Overview of NASA Power Technologies for Space and Aero Applications

Presented to

IEEE Cleveland Power and Energy Society

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October 16, 2014
Topics

• Space Power Development Objectives and Roadmap
• Aircraft Power Development Objectives and Roadmap
• Component Technology Development
Space Power Development Objectives and Roadmap
The Future of Human Space Exploration

*NASA’s Building Blocks to Mars*

**U.S. companies provide affordable access to low Earth orbit**

**Mastering the fundamentals aboard the International Space Station**

**Pushing the boundaries in cis-lunar space**

**Developing planetary independence by exploring Mars, its moons, and other deep space destinations**

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**
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.
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)
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
Potential Deep Space Vehicle Power System Characteristics

- Power 10 kW average
- Two independent power channels with multi-level cross-strapping
- Solar array power
  - 24+ kW Multi-junction arrays
- Lithium Ion battery storage
  - 200+ amp*hrs
  - Sized for deep space or low lunar orbit operation
- Distribution
  - 120 V secondary (SAE AS 5698)
  - 2 kW power transfer between vehicles

Deep space vehicle concept
Aero Power Development Objectives and Roadmap
Aircraft Turboelectric Propulsion

**Projected Timeframe for Achieving Technology Readiness Level (TRL) 6**

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)

<table>
<thead>
<tr>
<th>Power Level for Electrical Propulsion System</th>
<th>Today</th>
<th>10 Year</th>
<th>20 Year</th>
<th>30 Year</th>
<th>40 Year</th>
</tr>
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<tbody>
<tr>
<td>kW class</td>
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<tr>
<td>1 to 2 MW class</td>
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<td>2 to 5 MW class</td>
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<td>5 to 10 MW</td>
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<td>&gt;10 MW</td>
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National Aeronautics and Space Administration
Superconducting motor-driven fans in a continuous nacelle

Power is distributed electrically from turbine-driven generators to motors that drive the propulsive fans.
Advanced Power Technologies
Development Needs and Directions
Power System Taxonomy

Sources
- Solar Arrays
- Brayton Rotating Unit
- Stirling Radioisotope
- Fuel Cells

Power Management And Distribution
- Source Regulator
- Power Distribution
- Charge/Discharge Regulator
- Load Converters
- Power System Control
- Load Leveling

Energy Storage
- Batteries
- Flywheel Energy Storage

Loads
- Electric Propulsion
- Communications
- Instruments
- Actuators
## Photovoltaic Arrays

<table>
<thead>
<tr>
<th>Current State</th>
<th>Drivers</th>
<th>Missions</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Solar Cell Efficiency approx. 30%</td>
<td>• High Power Scalability</td>
<td>• Low cost, low mass blanket technology using automated manufacturing methods</td>
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<tr>
<td>• 6 mil thick, non-flexible cells</td>
<td>• Higher efficiency</td>
<td>• Large multi-hundred kilowatt solar arrays w/ improved stowed volume and deployability.</td>
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<tr>
<td>• Relatively high cost with only limited automation</td>
<td>• Lower Cost</td>
<td>• Arrays tailored for low intensity / low light operation</td>
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<tr>
<td>• Honey-comb panels @ 10-15 kW power levels</td>
<td>• Lower Mass</td>
<td></td>
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<tr>
<td>Current State</td>
<td>Drivers</td>
<td>Future State</td>
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</tr>
</tbody>
</table>
| MMRTG        | • Long duration deep space missions  
|              | • Greater distance from sun  
|              | • Planet surface ops  
|              | • Large power generations for nuclear electric propulsion  
|              | • 100sW – MW needs | • Advanced Stirling Generation  
|              | | > 20% Conversion Efficiency  
|              | | • Nuclear surface power  
|              | | • Large fission for NEP  

- **MMRTG**
  - 110 W modules
  - Low efficiency

- **Advanced Stirling Generation**
  > 20% Conversion Efficiency

- **Nuclear surface power**

- **Large fission for NEP**
# Batteries

<table>
<thead>
<tr>
<th>Current State</th>
<th>Drivers</th>
<th>Future State</th>
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</table>
| • Rechargeable: Ni-H$_2$ (45Wh/kg, > 10 years); Li-Ion (100 Wh/kg, > 5 years life)  
• Primary: Ag-Zn (100 Wh/kg; 20 cycles); Li-SO$_2$ (200 Wh/kg; 5 years life)  
• Heavy, Bulky  
• Safety Concerns | • Very high specific energy  
Rechargeable batteries to enable longer operation  
• Emphasis on safety  
• Longer cycle life  
• Extreme temperature environments | • “Beyond Li ion”  
Rechargeable Batteries: > 500 Wh/kg, 5 yrs  
• Rechargeable Li ion Long cycle life batteries: > 220 Wh/kg, 5 yrs  
• Primary: 1000 Wh/kg, > 20 yrs |
<table>
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<tr>
<th>Current State</th>
<th>Drivers</th>
<th>Future State</th>
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</thead>
</table>
| **Regenerative Fuel Cells** | • Power rating 2-10 kW  
• 35-50% Efficient  
• Life: 50 Cycles  
• Heavy, Bulky, Complex, Safety Concerns | • Longer missions – days / weeks  
• High Efficiency  
• “Passive” management of fluids and gasses  
• High Power Rating and energy storage capability  
• Long Life, high reliability, safe  
• Operate with flexible fuels | • Power Rating: 10-30 kW  
>8 hrs.  
• Operable with reactants at > 2000 psi to reduce tank volume  
• Life: 10,000 hours  
• 70% Efficient, Reliable & Safe  
• Solid oxide fuel cells capable of CO₂ processing and oxygen production |

| **Flywheels** | • Specific Energy  
50Whr/kg | • High power  
• Long life  
• High Energy Density  
• High Strength Fibers  
• Low Loss Bearings  
• Reliability  
• Mass | • Carbon fiber or Graphene specific power >200+ W-hr/kg.  
• Cycle life >150,000 cycles  
• Operating temperature  
• -150C to +150C |
<table>
<thead>
<tr>
<th>Current State</th>
<th>Drivers</th>
<th>Future State</th>
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<tr>
<td><strong>Power Conversion and Distribution Systems</strong></td>
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<tr>
<td>• Power converters 94% efficient</td>
<td>• Need for unique vehicle configurations</td>
<td>• Modular PMAD</td>
</tr>
<tr>
<td>• Power Distribution: 170V and 120 V</td>
<td>• Extreme Space environments</td>
<td>• Power Converter &gt;97%</td>
</tr>
<tr>
<td>• Switchgear – Solid State, Electromechanical Relays</td>
<td>• Maximize efficiency, power density, safety, reliability</td>
<td>• Voltage &gt;300V</td>
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<tr>
<td></td>
<td>• Minimize mass/volume, DDT&amp;E costs, integration and operations cost</td>
<td>• Novel Switching Devices</td>
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<td></td>
<td>• Superconductors</td>
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<td>• High radiation tolerance</td>
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<td><strong>Intelligent Power Management Systems</strong></td>
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<td><strong>Autonomous Vehicle Management with Ground Oversight</strong></td>
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<tr>
<td>• Spacecraft power managed by ground controllers</td>
<td>• Long term autonomous operations</td>
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<td>• Load and energy management under constrained capacity</td>
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<td>• Failure diagnostics and prognostics</td>
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<td>• Integration with Mission Manager</td>
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<tr>
<td><img src="image1.png" alt="Image of control room" /></td>
<td></td>
<td><img src="image2.png" alt="Image of satellite" /></td>
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</table>
# Electric Machines for Commercial Aircraft Propulsion

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<th>Future State</th>
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<tr>
<td>• Commercial aircraft use turbofans or turbo props. Electric aircraft propulsion only implemented on small experimental planes. • Motors, generators, power distribution, and energy storage to heavy and inefficient to exceed performance of baseline system</td>
<td>• High Specific Power Electric Machines (&gt;8HP/lb) • High Efficiency Electric Machines • High reliability/redundancy • High Specific Energy batteries for some configurations</td>
<td>• 10-100MW aircraft propulsion electric system for regional, single isle and larger commercial aircraft. • Reduced aircraft fuel burn, NOx emissions, and noise • Electric propulsion power system able to meet or exceed current safety standards (engine out, redundancy, others).</td>
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