Air Force
Power Requirements

January 24, 2006

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Power Division
Propulsion Directorate
Air Force Research Laboratory

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**Report Documentation Page**

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Standard Form 298 (Rev. 8-98)
Purchased by ANSI Std Z39-18
Outline

• Our Recent Heritage – MEA

• Our Plan – HiPAC

• HiPAC Technologies

• Summary

Powering the United States Air Force
All-electric aircraft eliminates complex, inefficient, maintenance intensive...

- Hydraulics
- Bleed Air Pneumatics
- Mechanical (gearbox) Subsystems

Savings in $B’s with improved warfighting

Enables mission available power for lethal airborne directed energy weapon
MEA Generation I Concept
Transition to Lockheed F-35

Affordable, High-Performance Baseline for F-35

AFTI/F-16 Demonstration Validates
More-Electric Aircraft Technologies

Common Components

- Inverter/Converter/Controller (2) – Provides Conditioned 270-VDC Power to Flight Critical Actuation System
- 270-VDC Emergency Generator – Provides Independent Source of Electrical Power
- 270-VDC Battery – Provides Uninterruptible, Flight-Critical Power
- Starter/Generator – Source for Redundant, Flight-Critical Power
- Power Drive Electronics – Provide Modulated 270-VDC Power to Flight Control Actuators
- Electro-hydrostatic Actuators – Provide Redundant Control Power at Each Control Surface

F-35 Subsystems Suite
Identical to J/IST
From Vision to Reality

F-35 IS THE FIRST TRULY “MORE ELECTRIC” AIRPLANE

- Electric Engine Start
- Electric Power & Thermal Mgt System
- Electric Flight Control Actuation
- Electric Flight Control Power Systems

Electric Engine Start Ground Demo

Starter/Generator / Electric Flight Control Actuation Flight Demo

MEA Thrust Initiated In 1987
Exponential Growth for Power and Thermal Technology

**Baseline**
- F-22 130 KWe
- ~100 Elec Loads
- No 270 VDC Flt Critical Loads

**State of the Art**
- F-35 160KWe
- 270 VDC Flt Critical Loads
- Int. Subsystems
- External S/G

**Far Term**
- Multi-Megawatt
- Enabling Weapons

*Technology Push*
- Exponential Growth for Power and Thermal Technology
**Exponential Growth for Power and Thermal Technology**

- **Technology Push**
- **Requirements Pull**

**STATE OF THE ART**
- **F-35 160KWe**
- **270 VDC Flt Critical Loads**
- **Int. Subsystems**
- **External S/G**

**BASELINE**
- **F-22 130 KWe**
- **~100 Elec Loads**
- **No 270 VDC Flt Critical Loads**

**FAR TERM**
- **Multi-Megawatt**
- **Enabling Weapons**

**TACTICAL DIRECTED ENERGY WEAPONS**

- **UCAV**
- **JSF**
- **AADT**
- **LRS**

**MORE ELECTRIC AIRCRAFT**

**INCREASED ON-BOARD POWER**

- **1995**
- **2005**
- **2015 +**
DE Weapons Need Unprecedented Power & Thermal Management

Projected Capability Needs an Order-of-Magnitude Over the Next 10+yrs.

20+ yrs 60% Growth

Required Technology Availability

Power Level (KW)

- F-35
- Continuous
- Solid State Tactical Laser
- Airborne Active Denial
- Airborne Electronic Attack
- F-15
- F-16
- F-22
- Low Duty Cycle
- 1975
- 1980
- 1985
- 1990
- 1995
- 2000
- 2005
- 2010
- 2015
HiPAC Technical Program Areas

- High Temperature Power System Components
- High Temperature Thermal Control Systems
- EMI Immunity
- Integrated Engine / Power Extraction
- Smart Power: Prognostics & Health Management
- MW Power Generation
- MMW Power Generation
- Active High Flux Thermal Control System
- Lightweight Compact Power Conditioning
- Energy Storage
- Electrochemical Power Generation
- MEMS Power Generation
- MEMS Thermal Management
- Pulse Power Components
- Subsystem Integration
Micro-Mini Platforms

Small Platforms with sub kW Power Requirements

Technologies:
• MEMS Power Generation
• MEMS Thermal Management
• Batteries
• Fuel Cells
Munitions / Small UAVs with 1-100 kW Power Requirements

Technologies:
- EMI Immunity
- Integrated Engine / Power Extraction
- Smart Power – Prognostics and Health Management
- Electrochemical Power Generation
- Light Compact Power Conditioning
- Energy Storage
Low Spool Generator for Global Hawk

Enables Advanced Sensor Upgrades for Global Hawk

POWER TECHNOLOGIES BENEFITS:
• 15% Thrust Improvement at Altitude
• 7.5X Increase in Power Generated

GLOBAL HAWK CAPABILITIES

NOW:
- 2000 lb Payload
- 24 Hour on Station
- 1200 NM range/ 60K ft altitude
- 10 KVA Payload Power

FUTURE:
- 3000 lb Payload
- 20 Hour on Station
- 1200 NM range/ 60K ft altitude hold
- 25 KVA (Near-term); 75 KVA (Far-term)

AE3007 ENGINE - GLOBAL HAWK PROPULSION

Rolls-Royce
Tactical Aircraft

Tactical Aircraft with 100-500 kW Power Requirements

Technologies:
- High Temperature Power System Components
- High Temperature Thermal Control Systems
- Energy Storage
- Integrated Engine / Power Extraction
- EMI Immunity
- Smart Power: Prognostics & Health Management
- Lightweight Compact Power Conditioning
- Electrochemical Power Generation
Li Ion Battery

• Lithium Ion Technology Developed Under Joint AFRL/NASA/JPL Program Transitioned to B-2, F-35, and Mars Rovers

• B-2 Batteries >350 Flight Test Hours Logged

• Mars Rover Batteries Fully Operational After 7 Month Cruise Through Space
Revolutionary Capacitor Development

- Low cost DLC thin film in-house process scale-up (Mar 01); Commercialization by FY04 (energy density)

- Enables DEW - - 2X increase in energy density
- Reduces size, weight & volume

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<tr>
<th>DIELECTRIC</th>
<th>DIELECTRIC CONSTANT</th>
<th>FILM THICKNESS</th>
<th>BREAKDOWN STRENGTH</th>
<th>UPPER-LIMIT TEMPERATURE</th>
<th>ENERGY DENSITY</th>
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<tr>
<td>POLYCARBONATE</td>
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<td>3 m</td>
<td>5 KV/mil</td>
<td>125°C</td>
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<td>FLUORENE POLYESTER (FPE)</td>
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<td>3 m</td>
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<td>25 KV/mil</td>
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Large Platforms

Large Platforms with 250 kW - 2+ MW Power Requirements

Technologies:
- MW-MMW Power Generation
- Integrated Engine / Power Extraction
- High Temperature Power System Components
- High Temperature Thermal Control Systems
- EMI Immunity
- Smart Power: Prognostics & Health Management
- Lightweight Compact Power Conditioning
- Energy Storage
- Electrochemical Power Generation
Optically Triggered SiC Switch

TECHNICAL CHALLENGES:
Device design is foundational.
Carrier transport and optical generation not quantified.

APPROACH:
• Develop key fabrication components
  - SiC photo-transistors (600V, 60-150A)
  - SiC “PGBT”-based switches
  - 2-D modeling in parallel with fab.
• Demo devices in electric actuator drive controllers or I-H motor drive

OBJECTIVE & PAYOFF:
Reduce actuator weight while providing photonic switching device to satisfy the robust actuator switching requirements for an EMI invulnerable FBL/PBW airframe concept.
Directed Energy Concepts with 250 kW - MMW Power Requirements

Technologies:
- Integrated Engine / Power Extraction
- MW-MMW Power Generation
- Active High Flux Thermal Control System
- Lightweight Compact Power Conditioning
- Energy Storage
- Pulse Power Components
- EMI Immunity
- High Temp. Power System Comp.
- High Temperature Thermal Control Systems
- Smart Power: Prognostics & Health Management
Multimegawatt Electric Power System

1-5 MW Capability Needed for Multiple Applications

Directed Energy Weapons

Army Future Combat Systems Electric Weapons

Navy Distributed Power

E-10A
The overall efficiency of solid state lasers varies from 10% to 30%, thus large amounts of waste heat must be managed.

- As an example, for a 10% efficient laser:

Output:
- Engine: 1.177 MW
- Generator: 1 MW
- Diodes: 500 kW
- Slab: 100 kW

Laser:
- 1076 kW

Waste Heat:
- Diode output, lifetime strongly impacted by operating temperature

Laser Beam

Diode Waste Heat

Slab Waste Heat

176 kW 20 W/cm²
500 kW 400 W/cm²
400 kW 200 W/cm²
High Power for Aircraft Initiative

Five Power Regimes from Watts to Multi-Megawatts

Meet Today’s and Tomorrow’s Need for Unprecedented Power and Thermal Management

System Approach to Integrated and Optimized Weapons Power and Thermal Management

Powering the United States Air Force!