Aerojet

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Innovative In-Space Transportation for Servicing Applications

Presentation to

NASA GSFC Workshop

March 26, 2010

Approved for Public Release
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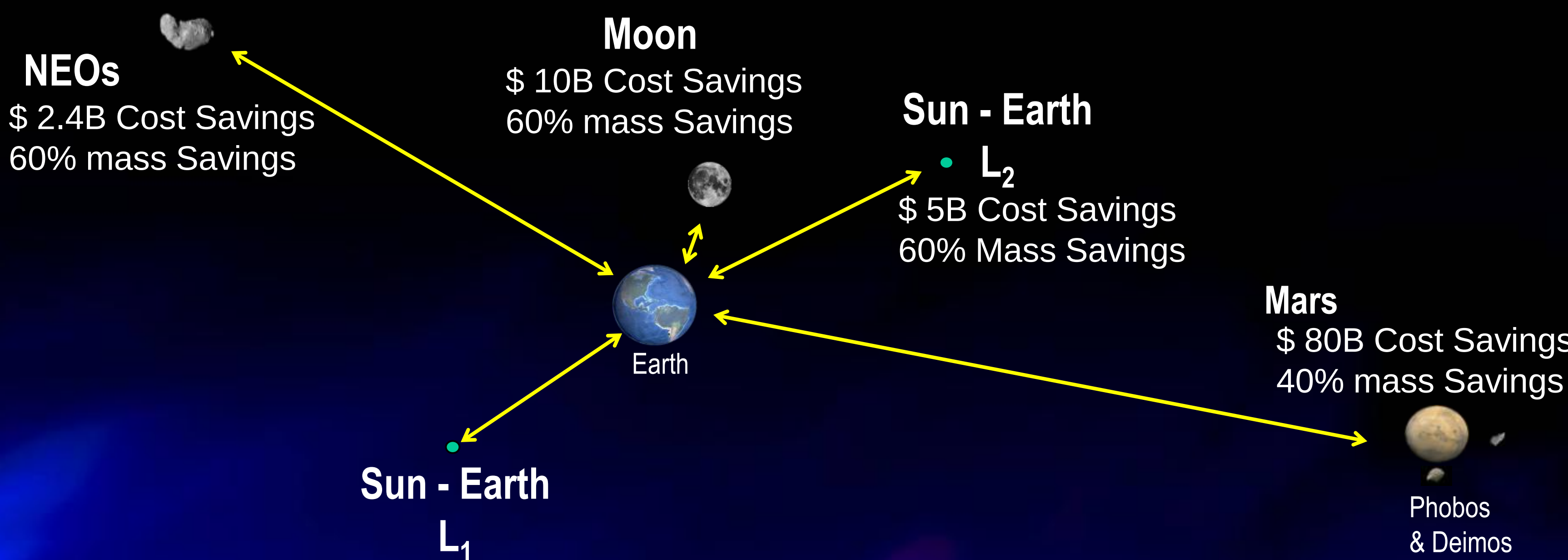
High Efficiency In-Space Transportation Payoff



Separate cargo transport with high specific impulse provides:

- Large reduction in Initial Mass to LEO (40%-60%)
- Substantial Mission Cost Savings
- Flexible: Applies across all destinations

SEP Tug enables a Low Cost, Radical Change In Space Transportation

AEROJET

World Leader in Electric Propulsion

Aerojet has 100% Mission Success on all In-Space Propulsion

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Aerojet Electric Propulsion Heritage

1983 – First Flight of Electrothermal Hydrazine Thruster (EHT) RCA Astro

1991 – First Flight of Improved Electrothermal Hydrazine Thruster (IMPEHT)
- Flying on 131 satellites today

1993 – First Flight of Hydrazine Arcjet System Telstar 4

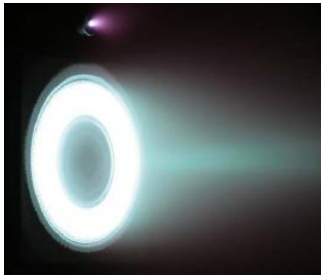
1996 – First Flight of 2 kW Hydrazine Arcjet System
- Flying on 51 satellites today

1998 – First Flight of Hall Thruster System on Western Spacecraft STEX

1999 – Highest Power EP Device Flown – 30 kW Ammonia Arcjet System – ARGOS/ESEX

NASA Investment in R&D and Flight Demonstrations Has Been Critical to Commercialization of Electric Propulsion by Aerojet

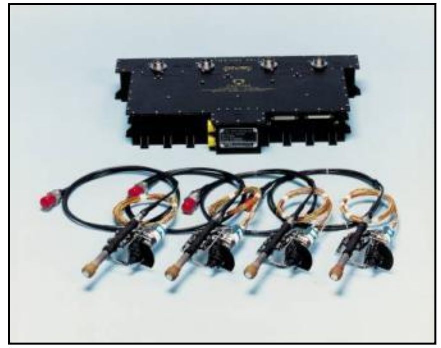
2002 – First All Propulsive ACS – Pulsed Plasma Thruster (PPT) System EO-1



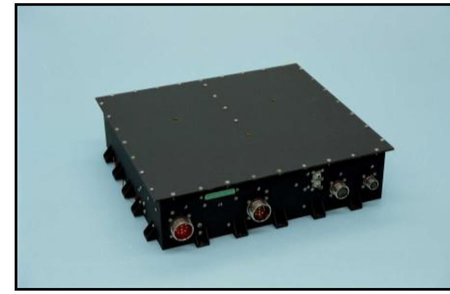
2010 (Expected) – Highest Power Hall Thruster System Demonstration Advanced EHF

Aerojet's EP Power Processing Experience

2kW Series 7000 Arcjet PCUs (1993)

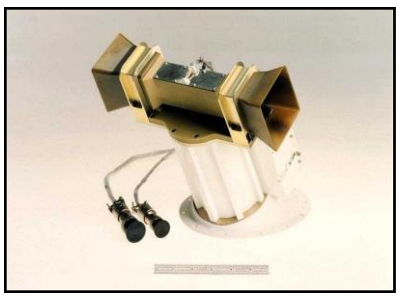


4.4kW A2100 Arcjet PPU (1995)



HTPS 4.5 kW PPU (2006)

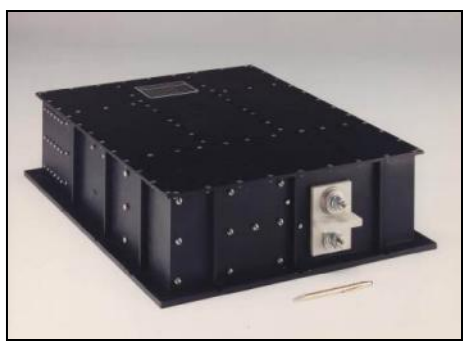
500W IMPEHT PCU (2002)



E0-1 PPT (1993)

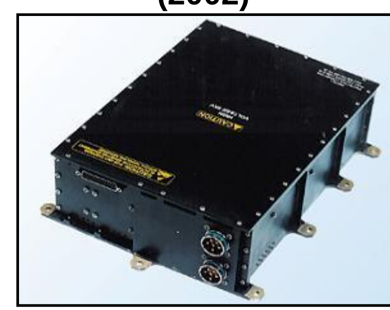
- Nine (9) EP PPU Products Qualified
- Over 100 Flight Units Delivered

4.4kW A2100 Switch Box (1995)



30kW ESEX Arcjet PCU (1993)

1.5kW STEX Hall PPU (1997)



2kW DRTS Arcjet PPU (1997)

Solar Electric Propulsion for In-space Transportation

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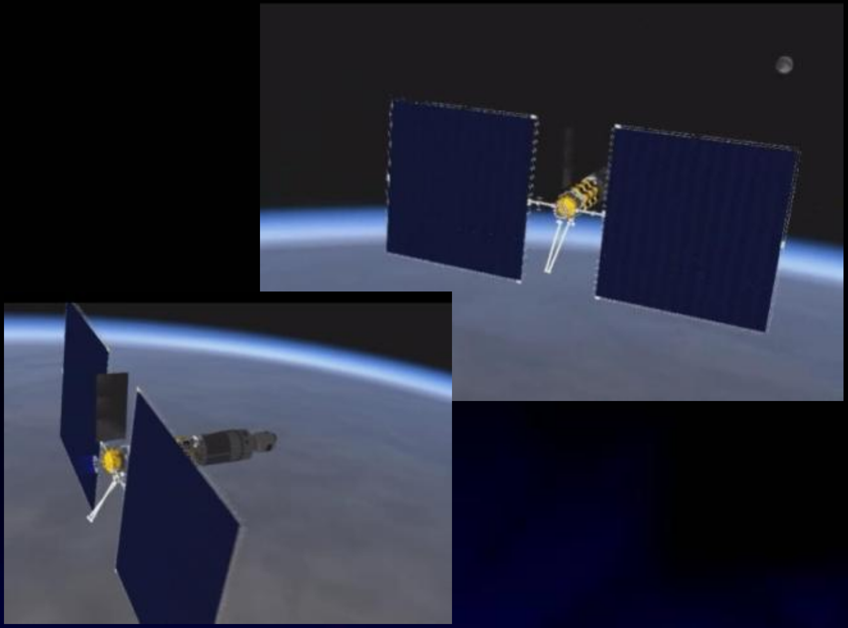

Dawn Spacecraft

- Exploring asteroids Ceres and Vesta
- First SEP Science Mission
- EP Enables Visits to Multiple Targets
- EP Provides Relaxed Launch Windows

SEP Cargo Tug Spacecraft

- Haul cargo from LEO to targets and back
- Scales from heritage platforms
- Provides Increased Mission Mass and Power Capability
- Reusable, Scalable and Extensible

Low Risk Technology Investments Needed for Scale-up In System Power and Flight Demonstration

Flight Electric Propulsion (EP) Power Levels are Consistent with 150kW by 2020

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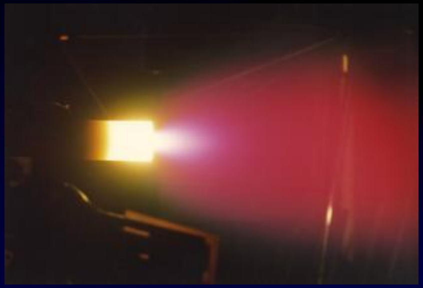
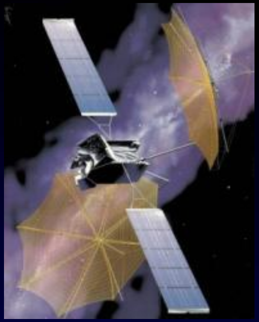
Flight Programs

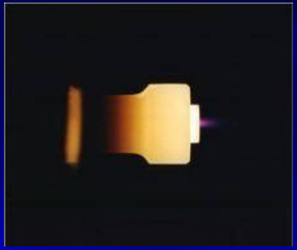
ESEX Arcjet
26 kW



Advanced EHF
10 kW

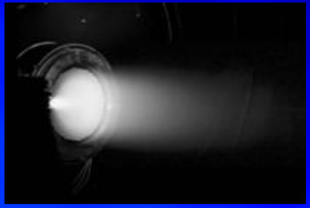


A2100™
4 kW



Deep Space-1
2.5 kW

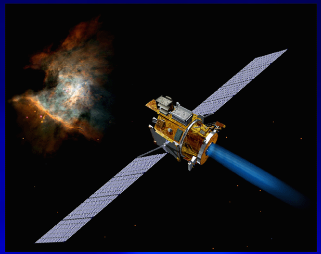
Hayabusa
350 W

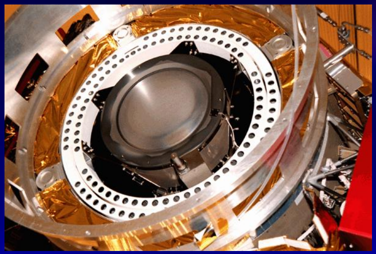


- **Thruster Technologies have been Demonstrated**
- **Available Power for EP is Increasing**

Maturity of Electric Propulsion

- Electric Propulsion (EP) launched on ~200 spacecraft
- All new large comsats, (i.e. A2100™, FS1300, BSS 702) use electric propulsion
- Dramatic improvements in Solar Array technology in recent years
  - Efficiency - from 19% to 28% in past 10 years - 37% demonstrated
  - Specific Mass – 45 W/kg(1998), 180 W/kg (Today), 350 W/kg (2010)
- Demonstrated lifetimes in excess of 30 khr (5 years operational time)
- LEO to Lunar Orbit transfer with EP, already demonstrated on SMART-1 by Europeans
- Transfer from asteroid Itokawa accomplished by Japanese on Hayabusa





Electric Propulsion Used <u>Today</u> at Power Levels up to 20 kW

SEP Tug Applications

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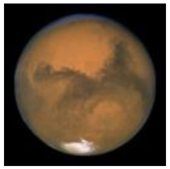


Mars
~14km/s from LEO

Mars Exploration Logistics
- LEO-LMO environment characterization
- Orbiter delivery
- Lander delivery
- Sample return mission support
- Human lander pre-positioning

Moon
8km/s from LEO

Lunar Exploration Logistics
- LEO-LLO environment characterization
- Orbiter delivery (Observers, Lunar GPS constellation)
- Lander delivery
- Human lander pre-positioning

L1, L2
~6 to7km/s from LEO

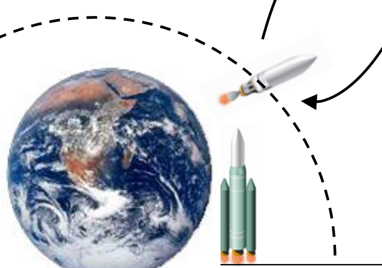
Large Telescope Logistics
- Reboost
- Refuel
- Repair
- Upgrade

MEO, GEO
<6km/s from LEO

Satellite Servicing
- Reboost
- Refuel
- Repair
- Upgrade

LEO

Autonomous Rendezvous
- Refuel tug vehicle
- Drop off payloads (sample return missions)
- Pick-up new payloads
- Re-purpose tug vehicle

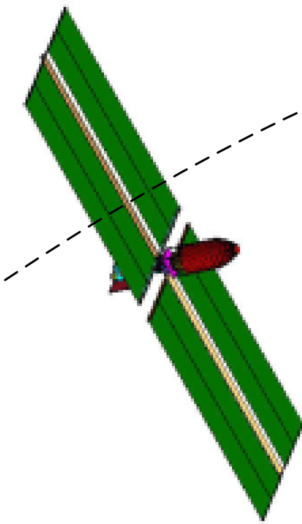


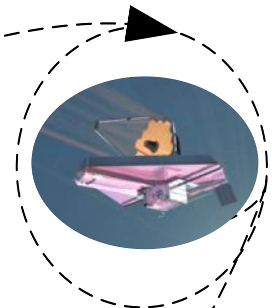
SEP Tug provides Evolutionary Path to Sustainable Human Exploration

SEP Tug – Concept of Operations

Destinations

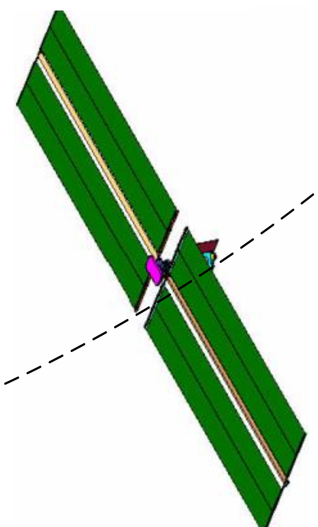
- – L1, L2
- – Moon
- – Mars
- – MEO
- – NEO

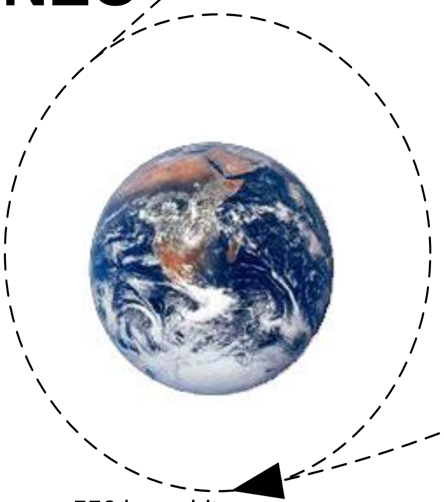




Typical Telescope Servicing Mission Cargo Manifest:

- New Instruments
- New Gyros
- Cryogens
- Fuel





Baseline Design – 5+ Round Trips

Missions

- – Satellite Refueling & Servicing
- – Fuel Depot Transfer
- – Autonomous Rendezvous
- – Debris Remediation
- – Deploy Telescopes & Return

Electric Thruster Technology

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	Current (TRL = 6 or above)	Near Term (TRL = 4 - 5)	Future (TRL = 3 or below)
Hall Thruster	 4.5 kW 290 mN 1790 sec	 20 kW 1.3 N 2200 sec	 150 kW 6.0 N 3300 sec
Ion Thruster	 7 kW 240 mN 4200 sec	 25 kW 540 mN 6000 sec	

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SEP Tug Evolutionary Development

2022

2014

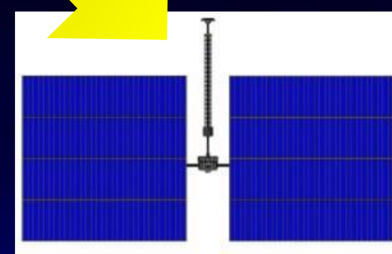
2018

500 kW SEP Tug

Fully Operational Cargo Transport

30 kW System Demo

Near Term Demo:
- Prove orbital maneuvering
- Measure radiation effects
- Assess system interactions
- Pathfinder for operations



100 kW System Demo

Mid Term Demo:
- Scale up of key systems
- On-orbit refueling
- Autonomous Rend. & Dock
- Payload retrieval

SEP Tug capability is achievable within the NASA planned budget and schedule

Summary

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- **Aerojet is a World Leader in Electric Propulsion**
- **Investment in Innovative In-Space Propulsion has High Payoffs**
  - **SEP Tug will cut the cost of logistics transportation in half**
  - **Technologies needed for a space tug are ready for demonstration**
- **Key to developing a more economic In-space transportation architecture are investments in:**
  - **In-Space Electric Propulsion**
  - **Solar Array Technology**
  - **Power Conversion**
- **Aerojet led the 2005 NASA ESRT program to develop a 600kW SEP Tug for lunar mission logistic support**

Our Goal is to Develop an Evolutionary Path to Change the Economics of Space Transportation by Enabling Low Cost Transfer of Cargo and Supplies

Why does propulsion matter?

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- "Any new capabilities that the space-faring nations will have depend in large part on the progress of propulsion research…The few million dollars that have been spent by NASA for advanced propulsion research have been devoted almost entirely to squeezing another few percent out of hydrogen-oxygen chemical propulsion systems. Scarcely a cent has been spent on genuine new technology. If you spend all your resources on one percent improvements, and ignore anything that might give you factor-of-ten improvement, then of course you are immortalizing a level of technology that otherwise would have inevitably given way to new, superior systems."
  - John S. Lewis (ca. 1987)

Contact Information

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