Electric Propulsion: Challenges and Opportunities

Active Technology Project (2017 - 2022)

Project Introduction

This project will design, build, and test a 1 megawatt electric machine and thermal management system that is targeted for aircraft propulsion applications and achieves a specific power density exceeding 14 kilowatt/kilogram (active mass) with 99% efficiency. The machine will be integrated with its power electronics drive operating at voltages greater than 2000 Volt dc and achieving a 25 power density and 99% efficiency. The machine will be studied as part of an overall aircraft system which will include an energy management system.

The system integration work is led by Georgia Tech. After first providing the initial requirements for the mission, they then resized the vehicle based on the preliminary technology goals. Trade studies were performed and showed not only the benefits of distributed propulsion but also the contribution of the hybridization of the system on a regional aircraft. A hybrid-distributed propulsion provided at 15% fuel burn reduction compared to a next generation A320 aircraft. With the addition of boundary layer ingestion (yet to be demonstrated) we can achieve a significant reduction of fuel burn and carbon dioxide emission of 23%.

Power electronics work is being performed at Ohio State's Center for High Performance Power Electronics (CHPPE) lab. The team is developing advanced technology required to achieve high-efficiency high-power-density power electronics converters that achieve reliable operation with 2 kilovolt dc bus voltage in a harsh working environment.

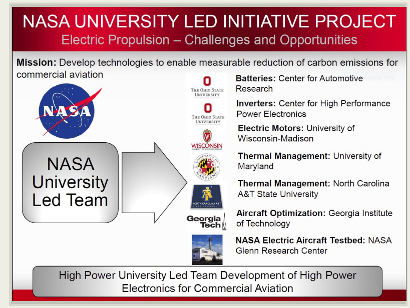
Efforts are in 3 major technology areas:

- Partial discharge study for power electronics and electric machines at low air density;
- Power module and power converter designs to achieve high power density;
- Advanced control strategies and protection schemes for aircraft onboard power

The work completed thus far has shown that the target power densities are achievable and most importantly that partial discharge at low ambient pressure can be controlled.

The focus on energy storage is to integrate the electro-mechanical thermal characterization methods with the performance, safety and durability of the battery cells. The team at Ohio State's Center for Automotive Research is working with the most advanced cell producers to design and demonstrate novel Energy Storage System based on lithium-ion batteries and is optimizing the integration of these cells for the airplane mission.

The aim of this technical thrust is:



The Ohio State University's Electric Propulsion ULI Project

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- Characterization and modeling of high energy density state of the art and advanced battery technologies based on experimental testing, including energy density assessment, electro-thermal modeling, aging models, analysis of behavior at extreme conditions;
- Design exploration for high level pack sizing under performance, durability, cost and weight constraints (activity in collaboration with Georgia Tech);
- Battery Management System for pack control and safe operation, including dynamic power limits estimation of the cells considering temperature and aging, estimation of state of charge and state of health, safe operation at high voltage, cell balancing;
- Pack Architecture (modules and submodules) that enhances modularity, capability of reconfiguration and adaptation in case of fault, self-diagnosis, and operation with state-of-the-art charging infrastructures.

A high performing motor was identified early as one of the challenges of the program. A thorough integration of the mechanical and electromagnetic design were required. The Center of Design and Manufacturing Excellence (CDME) at The Ohio State University was engaged early to work with the University of Wisconsin team to develop the motor. The teams have worked closely to develop a well-integrated design could be made available first in a 200 kilowatt machine and then in a 1 megawatt motor. The team plans to run the 200 kilowatt machine in the laboratory and the 1 megawatt machine at the NASA Electric Aircraft Testbed facility.

Thermal cooling for a high megawatt electrical machine is undoubtedly a major challenge. The thermal management system is being addressed by the University of Maryland and North Carolina A&T State University. New designs were investigated and the team kept close communication as to what was needed between these Universities as well as the University of Wisconsin and Center of Design and Manufacturing Excellence (CDME) at The Ohio State University as they worked on the development and production of the 200 kilowatt and 1 megawatt reliable design.

Anticipated Benefits

This project will demonstrate capabilities required for adoption of electric machines for aircraft propulsion in the commercial aircraft fleet with the objective of reducing measurable carbon dioxide impact from large commercial aircraft (regional, single and twin aisle).

Organizational Responsibility

Responsible Mission Directorate:

Aeronautics Research Mission Directorate (ARMD)

Lead Organization:

Ohio State University

Responsible Program:

Transformative Aeronautics Concepts Program

Project Management

Program Director:

John A Cavolowsky

Project Manager:

Koushik Datta

Principal Investigator:

Mike J Benzakein

Co-Investigators:

Marcello Canova
Thomas Jahns
John Kizito
F P Mccluskey
Jin Wang
Gokcin Cinar
Matilde D’arpino

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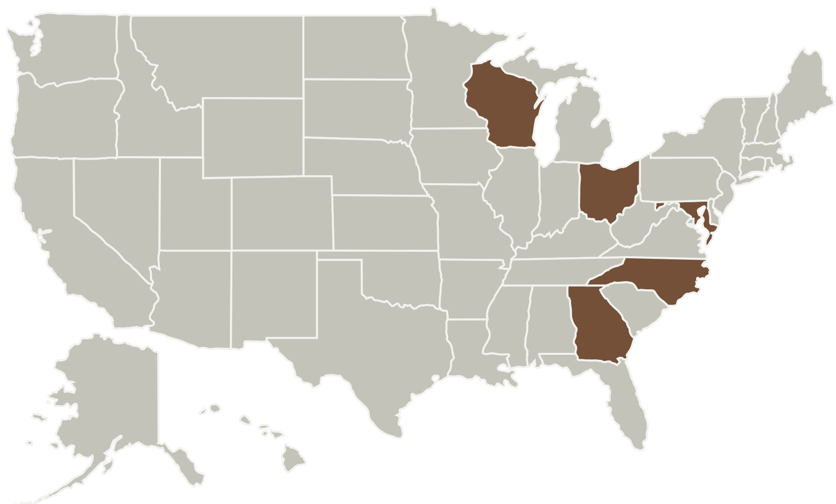
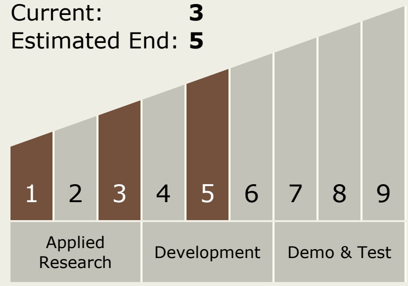
Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
Ohio State University	Lead Organization	Academic	Columbus, OH
Georgia Institute of Technology	Supporting Organization	Academic	Atlanta, GA
Marquette University	Supporting Organization	Academic	Milwaukee, WI
North Carolina Agricultural and Technical State University	Supporting Organization	Academic	Greensboro, NC
University of Maryland	Supporting Organization	Academic	College Park, MD
University of Wisconsin	Supporting Organization	Academic	Madison, WI

Technology Maturity (TRL)

Start: **1**
Current: **3**
Estimated End: **5**



Technology Areas

Primary:

- TX01 Propulsion Systems
  └ TX01.3 Aero Propulsion
    └ TX01.3.9 Hybrid Electric Systems

Other/Cross-cutting:

- TX01 Propulsion Systems
  └ TX01.3 Aero Propulsion
    └ TX01.3.8 All Electric Propulsion

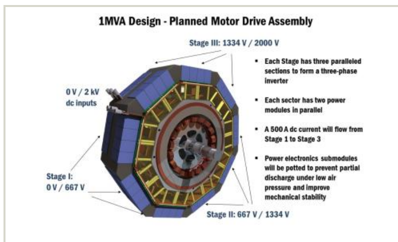
Target Destination
Foundational Knowledge

Supported Mission Type
Push

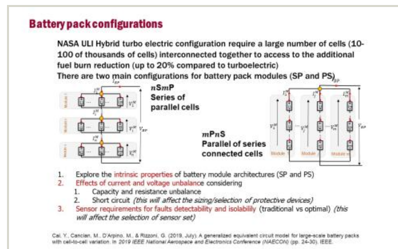
Primary U.S. Work Locations	
Georgia	Maryland
North Carolina	Ohio
Wisconsin	

Images

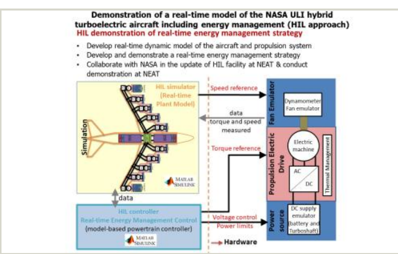
1 MW SPM Machine Development
1 MW SPM Machine Development *(https://techport.nasa.gov/image/40822)*



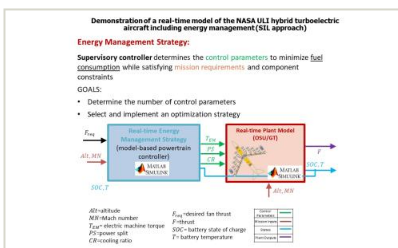
1MVA Design - Planned Motor Drive Assembly
1MVA Design - Planned Motor Drive Assembly *(https://techport.nasa.gov/image/40823)*



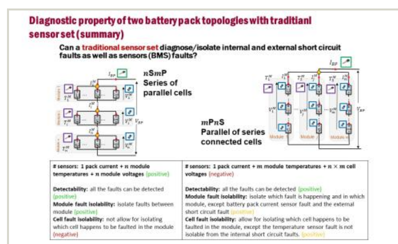
Battery pack configurations
Battery pack configurations *(https://techport.nasa.gov/image/40827)*



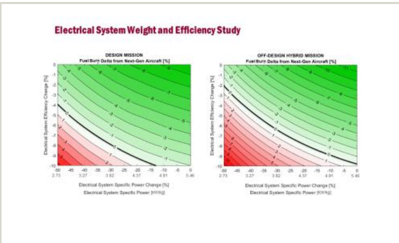
Demonstration of a real-time model of the NASA ULI hybrid turboelectric aircraft including energy management (HIL approach)
HIL demonstration of real-time energy management strategy *(https://techport.nasa.gov/image/40830)*



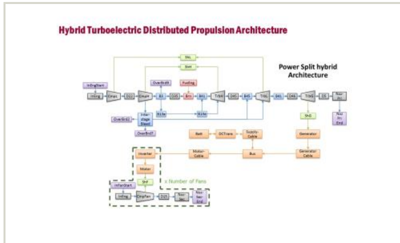
Demonstration of a real-time model of the NASA ULI hybrid turboelectric aircraft including energy management (SIL approach)
Demonstration of a real-time model of the NASA ULI hybrid turboelectric aircraft including energy management (SIL approach) *(https://techport.nasa.gov/image/40831)*



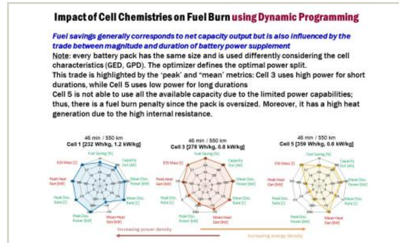
Diagnostic property of two battery pack topologies with traditional sensor set (summary)
Diagnostic property of two battery pack topologies with traditional sensor set *(https://techport.nasa.gov/image/40828)*



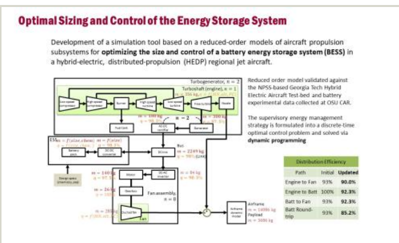
Electrical System Weight and Efficiency Study
Electrical System Weight and Efficiency Study
(https://techport.nasa.gov/image/40820)



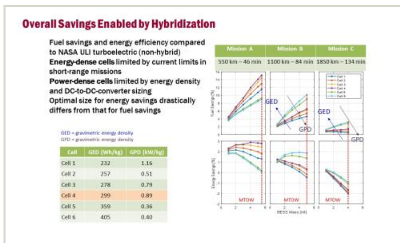
Hybrid Turboelectric Distributed Propulsion Architecture
Hybrid Turboelectric Distributed Propulsion Architecture
(https://techport.nasa.gov/image/40818)



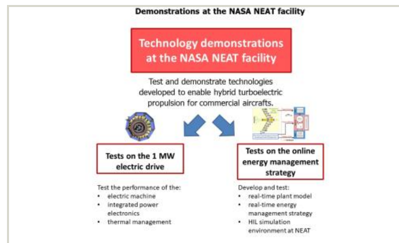
Impact of Cell Chemistries on Fuel Burn using Dynamic Programming
Impact of Cell Chemistries on Fuel Burn using Dynamic Programming
(https://techport.nasa.gov/image/40826)



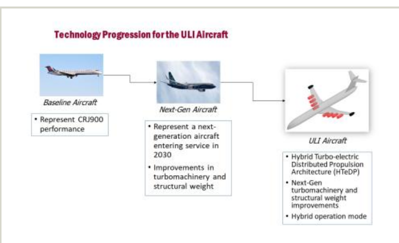
Optimal Sizing and Control of the Energy Storage System
Optimal Sizing and Control of the Energy Storage System
(https://techport.nasa.gov/image/40824)



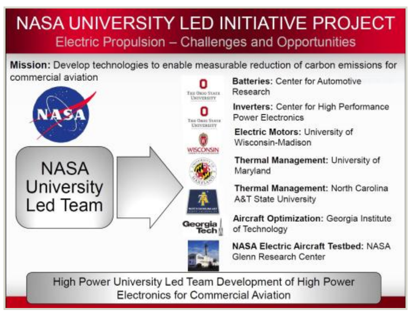
Overall Savings Enabled by Hybridization
Overall Savings Enabled by Hybridization
(https://techport.nasa.gov/image/40825)



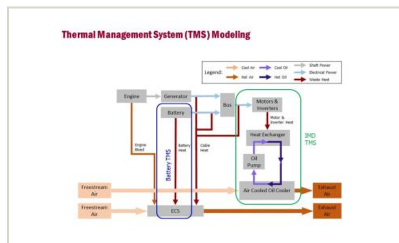
Technology demonstrations at the NASA NEAT facility
Demonstrations at the NASA NEAT facility
(https://techport.nasa.gov/image/40829)



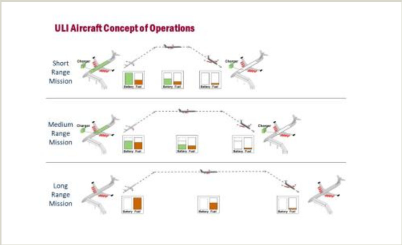
Technology Progression for the ULI Aircraft
Technology Progression for the ULI Aircraft
(https://techport.nasa.gov/image/40816)



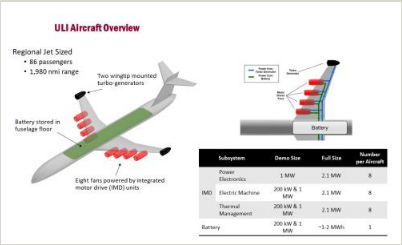
The Ohio State University's Electric Propulsion ULI Project
The Ohio State University's Electric Propulsion ULI Project
(https://techport.nasa.gov/image/40814)



Thermal Management System (TMS) Modeling
Thermal Management System (TMS) Modeling
(https://techport.nasa.gov/image/40819)



ULI Aircraft Concept of Operations
ULI Aircraft Concept of Operations
(https://techport.nasa.gov/image/40821)



ULI Aircraft Overview
ULI Aircraft Overview
(https://techport.nasa.gov/image/40817)

Links

A Comprehensive PD Study Method on Power Modules with Ultra-high dv/dt Output
(https://doi.org/10.1109/WiPDA46397.2019.8998918)

A generalized equivalent circuit model for large-scale battery packs with cell-to-cell variation
(https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwjouLKoq_znAhUzkHIEHT5NC7gQFjAAegQIARAC)

A simulation tool for battery life prediction of a Turbo-Hybrid-Electric Regional Jet for the NASA ULI Program
(https://doi.org/10.2514/6.2019-4469)

An Update on Sizing and Performance Analysis of a Hybrid Turboelectric Regional Jet for the NASA ULI Program
(https://smartech.gatech.edu/handle/1853/63769)

Cooling Of a Hot Substrate with Supersonic Nozzle
(https://www.uab.edu/engineering/me/images/Documents/about/early_career_technical_journal/2018-Journal-UAB-ECTC-Section0.pdf)

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(https://smartech.gatech.edu/bitstream/handle/1853/63770/AIAAPEForum_Shi_2020_ElectricalPropulsion_ThermalManagement.pdf?sequence)

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(https://doi.org/10.1109/WiPDAAsia.2018.8734633)

Dynamic Voltage Balancing for the High-Voltage SiC Super-Cascode Power Switch
(https://ieeexplore.ieee.org/document/8742642)

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(http://www.ieee-ecce.org/2019/conference/tutorials-6/)

Heat Transfer Enhancement in an Axially Rotating Pipe with Twisted Tape Insert
(https://www.researchgate.net/publication/339015034_Heat_Transfer_Enhancement_in_an_Axially_Rotating_Pipe_with_Twisted_Tape_Inser)

High voltage SiC super-cascode power switch parameter optimization for loss reduction
(https://doi.org/10.1109/APEC.2018.8341246)

Investigation of a Cooling System for a Hybrid Airplane
(https://doi.org/10.2514/6.2018-4991)

Optimal Design and Control of Battery Energy Storage Systems for Hybrid Turbo-Electric Aircraft
(https://www.sae.org/publications/technical-papers/content/2020-01-0050/)

Optimization Method to Eliminate Turn-on Overvoltage Issue of the High Voltage SiC Super-Cascode Power Switch
(https://doi.org/10.1109/SPEC.2018.8636013)

Performance of a Gravity Independent Heat Pipe
(https://www.uab.edu/engineering/me/images/Documents/about/early_career_technical_journal/2018-Journal-UAB-ECTC-Section0.pdf)

Sizing and Performance Analysis of a Turbo-Hybrid-Electric Regional Jet for the NASA ULI Program
(https://doi.org/10.2514/6.2019-4490)

Sizing and Performance Analysis of a Turbo-Hybrid-Electric Regional Jet for the NASA ULI Program
(https://doi.org/10.2514/6.2019-4490)

Smart Resistor for Stability Improvement of the dc Link in Turbo-Electric Aircrafts
(https://www.researchgate.net/publication/333427917_Smart_Resistor_for_Stability_Improvement_of_the_dc_Link_in_Turbo-Electric_Air)

Smart Resistor: Stabilization of DC Microgrids Containing Constant Power Loads Using High-Bandwidth Power Converters and Energy
(https://ieeexplore.ieee.org/document/8688445)

Thermal Management Challenges in Turbo-Electric and Hybrid Electric Propulsion
(https://doi.org/10.2514/6.2018-4695)