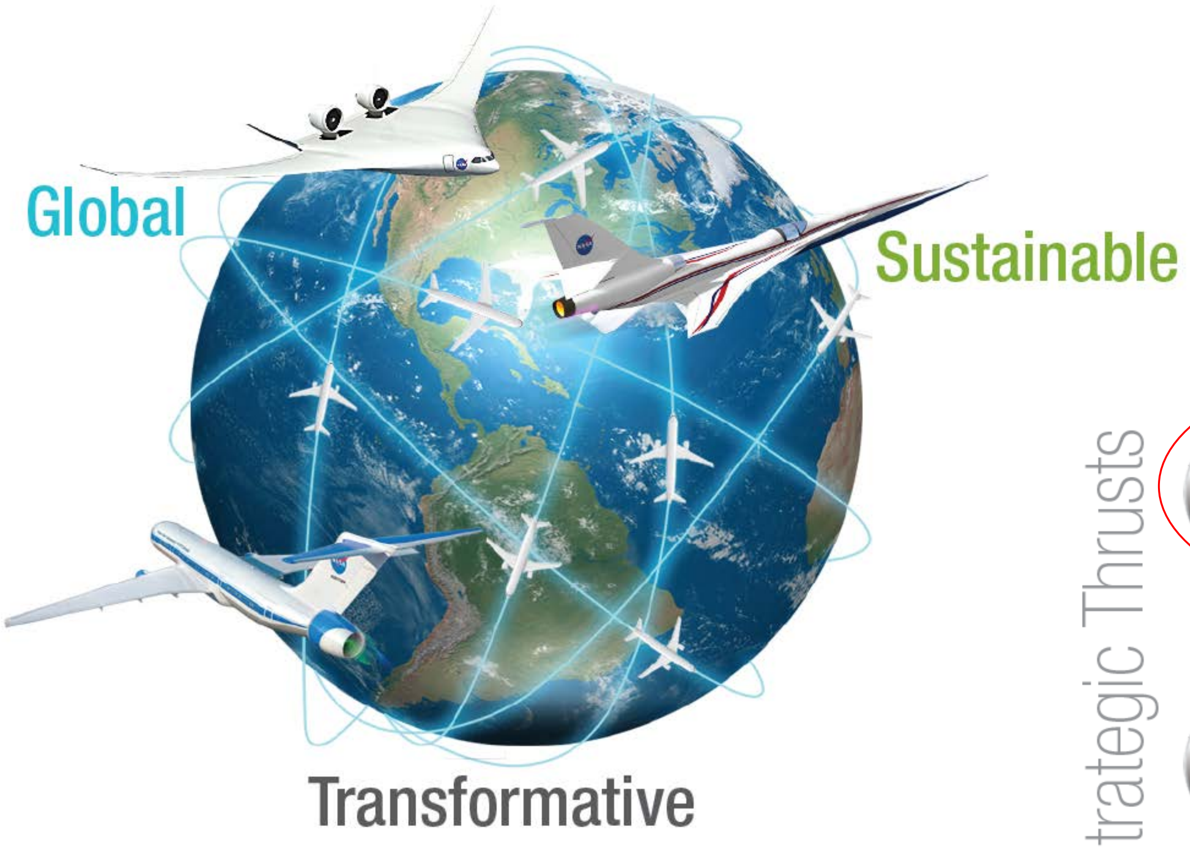
NASA Investments in Electrified Propulsion

Presented to the International Forum for Aviation Research
Electric-Hybrid Propulsion Working Group Workshop #2
Budapest, Hungary
27 November, 2019

Amy Jankovsky
Manager, Electrified Aircraft Powertrain Technologies
Advanced Air Transport Technologies Project
NASA Glenn Research Center

NASA's Aeronautics Research Mission Directorate



Primary Drivers for Electrification R&D

6 Strategic Thrusts

- 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)

Airspace Operations and Safety Program (AOSP)

Integrated Aviation Systems Program (IASP)

Transformative Aeronautics Concepts Program (TACP)

Revolutionary Vertical Lift Technologies

Advanced Air Transport Technologies

Flight Demonstrations & Capabilities

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

Enable New Aero Efficiencies

Power Sharing

Distributed Thrust Control

Standards and Means of Compliance

High Efficiency Power Distribution

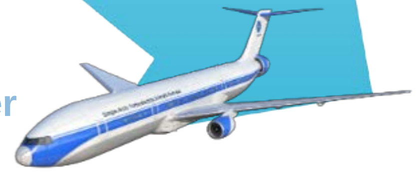
Power Rich Optimization

Non-flight Critical First Application

Fundamental Challenges (e.g. materials)

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 sing 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

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

SAFETY and AIRWORTHINESS
FMECA (failure mode, effects, and criticality analysis)
component reliability and life cycle
crashworthiness
propulsion system failures
high voltage operational safety

Quadrotor + Electric

Tiltwing + TurboElectric

Side-by-side + Hybrid

Lift+Cruise + TurboElectric

STRUCTURE AND AEROELASTICITY
structurally efficient wing and rotor support
rotor/airframe stability
crashworthiness
durability and damage tolerance
high-cycle fatigue

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

ROTOR-WING INTERACTIONS
conversion/transition
interactional aerodynamics
flow control

AIRCRAFT DESIGN
weight, vibration
handling qualities
active control

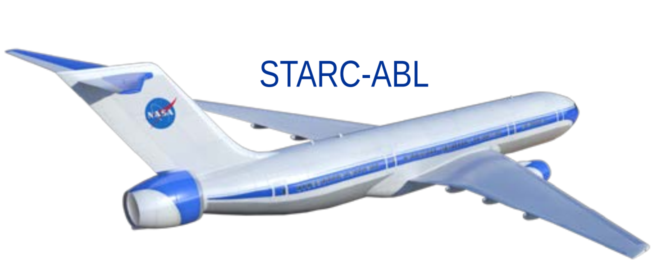
Red = primary RVLT research area
Blue = secondary RVLT research area

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

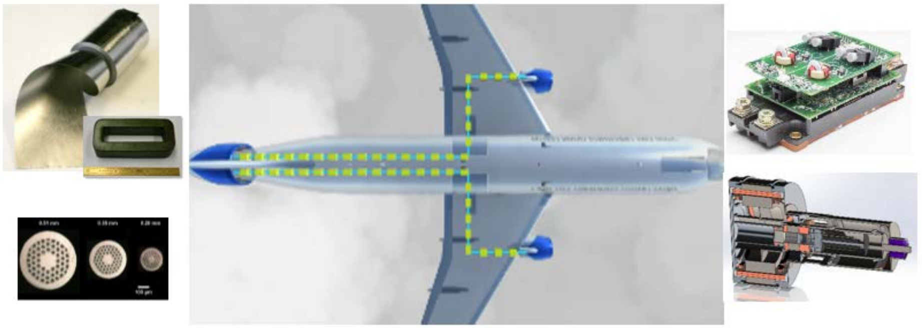
Electrical Powertrain Technologies
- Electrical power components (e.g. machines, converters, circuit interrupters)
- Electric system architectures
- Advanced materials

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



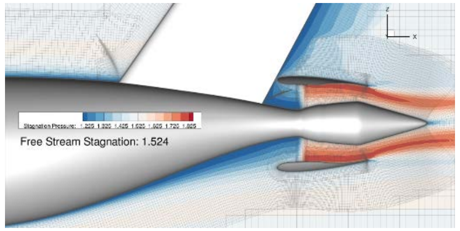
STARC-ABL

Pegasus



EAP Powertrains

Tailcone Thruster CFD Assessment



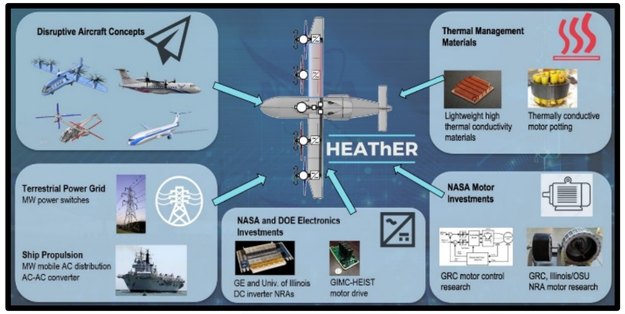
Technologies and capabilities to enable air vehicles to leverage benefits of electricity in their propulsion systems.

Transformational Aeronautics Concepts

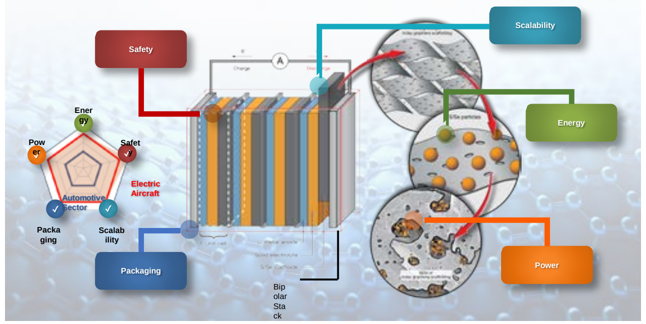
Convergent Aeronautics Solutions Projects

- **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



HEATHER



SABERS

Camien Additively Manufactured Motor

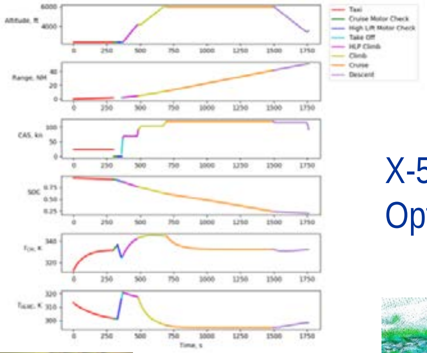
Transformational Aeronautics Concepts

Transformational Tools and Technologies

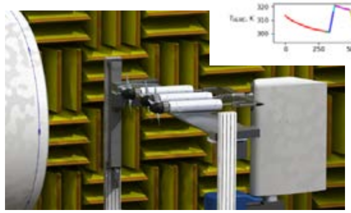
- Multidisciplinary analysis and optimization (MDAO) applications - X-57 mission planning, boundary layer studies
- High voltage transmission systems
- Materials for EAP
- Urban Air Mobility tools

University-led Initiatives

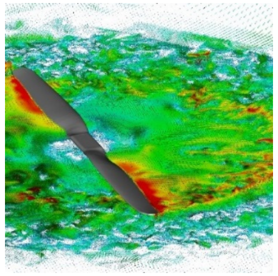
- CHEETA: Center for Hydrogen-Energy Electric Transport Aircraft (CHEETA) - cryogenic hydrogen system to power all-electric aircraft led by University of Illinois, Urbana-Champaign
- Ohio State University project to work electric propulsion challenges, including high power density electric machines and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



X-57 Cruise Optimization



Multi-prop and Wing Testing for Distributed Electric Propulsion



Straight-up Imaging of Quadcopter Blade

Cheeta Concept

Thank you for the opportunity to participate in this very exciting series of workshops