Future NASA Power Technologies for Space and Aero Propulsion Applications

Presented to

Workshop on Reforming Electrical Energy Systems Curriculum

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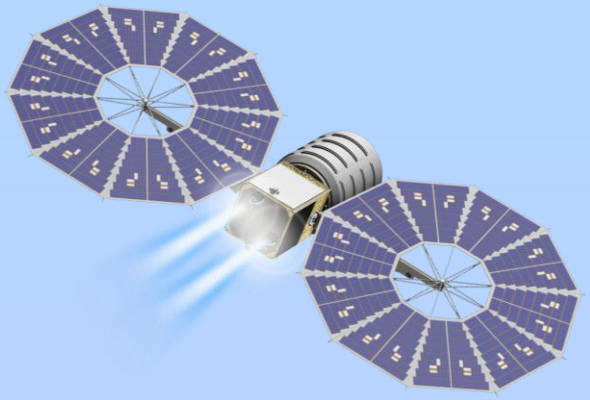


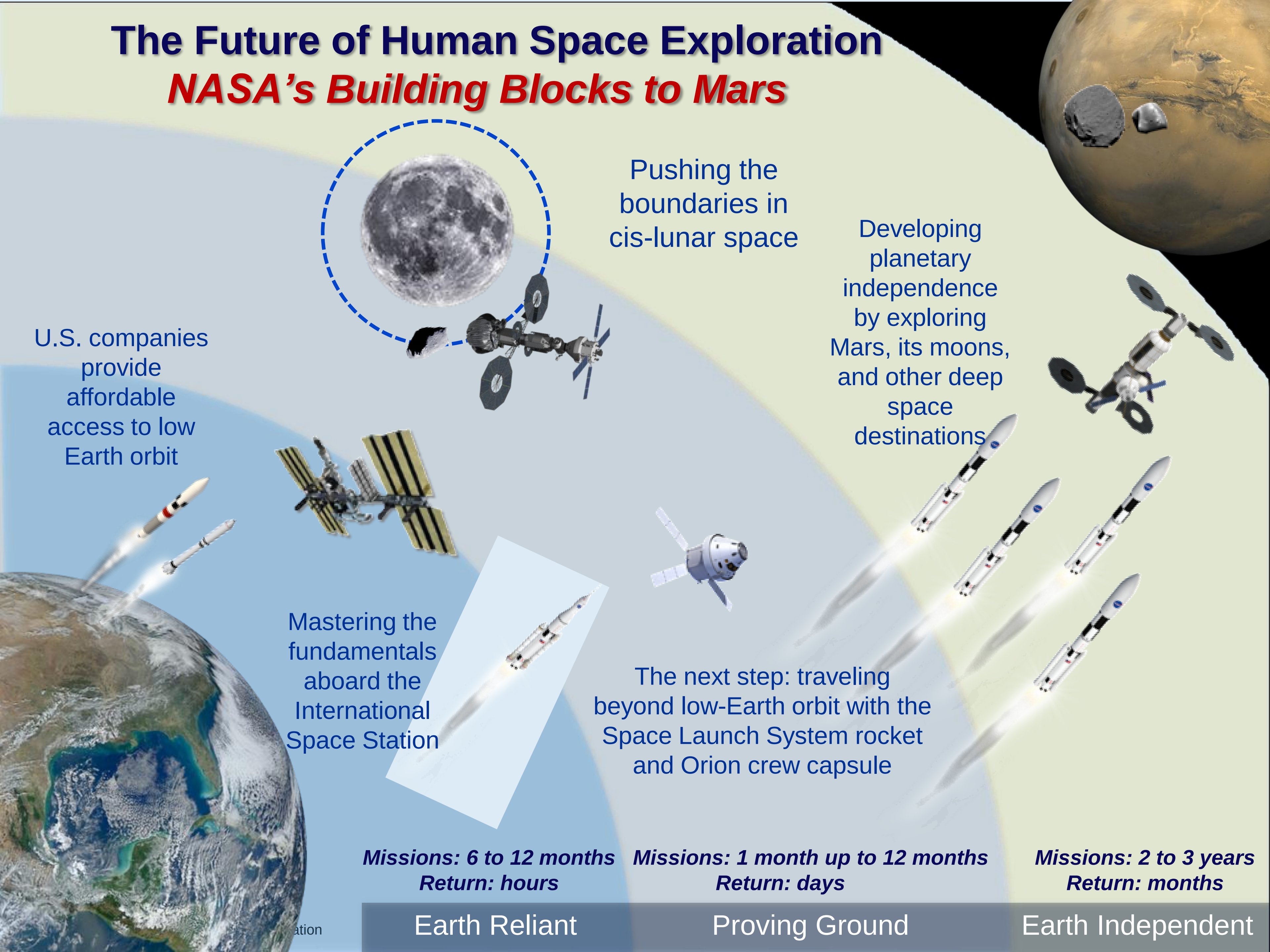
Discussion Topics

- Exciting students on electrical engineering
- Space Power Development Objectives and Roadmap
- Aircraft Power Development Objectives and Roadmap
- Observations on student needs
- Take Aways

Exciting Students on Electrical Engineering

- One of the key themes at the last workshop was the need to excite students on EE
- In subsequent discussions the seems to be two big draws for students
  - Make a difference in people's lives
  - Need to develop new "things" to achieve the above
- For example: Areas such as biomedical engineering are of great interest because of the potential societal impact
  - Even though the area does not pay as well as EE
- To that end electrical propulsion for space and aeronautics applications holds the potential to have resource impacts on earth and open up space for commercial use and exploration

Space Power Development Objectives and Roadmap


The Future of Human Space Exploration
NASA's Building Blocks to Mars
Pushing the boundaries in cis-lunar space
Developing planetary independence by exploring Mars, its moons, and other deep space destinations
U.S. companies provide affordable access to low Earth orbit
Mastering the fundamentals aboard the International Space Station
The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion crew capsule
Missions: 6 to 12 months
Return: hours
Missions: 1 month up to 12 months
Return: days
Missions: 2 to 3 years
Return: months
Earth Reliant
Proving Ground
Earth Independent

Advanced Vehicles for Exploration

Orion / MPCV

- 4 Crew
- 2.5 times volume of Apollo
- 16.5 feet in diameter
- (4)solar arrays 11.1kW power total
- Four 120 Volt power channels w/ SiC Switching
- (4) Lithium Ion 30 amp*hr batteries

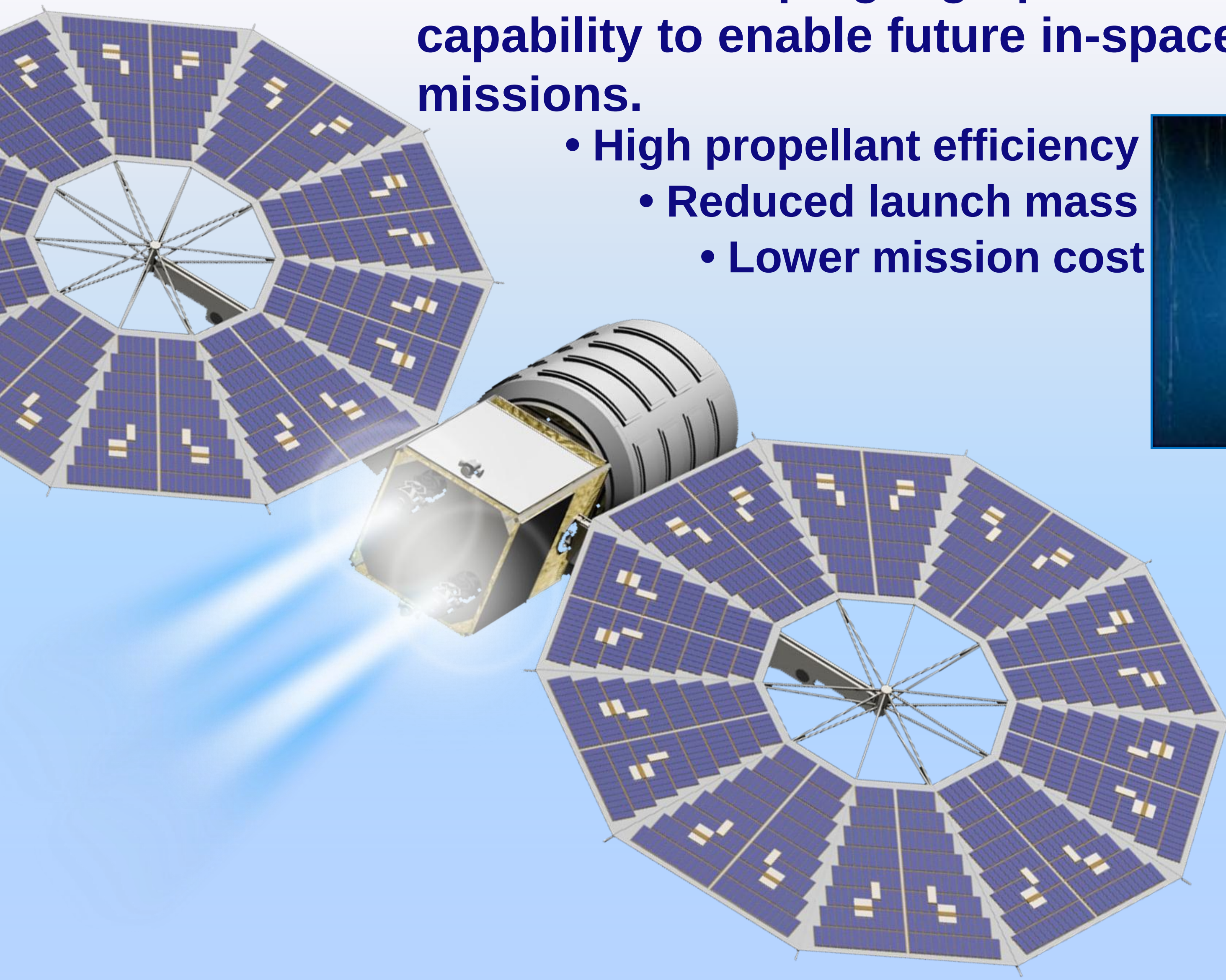
SLS launch Vehicle

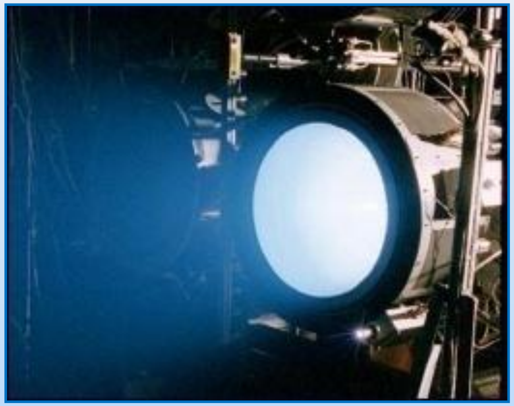
- 70 metric tons scalable to 130 metric tons
- LOX propulsion based on Shuttle

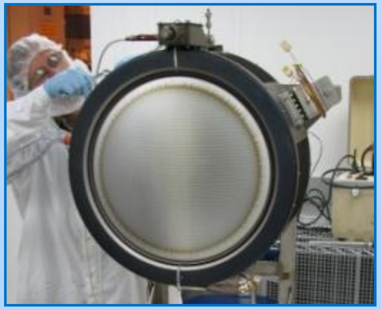
Solar Electric Propulsion (SEP)

NASA is developing high-performance SEP capability to enable future in-space exploration missions.

- **High propellant efficiency**
- **Reduced launch mass**
- **Lower mission cost**

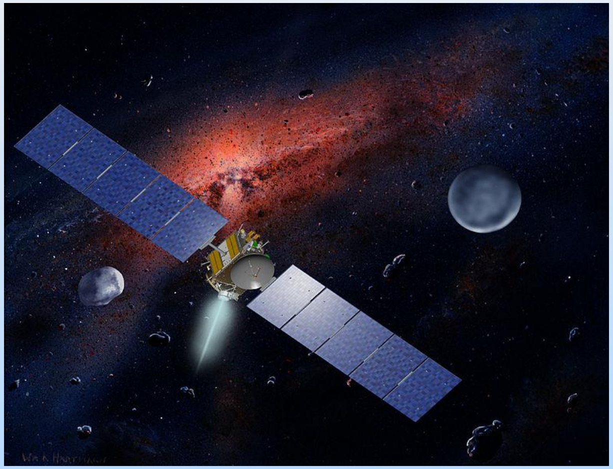




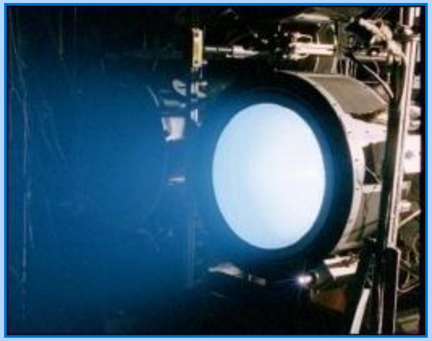


What is Solar Electric Propulsion?

This:



Dawn Spacecraft



Ion Engine

- A low mass / high efficiency propulsion system typically used for reconnaissance of planets and asteroids

- Results in very long travel times for missions – Not high speed intercept

- Real ion propulsion develops fractional Newton's or fractional lbs of thrust

Not That:

Twin Ion Engine (TIE) Fighter from Star Wars

Solar Electric Propulsion (SEP)

Description

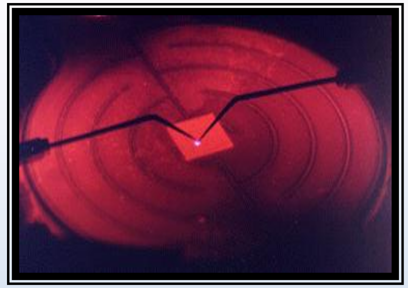
- Provides high propellant efficiency or ISP = 3000 vs 450 for H2 / O2 Prop.
- Fuel -- Xeon gas
- Reduced launch mass over chemical systems

GRC Role

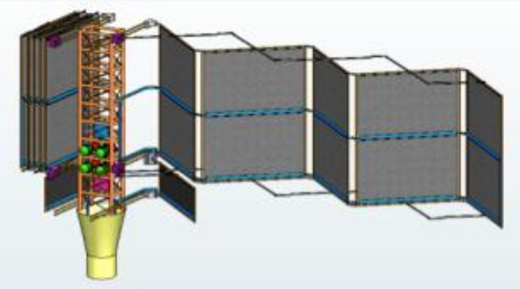
- Block I vehicle power 50kW (BOL) and 42kW (EOL)
- Extendable to 150klW
- Operates over a range from 0.8 AU to 1.9AU
- Applicable to a wide variety of missions
  - Asteroid Retrieval
  - Cargo
  - Orbit Stabilization

Long-Range Space Power Technology Developments

Autonomous power management



Radiation tolerant wide Band-gap semiconductors



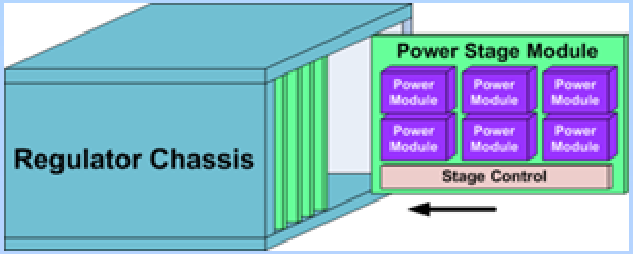
Nuclear surface power

Advanced energy storage systems

High power solar arrays

Non-flow through fuel cells

Efficient, high voltage power processors



Modular power electronics

Aero Electric Power and Propulsion

Aircraft Turboelectric Propulsion

Projected Timeframe for Achieving Technology Readiness Level (TRL) 6

Power Level for Electrical Propulsion System

Spinoff Technologies Benefit More/All Electric Architectures:
- High-power density electric motors replacing hydraulic actuation
- Electrical component and transmission system weight reduction

>10 MW
- Turboelectric and hybrid electric distributed propulsion 300 PAX

5 to 10 MW
- Hybrid electric 737–150 PAX
- Turboelectric 737–150 PAX

2 to 5 MW class
- Hybrid electric 100 PAX regional
- Turboelectric distributed propulsion 150 PAX

1 to 2 MW class
- Hybrid electric 50 PAX regional
- Turboelectric distributed propulsion 100 PAX regional

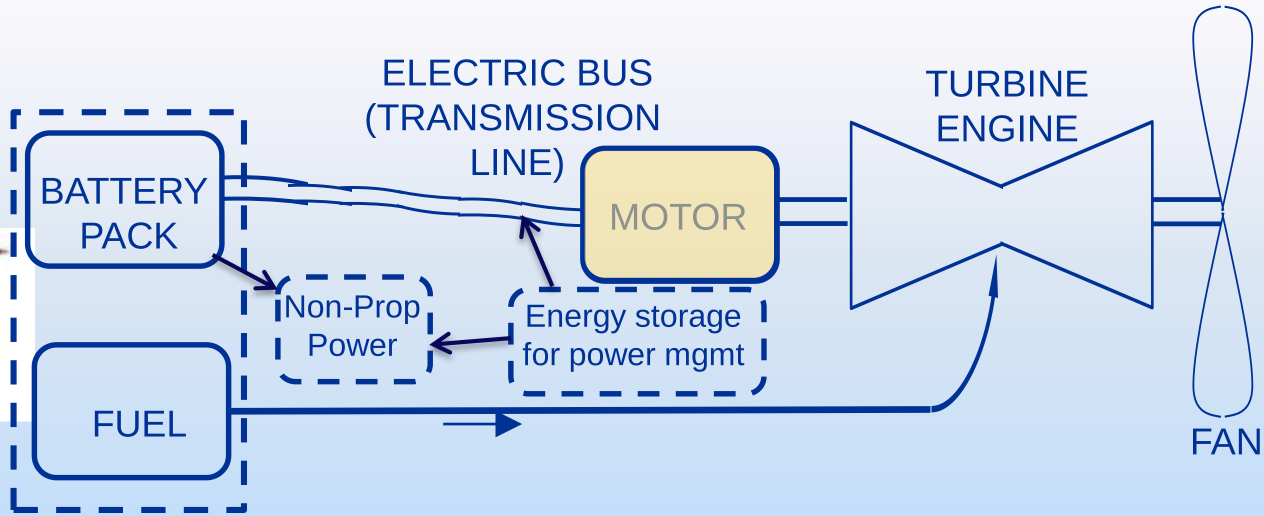
kW class
- All-electric and hybrid-electric general aviation

(Power level for single engine)

Today | 10 Year | 20 Year | 30 Year | 40 Year

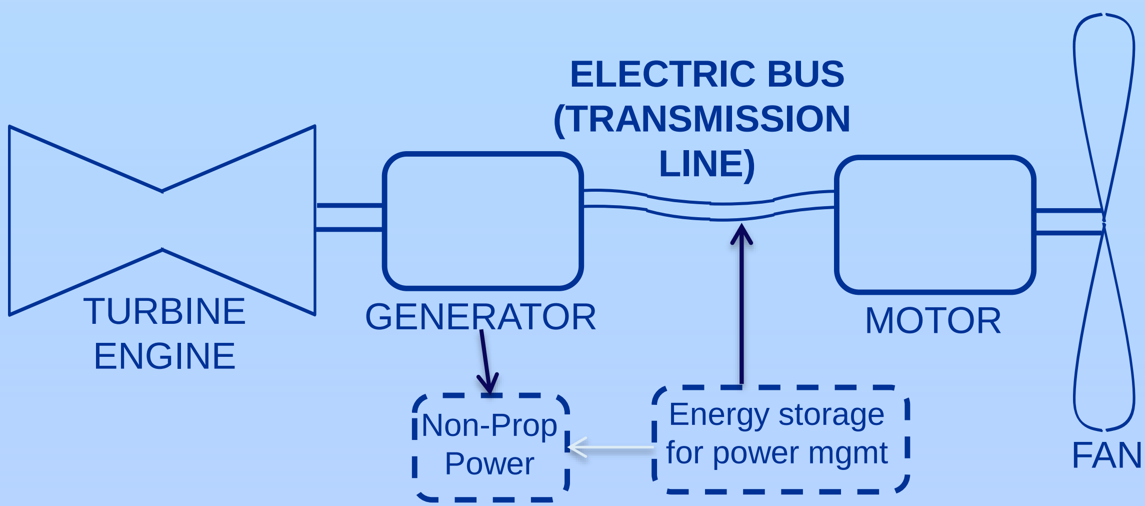
Possible Future Commercial Large Transport Aircraft

Hybrid Electric



Both concepts can use either non-cryogenic motors or cryogenic superconducting motors

Turbo Electric



Benefits Estimated For Electric Propulsion

Hybrid Electric Propulsion

- ~60% fuel burn reduction
- ~53% energy use reduction
- 77-87% reduction in NOx
- 24-31 EPNdB cum noise reduction

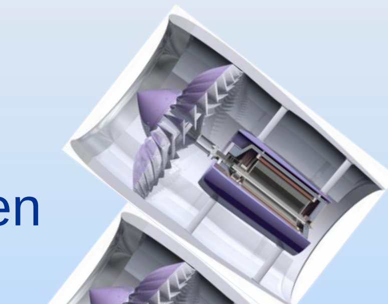
Turbo Electric Propulsion

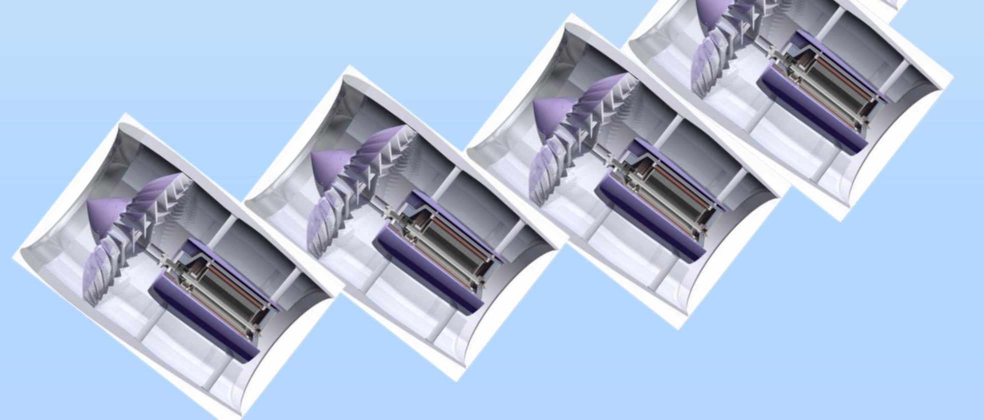
- ~63% energy use reduction
- ~90% NOx reduction
- 32-64 EPNdB cum noise reduction

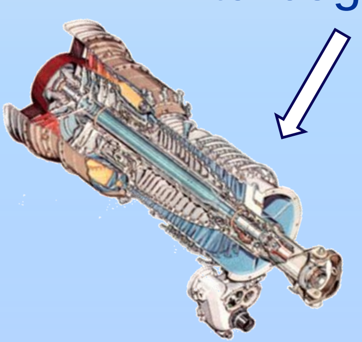
Aircraft Turboelectric Propulsion

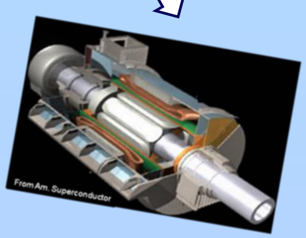
Wingtip mounted superconducting turbogenerators

Superconducting motor-driven fans in a continuous nacelle



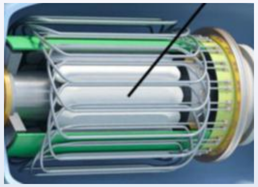




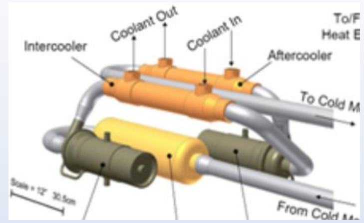


Power is distributed electrically from turbine-driven generators to motors that drive the propulsive fans.

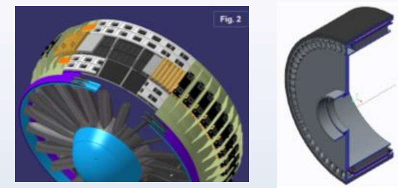
Long-Range Aero Power Technology Development



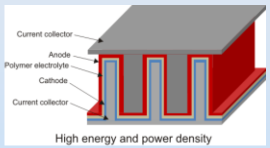
Fully Superconducting Motor/Generators



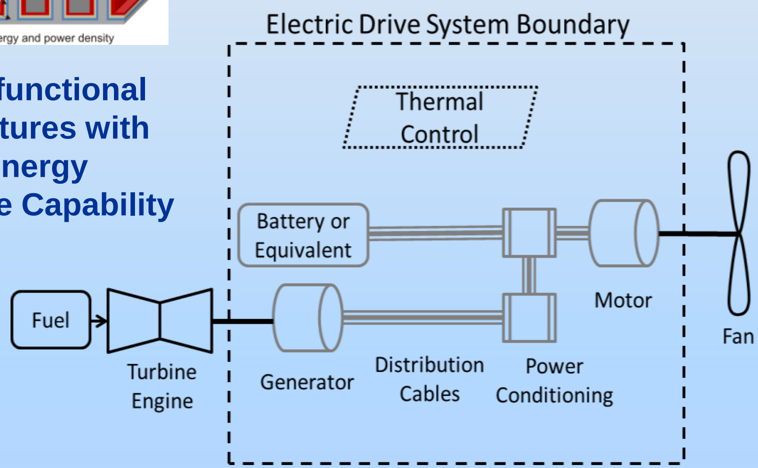
Lightweight Cryogenic Coolers



High Specific Power/Efficiency Non Superconducting Motor/Generators

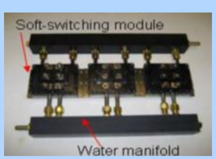


Multifunctional Structures with Energy Storage Capability



Lightweight/ High Specific Power Thermal Management

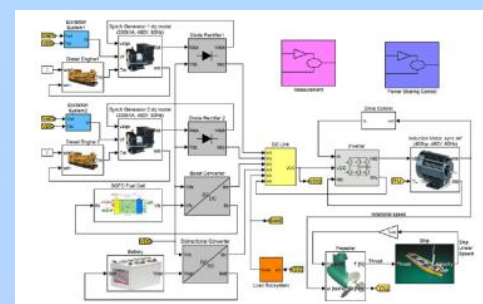
Wide Band Gap Semiconductor Power Electronics with High Power Density



Soft Switch, Matrix, capacitor and Other Advanced Power Electronics

High conductivity Wire/ Advanced Insulation Cable

Superconducting Cable



Advanced Power Architecture, Power system modeling and simulation, Control System Architecture

Observations on Student Needs

- **Students need to be made aware that Electric Power and Electrical Engineering are import fields necessary to maintain our standard of living**
- **To be successful students need to have hands on experience with hardware**
- **Presentation Skills (Presentation development and public speaking)**
- **Ability to work in multi-disciplinary teams – mechanical, electrical and software**
- **Capability for design and synthesis as opposed to analysis**
- **Understand the political, business and financial components as well as the technical component to all solutions**
- **Appreciation of systems technology and its impact on large power systems – electrical, mechanical, thermal.**

Students need to develop a broad skill set beyond a narrow technical specialty to be successful.

Take Aways

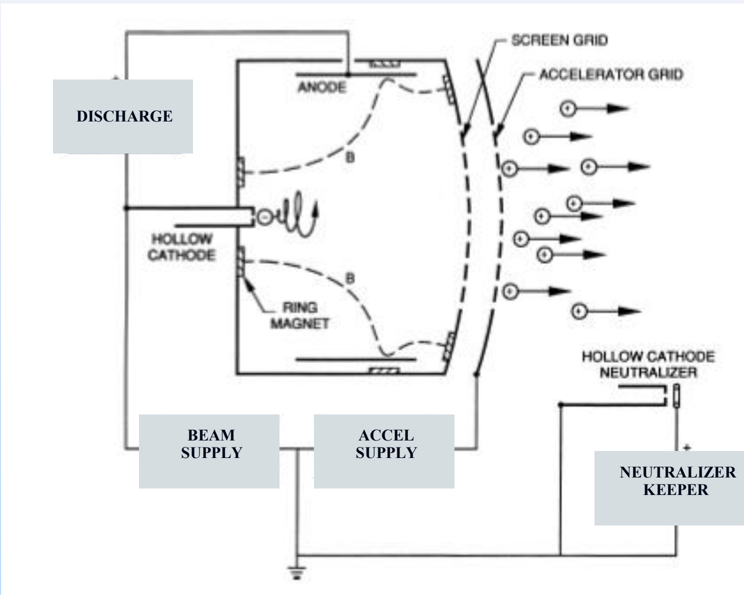
- **Students need to be made aware that Electric Power and Electrical Engineering are important fields necessary that enable the lifestyle of modern society**
- **We need to market ourselves as not only as enablers of modern society but practitioners who are building a better society that**
  - **Conserving natural resources – high efficiency electrical system**
  - **Keeping the environment clean**
  - **Enabling humanity to continue to explore and understand its place in the Cosmos**
- **Make students aware that new power technologies need to be developed to sustain our lifestyle and explore new frontiers**

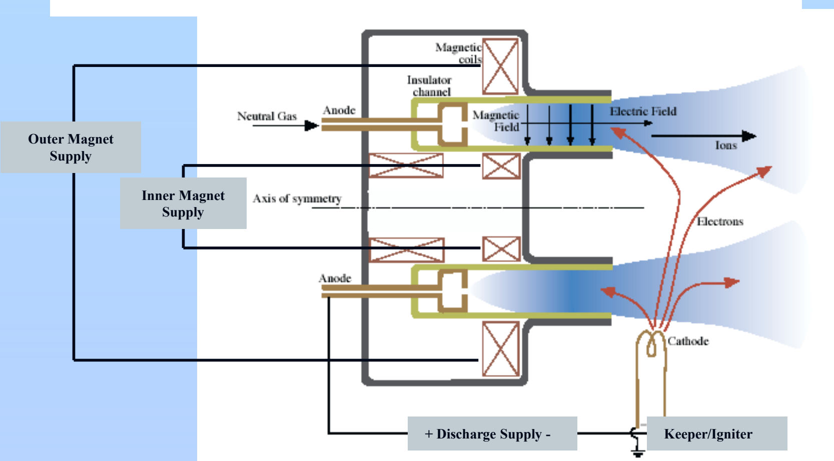
Questions?

Back-up Slides

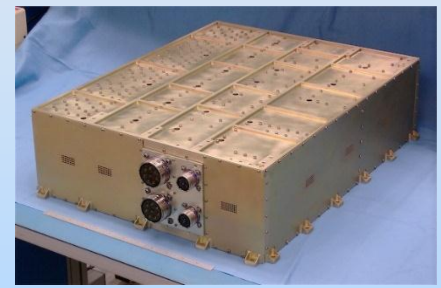
Electrostatic Thrusters

- Generate high voltage for ion (plasma) acceleration

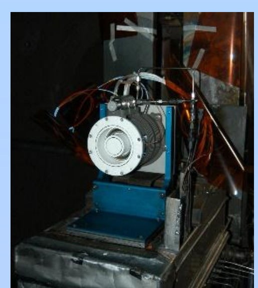




<u>Ion</u> thrusters use high voltage grids to create an electrostatic field, the PPU produces 1800 V for the beam supply.



<u>Hall</u> thrusters use magnetically trapped electrons to create an electrostatic field, PPU produces 300 to 800V for the HET discharge supply.



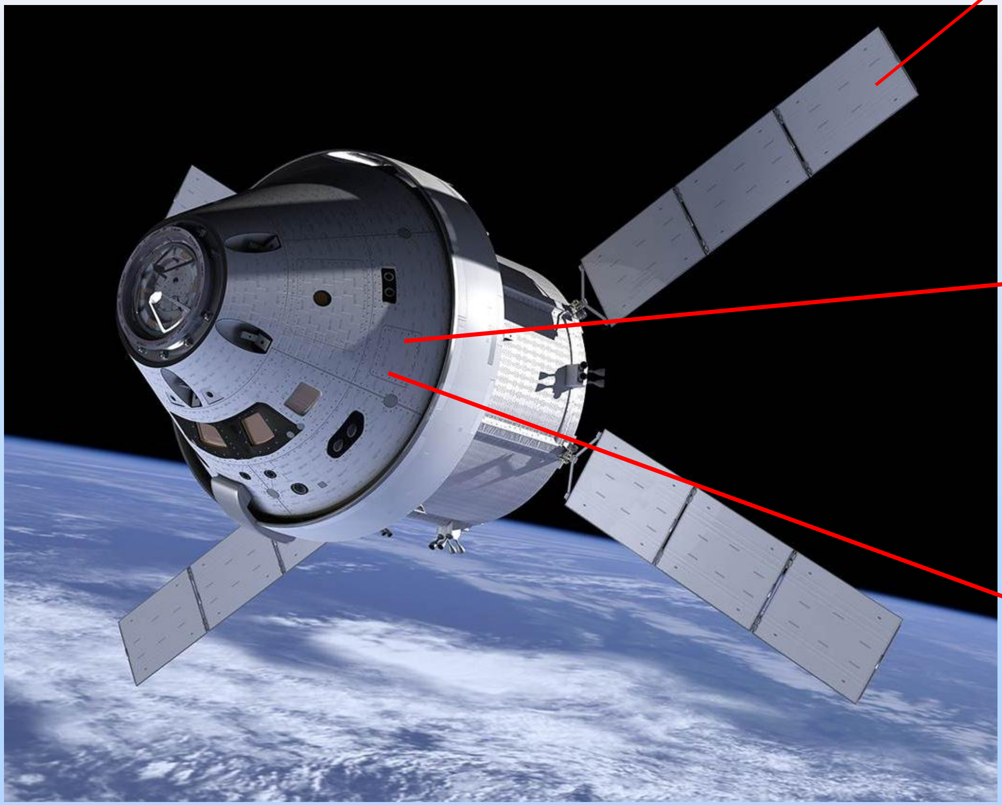
National Aeronautics and Space Administration

The Space Launch System (SLS)

- Designed to carry the Orion spacecraft, cargo, equipment and science experiments to Earth's orbit and destinations beyond.
- The SLS will have an initial lift capacity of 70 metric tons and will be evolvable to 130 metric tons.
- It will use a liquid hydrogen and liquid oxygen propulsion system, which will include the RS-25 from the Space Shuttle Program for the core stage and the J-2X engine for the upper stage.
- SLS will use solid rocket boosters for the initial development flights, follow-on boosters will be competed based on performance requirements and affordability considerations.

Initial 70 metric ton configuration

Orion MPCV Electrical Power System



Solar Array Wings
- 4 wings with 3 deployable panels
- Triple junction solar cells for high conversion efficiency
- Two axis articulation for sun tracking
- 11.1 kW total power for user loads and battery recharge

Battery Energy Storage
- 4 batteries of ≈ 30 A-hr each
- Li ion chemistry for high energy density
- High voltage for direct connection to power distribution
- Cell balancing for high charge/discharge cycle life

Power Distribution Equipment
- 4 power distribution channels
- High voltage (120 VDC) distribution for reduced weight
- Current-limiting SiC switchgear for fault protection
- Transient protection for lightning strikes (on ground)