

RTX Electrification and Sustainability Virtual Workshop, 2021
NASA Electrified Aircraft Drivetrain Summary

Presented by: Nuha Nawash
NASA Glenn Research Center
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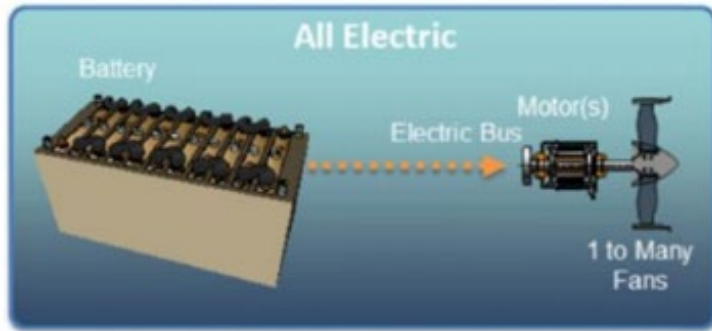
- Drivetrain Primer
- NASA EAP Research and Applicability
- Drivetrain Background
- EAP Activities
- Validation
- Testing & Verification
- Conclusion

Drivetrain Primer



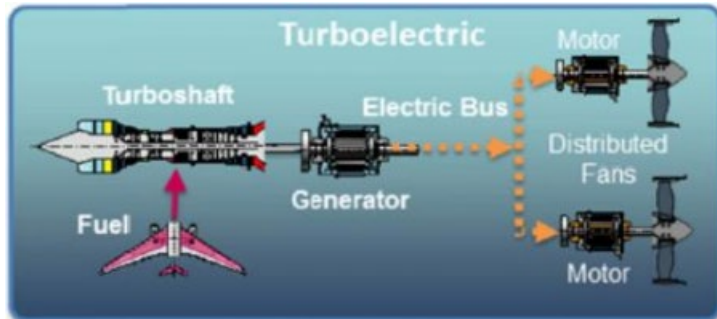
All-electric

Use Electric Energy Storage as only power source



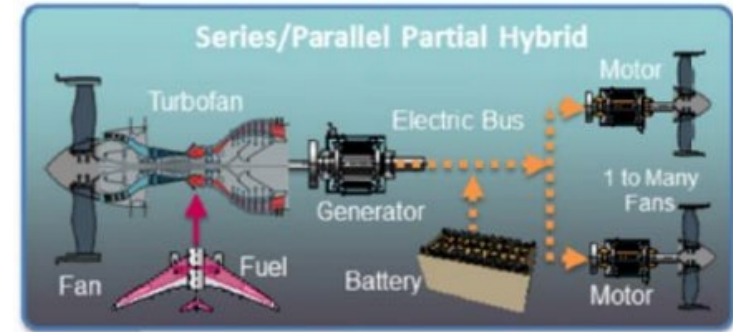
Turbo-electric

Use a Turbine driven generator as a power source



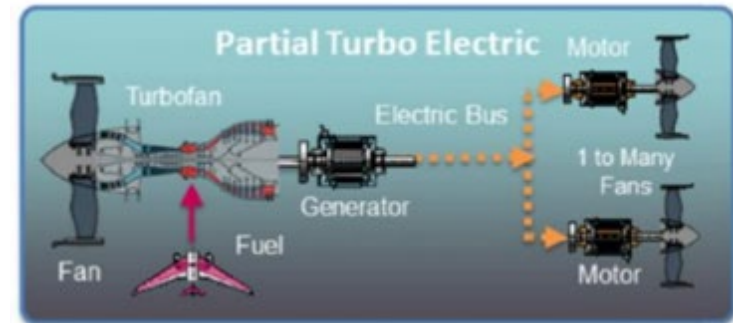
Hybrid-Electric

Use a turbine driven generator combined with electrical energy storage as a power source



Partially Turbo-Electric

Split thrust between a turbofan and motor driven fans



NASA EAP Research and Applicability



- **NASA evaluating EAP technology across a range of markets/ vehicle types**
 - EAP Activities have been studied & executed over the last 10 years
 - Work spans from fundamental research to flight demonstrations
- **Overarching Strategy**
 - Create and demonstrate enabling technology for end-to-end power systems/drivetrains
 - Transfer knowledge to industry
- **MW & Sub-MW class EAP Systems can be utilized across a range of aircraft**
 - All-electric, hybrid-electric, and turbo-electric applicability varies across missions



VTOL

Aircraft

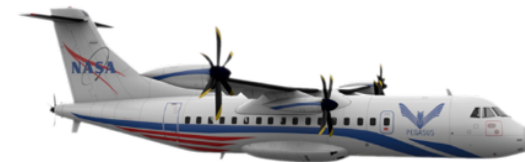
Projects

RVLT; TEEM



Small GA/Turboprop

X-57



Regional Turboprops &
Turbofans

Pegasus



Single Aisle

EAPT; EPFD

RVLT



- Focused on eVTOL applications
- Utilizes concept vehicle design for studies
 - Includes all-, hybrid-, and turbo-electric drivetrains
 - Sub-MW to MW level
- Some Focus Areas
 - Acoustics/Noise Signatures of Loads
 - Power Quality & Power System Integration
 - Standards & Best Practices
 - System Sizing Software Packages

Quadrotor “Air Taxi”
Battery



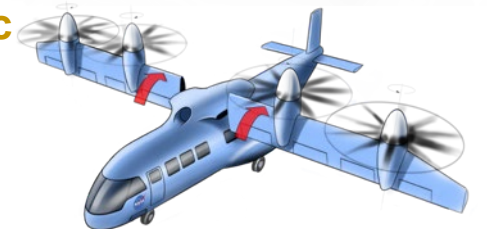
Side by Side “Vanpool”
Parallel Hybrid



Lift+Cruise Air Taxi
Turbo-Electric



Tilt wing “Airliner”
Turbo-Electric

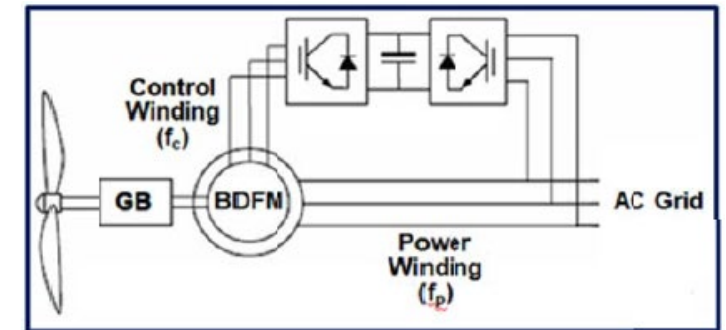
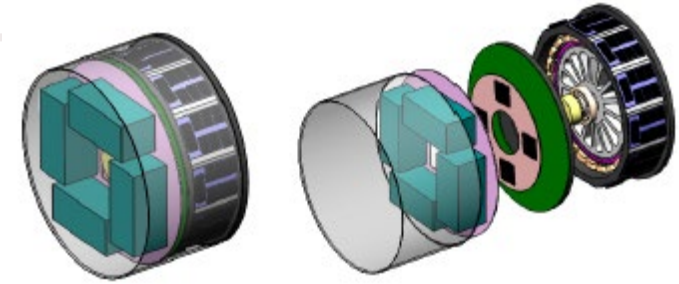


RVLT Motor Design Efforts – Goal: Improved Motor Reliability



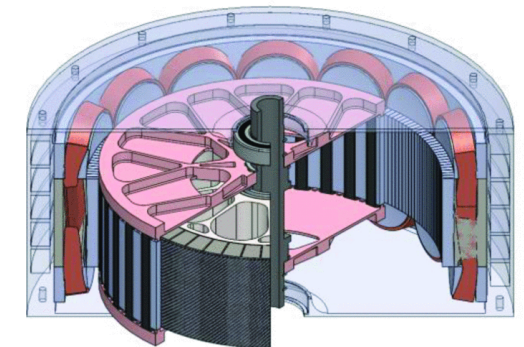
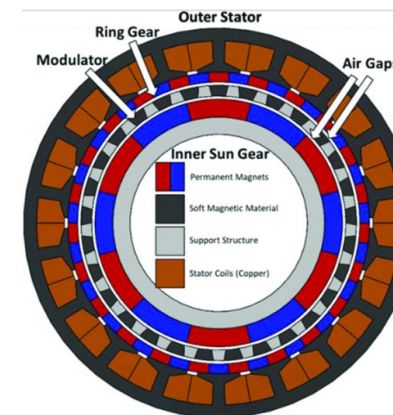
- **External Efforts¹: 2 Contract Funded Design**

- 1) University of Wisconsin via OSU ULI
 - Integrated, fault-tolerant motor/drive design for RVLT quadcopter
- 2) Balcones Technologies vis Phase III NASA STTR
 - Developing Brushless Doubly-Fed Machine (BDFM) design for RVLT-class vehicle (100-200 kW)



- **Internal Efforts²:**

- 1) Magnetically Geared Motors and Novel Designs
 - Exploring trade space of reliable motor topologies for UAM applications using in-house codes.
Example: Outer Stator Magnetically Geared Motor
- 2) Winding Reliability Model Development
 - Developing modeling and experimental capability to explore/predict winding reliability



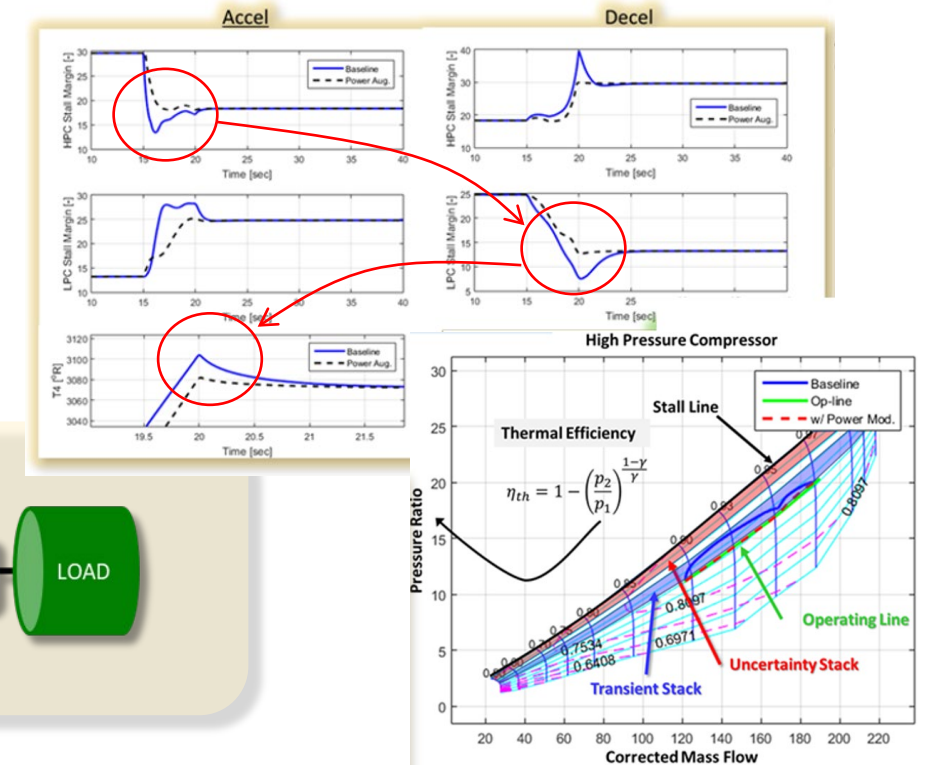
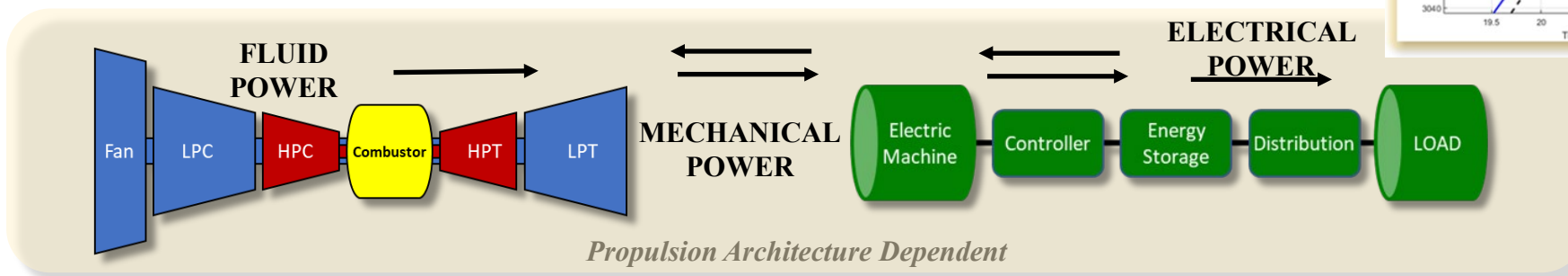
1. J. Swanke, T. Jahns, "Reliability Analysis of a Fault-Tolerant Integrated Modular Motor Drive (IMMD) for an Urban Air Mobility (UAM) Aircraft Using Markov Chains." 2021 AIAA/IEEE Electric Aircraft Technologies Symposium (EATS).

2. T. F. Tallerico, Z. A. Cameron, J. J. Scheidler and H. Hasseeb, "Outer Stator Magnetically-Geared Motors for Electrified Urban Air Mobility Vehicles," 2020 AIAA/IEEE Electric Aircraft Technologies Symposium (EATS), New Orleans, LA, USA, 2020, pp. 1-25.

TTT/Turbine Electrified Energy Management – TEEM (Hybrid)



- Utilizes Energy Management Control – Concept Being Applied to RVLTV Vehicle
 - Improves Operability, Robustness, Propulsion System Responsiveness
- Significantly impacts turbomachinery design and propulsion architecture through reduction of transient stack margin
 - Opens Design Space
 - Improved Efficiency
 - Lower Weight and Volume

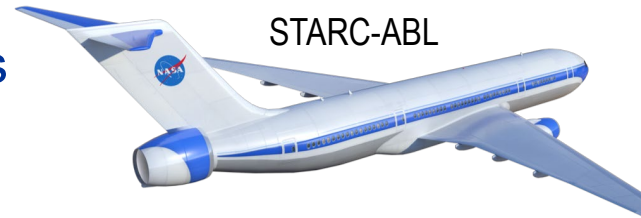


AATT/EAPT



System Level

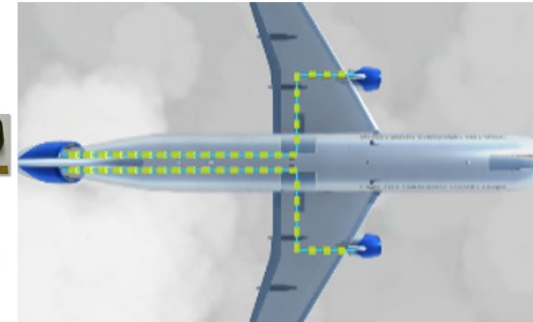
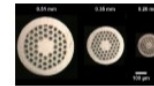
- Airplane concepts & systems analysis tools
- Boundary layer ingestion and other propulsion airframe integration benefits
- Electric system architectures
- Test capabilities



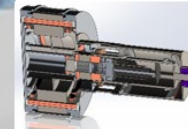
STARC-ABL



PEGASUS



EAP Powertrains



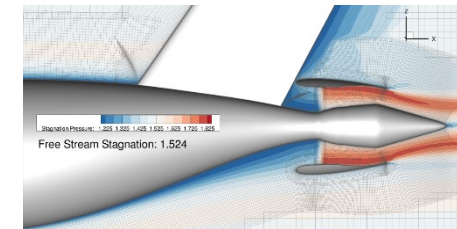
Electrical Powertrain Technologies

- All-, hybrid-, turbo-electric systems
- Electrical power components (e.g. machines, converters, circuit interrupters)
- Advanced materials

Coupled turbine systems

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

Tailcone
Thruster CFD
Assessment



Technologies and capabilities that enable air vehicles to leverage benefits of electrified propulsion

Electrified Powertrain Flight Demonstration (EPFD) Project



- **Establishing Project Partnerships throughout industry**
 - Accelerate integrated MW class power system maturation
 - Thin haul, regional & next generation SA Markets
- **Goals:**
 - Accelerate US Industry technology readiness and competitiveness
 - Facilitate new aviation industry S-Curve
 - Address gaps in regulations and standards
 - Acquire ground/flight data to advance/mature design & modelling tools
 - Transition technology to global fleet by 2035
- **NASA currently evaluating industry team proposals for integrated flight demos**

NASA Test Platforms- Ground Based

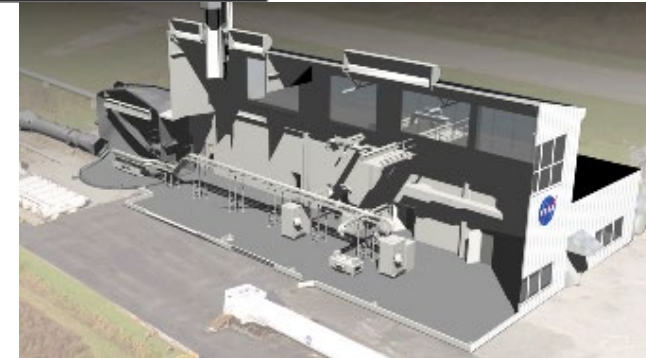
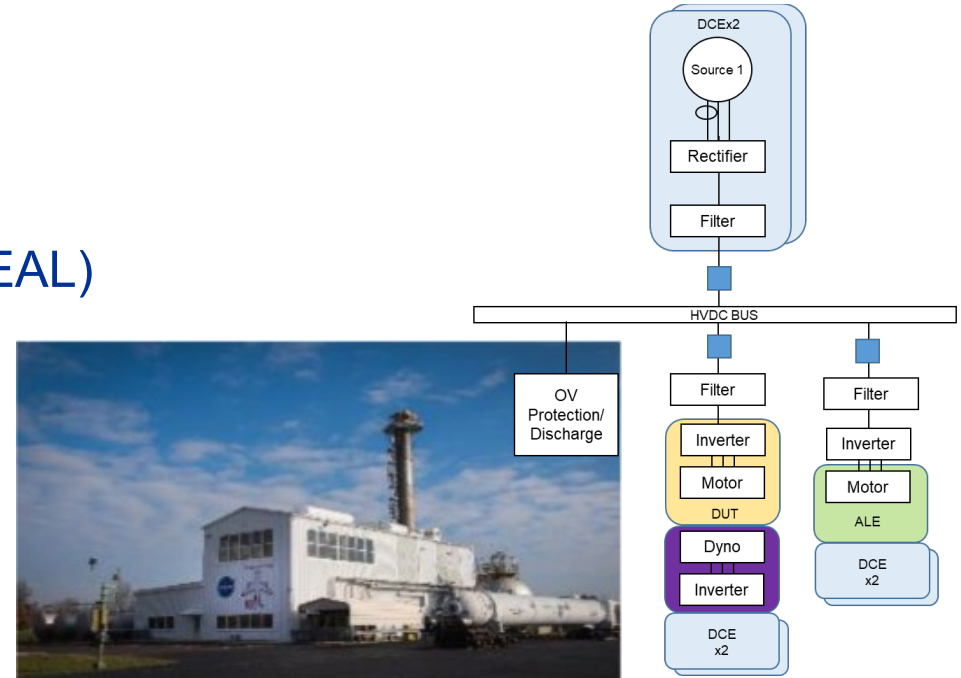


- **NASA has constructed numerous platforms for EAP Drivetrain Research and Testing**

- RVLT (<1kVdc, <1MW)
 - Scaled Power Electrified Drivetrain (SPEED)
 - Advanced Reconfigurable Electrified Aircraft Lab (AREAL)
- EAPT (>1MW) – NASA Electrified Aircraft Testbed (NEAT)

- **Areas of Interest**

- Power Quality & Integration
- Component Performance Evaluation
- Electromagnetic Interference
- Altitude Testing
- Inform Standards & Best Practices
- Energy Management & more





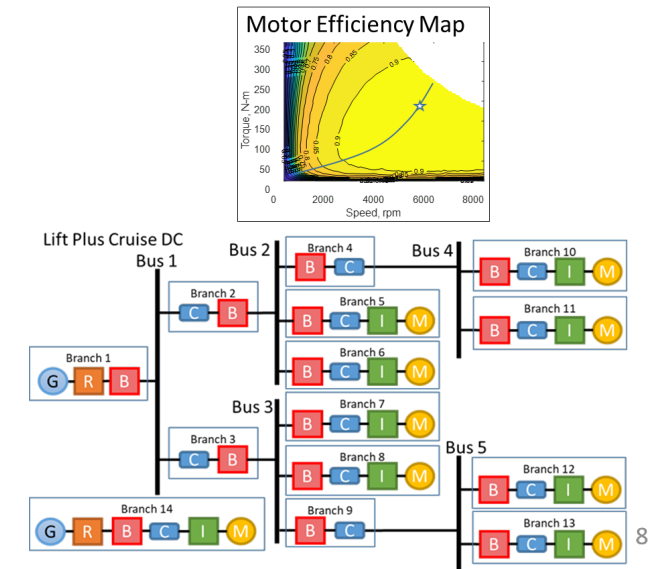
- **NASA has invested in multiple software packages for EAP Drivetrains**

- NDARC (RVLT)
- EPS-SAT (RVLT)
- NPSS® (Various)
- OpenMDAO (TTT)

- **Non-inclusive capabilities across packages**

- Component & Architecture trades/ sensitivity analysis
- Component, sub-system, and system performance evaluations across missions
- Integrated System Sizing

- **Internal and publically available models updated based on Test Platform Data**



Conclusion



- **NASA is broadly investing in Electrified Aircraft Propulsion (EAP)**
- **NASA investments are guided by a combination of potential market impacts and technical key performance parameters.**
- **The impact of EAP varies by market and NASA is considering three markets: on-demand mobility, short haul regional air transport, and national/international.**
- **Technical advances in key areas have been made that indicate EAP is a viable technology.**
- **Flight and ground-based research, along with modeling & analysis, is underway to demonstrate integrated solutions (drivetrains) and inform standards and certification processes.**