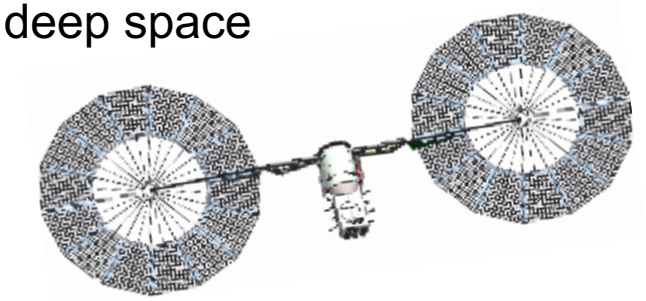
- **Fuel is storable, does not boil off, and can be resupplied**
- **Advanced EP provides the ability to move habitat systems to various orbits around the moon**
  - Halo, Lagrangian, or other Earth-Moon orbits
- **Analyses of in-space orbit transfers in the lunar vicinity shows a 5 to 15 fold savings in propellant with this system as compared to chemical-only systems with equivalent trip times**
- **Early use supports ensured extensibility to Mars class system**
  - Also directly applicable to a wide range of robotic and human spaceflight missions

* Chart reference NAC HEOC presentation July 25, 2018

Scalability to Higher Power Systems for Deep Space Human Exploration

- **High-power, 40-kW class system would be a step up from current technology and on the path to much higher power systems.**
  - Range of powers: 150 kW to 300 kW
- **Electric propulsion technology scalable**
  - Several Hall thrusters of higher power (~50kW) have been validated in a laboratory environment
  - Power Processing Unit (PPU) design is modular
- **The solar array is scalable beyond the 90kW class with the use of additional wings.**
- **The power per thruster/PPU string is a mission dependent system-level trade between fewer higher-power strings and more numerous lower-power strings.**
  - Current technology to demonstrate large scale SEP capability and performance also scales to the higher power vehicles to validate higher power generation and EP system capability in deep space





* Chart reference NAC HEOC presentation July 25, 2018

Approach to PPE Development

- **PPE would leverage advanced solar electric propulsion (SEP) bus formulation progress from ARM**
  - **Directly use U.S. industry current commercially available spacecraft capabilities**
  - **Infuse STMD developed advanced SEP technology**
  - **Align with U.S. industry plans for future use of SEP**

* Chart reference NAC HEOC presentation July 25, 2018