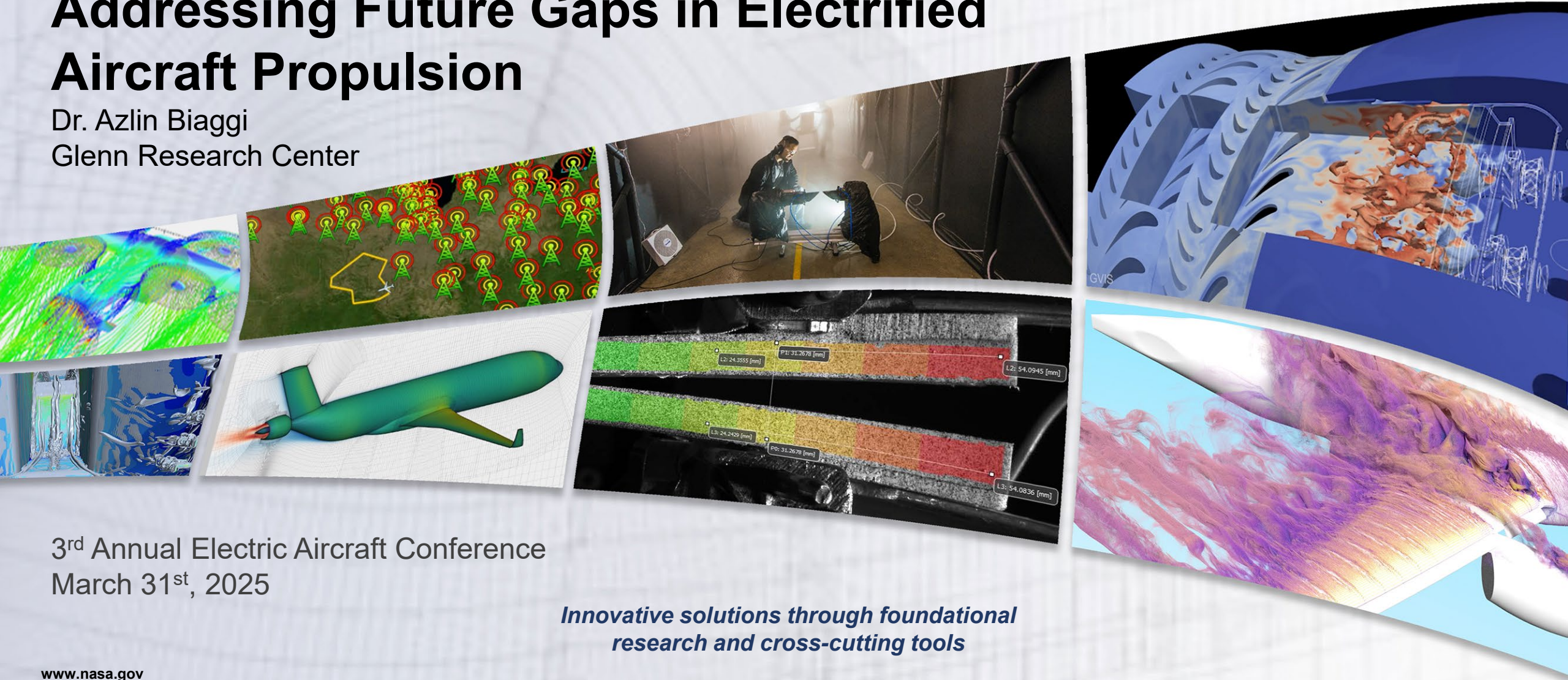


## Transformational Tools and Technologies (T<sup>3</sup>) Project

# Addressing Future Gaps in Electrified Aircraft Propulsion

Dr. Azlin Biaggi  
Glenn Research Center



3<sup>rd</sup> Annual Electric Aircraft Conference  
March 31<sup>st</sup>, 2025

*Innovative solutions through foundational  
research and cross-cutting tools*

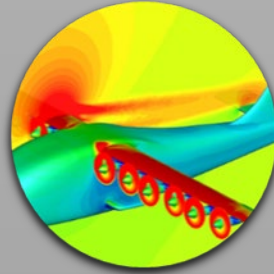
# Outline

1. Brief introduction
2. Propulsion Controls for Hybridized Systems
  - Turbine Electrified Energy Management (TEEM)
  - Versatile Electrically Augmented Turbine Engine (VEATE) Gearbox
  - Advanced Geared Turbofan 30k<sub>lbf</sub> Thrust Electrified (AGTF30-e)
  - Hybrid Propulsion Emulation Rig (HyPER) Lab
  - SmartFan
  - REconfigurable Aircraft Piloted Evaluation Research (REAPER) Lab
3. Aircraft Design Using Multi-Disciplinary Analysis and Optimization (MDAO)
  - Aviary
  - Uncertainty Quantification
4. Batteries for Aviation
  - Solid State Energy Storage Research
  - Sensors and Prognostics
  - Advanced Thermal Management Materials and Packaging Concepts
5. Sustainable High Voltage (HV) Power Wires/Cables
  - Focus Areas
  - Micro-Multilayered Multifunctional Electrical Insulation (MMEI)
  - Electrical Insulation Work – Composites
  - Automated Materials Lab (AML)/Modeling
  - Vision/Strategy
6. Summary

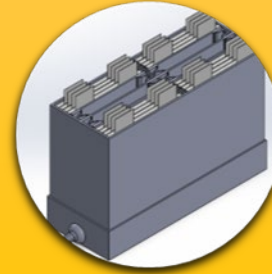
**Enable the performance, reliability, and durability of electrified propulsion systems by conducting enduring research and developing innovative materials, components, tools, and methods**



**Understanding the role of hybridized propulsion controls in optimizing system performance**



**Analyzing future aircraft designs and propulsion systems for enhanced efficiency and sustainability**



**Exploring solutions for the energy storage limitations in electric aircraft**

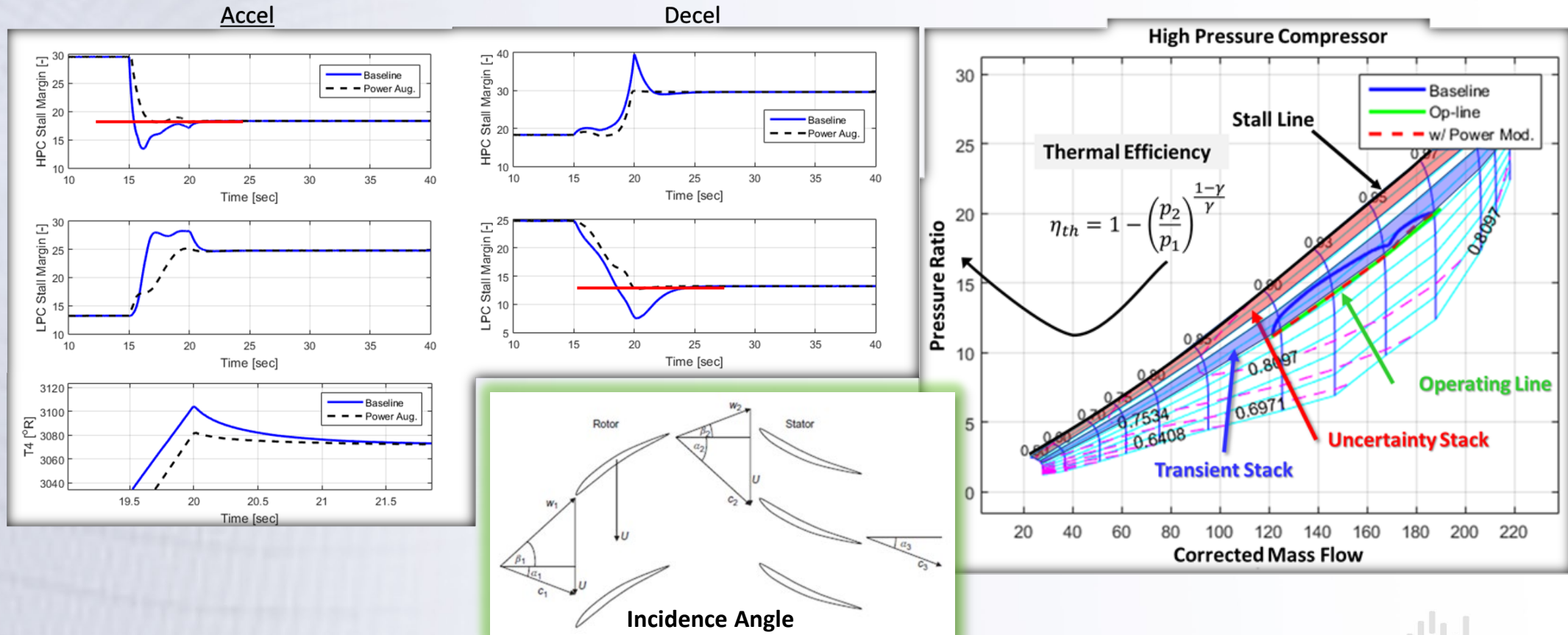


**Exploring solutions for high voltage challenges**

**Foundational Electrified Aircraft Propulsion**

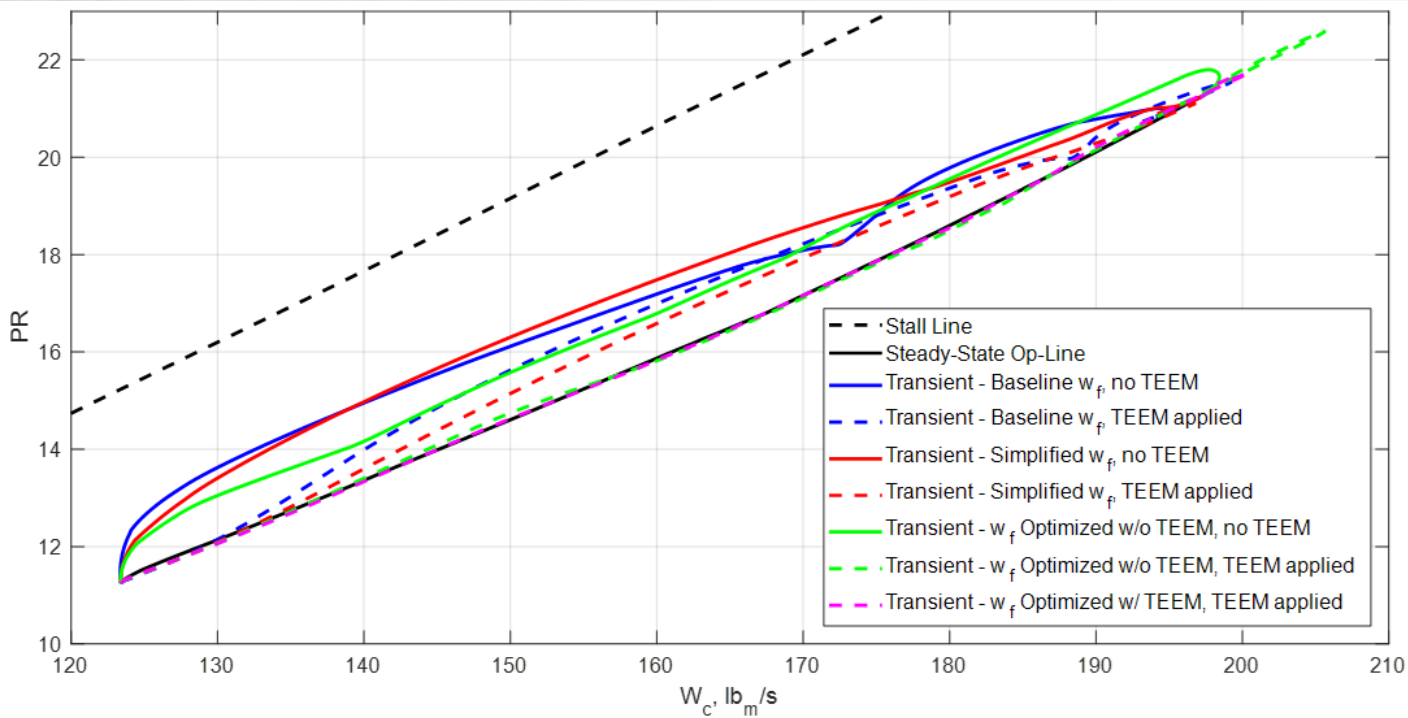
# The Importance of Turbine Electrified Energy Management (TEEM)

- Active turbine engine control is typically accomplished through the manipulation of fuel flow.
- To maintain compressor stability across the operating range, fuel flow rate-of-change is limited and scheduled actuation of variable geometry and compressor bleed is used to improve stage matching.
- All of these affect the **flow incidence angle across the blading**, which is the fundamental cause of instability.



# Optimizing TEEM – Torque Shaping

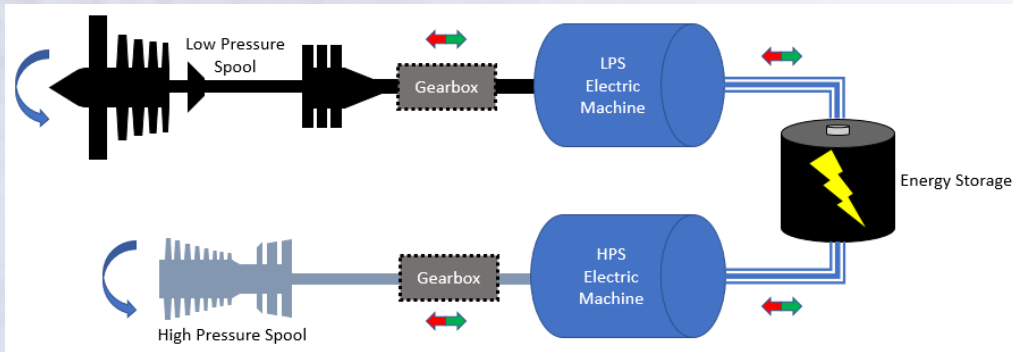
- Electric machines make very good actuators for turbomachinery stability control, having about 1000x bandwidth of engine thrust output, bi-directional torque at typically less than 20% of the fuel power.
- They can force beneficial changes to rotational speed independent of fuel driven gas path velocity/power.



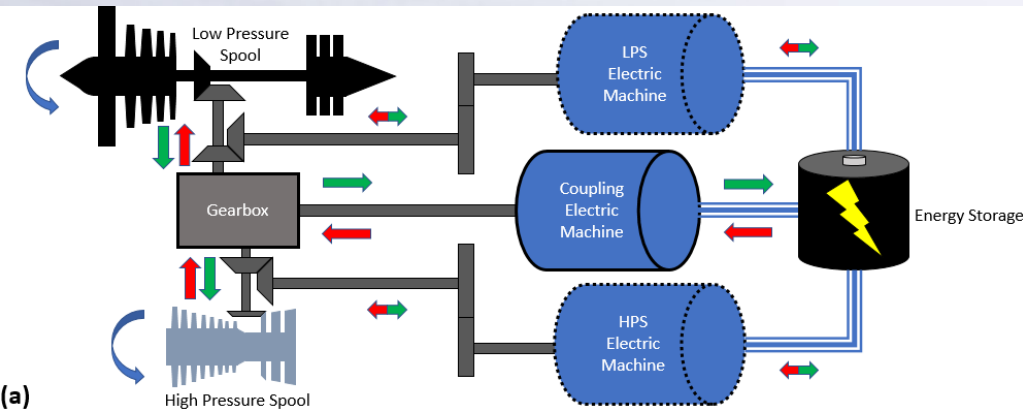
- Results to date indicate there is significant capability with electric actuation to force the system to respond *as if at steady state* even while undergoing transient throttle movements.
  - Design the control and power system to optimize the cost/benefit trade (what defines optimal?)
  - Consider constraints and particularly the balance of operability, responsiveness, and weight
  - Coordinate electric machine torques with traditional engine actuators
- To optimize appropriately we need to improve the model fidelity by incorporating more transient dynamic effects from heat and the gas path.

# Versatile Electrically Augmented Turbine Engine (VEATE) gearbox

- NASA innovation for the integration of electric machines in hybridized turbine-based propulsion architectures.
- The idea transforms the common accessory gearbox, that is presently used on aircraft for electric power off-take and to start the engine, into an active, performance-enhancing capability.
- This is a collaboration with **Penn State and the University of Tennessee** to develop the concept for feasibility.



*Baseline configuration with dedicated electric machines independently connected through an Accessory gearbox to both engine spools.*



*(a) VEATE configuration with smaller electric machines connected through a multi-input/multi-output planetary gearbox to both engine spools*

- In a recent analysis, the technology was used to look at performance and weight impacts for several hybrid operating modes; Thrust Boost, Large Power Extraction, and a bidirectional mode that provides transient control and bleedless operation under low engine power.
- In each case, there was significant weight reduction in the electrical power system with the same or improved performance relative to the baseline engine system that uses dedicated electric machines connected via a passive accessory gear box.

# Advanced Geared Turbofan 30k<sub>lbf</sub> Thrust Electrified – (AGTF30-e)

**Objectives:** Develop and publicly release an updated version of the AGTF30 Advanced Geared Turbofan 30,000lbf engine model that incorporates hybridization options that have relevancy to future aviation, primarily electrified aircraft propulsion (EAP).

**Result:** The AGTF30-electrified (AGT30-e) – a transient engine model with user selectable hybridized architecture

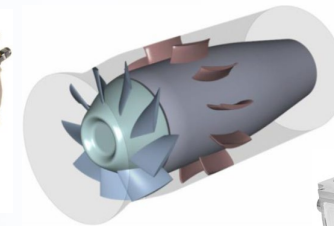
- **Primary electrification options:** standard/conventional engine, boost (enables electric power *injection* to augment engine fan thrust), or power extraction (large electric power *extraction* for distributed electric thrust production)
- **Secondary electrification options:** bi-directional electric power transfer (transfer power between multiple engine shafts and/or energy storage devices) to support advanced features like turbine transient operability, bleedless low power operation, and in-flight (battery) charging
- **Hybrid integration options:** offers passive and actively controlled options for integrating EMs with the turbine engines.

## Significance:

- Provides a virtual testbed for simulating various EAP technologies
- Provides a means of interacting with the greater aerospace community through providing a useful tool and a foundation for collaboration

POC: Jonathan Kratz/GRC-LCC

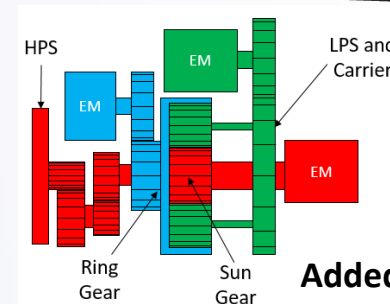
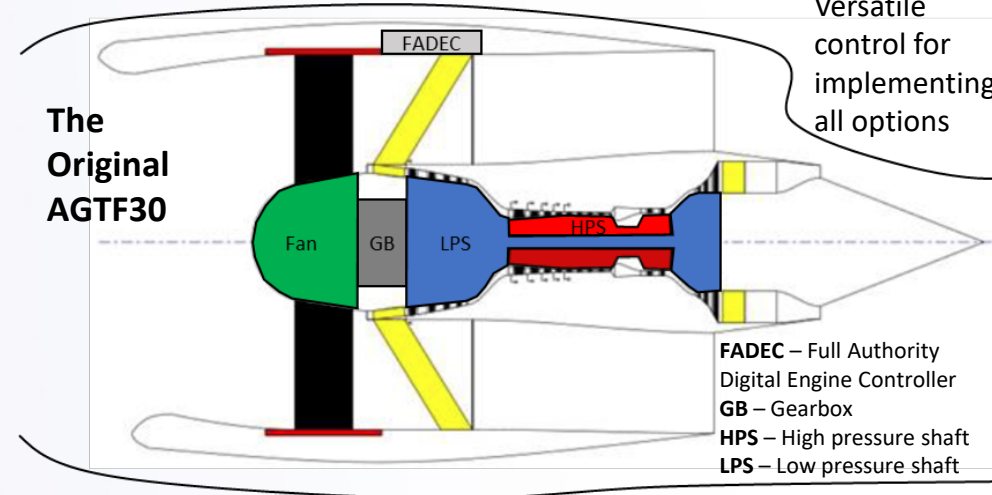
## Added Features



Power consumption representative of external propulsors



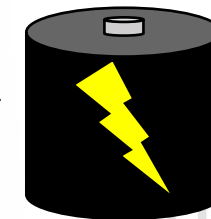
EMs for various uses (boost, power extraction, etc.)



## Added Features

Engine-EM integration options

Energy storage for boost and TEEM



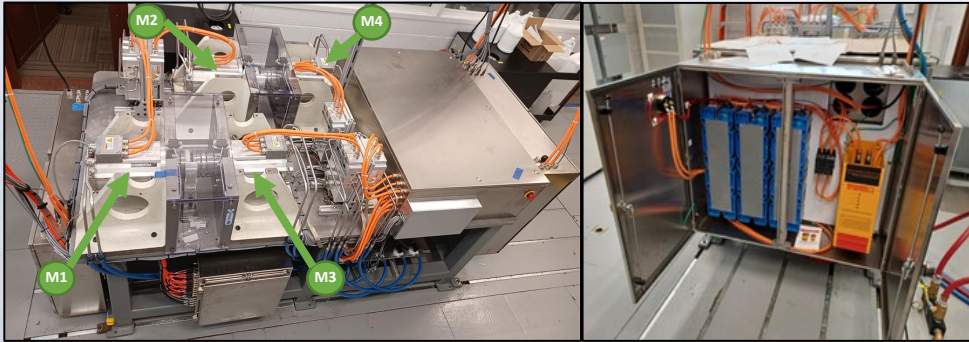
# Hybrid Propulsion Emulation Rig (HyPER) – Hardware-in-the-Loop Controls Testbed

Leveraging Hardware-in-the-Loop Testing for Rapid Development of Propulsion Control Technology

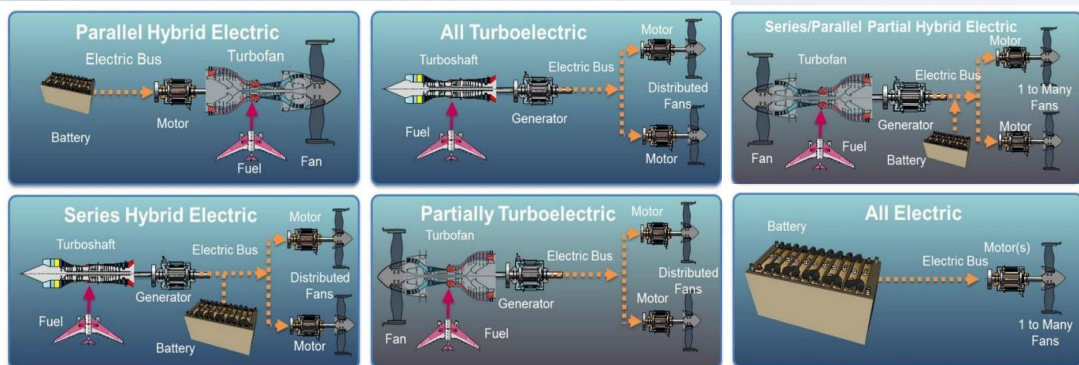
## Challenge

- Hybrid-electric and all-electric propulsion systems offer potentially significant benefits over state-of-the-art aircraft propulsion systems, including reduced fuel burn and improved system responsiveness and safety
- Hybrid-electric propulsion technologies incorporate multiple tightly coupled subsystems and require robust control to enable the delivery of their potential improvements
- Testing these systems is both slow and costly

## Photos of the HyPER test article



## NASA Reference Electrified Aircraft Propulsion Architectures



## Expected Impacts

- Improved ability to rapidly test and iterate control technologies for hybrid-electric and all-electric aircraft propulsion systems in a low-cost and sustainable way
- Decrease risk when testing electrified aircraft propulsion control algorithms on turbomachinery and flight systems
- Improve understanding of electrical and electro-mechanical components in electrified aircraft powertrains

## Solution

- HyPER provides a low-cost, low-risk, sustainable, and reconfigurable testbed for validating control algorithms developed for electrified aircraft propulsion systems
- HyPER enables the dynamic behavior of turbomachinery (torque and speed responses) to be scaled and emulated using electric machines
- By compiling different underlying propulsion system models, HyPER can be reconfigured to represent a wide variety of electrified aircraft propulsion systems and architectures
- Testing in HyPER validates the performance of a new control algorithm with real electrical and electro-mechanical actuators and sensors operating at a realistic power level

## Next Steps

- Continue using the testbed to validate control approaches for a wide variety of electrified aircraft propulsion systems
- All six of the NASA reference electrified aircraft propulsion architectures will be demonstrated using HyPER

## Results

- HyPER has been used to validate control algorithms for systems such as the AGTF30 parallel hybrid turbofan and the STARC-ABL, and SUSAN aircraft concepts
- Test results have shown that the test rig performance matches simulation predictions, and have been used to validate control approaches for the systems listed above and reduce risk prior to testing in larger, more expensive facilities

## Partners and/or Participants

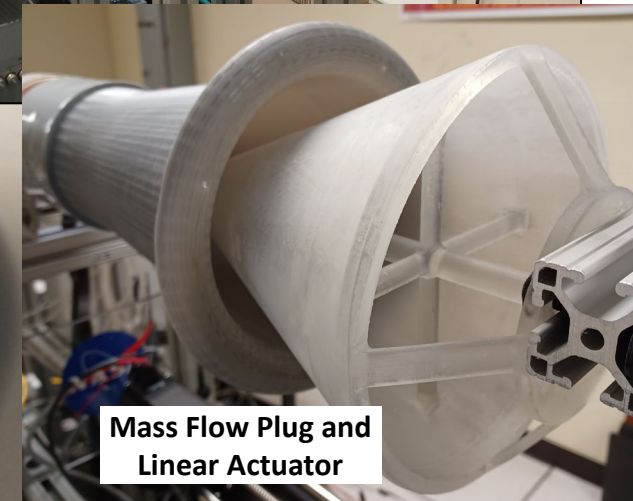
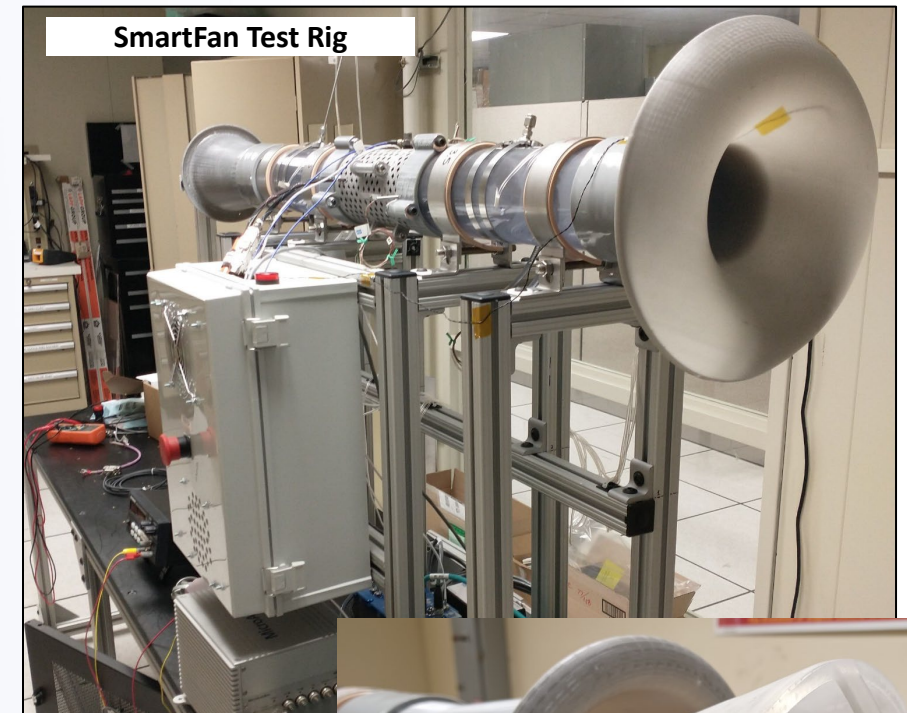
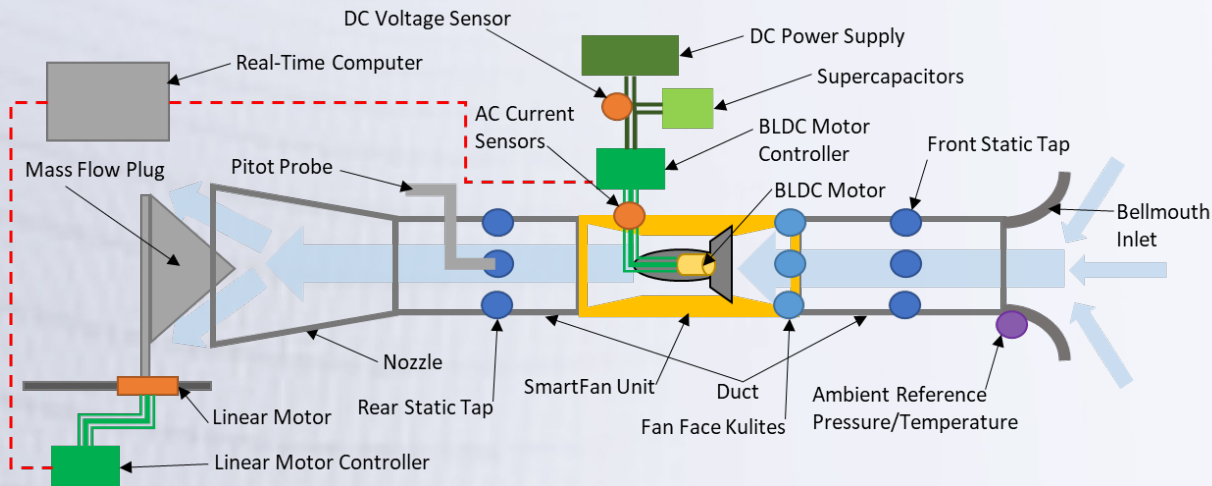
- NASA ARMD, Transformative Aeronautics Concepts Program, Transformational Tools and Technologies Project
- NASA Advanced Air Vehicles Program, Hybrid Thermally Efficient Core Project

# SmartFan Intelligent Electric Propulsor Testbed

Small scale, intelligent Electric Engine with local power management and stability control

**SmartFan:** Small scale electric engine test rig with local power management and stability control

- **Details:** Used to test and validate new energy management technologies and control approaches for instability detection and mitigation for stand-alone electric propulsors. Testbed construction is complete and system characterization and checkouts are ongoing.
- **Impact:** Potential benefits for decoupling propulsors from power source for improved power system stability while increasing the stable operating range for thrust production. Also provides a design reference baseline for compressor performance and modeling tool validation (FUN3D, EMTAT/T-MATS)



# REconfigurable Aircraft Piloted Evaluation Research (REAPER) Lab

- The REconfigurable Aircraft Piloted Evaluation Research (REAPER) Lab at NASA Glenn is utilized for propulsion controls research and development
- Features:
  - A closed, two-seat cockpit
  - A motion base that provides roll and pitch actuation
  - Integrated out-the-window displays
  - As a standalone simulator, it can be configured to represent a variety of aircraft
  - Based on the X-Plane 11 Software from Laminar Research
- X-Plane is user-accessible so
  - Researchers can develop their own real-time dynamic aircraft and propulsion system models and control systems, and interface them to the simulator, taking advantage of the realistic immersive environment for pilot-in-the-loop evaluation
  - Pilot controls and displays are programmable, so they can be repurposed for a given application, enabling flexibility in how the pilot interacts with the simulation
  - This provides the opportunity to investigate the installed performance of new concepts, such as novel airframes utilizing electrified aircraft propulsion, from an operational perspective



# Aircraft Design Using MDAO

## Aircraft Design and Mission Analysis

**Challenge:** MDAO state of the art has advanced beyond the state of adoption; Existing aircraft design capabilities are severely limited in their ability to provide meaningful trends for hybrid-electric and all-electric aircraft

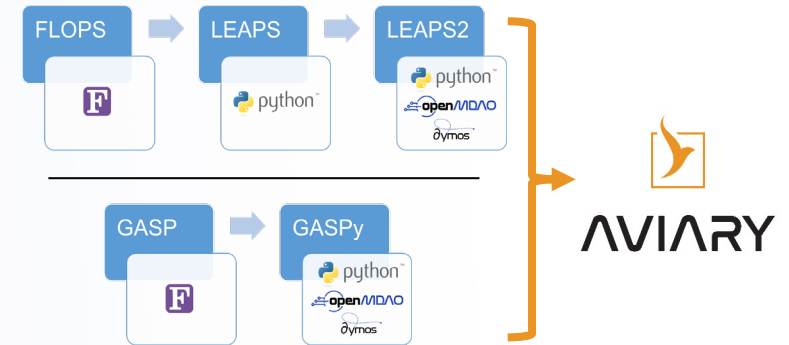
**Project Goals:** Develop Next Generation Aircraft Design Tools for EPFD, AATT, SFNP, SFD and other stakeholders (CST, HTP, etc.). Embed efforts and associated milestones with ARMD. Broaden impact by releasing open-source codes with low barriers for adoption. Enable conceptual design of N+4 aircraft considering such systems as hydrogen propulsion.

**Details:** Reimplemented legacy aircraft sizing codes using state of the art numerical methods. Optimized an advanced TTBW configuration. External public source release of Aviary v1.0 along with multiple open source models completed December '23. Ongoing release of features and bug-fixes

### Impact:

- Multidisciplinary, multicenter, early career leadership
- Expanded “toolbox” and Highly integrated into AATT MBSA/E efforts.
- Foundational mission analysis and vehicle sizing for MBSA/E TTBW and SFD digital flight test.
- Free and available to the public, Aviary enables aircraft design for underserved institutions




**Partners:** AATT, EPFD, SFD, Academia, Industry, Government Labs, International Partners. New “challenge problem” operational model for Aviary



# Aviary: A Transformational Tool

## What is Aviary?

AVIARY is NASA's next-generation aircraft modeling and optimization framework. Our goals are to:

- Combine the capabilities of legacy codes (FLOPS and GASP) into a single tool which can run them both together
- Use a modern code architecture, built on , to construct modular components that can be easily modified or replaced with custom tools or methods
- Perform state-of-the-art coupled optimization with , 
- Provide capability to analyze advanced future aircraft concepts, including EAP
- Open-source release for maximum impact to the aerospace research community

Combine legacy tools

Modular for modification and substitution

Coupled Optimizations

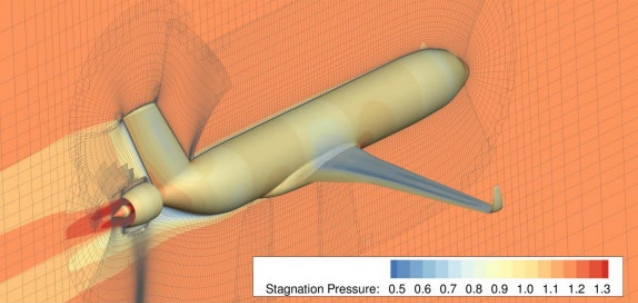
Analyze advanced concepts

Open source software

# Aviary: A Transformational Tool

## Why Do We Need Aviary?

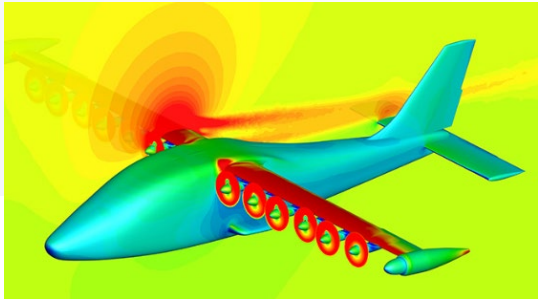
To drive overall efficiencies higher, couplings between disciplines need to be exploited. Optimal solutions are often non-intuitive.



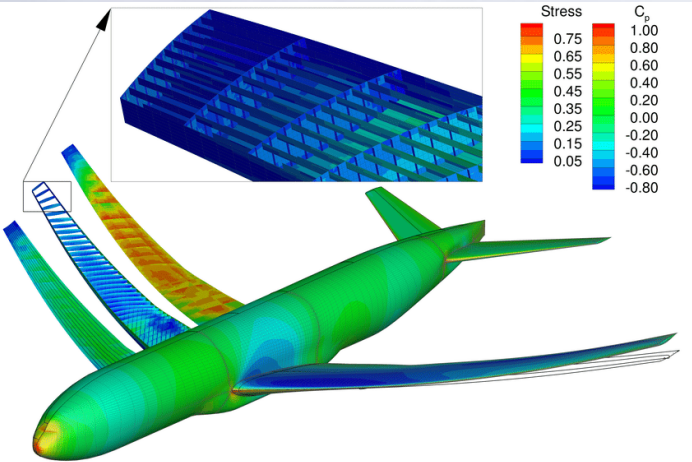
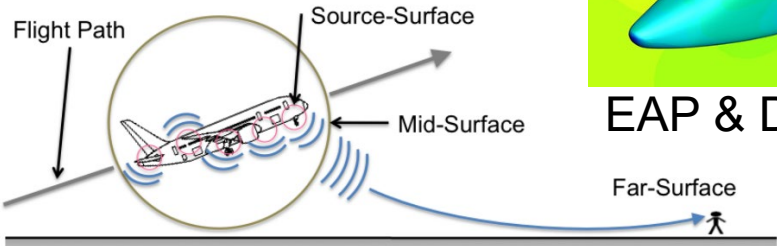
aero-propulsive couplings



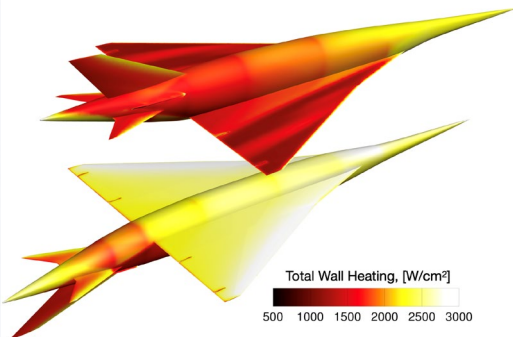
aero-acoustic couplings



EAP & DEP couplings

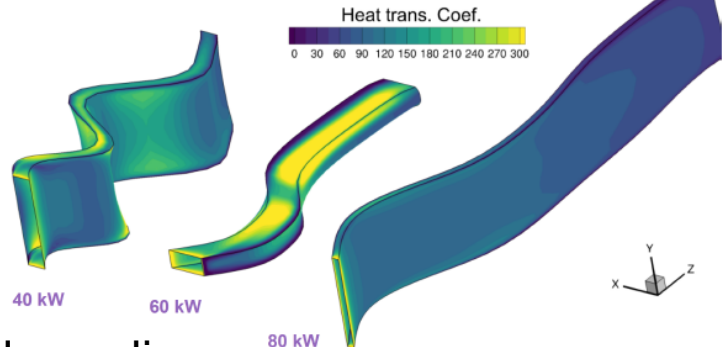


aero-structural couplings



aero-thermal couplings

Aerothermal design of heat exchanger passages



# Uncertainty Quantification

## Design Under Uncertainty Methods and OpenMDAO Integration

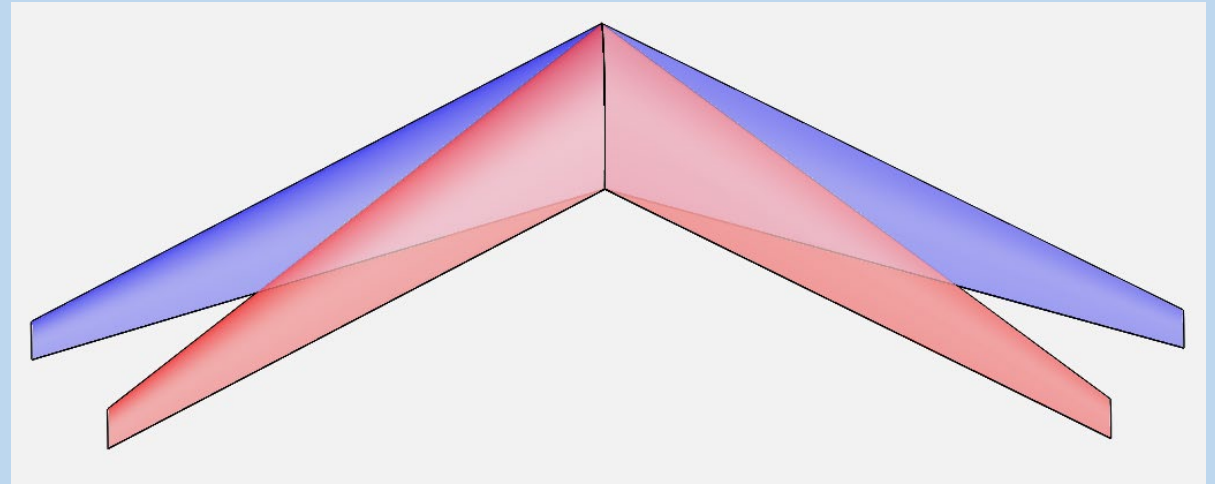
**Challenge:** New unconventional aircraft concepts bring new challenges and more uncertainties than vehicles significant experience

**Project Goals:** Extend gradient-based MDO with analytical derivatives to design under uncertainty. Address the two primary roadblocks to implementation of design under uncertainty: computational costs and added complexity of UQ integration. Integrate uncertainty analysis into “native” MDO tools for analysis and optimization

**Details:** Developed novel methods for integrating polynomial chaos-based UQ into MDAO frameworks.

### Impact:

- Seamless integration between deterministic optimization in OpenMDAO and design under uncertainty in OpenMDAO
- In two years, we’ve addressed a major technical concern surrounding MDAO and UQ work
- A CFD 2030 ending goal for MDAO within sight



Comparison of optimal wing planform designs  
(deterministic in blue, uncertain in red)

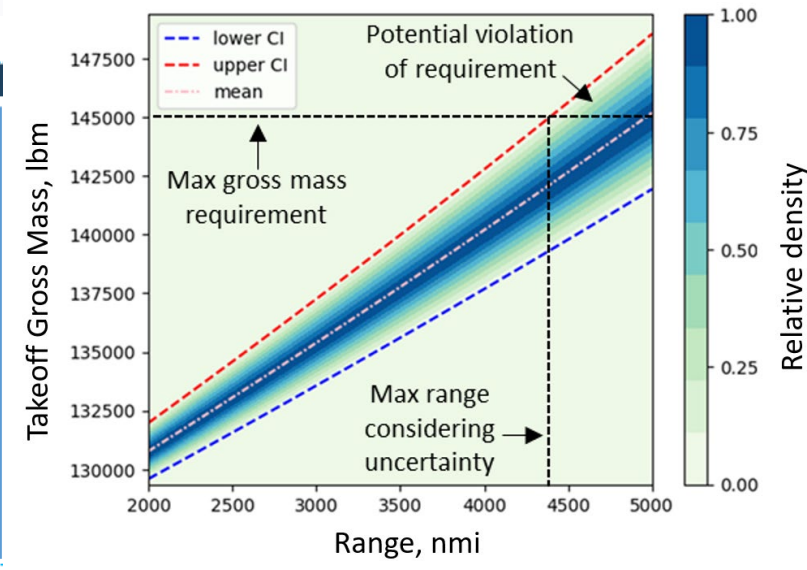
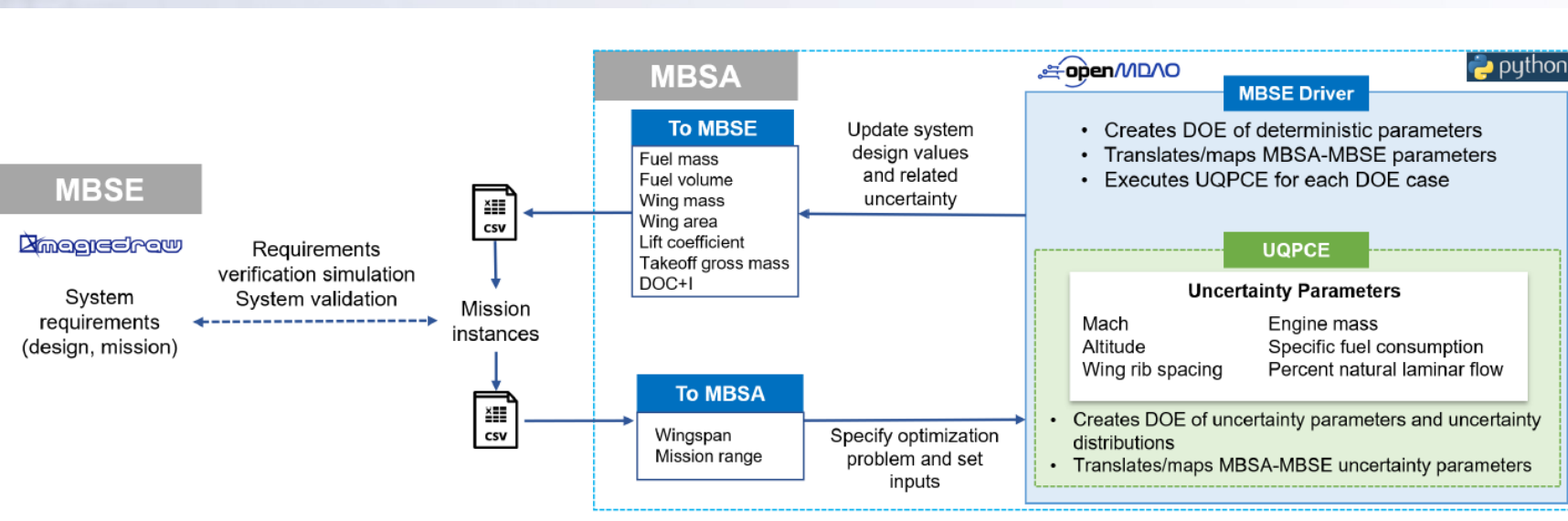
Function calls for finite difference optimization: 30,952  
Function calls for analytical derivative optimization: 3,816

**Computational costs reduced by 87.7%**

# Uncertainty Quantification

## Uncertainty Quantification Integration into Model Based Systems Analysis and Engineering

- The integration of UQ enables engineers to assess and mitigate uncertainties associated with a system model, design parameters, and constraint inputs, leading to more complete design studies and better informed decision-making processes. Specific objectives of this research were to:
  - Develop an open, cross-project, cross-program, external-capable MBSA&E framework building off ARMD's investments and capabilities across the AAVP and other programs.
  - Conduct coordinated, integrated systems analysis studies using common, open, reference and vision vehicle models
  - Conduct technology benefit assessments and sensitivity studies.
- An AIAA Aviation paper was presented detailing this work: *"Integration of Uncertainty Quantification in a Model Based Systems Analysis and Engineering Framework"* Fazal et. al AIAA-2024 DE-02/ACD-13

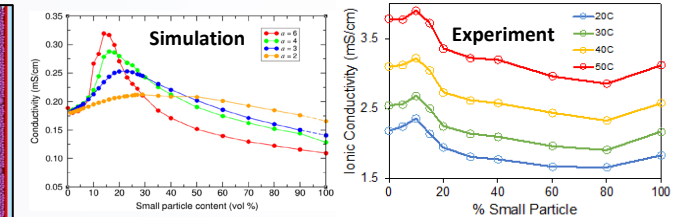
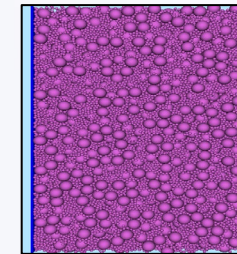
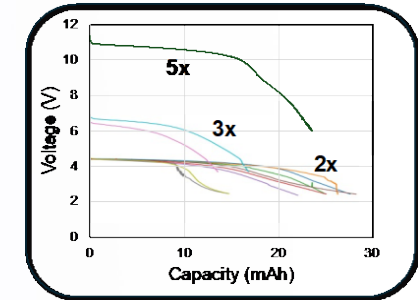


# Aviation Battery R&D

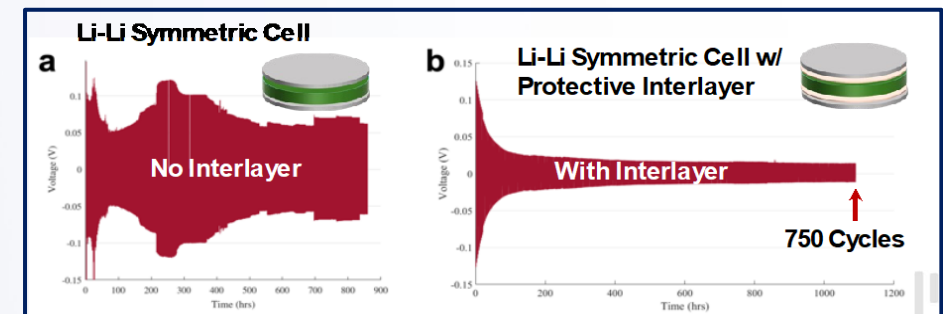
## Solid State Energy Storage Research

Advanced, high performance chemistries to extend range and overall system performance

- Bipolar Stacks
  - Bipolar stack architecture allows convenient packaging with potentially improved energy density and power of solid-state batteries
- Scalable Processing Techniques
  - Reinforced, flexible, lightweight films for improved manufacturability and energy/power
- Particle Dynamics Model
  - Integrated particle dynamics model informs experimental design towards accurate performance prediction
- Improving Cyclability
  - Li metal anode engineering is key toward highly cyclable solid-state batteries



Example: Bimodal Solid Electrolyte Ionic Conductivity



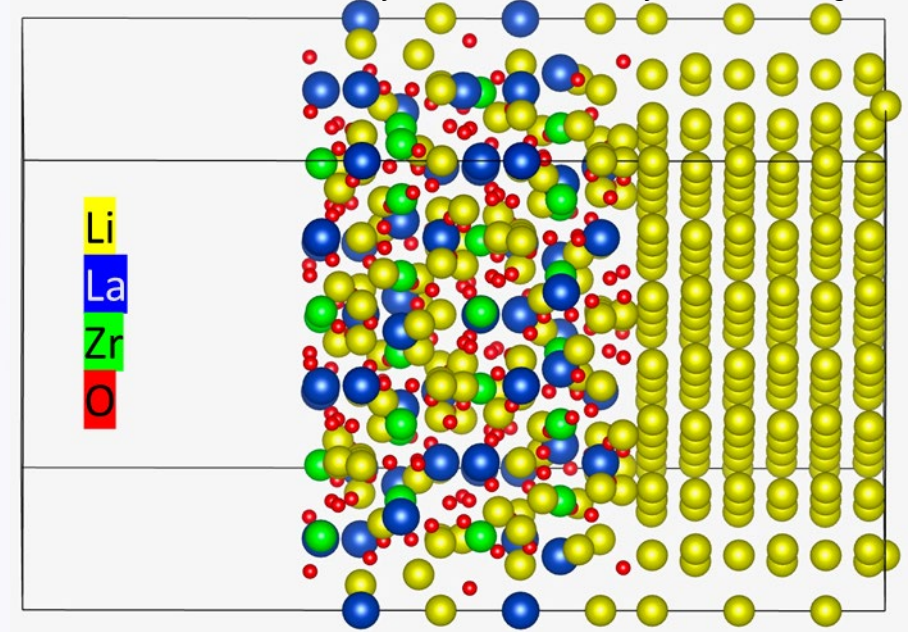
# Aviation Battery R&D

## Solid State Energy Storage Research

### Improved Prediction Methods for Solid-State Battery Interfacial Stability

- **Problem Statement:** Establishing a computational approach to accurately predict electrochemical stability of interfaces is key to rapid designing of next-generation of all-solid-state Li-battery configurations. The state-of-the-art (SOA) method (vacuum-slab model) is less than reliable.
- **Goal:** Benchmark a new computational approach on well-known, stable battery interface of Li and LLZO, an emerging solid-state electrolyte.
- **Approach:** Generate low-energy LLZO structures, generate an ensemble of Li-LLZO interfacial structures, and ensemble-average electronic energy level alignment to predict stability and its margins.
- **Current Accomplishments:**
  - Demonstration of capability to rapidly generate low-energy structures and low-energy interfaces.
  - Demonstration of more reliable stability prediction of Li-LLZO.
  - Manuscript nearing submission
- **Significance:**
  - The new approach will more accurately predict interfacial stability.
  - The new insights will guide toward battery designs

Atomistic model of solid electrolyte (left)-lithium anode (right) interface. Interfacial stability is crucial for battery material design.



	High Fidelity (this work)	SOA
LLZO stability vs Li	1.5 eV	0.3 eV
Cathode voltage allowed	4.9 eV	6.1 eV

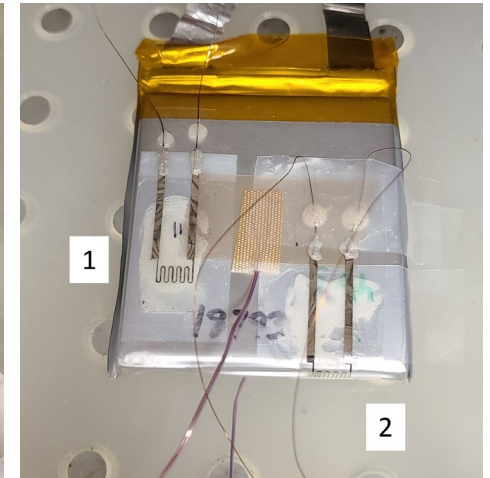
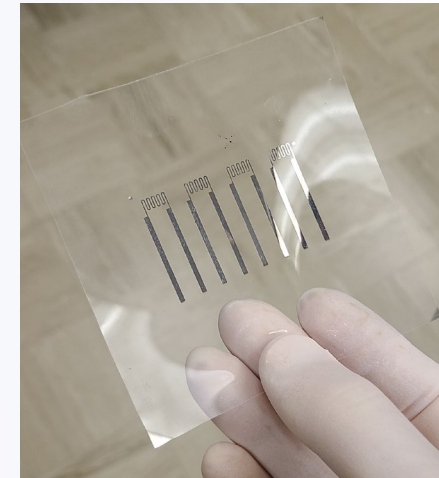
Comparison of methods (high fidelity vs SOA) shows significant differences which highlights the need for more accurate and more efficient methods for computational design of battery materials.

# Aviation Battery R&D

## Development of embedded sensors and prognostics to detect failures

### Volumetric/Strain Sensor

- **Problem Statement:** Li-ion cells undergo non-negligible volumetric changes during cycling. Anode swells during intercalation, ranging from ~3-300% depending on material. Monitoring volumetric changes over lifetime adds a useful variable in predicting cell state of health and lifetime prognosis.
- **Goal:** Develop a custom designed sensor we can adhere to any off-the-shelf battery cell, pack, or module, to prognose state of health and any anomalous aging behavior, to avoid any potential catastrophic events.
- **Approach:** Thin film sensors deposited directly onto pouch cell material as well as on patch material to be applied to various battery module locations
- **Current Accomplishments:**
  - Initial testing of a battery cell with an advanced strain sensor attached to assess expansion and contraction of the cell.
  - Longevity flexile testing of sensor design and substrate

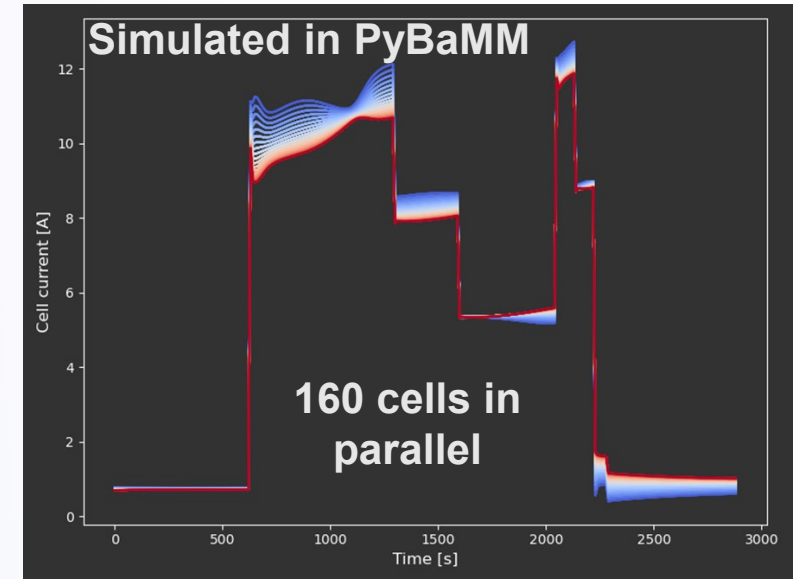


# Aviation Battery R&D

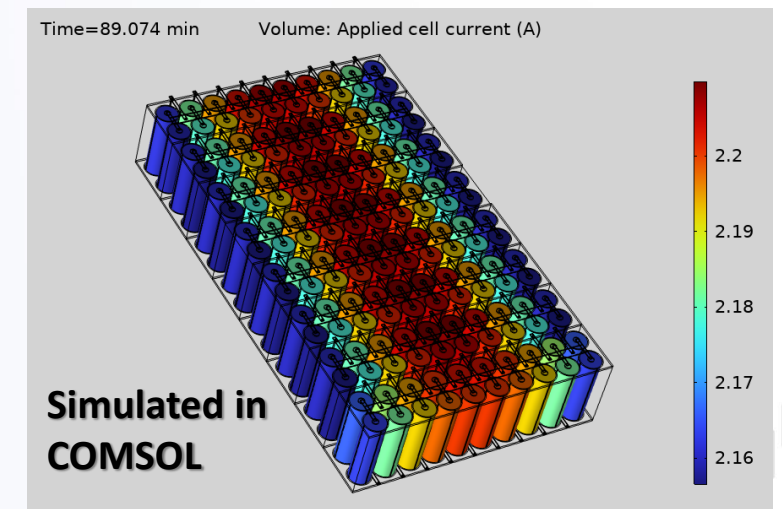
## Development of advanced thermal management materials and lightweight, strong packaging concepts

### High-fidelity simulations for the design and safety of battery packs

- **Problem Statement:** The effect of cell current variability on battery safety in a battery pack with many parallel cells
- **Goal:** Identify the threshold on the number of parallel cells or current sensors for the safe operation of a battery pack upon aging
- **Approach:** Simulate the X-57 battery pack, which has a brick with 20 cells in parallel; such 128 bricks are connected in series to form a pack.
- **Current Accomplishments:**
  - Tested 1D electrochemical model with 180 cells in PyBaMM with the X-57 flight profile
  - PyBaMM shows most of the variability comes from contacts and welds
  - Similarly, a COMSOL model with 3D cells to simulate thermal response and a 0D lumped electrochemical model
- **Significance:** *Current battery designs for aircraft have several cells in parallel, and their currents are not monitored; thus, state-of-safety cannot be monitored.*



**Current variability**

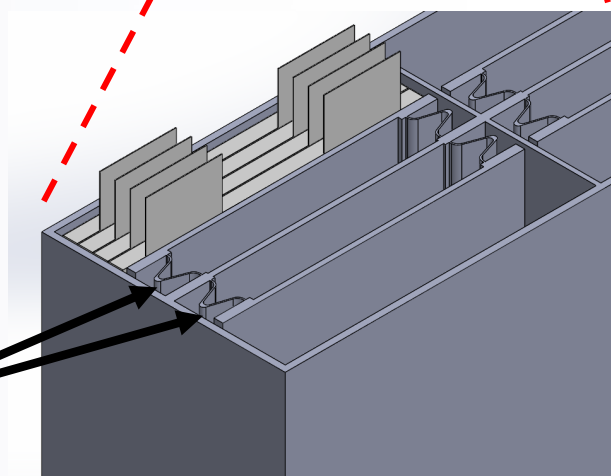
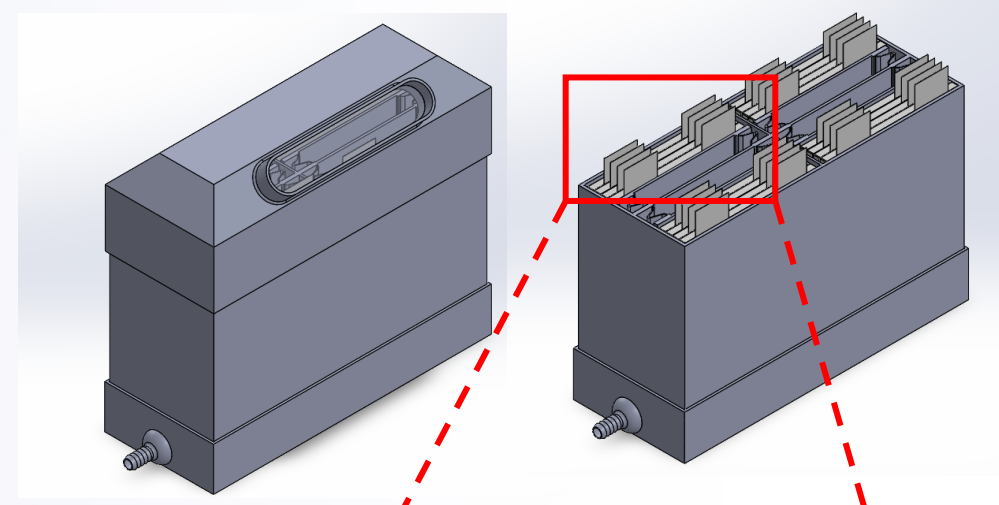
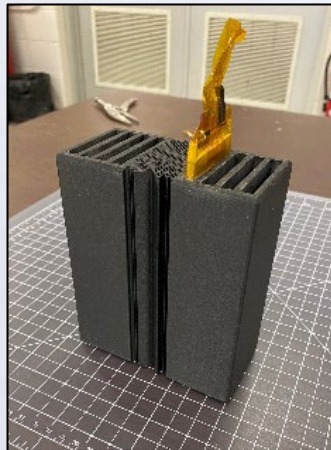
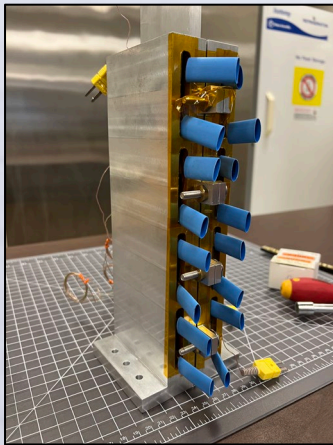


# Aviation Battery R&D

## Development of advanced thermal management materials and lightweight, strong packaging concepts

### BEAST (Battery Enclosures for Advanced Safety and Thermal)

- Design approach incorporates a passive/active thermal control approach. Passive materials will be used to move the thermal waste heat away from the cells into a cooling reservoir (shown at the bottom) where coolant can be actively circulated to remove the waste heat and transfer it to the vehicle thermal system.
- Battery pouch cells generally require some level of compression to achieve optimum performance. A potential approach to provide consistent compression relies on compliant mechanisms to apply compression without the need for plates or screws (shown to the left of the top of the cells). This approach may also have the ability to move with the cells as they expand and contract with cycling, providing a consistent level of compression.



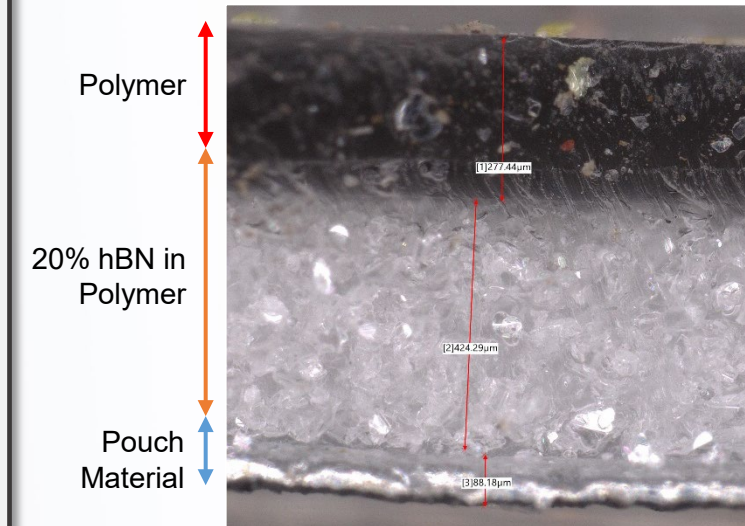
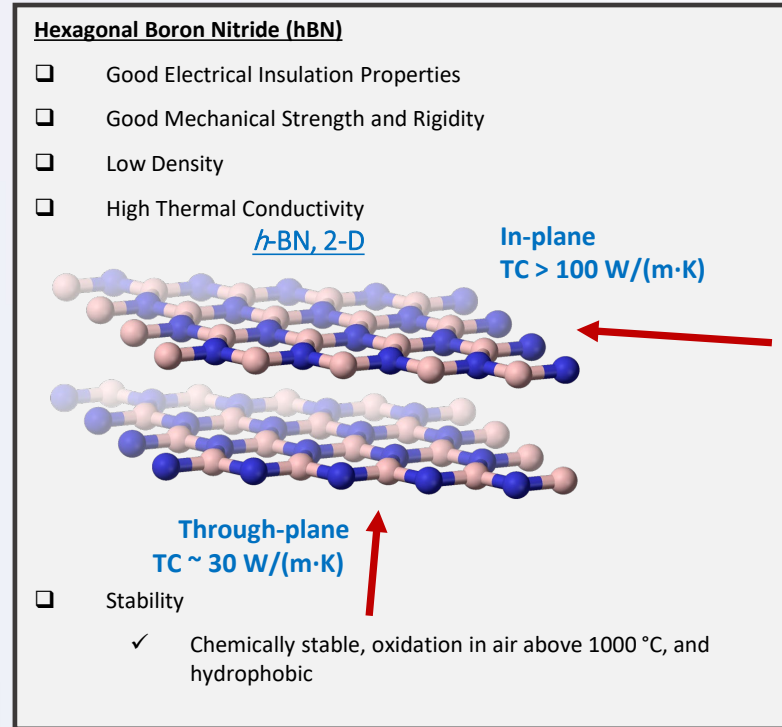
Evolution of battery packaging concepts

# Aviation Battery R&D

## Development of advanced thermal management materials and lightweight, strong packaging concepts

### Hexagonal Boron Nitride (hBN) as a Potential Heat Transfer Solution for Batteries

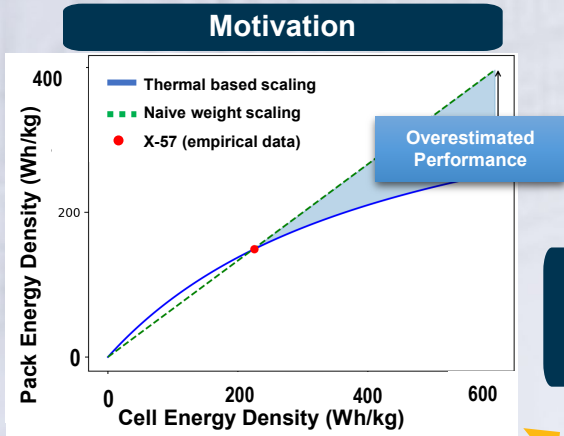
- hBN may enable the efficient removal of battery waste heat out of the battery module but not transmit the heat from cell to cell
- Use a high temperature polymer to help maintain layer integrity for longer time in a thermal runaway situation.
- Create a gradient of high loading of hBN to just polymer.
- Use the advantage of hBN directional settling that will preferentially transfer heat in one direction
- ***The team has successfully deposited onto battery pouch cell material***



Modeling is being explored to help identify the best gradient and polymer for this challenge.

# Evolution of Battery Research to Higher TRLs

Collaborations across ARMD advancing battery research for electric aviation



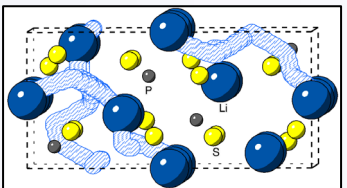
**Batteries for High Performance and Safety**

Improved scaling laws from cell to pack level are needed (FY20)

Advanced thermal management materials and lightweight, strong packaging concepts (FY21)

**Battery Enclosures for Advanced Safety and Thermal (BEAST) (started in FY23)**

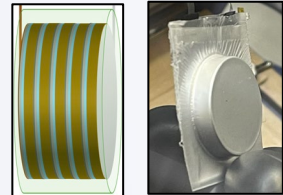
**Modeling (FY20)**



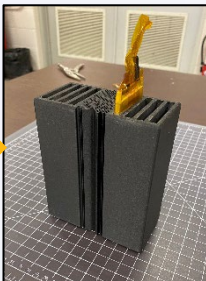
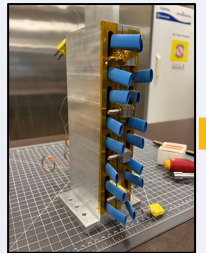
**Sensors (FY24)**



**Solid State Electrolytes (FY24)**



**CAS transitions**



**Evolution of packaging concepts**



**Open eVTOL Subproject – Flight Demonstration and Capabilities (FDC) Project**



**NASA D-Site – Future site for aircraft battery testing**

**Graduating research from cell level to battery pack to vehicle integration design and modeling**

# Sustainable High Voltage (HV) Power Wires/Cables

## Enabling Safety and Reliability in High Power Electric Aircraft Propulsion (EAP) Systems

### 3 Focus Areas:

#### 1. Lightweight Conductor Work

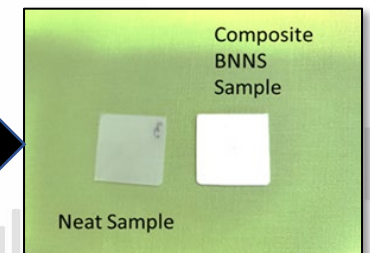
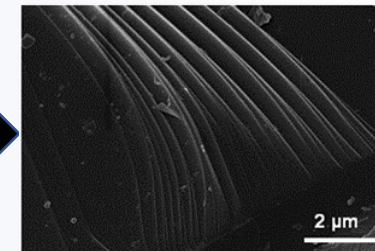
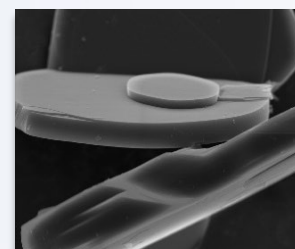
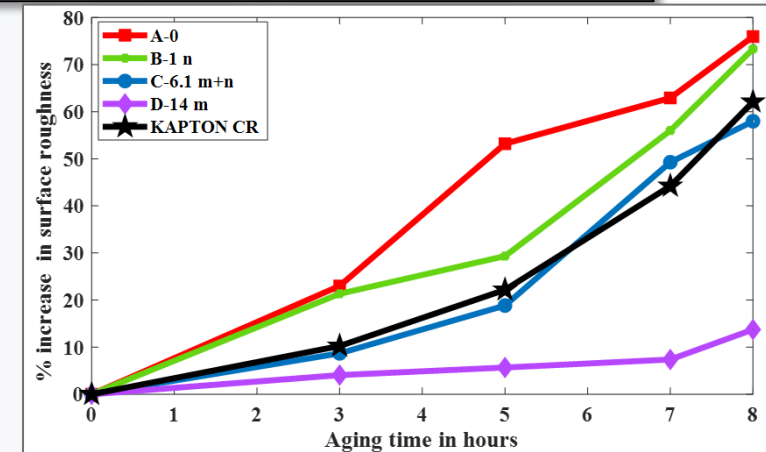
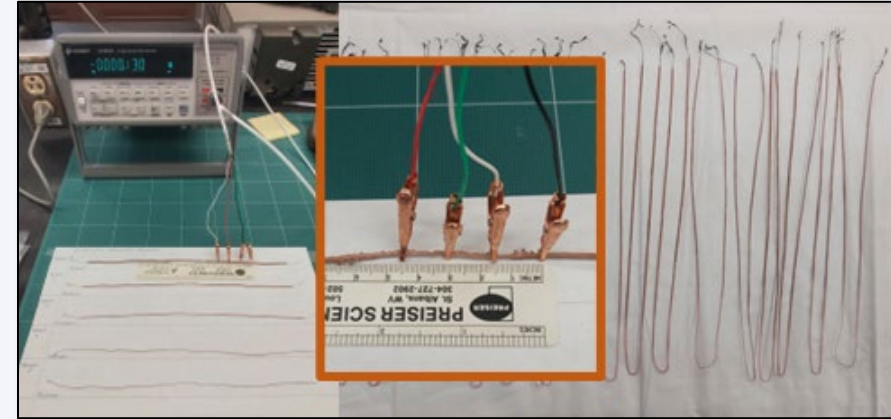
- Cu/CNT Research: Demonstrated reproducibility of CU/CNT composite conductor with 4% increase in electrical conductivity.
- Demonstrated **27-foot Cu/CNT composite** with uniform thickness along the length.

#### 2. Electrical Insulation Work – Composites

- Preliminary results on in-house extruded polymer films with commercial off the shelf BN fillers showed improved erosion resistance over the SOA Corona-resistant Kapton from surface charging in composite. (Manuscript in progress)

#### 3. Electrical Insulation Work – Engineered Fillers

- Process Optimization of NASA h-BN **completed**.
- Engineered BN fillers are being incorporated into various polymer.

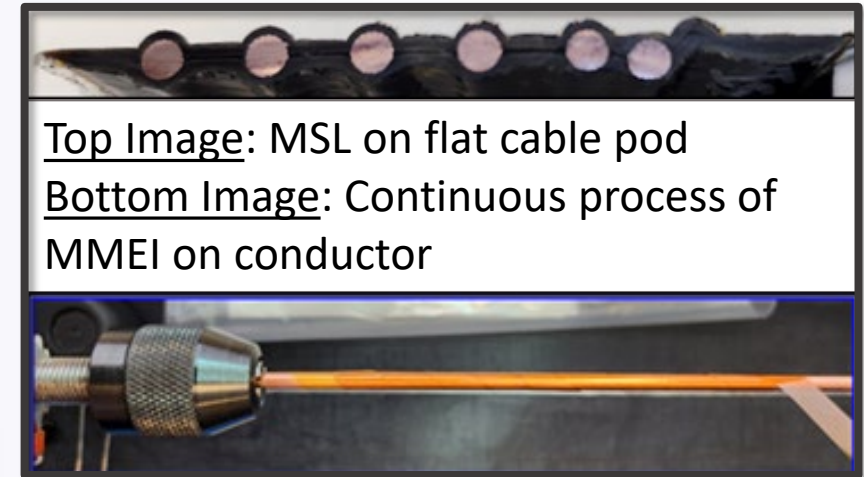
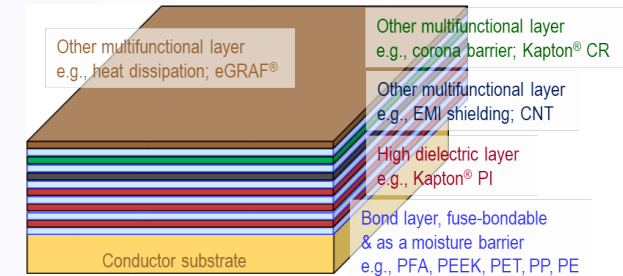


# Sustainable High Voltage (HV) Power Wires/Cables

## Enabling Safety and Reliability in High Power Electric Aircraft Propulsion (EAP) Systems

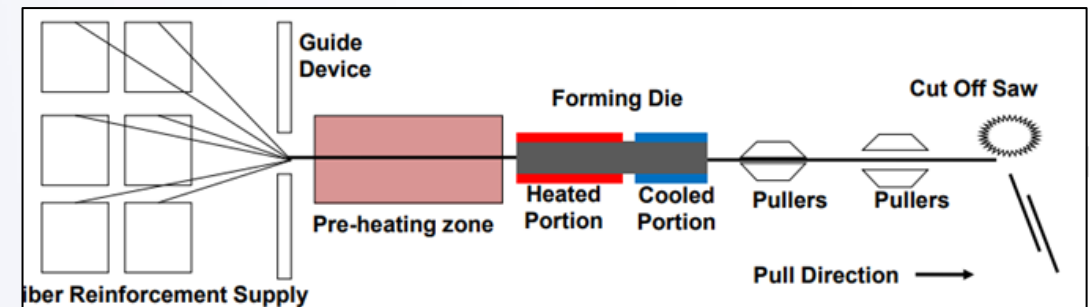
### Demonstrated Manufacturability of Micro-multilayered Multifunctional Electrical Insulation (MMEI) on Cable

- **Problem Statement:** MMEI concept is difficult to manufacture in a continuous processes compared to SOA extrudable electrical wiring processes.
- **Goal/Approach:** Demonstrate manufacturability of *multi layered* MMEI in continuous process. Design a process such as High-Speed Precision Taping; Hot-melt calendaring; Pultrusion; Die forming/Over-jacketing extrusion; or combinations of them; or something new.
- **Current Accomplishments:** Prototype achieved 24.3 kV/mm dielectric strength at 0.59 g/in insulation density and also achieved much higher Partial discharge inception and extinction voltages (PDIV/PDEV) than those of the SOA cable. at significantly lower insulation density, 0.6 g/in (MSI-MMEI) vs. 1.33 g/in (GORE) in the
- **Significance:** Demonstrated MMEI manufacturability with a 55% decrease in insulation density with improved PDIV/PDIE.



Top Image: MSL on flat cable pod

Bottom Image: Continuous process of MMEI on conductor



# Sustainable High Voltage (HV) Power Wires/Cables

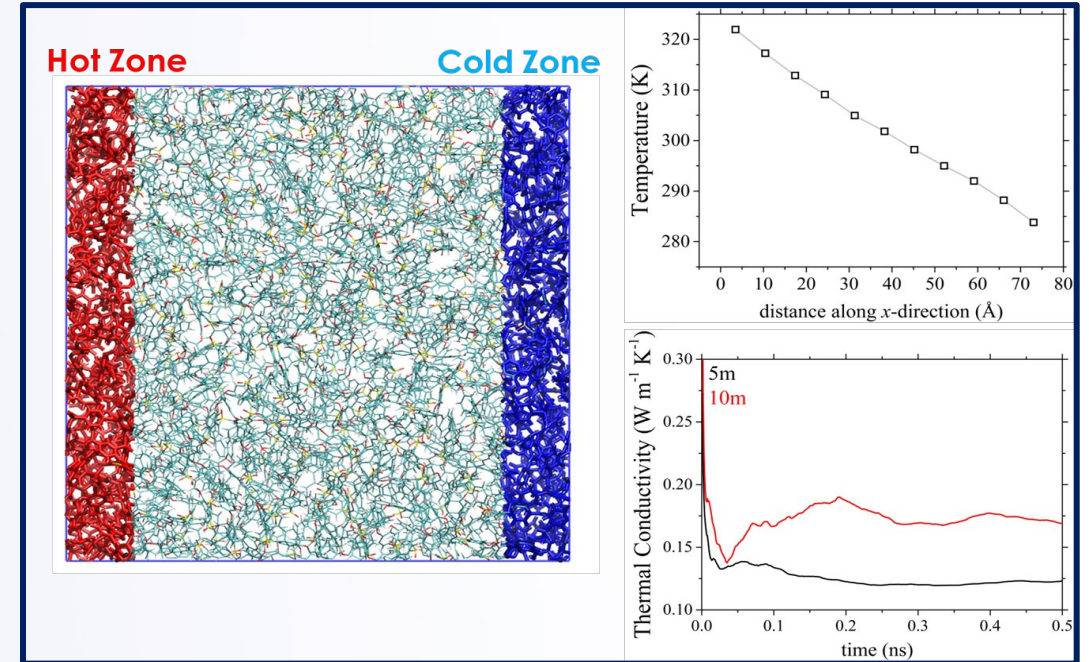
## Enabling Safety and Reliability in High Power Electric Aircraft Propulsion (EAP) Systems

### Thermal Conductivity of polyphenylsulfone (PPSU) through Molecular Dynamics (MD) Simulations in polymer completed

- Very good agreement of the predicted thermodynamic, dynamic and thermal properties with the corresponding experimental data was recorded.
- By increasing PPSU's molecular weight, our predictions get closer to experimental data, as expected.
- This simulation approach is not solely focused on the prediction of the properties of PPSU but rather enables the virtual design of polymers that have never been synthesized yet.

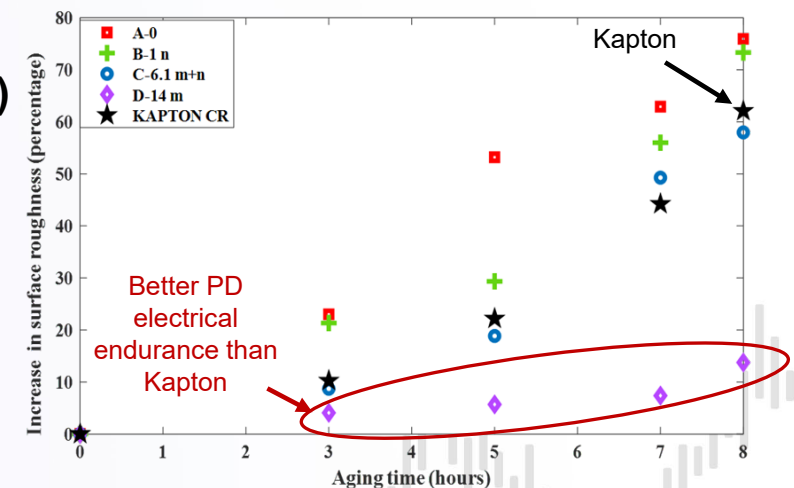
### Enabling Safety and Reliability in High Power Electric Aircraft Propulsion (EAP) Systems

- NASA composites showed improved resistance to partial discharge (PD) over SOA corona-resistant Kapton
- Derived an **insulation aging indicator based on electrical stresses: the Cumulative Extrinsic Stress (CES)**
- The CES indicator could be used in real time to monitor the health of electrical insulation during EAP operations. This **indicator is a game changing measure towards safety and reliability** when combined with continuous health monitoring of electrical wiring systems



$$CES_i(t) = A_i(t) \cdot rr_i(t)$$

Cumulative Extrinsic Stress (CES), as function of time, where  $A_i(t)$  is the PD magnitude and  $rr_i(t)$  is the PD repetition rate



\*In collaboration with FSU

# Sustainable High Voltage (HV) Power Wires/Cables

## Enabling Safety and Reliability in High Power Electric Aircraft Propulsion (EAP) Systems

### Established Automated Materials Lab (AML)

- Automated Materials Laboratory coupled with machine learning aims to accelerate materials discovery and optimization by continuous preparation of samples and analysis with minimum interaction from a researcher.
- The integration of ML with the AML has the potential of automation in other materials processes such as metals, ceramics and polymers, bringing endless benefits for many Aeronautics applications.

### Coupled Electric-Thermal Models for HV Cables Implemented

- Simulation to assess performance analysis of Next Generation Nano-Micro-Multilayered-Multifunctional Electrical Insulation (MMEI) power cable under all-electric aircraft operating conditions.
- A commonly used insulator material was implemented in COMSOL with the non-linear properties taken from the literature, and the resulting voltage, electric field, and temperature distributions were compared with the literature.
- This provides confidence in the implementation of the equations and the material property to simulate the physics for a nominal cable.

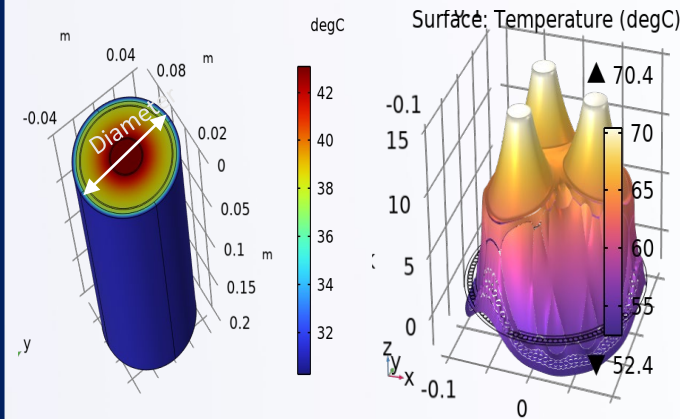


Automated Materials Laboratory (AML)

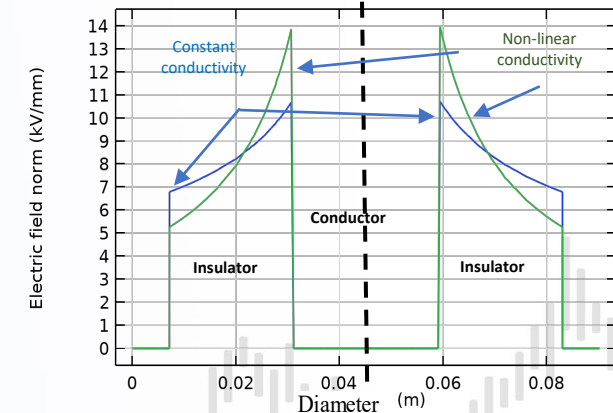


32 samples are being prepared at the same time

Temperature Distribution across a single fiber and a conductor with three fibers



Electric Field Distribution across the insulator for two empirical electrical conductivity models for the insulator



# Sustainable High Voltage (HV) Power Wires/Cables

Enabling Safety and Reliability in High Power Electric Aircraft Propulsion (EAP) Systems

## LONG-TERM VISION STRATEGY

h-BN particles



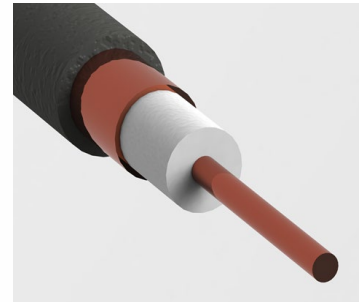
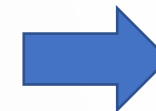
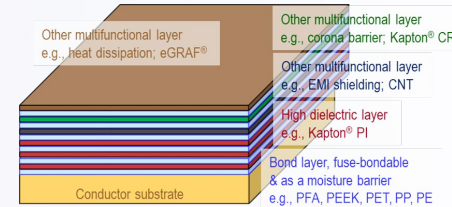
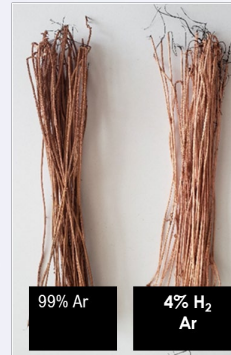
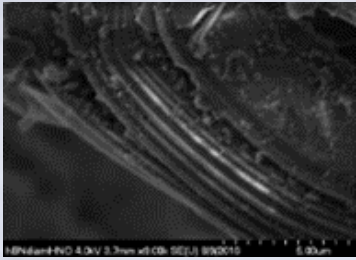
mix into polymer



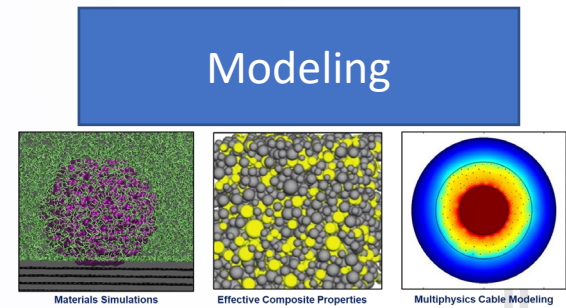
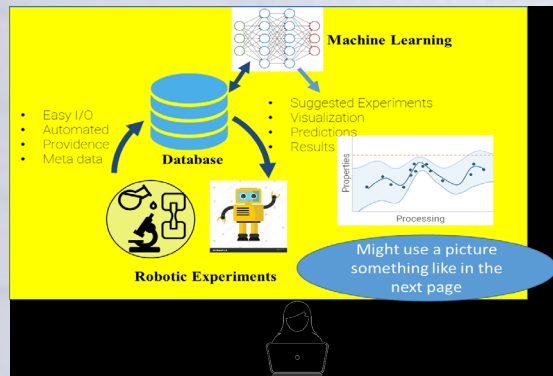
coat conductors with n-MMEI



make a wire/ cable



Testing + ML + Automatized lab Modeling to inform experiments/development

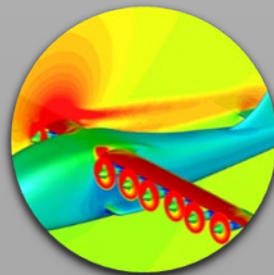


Multiscale and multifunctional (thermal, electric, mechanical) design of high voltage power cables

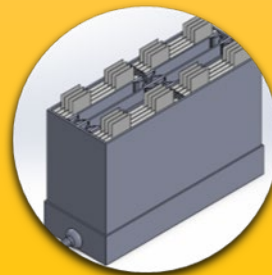
**Enable the performance, reliability, and durability of electrified propulsion systems by conducting enduring research and developing innovative materials, components, tools, and methods**



**Understanding the role of hybridized propulsion controls in optimizing system performance**



**Analyzing future aircraft designs and propulsion systems for enhanced efficiency and sustainability**



**Exploring solutions for the energy storage limitations in electric aircraft**



**Exploring solutions for high voltage challenges**

**Foundational Electrified Aircraft Propulsion**

