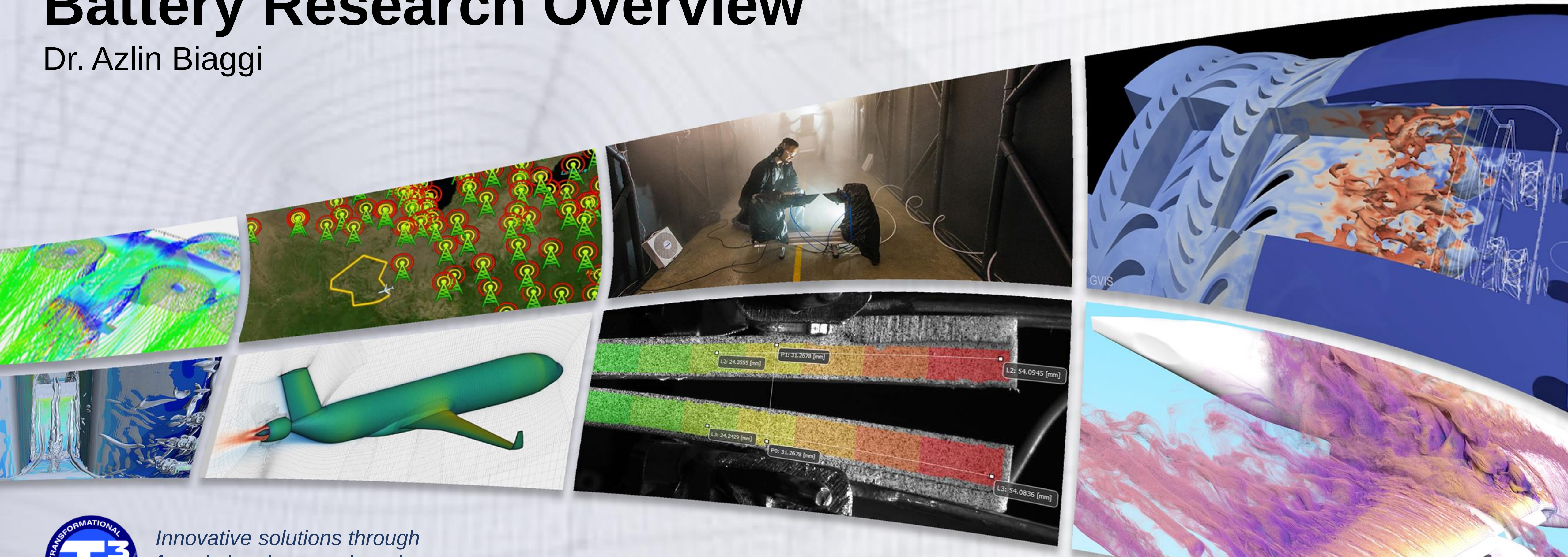
National Aeronautics and Space Administration

Transformational Tools and Technologies (T^3) Project

Battery Research Overview

Dr. Azlin Biaggi



Innovative solutions through foundational research and cross-cutting tools

Event: ASM Cleveland Chapter 2025 Symposium - Materials in Battery and Energy Storage

Location: Case Western Reserve University

Date: 29 January 2025

NASA Aeronautics is One of Five Mission Directorates

Aeronautics

NASA explores technologies that reduce aircraft noise and fuel use, get you gate-to-gate safely and on time, and transform aviation into an economic engine at all altitudes.

Space Technology

NASA technologies developed for spaceflight benefit our everyday life. The Artemis program proves and matures what those technologies can do and reduces risk for exploration of Mars and beyond.

Science

NASA and the nation's science community use space observatories conduct scientific studies of the Earth from space to visit and return samples from other bodies in the solar system, and to peer out into our galaxy and beyond.

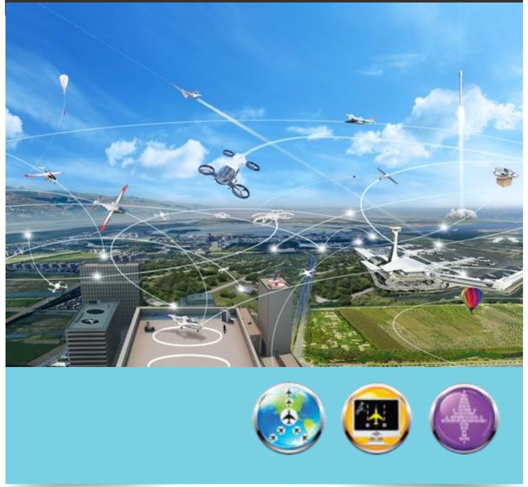
Exploration Systems Development

NASA's Artemis program is defining and creating the steps path from Earth back to the Moon and on to Mars, including the Orion capsule, the Space Launch System, Exploration Ground Systems, the Gateway, and Human Landing System.

Space Operations

NASA's work in beyond low-Earth orbit includes commercial launch services to the International Space Station, exploration systems, space transportation systems, and broad scientific research on orbit.

Airspace Operations and Safety Program



Advanced Air Vehicles Program

Integrated Aviation Systems Program

Transformative Aeronautics Concepts Program

Aerosciences Evaluation and Test Capabilities Portfolio

ARMD PROGRAMS

Transformational Tools & Technologies (T^3) Project

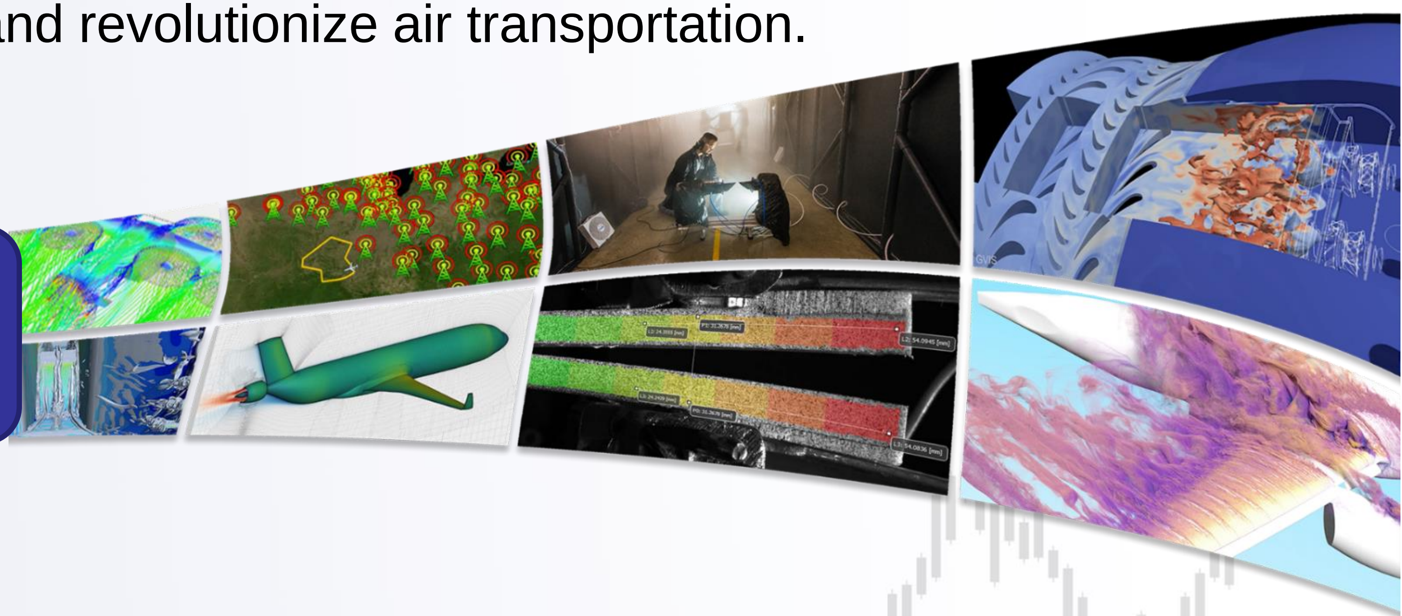
Discover, develop, and transition innovative solutions through foundational research and cross-cutting tools and technologies for the aviation community

T^3 is the home of enduring research within the ARMD portfolio, undertaking research that often focuses on longer-term challenges.

We sustain critical aeronautics core competencies for the Nation and conduct exploratory research with breakthrough potential.

Our tools and technologies provide innovations that impact aeronautics research throughout the community and revolutionize air transportation.

Delivering cutting-edge research, leading community vision studies, and providing valuable data and innovations



T^3 FY25 Organizational Structure

Resource & Project Support
Business Lead and GRC Analyst: Gene Storer (GRC)
Center Analysts: Cecelia Town (ARC),
Alee Pacheco (AFRC), Tracey Frisby (LaRC)
NRA Manager: Tracey Frisby (LaRC)
Risk Manager: Ramel Panaguiton (LaRC)
Strategic Comm Specialist: Diana Fitzgerald (LaRC)
Project Support Specialist/Scheduler: Marie Mion (GRC)

Executive Team
Project Manager – Michael Rogers (ARC)
Deputy Project Manager – Dale Hopkins (GRC)
Associate Project Manager – Vanessa Aubuchon (LaRC)

Project Center Liaisons

ARC	Andrew Meade
AFRC	Robert Navarro
GRC	Azlin Biaggi-Labiosa
LaRC	Melissa Rivers

Enduring Disciplines Research Areas

Discipline Strategy Management
Dale Hopkins & Vanessa Aubuchon

Disciplines	Tech Leads
Autonomous Systems (AS)	George Gorospe (ARC)
Communications, Navigation & Surveillance (CNS)	Eric Knoblock (GRC)
Multidisciplinary Design, Analysis & Optimization (MDAO)	Ben Phillips (LaRC)
Controls – Propulsion	Dennis Culley (GRC)
Controls – Flight	***Mike Acheson (LaRC)***
Icing	Chris Porter (GRC)
Innovative Measurements (IM)	Mark Wernet (GRC)
Revolutionary Computational Aerosciences (RCA)	Mujeeb Malik (LaRC)
Materials and Structures (M&S)	Steve Arnold (GRC)
Combustion	Jeff Moder (GRC)

Sub-projects
(Aligned with ARMD Priorities)

Foundational Electrified Aircraft Propulsion
MDAO
Controls
M&S
Azlin Biaggi-Labiosa
Sub-project Manager

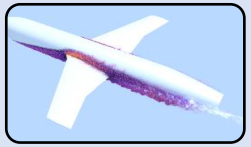
Revolutionary Aviation Mobility
AS
CNS
MDAO
Controls
Siena Whiteside
Sub-project Manager

Reduced Life Cycle Cost
IM
RCA
M&S
Icing
Melissa Rivers
Sub-project Manager
Sheida Hosseini
Deputy SPM

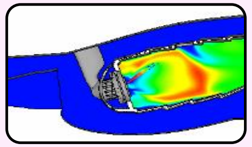
T^3 conducts foundational research with its discipline-based expertise to enable innovation in aeronautics & executes multidisciplinary projects to apply concepts in a system-level context

Nine Disciplines Focused on Foundational Research

Sustaining Critical Core Competencies for the Nation

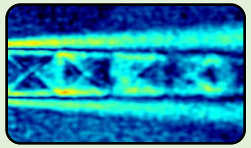


Revolutionary Computational Aerosciences
Algorithms, modeling and validation experiments, transition, aeroelasticity



Combustion
Modeling & Experiments

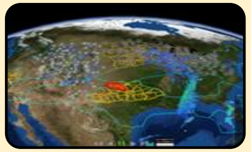
Materials & Structures
Fit for purpose materials, metals, composites, additive manufacturing



Innovative Measurements
Cutting-edge measurement techniques

Multidisciplinary Design, Analysis, Optimization
Foundational tools, uncertainty quantification

Autonomous Systems
Advancing capabilities throughout the aviation system



Communications, Navigation, Surveillance
Novel spectrum & antenna capabilities **[RAM]**

Controls
Flight [**RAM**] & Propulsion [**FEAP**]

Icing
Address icing for new vehicles [**RLCC**]

Three Sub-projects Aligned with ARMD Priorities

Executing multidisciplinary projects to apply concepts in a system-level context

Foundational Electrified Aircraft Propulsion

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

Sub-project Research

- Battery system architecture design and testing
- Potential battery materials identification
- Aviary open-source aircraft design tool
- High voltage power cables model for electric materials
- Propulsion controls – energy management control hardware-in-the-loop

MDAO – M&S – Propulsion Controls

Reduced Life Cycle Cost

Reduce the life cycle cost of aircraft to enable the U.S. aircraft industry to stay competitive worldwide

Sub-project Research

- Certification by Analysis (CbA) with computational fluid dynamics tools
- Community-sourced resources for High Lift Common Research Model (CRM-HL)
- Icing tools to validate simulation
- Computational Materials-informed Qualification and Certification (Q&C) of additive manufacturing (AM) materials
- Researching materials to reduce weight and improve performance

IM – RCA – Icing – M&S

Revolutionary Aviation Mobility

Provide leading edge tools, technologies, and research findings to enable increasingly autonomous AAM transportation in the UML-4+ timeframe

Sub-project Research

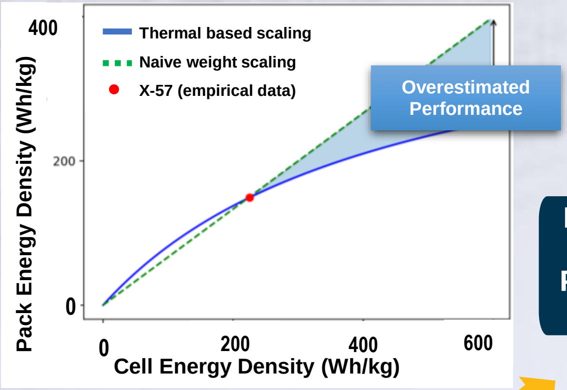
- m:N operational roadmap and critical tool and technique research
- Human autonomy teaming
- Intelligent contingency management
- Crowdsourcing aviation sensing data
- Efficient design & testing of AAM vehicles
- Distributed sensing
- Communication, navigation & surveillance

AS – CNS – MDAO – Flight Controls

Evolution of Battery Research to Higher TRLs

Collaborations across ARMD advancing battery research for electric aviation

Motivation



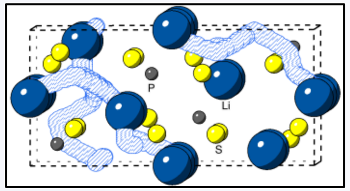
Improved scaling laws from cell to pack level are needed (FY20)

Batteries for High Performance and Safety

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

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

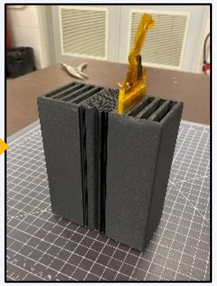
Modeling (FY20)



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

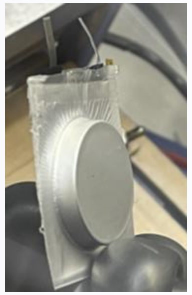
Graduating research from cell level to battery pack to vehicle integration design and modeling

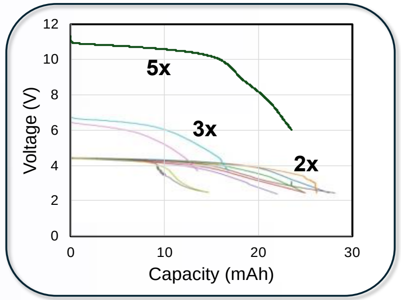
Aviation Battery R&D

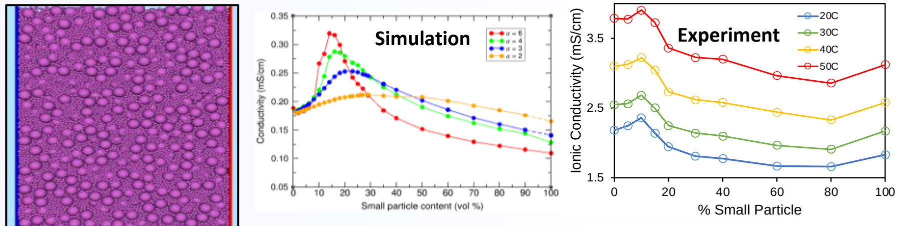
Solid State Energy Storage Research

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

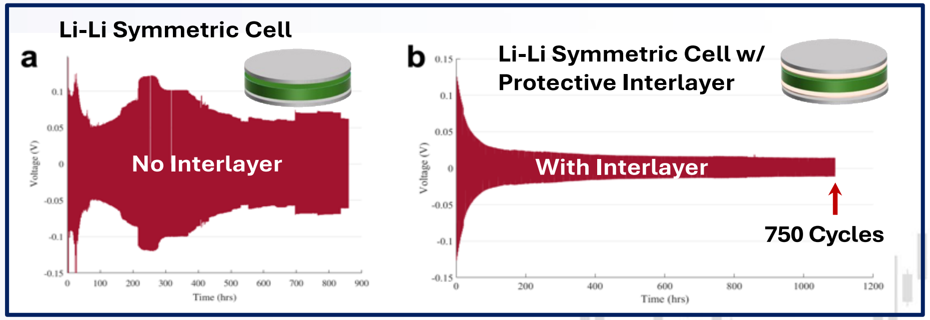
- Bipolar Stacks
  - Bipolar stack architecture allows convenient packaging with potentially improved energy density and power of solid-state batteries
- Scalable Processing Techniques
  - Reinforced, flexible, lightweight films for improved manufacturability and energy/power
- Particle Dynamics Model
  - 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



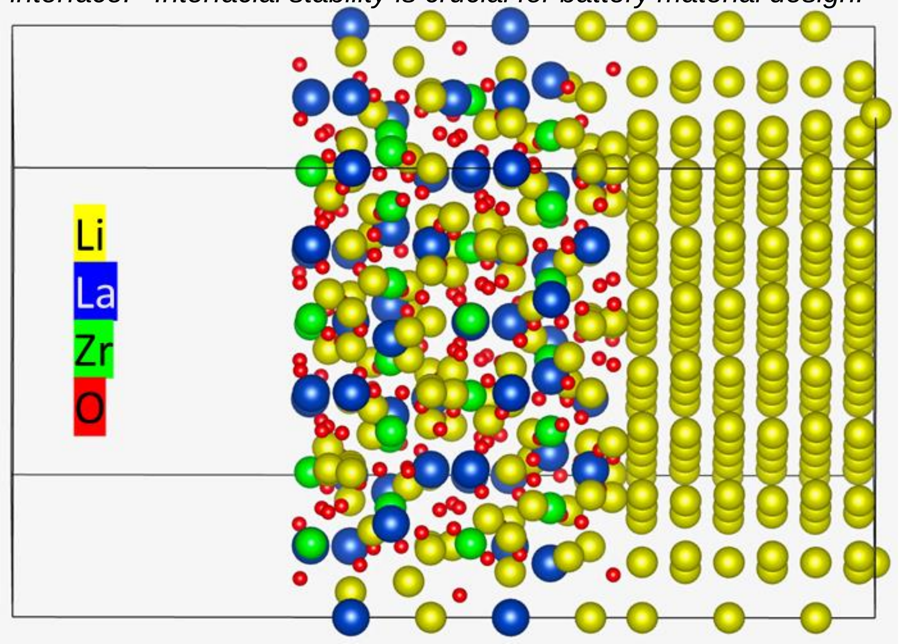
Aviation Battery R&D

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

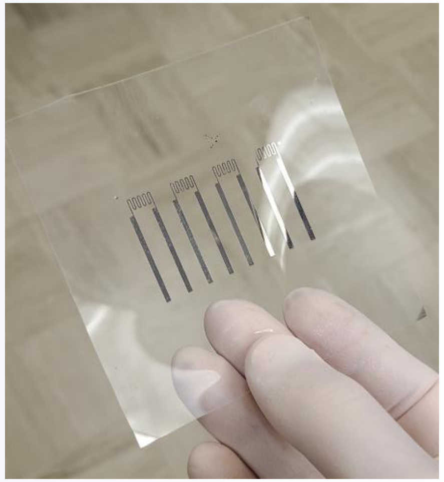
Comparison of methods (high fidelity vs SOA) shows significant differences which highlights the need for more accurate and more efficient methods for computational design of battery materials.

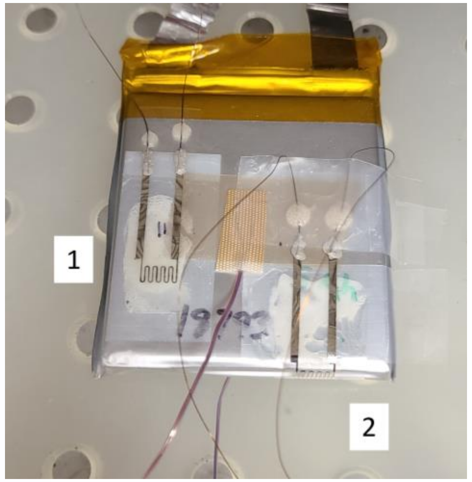
Aviation Battery R&D

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 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





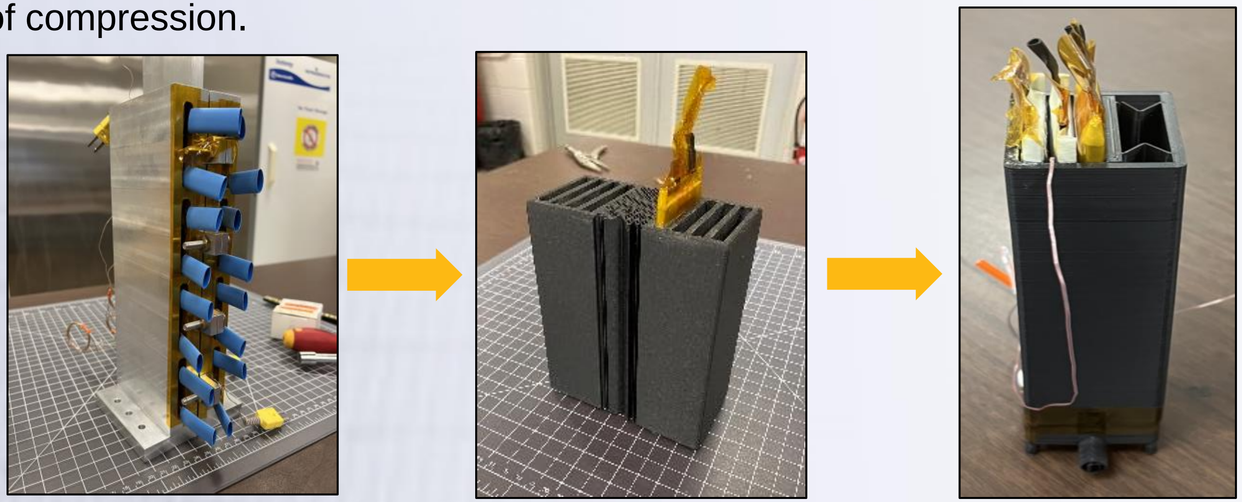
BEAST (Battery Enclosures for Advanced Safety and Thermal) continues rapid, iterative experimentation.

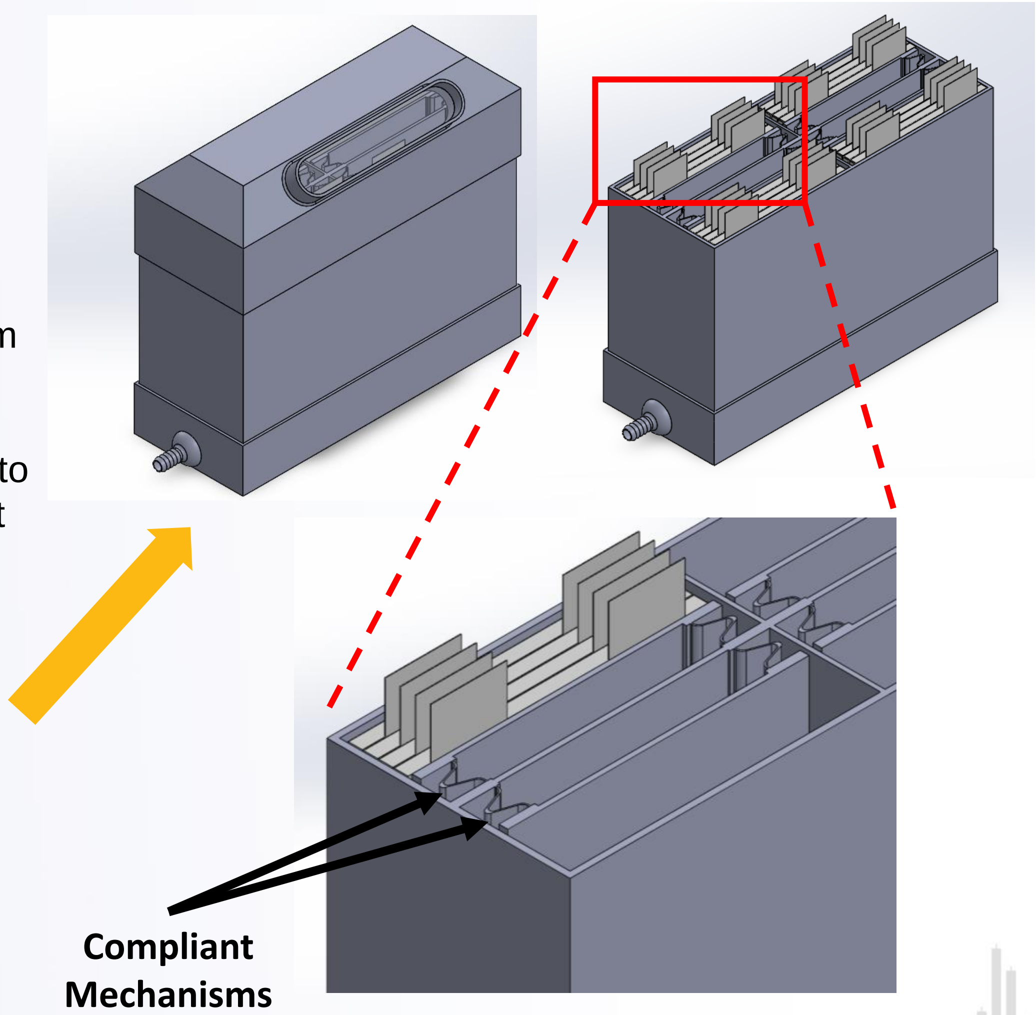
Aviation Battery R&D

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 right 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.





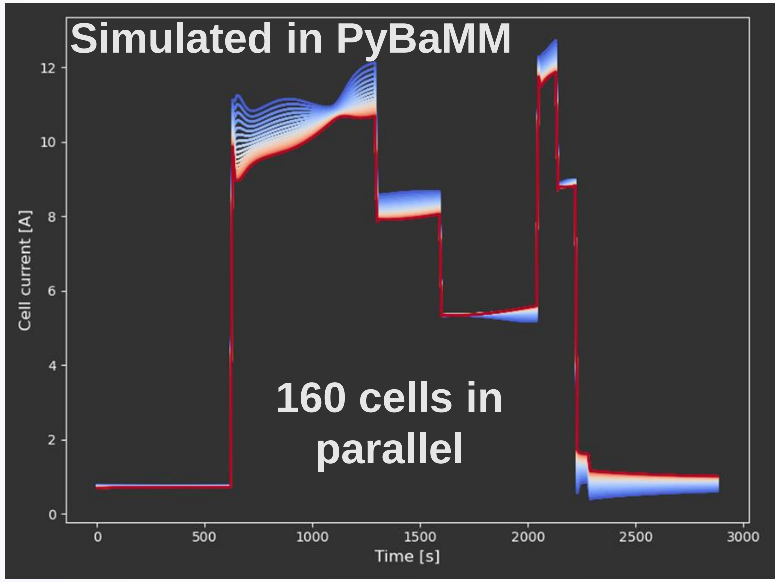
Evolution of battery packaging concepts

Aviation Battery R&D

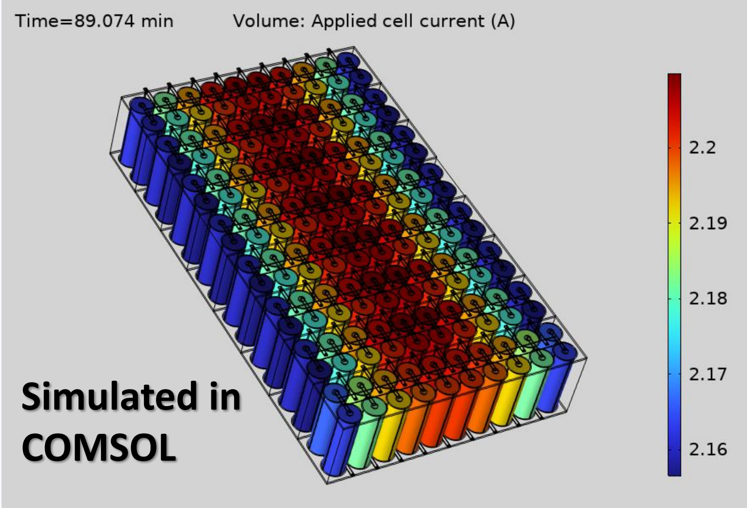
Development of advanced thermal management materials and lightweight, strong packaging concepts

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 PyBaMMwith 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

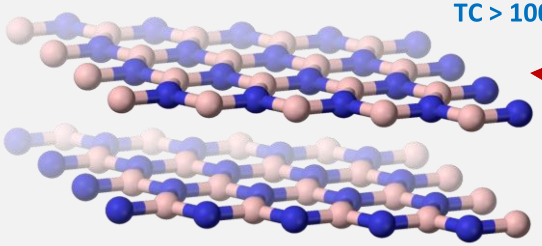
Development of advanced thermal management materials and lightweight, strong packaging concepts

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***

<u>Hexagonal Boron Nitride (hBN)</u>

- ❑ Good Electrical Insulation Properties
- ❑ Good Mechanical Strength and Rigidity
- ❑ Low Density
- ❑ High Thermal Conductivity

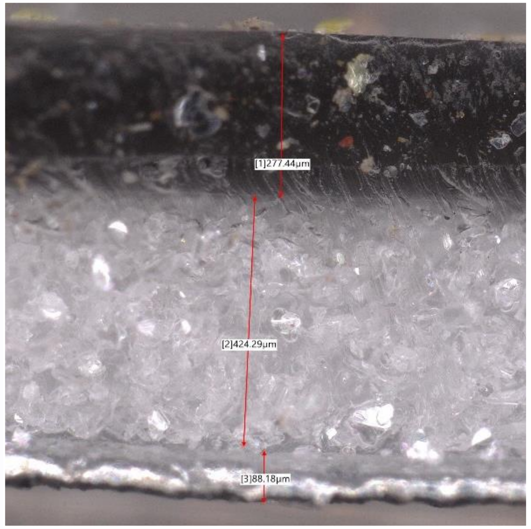


- ❑ Stability
  - ✓ Chemically stable, oxidation in air above 1000 °C, and hydrophobic

Polymer

20% hBN in Polymer

Pouch Material



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

THANK YOU!

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