UAS Hybrid Power & Propulsion

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AFRL/RQ Power and Control
Meet in front lobby Building 18
Lab Tour of Building 23

Any questions, call my cell
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AFRL Technical Directorates & Competencies

AF Office of Scientific Research
- Aerospace, Chemical & Material Sciences
- Education & Outreach
- Mathematics, Information, & life sciences
- Physics & Electronics

Aerospace Systems
- Air Vehicles
- Control, Power & Thermal Management
- High Speed Systems
- Space & Missile Propulsion
- Turbine Engines

Directed Energy
- Directed Energy & EO for Space Superiority
- High Power Electromagnetics
- Laser Systems
- Weapons Modeling and Simulation

Information
- Autonomy, C2, & Decision Support
- Connectivity & Dissemination
- Cyber Science & Technology
- Processing & Exploitation

Human Performance
- Bio-effects
- Decision Making
- Human Centered ISR
- Training

Munitions
- Fuze Technology
- Munitions AGN&C
- Munitions System Effects Science
- Ordinance Sciences
- Terminal Seeker Sciences

Sensors
- Advanced Devices & Components
- Layered Sensing Exploitation
- Multi-Int Sensing (RF/EO)
- Spectrum Warfare

Space Vehicles
- Space Electronics
- Space Environmental Impacts & Mitigation
- Space OE/IR
- Space Experiments
- Platforms & Operations Technologies

Materials and Manufacturing
- Functional Materials & Applications
- Manufacturing & Industrial Technology
- Structural Materials & Applications
- Support for Operations
Power & Control Division
Vision (AFRL/RQQ)

Expanding AF mission capabilities by leading the research, development, and transition of flight-critical, responsive, integrated vehicle systems

Flight Control Automation

Autonomous Systems

Flight Critical, Responsive, Integrated

Electrical Power

Thermal Management
Power & Control Technology Portfolios

- ACAT
- Aerospace Control Systems
- Enhanced Mobility Operations
- Autonomous Systems
- Tactical Autonomy
- Airspace Integration
- UAS Power & Control
- P&T Architecture & Integration
- State Awareness & Real-Time Response
- Computational Engineering
- Integrated Vehicle Technologies
- Thermal Systems
- Power & Thermal Management
- Electrical Power Systems
- Electro-Mechanical Systems
- Modeling, Simulation, & Assessment

UNCLASSIFIED
UAS Power & Control
Vision & Approach

• AF Vision Statement: To Deliver Affordable and Integrated SUAS Assets with the Following Attributes:
  – Exponential Force Multiplier
    • Cross domain integration across mission sets
  – Easily Integrated Asset
    • Deployable by a variety of means, providing flexibility, reach, penetration, and integration with joint forces
  – Cost Savings Enabler
    • Employing low cost SUAS with increased functionality improves combat effectiveness and efficiency

• Approach:
  – Leverage unique expertise in hybrid power and flight control technologies to address current and future UAS requirements
  – Explore hybrid propulsion system architectures and control strategies
  – Foster critical industry / Govt partnerships to develop, demonstrate and transition technologies into next generation UASs
  – Perform integrated UAS ground/flight testing to validate technology predictions
  – Coordination of R&D Across DoD / Govt Agencies, and International Partners
SUAS Power/Propulsion
Key Challenges

Enhanced Hybrid Electric Power/Propulsion Systems
- Increased Endurance
- Excess Payload Power
- Quiet Operation
- Increased System Reliability

Small UAV / RPA Systems
**SUAS Power/Propulsion Goals**

**Near Term <2021**
- > 500 hrs MTBF
- Up to 2x Range/Endurance
- 10% Dash Capability
- 25% Payload Power Growth

**Mid Term <2026**
- > 2000 hrs MTBF
- Up to 4x Range/Endurance
- 50% Dash Capability
- 100% Payload Power Growth

Logistic Fueled STUAS
Hand-Launched SUAS
Air-Dropped TLEU

(***Group 1 – Group 3 Propulsion***)

Recoverable Air-Dropped UAS
Large Class UAS APU

(***Group 1 – Group 3 Propulsion***)
(***Group 4 / Group 5 Secondary Power***)

[Images of SUAS and propulsion systems]
Advanced Power & Thermal Research Laboratory (Bldg 23)

- 44 Laboratories, 54,000 square feet total lab space.
- Redundant chilled (1.5 MW) and tower (500 kW) water cooling systems.
- 5 MW of connected electrical power - 480 VAC, 208 VAC
- Reconfigurable lab spaces

**Power Generation, Storage, and Distribution**

- **Power Semiconductors**
  - Silicon Carbine
  - Nanoscale Thin Films
  - Atomic Layer Deposition

- **Wide Temp Dielectrics & Capacitors**

- **Magentics**
- **Hi Temp Superconductivity**

- **Batteries**
  - Solid State
  - High Energy Hybrids

**Thermal Transport, Storage, and Conversion**

- **Characterization of Evaporating Fluids**
  - High Rate Heat Exchange

- **Carbon Nanotubes for Thermal Conductivity**

- **Electric Actuation TM**

**Modeling, Simulation, Analysis, and Test**

- Model Based Design
- Hardware-in-the-Loop Simulations
- Model Verification & Validation
Electrochemistry
In-House Research

Advanced Energy Storage/Energy Conversion Development

- Solid-State Lithium-Ion Battery
- High Performance Lithium-Oxygen Battery
- High Energy/High Power Hybrid Battery
- Battery Characterization and Analysis for Aircraft, DEW, and SUAV Applications
In-House R&D Program Product Areas

- Solid-State, Safe Li-Ion Cell
- Advanced Fabrication
- Structural Cell Design

Safe
- Non-flammable in military environment

Lightweight
- Improved Energy Efficiency

Multifunctional
- Save system mass & volume

Structurally Robust
- Carry / conform to mechanical load

Efficient
- Provide energy storage
High Capacity Cathode Materials Functionalized with Carbon for Lithium-Ion Batteries

Dr. Joseph Fellner and Dr. Lawrence Scanlon --- (16RQCOR301)

Primary lithium batteries
- Lithium CFx batteries • Energy densities of 300-500 Whr/kg • Very high rates of heat generation when discharged at moderate to high rates • CFx discharge theoretical capacity of 865 mAh/g

Secondary lithium-ion batteries
- Flammable electrolytes • Some cathode active materials produce oxygen when heated • Cathode capacities of 150-200 mAh/g • Use of Ni/Co oxides can result in high cost

Organic Cathode Active Materials
- Very high primary discharge capacities of Cu phthalocyanine, >2200 mAh/g when integrated with CFx • Use of DFT can be used to help determine suitable organic materials for further use and development • Limitations in rechargeability of phthalocyanines - new organic-based rechargeable active materials to be developed

MAINT ACHIEVEMENTS:
- Design, fabrication, and testing of Li-based batteries • Demonstration of extremely high discharge capacities by use of a hybrid cathode chemistry • Ab-initio determination of cathode active material structure, capacity, and voltage • Determination of fundamental material parameters using XRD, BET, SEM, etc.

Main Achievements:
Combination of CFx and Copper Phthalocyanine (Pc) results in hybrid batteries with extremely high discharge capacities

HOW IT WORKS:
- CFx and nano-sized CuPc used as cathode active material • Discharge of CFx produces nascent nano-sized carbon greatly enhancing electrical conductivity • Two-voltage plateau cell with greatly enhanced capacity is the result

Assumptions and Limitations:
- DFT models are based at 0K • Hybrid cathode can only be discharged to achieve these high rates • DME electrolyte used is flammable

Current Impact
- 2-fold increase in primary battery discharge capacity with reduction in heat generation and state-of-charge indicator

Planned Impact
- Utilize the hybrid battery concept to enhance rechargeable organic cathode active materials • Hybrid primary battery concept to be used in future weapon systems • DFT-modeling used for future modeling of battery materials

Research Goals
- Completion of the hybrid battery concept into a solid-state cell • Discovery of new organic-based rechargeable cathode active materials • Discovery of new relationships of voltage and capacity for organic-based active materials

Status Quo

New Insights

Quantitative Impact

End-of-Phase Goal
Objective: To address key integration & hybrid controls issues for improved operational efficiency / reliability of hybrid electric UAS propulsion architectures

Approach:
- Develop a hybrid electric UAS propulsion test bed for collaborative research across AFRL, other Govt agencies, Industry, and Academia
- Research and explore novel energy optimized power management and control approaches for next generation series hybrid electric UASs

Key Challenges
- Integration
  - Power Management
  - Mechanical Coupling
  - Efficient System Design/ Energy Optimization
- Transient (non-steady state) operation
  - Efficient power controls / electrical protection
  - Fast transitions between operating points
- Validation / analysis of hybrid power system approaches

Modeling & Simulation
- Propulsion System Optimization Models (RQQ, RQT)
- Propulsion/Power System Trades (RQQ, RQT)
- Tip-to-Tail System Models (RQV)
- Aerodynamic Performance Analysis (RQV)

Hybrid Propulsion System Development
- Heavy Fuel Engines (RQT)
- Efficient/ Quiet Propellers (RQV)
- Electric Motors (RQQM)
- Fuel Cells/Batteries (RQQE)
- Power Management & Distribution (RQQE)
Wrap-Up

• Development of key power & control technologies to improve SUAS capabilities as a force multiplier

• Numerous collaborative efforts across Govt, Industry and Academia underway supporting all product areas

• Group 1 SUAS Long Endurance, Off-Board Sensing
  – Development of advanced long endurance SUAS technology providing remote sensing for off-board OPS
  – Addressing SOCOM / AFSOC requirements for stand-off and under weather off-board sensing
  – Near term transitions: TOBS and SURGE-V

• Logistics Fueled (JP-8) Quiet Hybrid-Electric Drive
  – Development of next gen hybrid electric power & propulsion solutions for extended endurance/range, reduced acoustic signatures, and modular/scalable to different SUASs
  – Addressing SOCOM and other Customer needs and requirements for long endurance, quiet operations

• Extended Reach Cooperative ISR and Targeting
  – Design/develop long endurance Group 3 recoverable air-launched SUAS with integrated flight controls enabling supervisory management of UAS and cooperative control of unmanned teams
  – Addressing SOCOM / AFSOC needs and requirements for extending MQ-9 operational reach and signature reduction

• High Efficiency, Fuel Flexible (JP-8, Jet-A, Diesel) Electric APU
  – Develop and demonstrate a high efficiency all-electric on-board aircraft APU for high-altitude, long-range unmanned aerial system (UAS) operations
  – Addressing needs and requirements for more on-board electrical power to support adv payloads and other subsystems
Questions