NASA Investments in Electrified Propulsion

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Primary Drivers for Electrification R&D

- Safe, Efficient Growth in Global Operations
- Transition to Alternative Propulsion and Energy
- Innovation in Commercial Supersonic Aircraft
- Real-Time System-Wide Safety Assurance
- Ultra-Efficient Commercial Vehicles
- Assured Autonomy for Aviation Transformation
NASA Programs and Electrified Aircraft Content

Advanced Air Vehicles Program (AAVP)
Revolutionary Vertical Lift Technologies
Advanced Air Transport Technologies

Airspace Operations and Safety Program (AOSP)

Integrated Aviation Systems Program (IASP)
Flight Demonstrations & Capabilities

Transformative Aeronautics Concepts Program (TACP)
Transformative Tools & Technologies
Convergent Aeronautics Solutions

R&D is managed by identifying and seeking to overcome Technical Challenges
NASA Electrified Aircraft Propulsion Strategy

All & Hybrid Electric, Distributed Propulsion
- On Demand Mobility
- Small Vehicle Focused

Turbo and Hybrid Electric, Distributed Propulsion
- Energy Efficient Propulsion
- Transport Class Focused

Power Sharing
High Efficiency Power Distribution
Power Rich Optimization
Non-flight Critical First Application

Standards and Means of Compliance
Power Sharing
Enable New Aero Efficiencies

Enable New Aero Efficiencies

Leverage learning at smaller scale to inform scale-up

Energy & Cost Efficient, Short Range Aviation

Energy & Cost Efficient, Transport Aviation

NASA Small Vehicle EAP

NASA Transport EAP
Urban Air Mobility

Studies – Market, Hazards and Failure Modes

Grand Challenges – First is planned for 2022
- Accelerate technology certification and approval
- Develop flight procedure guidelines
- Evaluate communication, navigation and surveillance options
- Demonstrate an airspace system architecture based on NASA’s Unmanned aircraft systems Traffic Management (UTM) construct
- Collect initial assessments of passenger and community perspectives on vehicle ground noise, cabin noise and on-board ride quality

Related and coordinated with work in other areas
- UAS traffic management
- UAS integration into the Nat’l Airspace
- Revolutionary Vertical Lift Technologies
- X-57 Flight Demonstrator
X-57 Maxwell Flight Demonstrator

- Explore all-electric propulsion
  - Fully electric transmission
  - High aspect ratio wing enabled by high lift system
  - Wingtip propellers at cruise to counteract wingtip vortices

Mod II
- Fully Electric P206T

Mod III
- Cruise configuration
- P2006T wing replaced with high aspect ratio wing (2X reduction in area)
- Cruise motors moved to wingtips

Mod IV
- Final Modification
- Integration of high lift motor system

**Goal** – Help develop certification standards for emerging electric aircraft markets.

**Design Driver** – 5 X increase in high-speed cruise efficiency, zero in-flight carbon emissions, and flight that is much quieter for the community on the ground.
Revolutionary Vertical Lift Technologies

**PROPULSION EFFICIENCY**
- High power, lightweight battery
- Light, efficient, high-speed electric motors
- Power electronics and thermal management
- Light, efficient diesel engine
- Light, efficient small turboshaft engine
- Efficient powertrains

**SAFETY and AIRWORTHINESS**
- FMECA (failure mode, effects, and criticality analysis)
- Component reliability and life cycle
- Crashworthiness
- Propulsion system failures
- High voltage operational safety

**OPERATIONAL EFFECTIVENESS**
- Disturbance rejection (control bandwidth, control design)
- Ops in moderate to severe weather passenger acceptance/ride quality cost (purchase, maintenance, DOC)

**PERFORMANCE**
- Aircraft optimization
- Rotor shape optimization
- Hub and support drag minimization
- Airframe drag minimization

**ROTOR-ROTOR INTERACTIONS**
- Performance, vibration, handling qualities
- Aircraft arrangement
- Vibration and load alleviation

**NOISE AND ANNOYANCE**
- Low tip speed
- Rotor shape optimization
- Flight operations for low noise
- Aircraft arrangement/interactions
- Cumulative noise impacts from fleet ops
- Active noise control
- Cabin noise
- Metrics and requirements

**STRUCTURE AND AEROELASTICITY**
- Structurally efficient wing and rotor support
- Rotor/airframe stability
- Crashworthiness
- Durability and damage tolerance
- High-cycle fatigue

**ROTOR-WING INTERACTIONS**
- Conversion/transition
- Interactional aerodynamics
- Flow control

**AIRCRAFT DESIGN**
- Weight, vibration handling qualities
- Active control

**SIDE-BY-SIDE + HYBRID**
- Quadrotor + Electric
- Lift+Cruise + TurboElectric

**TILTWING + TURBOELECTRIC**

Red = primary RVLT research area
Blue = secondary RVLT research area
Advanced Air Transportation Technologies

System Level
- Airplane concepts & systems analysis tools
- Boundary layer ingestion and other propulsion airframe integration benefits
- Thermal and fault management methods
- Flight and Propulsion Controls
- Test capabilities

Electrical Powertrain Technologies
- Electrical power components (e.g. machines, converters, circuit interrupters)
- Electric system architectures
- Advanced materials

Coupled turbine systems
- Integrated Electrical Machines
- Small core turbomachinery
- New material systems

Technologies and capabilities to enable air vehicles to leverage benefits of electricity in their propulsion systems.
Convergent Aeronautics Solutions Projects

- **AQUIFER**: Aqueous QUick-Charging Battery Integration For Electric Flight Research
- **LiON**: Lithium Oxygen Batteries for NASA Electric Aircraft
- **AQUIFER**: Boeing NASA collaboration (briefed separately)
- **HEATHER**: High-efficiency Electrified Aircraft Thermal Research. Reduce power conversion requirements and use low-loss electrical components to enable local thermal management solution for MW-class EAP
- **SABERS**: Solid-State Architecture Batteries for Enhanced Rechargeability and Safety. Develop a solid-state bipolar battery stack based on novel Li-S/Se chemistry and a non-flammable electrolyte for UAM (FY20 new start)
- **SPARRCI**: Sensor-based Prognostics to Avoid Runaway Reactions & Catastrophic Ignition. Enable safe battery operation with higher specific energy via embedded sensors and machine learning (FY20 new start)

**Completed Activities**: FUELEAP (SOFC), CAMIEN (AM Motor), LION (Li-Oxygen Batteries)
Transformational Tools and Technologies

- Multidisciplinary analysis and optimization (MDAO) applications - X-57 mission planning, boundary layer studies
- High voltage transmission systems
- Materials for EAP
- Urban Air Mobility tools

University-led Initiatives

- CHEETA: Center for Hydrogen-Energy Electric Transport Aircraft (CHEETA) - cryogenic hydrogen system to power all-electric aircraft led by University of Illinois, Urbana-Champaign
- Ohio State University project to work electric propulsion challenges, including high power density electric machines and high-voltage power electronics; integrated energy storage; power control and system integration
Thank you for the opportunity to participate in this very exciting series of workshops