Energy, Power, and Thermal Research Overview

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### Energy, Power and Thermal Research Overview

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Overview

• AFRL
• Drivers and Applications
• Technologies
• Questions
Leading the discovery, development, and integration of affordable warfighting technologies for our air and space force.
AFRL's Core Areas of Expertise

- Space Vehicles
- Directed Energy
- Sensors
- Human Effectiveness
- Propulsion
- Munitions
- Materials
- Information
- Air Vehicles
- AFOSR
AFRL People & Facilities

- 5,764 Government Employees
  - 4570 Air Force Civilian
  - 1194 Military
- 3,844 Onsite Contractors

- 10 Major R&D Sites across US
- 40 Sites World-Wide
- $40B Real Property & Capital throughout AFRL
• **RZ Portfolio addresses long-term AF capabilities**

  - Air-breathing High Speed Strike/ISR
  - Energy Security
  - Long Endurance ISR/Mobility
  - Energy Optimized Aircraft
  - Reusable Access to Space
  - Spacecraft Maneuverability
It’s An Exciting Time!

- TSSS
- HC Boost
- BRITES
- INVENT
- FUELS
- Hall Thrusters
- AIR FORCE RESEARCH LABORATORY
- Space & Missile
- Hypersonics
- Energy Power & Thermal
- Turbines
- ADVENT
- Sustainment
- HEETE
Key Planning Drivers

• **Energy**
  – Make energy a consideration in all we do
  – Ensure continued viability of propulsive energy sources
  – Optimize efficiency at the platform level to increase capabilities by minimizing thermal limitations and also to reduce fuel used

• **Thermal**
  – Address today’s thermal challenges and prevent tomorrow’s thermal limitations

• **System Integration**
  – Deconflict subsystem interactions and define/demonstrate interfaces

• **Infrastructure**
  – Invest in energy, power, and thermal research facilities to establish research foundation for the future
Energy, Power, and Thermal
(FY10-15 from FY11 PBR ~ $54M/year)

- Battlespace Fuels
- Special Purpose Power
- Energy Optimized Aircraft

- 64%
- 26%
- 10%
Energy/Power/Thermal Core Technical Competencies

- Power distribution and electronics
- Electrochemistry
- Mechanical energy conversion
- Thermal management
- Fuel utilization and characterization
- System integration and optimization
- Power and thermal analysis and M&S
Power Distribution and Electronics

- Performance evaluation and advanced insulations
- Energy storage
- Dielectrics
- Carbon nanotubes for power applications
- SiC device and module reliability
- Plasma physics for defect-free high temperature wide-band gap electronics
Power Distribution and Electronics

- Reduce defects by optimizing SiO₂-SiC interface using a low-T growth (300°C) process and atomic oxygen to remove C-atom (CO, CO₂)

- Large area die SiC switch evaluation at high-T
- Inductor design comparison

- Effects of EM fields, corona, discharges on aerospace power systems
- High voltage discharge breakdown experiments

- Demonstrate PCD films for HV isolation and heat spreading layers in high-T power electronic packages
- CNT interface for stress compliance for CTE_{PCD} ~ 1-2 ppm/K
Electrochemistry

- Solid-state electrolyte for Li-ion batteries
- Li-air chemistries for high performance batteries
- High performance SOFCs
- Battery evaluation and analysis
**Electrochemistry**

- Develop critical process parameters for scaling solid-state Li-ion batteries
- *ab initio* calculations model ionic/electronic transport in a “Phthalocyanine Complex”
- Results validated through synthesis processes

- Enable fuel-flexible capabilities to utilize energy-dense logistic fuels for SOFCs
- Optimize functional gradation to reduce interfacial impedance and increase fuel cell power density

- Evaluate and analyze electrochemical power technologies through simulation of mission profiles
  - Investigate problem solution
  - Recommend solutions
  - Solve aircraft systems integration problems

- Li-air chemistries for high performance batteries
  - New cathodic formulations by enhancing triple phase boundaries
  - *M&S* using classical thermodynamics and chemical species mole balance
Mechanical Energy Conversion

- High temperature superconductors
- Mega-Watt power generation
- Magnetic materials
- Thermoelectric power generation

- Mega-Watt power generation
  - Superconducting and conventional generators
  - Short-circuit, open-circuit and low-load endurance testing
  - Used performance results and empirical analysis to modify generator to improve performance
Mechanical Energy Conversion

- Develop YBCO superconductor properties for optimal performance
- Produce long lengths of YBCO coated conductors (DC and AC)
  - Minimize ac loss due to high power generation…lower heat loss
  - Stability and quench Issues
  - 1000A – 20,000A power transmission cables - lower weight and heat loss

- Soft magnetic material composites
  - High-T up to 500°C
  - Operating frequencies up to 1 MHz
- Hard magnetic materials
  - High-T hybrid systems
  - Exchange spring systems with improved energy products (NdFeB, SmCo/Fe, FeCo)

- Multilayered structures for thermoelectric power generation
  - Oxide materials
  - Promote phonon scattering to inhibit thermal flow and increase efficiency
  - Nanostructure dispersions
Thermal Management

- Thermal management of SiC power modules
- Fuel cooling of turbo machinery
- Loop heat pipe for electronics cooling
- Thermal energy storage for mega-Watt applications
- Vapor cycle technologies for on-demand high-flux cooling applications
Thermal Management

- Investigate and demonstrate SiC packaging technologies, target $R_{q,jc} = 0.15\text{cm}^2\text{K/W}$
  - Optimize heat transfer
  - Increase temp uniformity
  - Minimize CTE-related stress

- Investigate fuel cooling of rotating turbine components
- Combine experimental and modeling activities to understand fluid dynamics and thermal performance

- Dynamic LHP performance with time variant body forces for electronic component cooling
- On-demand VCS for high-flux cooling
- Time-accurate M&S and experimental validation (non-equilibrium physics, theoretical thermodynamics)
Fuel Utilization and Characterization

• Endothermic fuels and hydrocarbon propellants
• Develop and optimize alternative fuels technologies (AAFRF)
• Microbial activity in fuels
• Emissions reduction via fuel technologies
• M&S of fuels technology
• Fuel characterization and fundamental studies
• Small engine fuel testing
• Nanofuels
Fuel Utilization and Characterization

- Develop composition-based physical property models for endothermic fuels
- Thermal-oxidative deposition model enhanced
- Fuel system modeling tools for fuel system design
- Realistic heat flows
- Modules for various fuels
- Complex geometries
- Oxidation and deposition
- Emissions evaluation with alternative fuels
  - Research combustor
  - Military and commercial engines
- Conventional techniques
  - Particle size, mass, and number
  - Chemical analysis of particulates
  - Gaseous emissions
- Leverage small engine technologies for alternative and heavy fuels
System Integration and Optimization

- Basis for SIL/HIL approach to system integration and energy optimization
- Validate HIL concepts for SIL approach to optimize power, thermal management, and propulsion from an energy perspective
Power and Thermal Analysis and M&S

• Power and thermal M&S toolset development
• Power and thermal component and subsystem modeling
• Vehicle system-level modeling “Tip-to-Tail”
  – Power and thermal technology trades
  – Mission impact/benefits assessments for “energy optimized” vehicle architectures
Power and Thermal Analysis and M&S

**Engine (quasi-steady state)**
- Controls Return to Tank Flow
- Calculates engine heat loads
- Calculates net thrust
- Calculates fuel burn / SFC

**Fuel Thermal Management System (FTMS)**
- Fuel mass & temp
- Convection, conduction, radiation
- Ram air HX

**Power Thermal Management System (PTMS)**
- Air cycle or vapor cycle
- Cold air heat sink
- Heat sink for PAO loop

**Air Vehicle System (AVS)**
- 6-DoF to vehicle model
- Notional Long Range Strike
- Closed loop control over mission profile (speed, altitude, heading)
- Track metrics (range, endurance, fuel burn)
Summary

• Energy, power, and thermal are inter-related technologies and design considerations

• We investigate fuels, power and thermal devices and components, and system level M&S

• System optimization at the platform level saves energy and addresses thermal limitations

• International collaborations on energy, power, and thermal science and technologies are welcomed and desired
Questions?

Warfighters: Today’s and Tomorrow’s