Hybrid Electric Propulsion

Breakout Summary from NASA Aero-Propulsion Control Technology Roadmap Development Workshop
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Hybrid Electric Propulsion
Control Technology Development Needs
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Strategic Thrust 4: Transition to Low-Carbon Propulsion

- While high levels of aircraft and operational efficiency are required for the future, they will not be enough to produce absolute reductions in carbon emissions.

- Therefore, ARMD seeks first, to enable the use of alternative fuels, and second, to foster a fundamental shift to innovative aircraft propulsion systems that have the potential to produce very low levels of carbon emissions relative to the energy used.
<table>
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<th>Outcomes</th>
<th>2015</th>
<th>2025</th>
<th>2035</th>
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**Characterization and Integration of Alternative Fuels**
Characterization of alternative fuels, combustor concepts, and their integration requirements

**Scalable Alternative Propulsion Systems**
Technical study of alternative propulsion system architectures and research on key physical attributes and technology enablers to demonstrate fundamental feasibility
Hybrid Electric Propulsion: Current Technical Challenges

• **Electrical Technologies:**
  – The state of the art of electrical technologies for motors, generators, power distribution, and power electronics will need to advance to enable turboelectric propulsion concepts for large commercial aircraft.
  – Current NASA Work:
    • Next Slide

• **Aircraft Systems:**
  – Turboelectric aircraft propulsion systems present a number of challenges related to other aircraft systems (thermal management systems). More structurally and aerodynamically efficient configurations can help address these challenges.
  – Current NASA Work:
    • Next Slide
Convergent Aeronautics Solutions Project
Aircraft Hybrid/Electric Propulsion Activities

• **M-SHELLS – Multifunctional Structures for High Energy Lightweight Load-bearing Storage**
  - Integrates hybrid battery/supercaps into aircraft structure to increase effective specific power & specific energy
  - Converges advanced electrochemistries, microstructures, manufacturing, and nano-technologies

• **LION – Integrated Computational-Experimental Development of Li-Air Batteries for Electric Aircraft**
  - Investigates “electrolyte engineering” concepts to enables Li-Air batteries with high practical energy densities, rechargeability and safety
  - Converges advances in predictive computation, material science, and fundamental chemistry

• **HVHEP – High Voltage Hybrid Electric Propulsion**
  - Variable-frequency AC, kV, power distribution with DFIM machines for multi-MWe DEP applications
  - Minimizes constituent weights of power electronics, TMS, and fault protection

• **Compact High Power Density Machine Enabled by Additive Manufacturing**
  - 2 to 3x increase in specific power of electric machines for DEP enabled by additive manufacturing
  - Compact, lightweight motor designs/topologies, integrated cooling, and multi-material systems/components.

• **DELIVER – Design Environment for Novel Vertical Lift Vehicles – cryo-cooling HEP task**
  - Maximizing efficiency and power density of electronic components by cryogenic LNG-fuel cooling
  - Longer-range hybrid/electric UAS with reduced fuel-burn and emissions (CO2, sulfur, particulates)

• **FUELEAP – Fostering Ultra-Efficient, Low-Emitting Aviation Power**
  - GA aircraft / early-adopter application of JP-fueled SOFC power plant for clean, hybrid/electric architecture
  - Zero NOx electric power production at ~2x typical combustion efficiencies

• **SCEPTOR – Scalable Convergent Electric Propulsion Technology and Operations Research**
  - Seeks 5x reduction in cruise-energy-use by aerodynamic benefits of DEP & batteries in place of engines
  - DEP enables high efficiency wing & high performance wingtip motors for cruise
**Objective**
Key performance parameters and threshold level requirements for gas turbine aircraft augmented with electrical powertrain

**Propulsion System Conceptual Design**
- Concepts for system interaction exploration

**Integrated Subsystems**
- Flight control methodology for distributed propulsion

**High Efficiency/Power Density Electric Machines**
- Step change in component performance

**Flight-weight Power System and Electronics**
- High voltage power electronics, transmission, protection, and management

**Enabling Materials**
- Insulation, Conductors, Magnetic Materials
The Low Carbon Challenge is to enable carbon-neutral growth in aircraft operations:
Electrified Propulsion: NASA’s Approach

Build, Test, Mature Enabling Technologies and Knowledge Bases

- **Prove Out Transformational Potential:**
  - Explore and demonstrate vehicle integration synergies enabled by hybrid electric propulsion

- **Work toward full PAI and HEP:**
  - Increasingly electric aircraft propulsion with minimal change to aircraft outer mold lines

- **Certify, Operate:**
  - Single Aisle Transport

- **Build, learn, demonstrate:**
  - Small Aircraft

- **Gain experience through integration and demonstration on progressively larger platforms**

**Timeline:**
- **2020:**
  - Knowledge through Integration & Demonstration
- **2030:**
  - Small Aircraft
- **2040:**
  - Single Aisle Transport

**Environmental Benefit:**
- Modeling
  - Explore Architectures
  - Test Beds
  - Component Improvements
Electrified Propulsion Development

**Goal:** Enable the paradigm shift to electric, hybrid electric, and turboelectric propulsion for reductions in energy consumption, emissions, and noise

**Path:**
- Identify promising propulsion / vehicle configurations
- Buy-down risk for crucial technologies in
  - Flight Control: new knobs in vehicle and subsystems
  - Power Conversion: electric machines & electronics
  - Power Control: vehicle electric grid management
  - Fundamental Enablers: materials and analysis
- Demonstrate results in purpose-built flight demonstration
NASA Electrified Propulsion Takeaways

• NASA Aeronautics Strategic Thrust 4 - Transition to Low-Carbon Propulsion is supporting investment in alternative aircraft propulsion including electrified aircraft propulsion

• The NASA vision includes transforming aviation via new propulsion technologies integrated with airframes to
  – increase aircraft functionality
  – reduce carbon emissions
  – improve operational efficiency and reduce noise

• There are many possible Electrified Aircraft configurations

• NASA investment includes vehicle concepts and technology to support aircraft for
  – Small to midsize aircraft to increase mobility provide a new paradigm
  – Commercial transport aircraft to impact the current large carbon producing market segment
Scope of Discussion

• Focus is on Hybrid Electric Propulsion Control Technologies related to alternative propulsion systems to further improve efficiency and emissions

• Up until the present no NASA propulsion controls effort has been focused on Hybrid Electric Propulsion

• New NASA Hybrid Electric Propulsion controls technology effort to start in FY17
Subject Area: Hybrid Electric Propulsion

Thrust and Roadmap: Transition to Low Carbon Propulsion; Thrust 4B – Hybrid Electric Roadmap

Goals: Low Carbon Challenge to enable carbon-neutral growth in aircraft operations and reduce emissions and improve efficiency by a combination of efforts … one is to introduce scalable alternative propulsion concepts

Top 2-5 Control Technology Challenges For each Control Technology Challenge:

- Brief Description (What are we trying to do and why)
- Relevance to Goals
  - What is the Benefit – quantitative/qualitative
- Technology Development Focus and Time Frame
  - 5-10 years, 10-20 years, > 20 years
Report Out from Breakout Session Discussion
## Participants in Hybrid Electric Propulsion Breakout Session held Aug 18, 2016

<table>
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<tr>
<th>Name</th>
<th>Organization</th>
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High Level Technical Challenge Areas

- Switching/Load Management
- Architecture Specific Controls Integration & Optimization
- Integrated Flight and Propulsion Control
- Integrated dynamic modeling, controls and stability
- Fault detection, isolation, and reconfiguration/redundancy management
Switching/Load Management

− Brief Description:
  − Controls design for bus voltage regulation and source paralleling; balancing power extraction sources with turbomachinery operations for safety and efficiency; load management/optimization and active cooling controls to optimize integrated system operations, and improve efficiency and emissions throughout operating envelope

− Relevance to ARMD Goals:
  − Enable system integration, operability, safety, and efficiency/emissions

− Relevant Technologies:
  − Source paralleling and voltage regulation
  − Balancing and transitioning between power sources
  − Optimization of loads throughout flight profile
Architecture Specific Controls Integration & Optimization

– Brief Description:
  – Optimization of propulsion controls design for specific HEP hardware architecture and associated performance requirements for component designs; HEP hardware architecture study to determine the most beneficial integrated controls design for operability and performance

– Relevance to ARMD Goals:
  – Increases efficiency and minimizes system weight – System Integration, operability, and efficiency/emissions

– Relevant Technologies:
  – Modular modeling capability to simulate different HEP architectures for control design, determine subsystem performance specifications, and interface analysis
  – Understand the impact of transient control and operability requirements on HEP architecture
Integrated flight and propulsion control

Brief Description:
- Distributed propulsion systems will require tighter integration between flight controls thrust demand vs. propulsion thrust availability based on flight condition, load demand, and system efficiencies across multiple propulsors. Flight controls generation of distributed propulsion thrust will need to be consistent with what is achievable given the system configuration.

Relevance to ARMD Goals:
- Reduce weight, improved efficiency/emissions and operability

Relevant Technologies:
- Balancing power/load between distributed propulsors based on thrust demand from flight control
- Engine/Propulsor capability and condition communication to flight control
- More electric aircraft with electric/magnetic actuators
Integrated dynamic modeling, controls and stability

– Brief Description:
  – Integrated system dynamic modeling will be required to understand the interfaces and coupling between the various components – turbine engine, generator, power management and distribution, electric motor, and propulsor. Capability to perform dynamic analysis of system interfaces and associated component design specifications for integrated system stability, and development of systematic design process to ensure integrated system stability and performance at different levels of fidelity.

– Relevance to ARMD Goals
  – Enable design of efficient, low carbon footprint propulsion systems

– Relevant Technologies:
  – Understanding of dynamic system interfaces and modular integrated propulsion/power dynamic simulation development
  – Capability to do dynamic analysis at appropriate levels of fidelity
  – Data management design/analysis to insure command generation, system monitoring/recording, and synchronization for integrated system stability
Fault detection, isolation, and reconfiguration/redundancy management

- Brief Description:
  - Capability to perform HEP architecture specific system fault tree analysis and associated system design/redundancy to meet FAA fault probability requirements with aid of fault detection, isolation, and reconfiguration controls and system control robustness studies

- Relevance to ARMD Goals:
  - Enable design of HEP systems that are more amenable for practical application

- Relevant Technologies:
  - Integrated system fault modeling - subsystem requirements based on overall fault accommodation needs
  - Modular capability to conduct fault tolerance analysis specific to a HEP control architecture
References

• Key Documents Located at:
  http://www.aeronautics.nasa.gov/strategic-plan.htm

  – ARMD Strategic Plan (pdf)
  – ARMD Strategic Thrust 4: Transition to Low Carbon Propulsion (pdf)
  – Propulsion and Energy Systems to Reduce Commercial Aviation Carbon Emissions