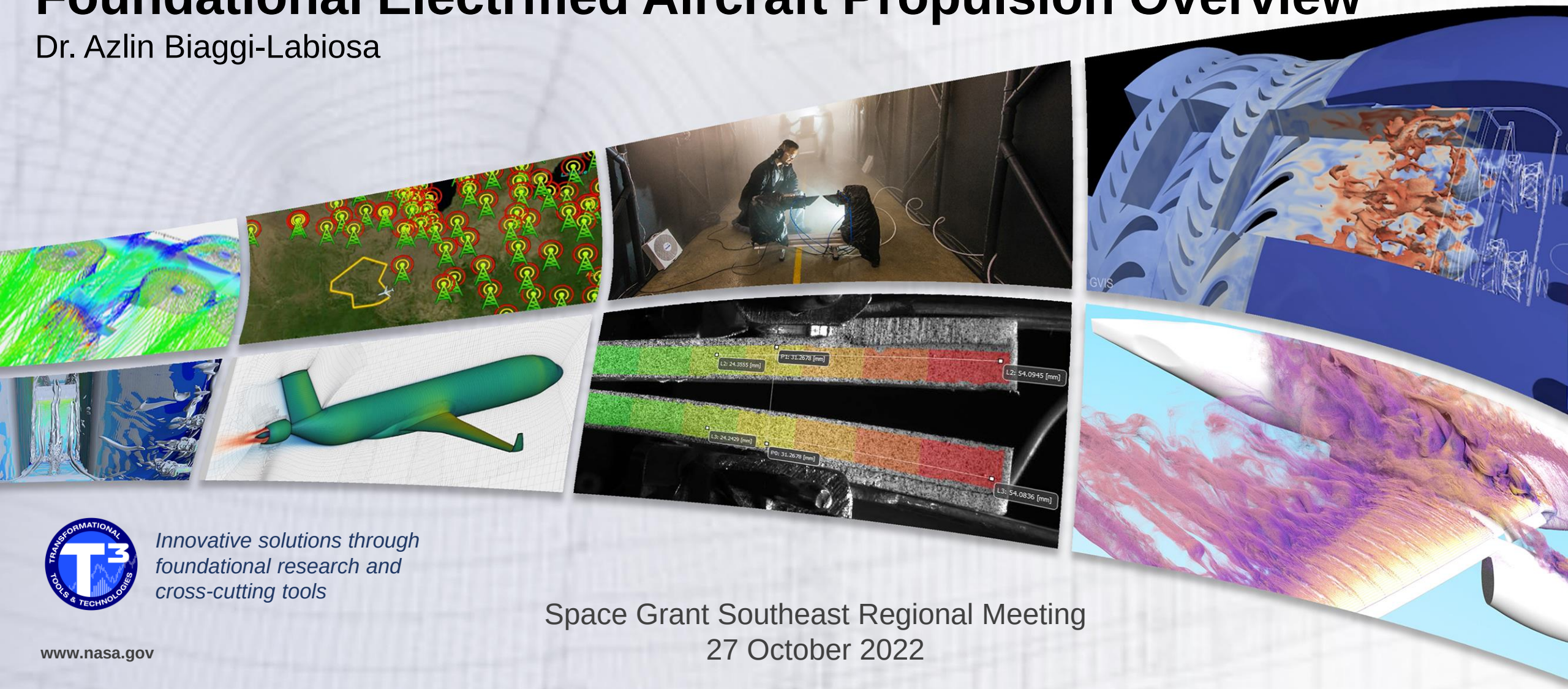
National Aeronautics and Space Administration

Transformational Tools and Technologies (T^3) Project

Foundational Electrified Aircraft Propulsion Overview

Dr. Azlin Biaggi-Labiosa



Innovative solutions through foundational research and cross-cutting tools

Space Grant Southeast Regional Meeting
27 October 2022

OUTLINE

- Why is NASA Investing in Electric Aircraft Propulsion (EAP)
- Transformational Tools and Technologies (T^3) Project Summary
- Foundational Electrified Aircraft Propulsion (FEAP) Subproject Overview and Achievements
- University Innovation (UI) Project Overview
- My Story

U.S. Aviation Climate Action Plan

Global Context for Sustainable Aviation

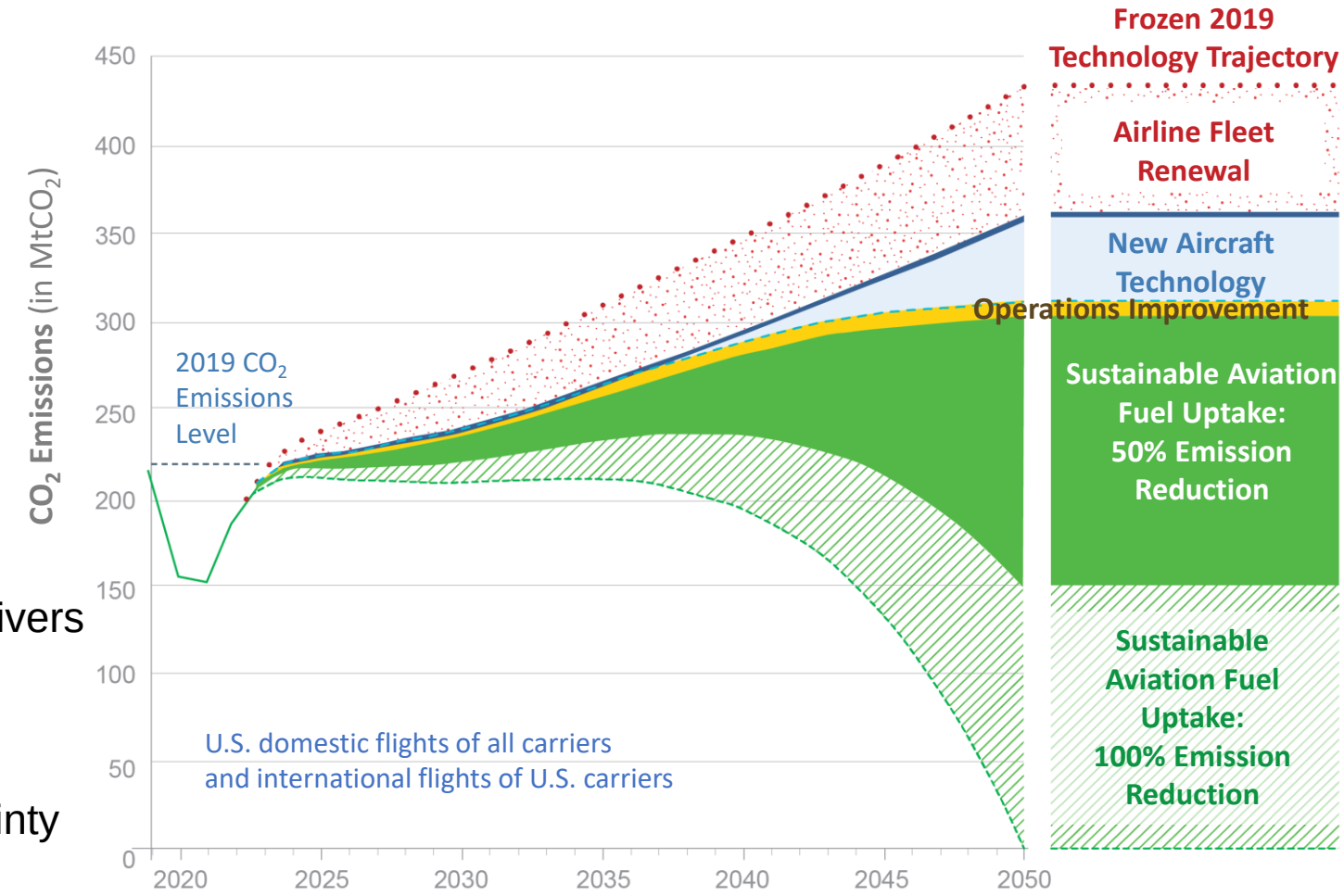
U.S. aviation goal is to achieve
net-zero greenhouse gas emissions by 2050

U.S. Aviation Climate Action Plan is aligned with

- U.S. economy-wide goal
- International Civil Aviation Organization
- Air Transport Action Group

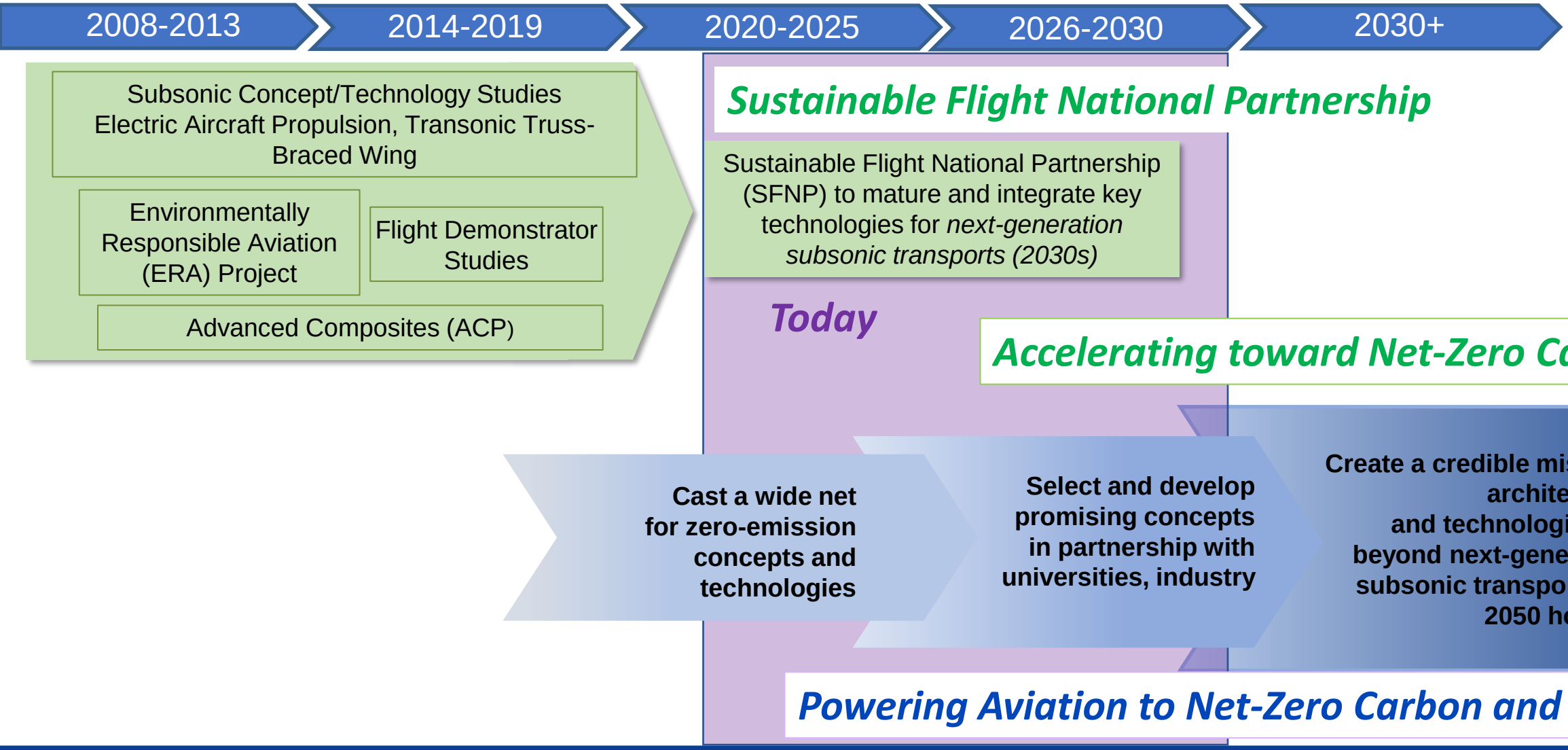
National and Aviation Community Policies acknowledge both CO_2 and non-CO_2 climate drivers

- Initial focus on activities addressing CO_2
- Gap in implementation activities for non-CO_2 drivers which comprise two-thirds of the net radiative forcing from aviation (great uncertainty in these estimates)



ARMD proposes to accelerate work towards the CO_2 reduction target, and fill a gap to address non-CO_2 climate drivers

ARMD Aviation Sustainability Strategy



Investment in innovation today paves the way to a net-zero carbon and beyond aviation future

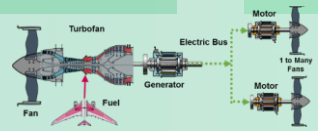
Collaboration in MW-Class EAP for Fixed Wing

Critical Commitment: Demonstrate practical vehicle-level integration of MW-class Electrified Aircraft Propulsion (EAP) systems, leveraging advanced airframe systems to reinvigorate the regional and emerging smaller (thin haul) aircraft markets and strengthen the single-aisle aircraft market.

Hybrid Turbofan

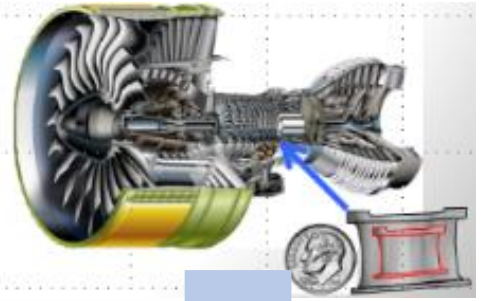
TTT/FEAP
Turbine Controls

HyTEC & AAVP
3X State of the Art



HyTEC (w/EPFD Cost Share
20% Power Extraction

HyTEC
Optimized Ground Demo



FAA
Standards and Regulations

FAA
CLEEN Program

MW EAP Powertrain

TTT/FEAP
Enabling Materials (HV insulation, conductors)

TTT/FEAP
MDAO Tools: Battery System Thermal Management Modeling

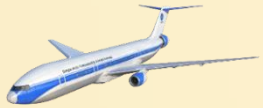
AATT
Enabling Materials

AATT
Components

AATT (w/EPFD Cost Share)
Ground Testing

TTT/FEAP
EAP Regulations and Standards

EPFD
Electrified Powertrain Flight Demonstrations



EAP-Enabled Aero Benefits

CAS
Feasibility Efforts

ULI & TTT/EAP (NRAs)
Technology Investments

AATT
Advanced Propulsor/Airframe Integration Work

TBD
Subsonic Flight Demonstrator

TACP/TTT, CAS, ULI

AAVP/AATT, HyTEC

IASP/EPFD

CONCEPTS
TRL 1-2

COMPONENTS
TRL 3-4

INTEGRATED SYSTEMS/GROUND TEST
TRL 4-5

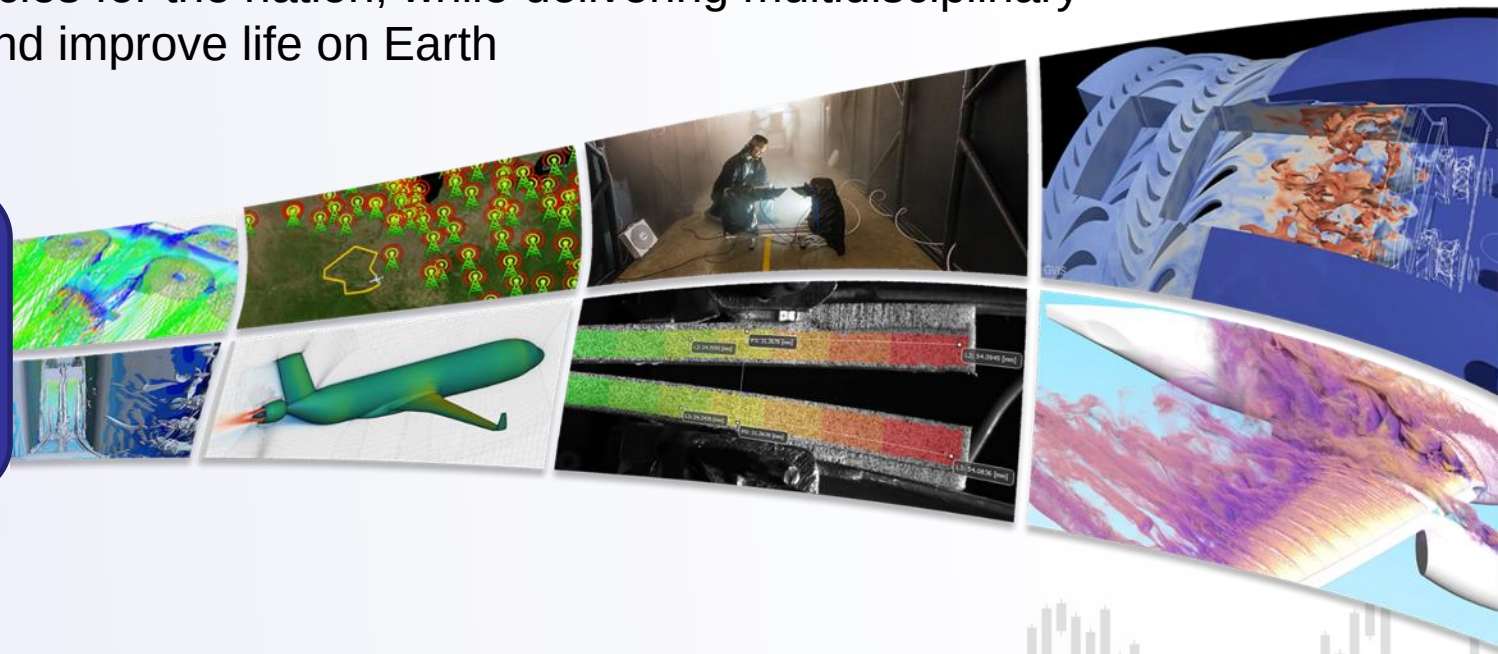
FLIGHT EXPERIMENTS
TRL 6-7

Transformational Tools & Technologies (T^3) Project

Explores the unknown through foundational research that inspires innovation in aeronautics, delivering revolutionary advances in essential areas such as autonomy, certification by analysis, advanced materials, and sustainable aviation

- Conducts exploratory research with breakthrough potential to inspire the world through discovery
- Enables fast, efficient design and analysis of advanced aviation systems from first principles
- Develops innovative tools and technologies to revolutionize air transportation
- Sustains critical aeronautics core competencies for the nation, while delivering multidisciplinary system-level results that benefit humanity and improve life on Earth

Delivering cutting-edge research, leading community vision studies, and providing the community with valuable data and innovations that impact aeronautics research throughout the ARMD portfolio



T³ Organizational Structure

Resource & Project Support
Business Lead: Gene Storer (GRC)
Center Analysts: Cecelia Town (ARC), Alee Pacheco (AFRC), Gene Storer (GRC), Tracey Frisby (LaRC)
NRA Manager: Tracey Frisby (LaRC)
Scheduler: Joyce Moran (GRC)
Strategic Comm Specialist: Diana Fitzgerald (LaRC)
Project Support Analyst: Jeanie Feagan (GRC)

Executive Team
Project Manager – Michael Rogers (ARC)
Deputy Project Manager – Dale Hopkins (GRC)
Associate Project Manager – Joe Morrison (LaRC)
Asst Project Manager for Special Topics – TBA

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 & Joe Morrison

Disciplines	Tech Leads
Autonomous Systems (AS) - Human Machine Teaming	Kelley Hashemi (ARC)
Communications, Navigation & Surveillance (CNS)	Eric Knoblock (GRC)
Multidisciplinary Design, Analysis & Optimization (MDAO)	Justin Gray (GRC)
Controls	Dennis Culley (GRC) Steve Riddick (LaRC)
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
Vanessa Aubuchon
Sub-project Manager

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

Fourth Sub-project?
Supersonics?
Sustainability?
M&S
Combustion
Azlin Biaggi-Labiosa
Sub-project Manager

T³ conducts foundational research with its discipline-based expertise to enable innovation in aeronautics & executes multidisciplinary projects to apply concepts in a system-level context

Foundational Electrified Aircraft Propulsion (FEAP) Subproject Overview

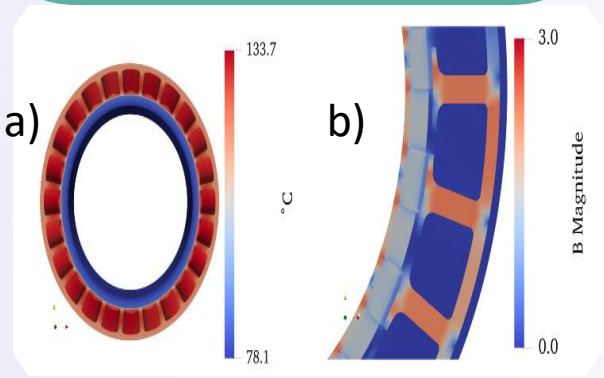
Enables the performance, reliability & durability of electrified propulsion systems by conducting enduring research & developing innovative materials, components, tools & methods that support needs in ARMD mission programs

Objective 1: Enable high voltage and high-power distribution for EAP Systems *(M&S)*

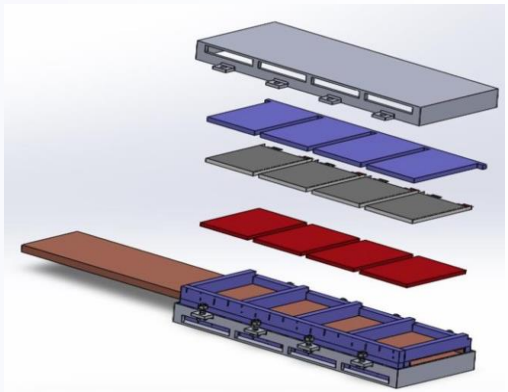
Objective 2: Develop optimization tools and methods for electric and hybrid-electric vehicle design *(MDAO, Controls)*

Objective 3: Develop safe battery technologies to improve performance metrics for EAP *(M&S, MDAO)*

Power Cable Model For Electric Materials



a) Electric Motor stator thermal analysis
b) Stator magnetic flux-density



Preliminary Battery Design Pack Configuration

Researching high voltage power cables to further sustainable aviation

Explore the unknown to develop robust, safe and reliable power cables for electric vehicle applications

Challenge

Sustainable aviation goals require efficient electric aircraft. High voltage operations with SOA cables need more insulation for higher voltage operation leading to increased weight and resulting in greater power needs.

Solution

Research viable materials to execute a multi-structural/layered approach that results in thinner, lighter, and longer lasting power cables.

Discovery Activities

- Evaluating two multi-functional system insulations (MMEI, BNNS composites) and a conductor material (CNT/Cu composites)
- Exploring modelling research to predict properties and performance in terms of material composition, order of insulation stacking layers, and the structure of the system

Partners

MMEI Testing

CNT Research

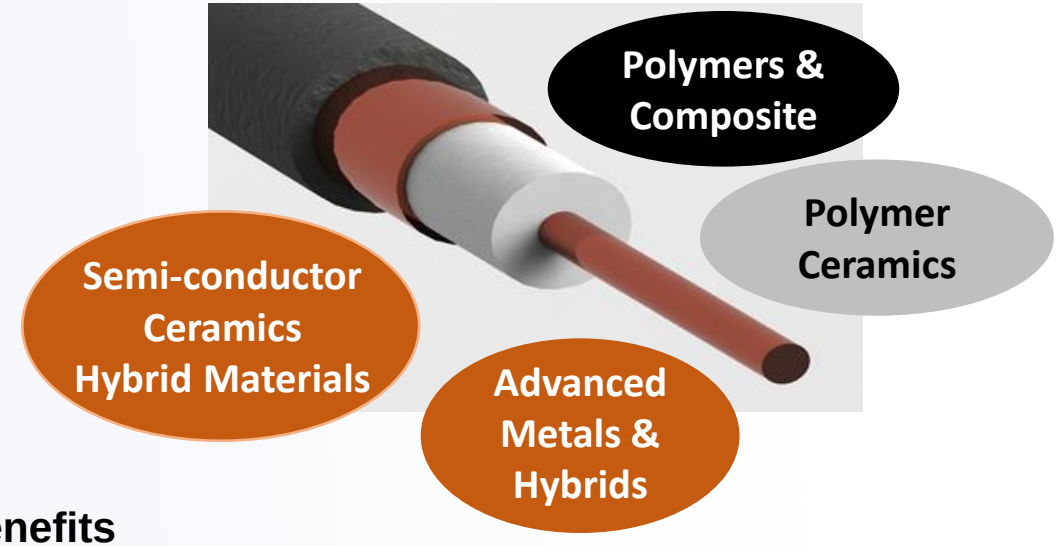
Standards Committees

MERSEN

UNIVERSITY OF Cincinnati

SAE INTERNATIONAL

Cables with multi-prong redundant system to improve safety



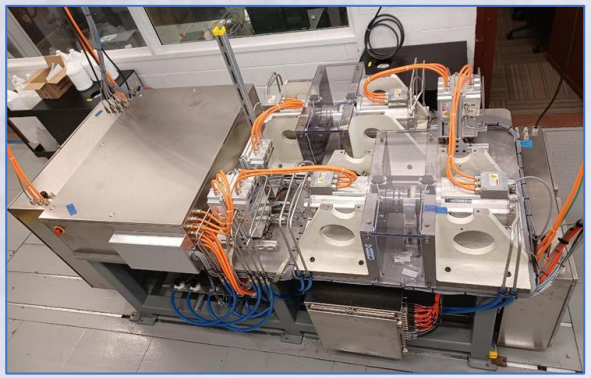
Benefits

- Thin, lightweight, and durable structures
- Reduce weight of cables while maintaining same performance outcomes as SOA cables.
- 20+ year insulation life will further sustainability goals and reduce maintenance costs for industry
- ***Significant contributions to two SAE AE High Voltage coordinating and standards committees to shape future requirements.***

Research sparked interest from ARMD and STMD Projects, DOE & SAE AeroTech

Propulsion Controls – *Energy Management Control Hardware-in-the-Loop*

Turbine Electrified Energy Management (TEEM) Control to enhance propulsion system stability in the hybrid-electric architecture



TEEM test article at High Performance Electromagnetic Rig (HiPER) Lab in SE-17

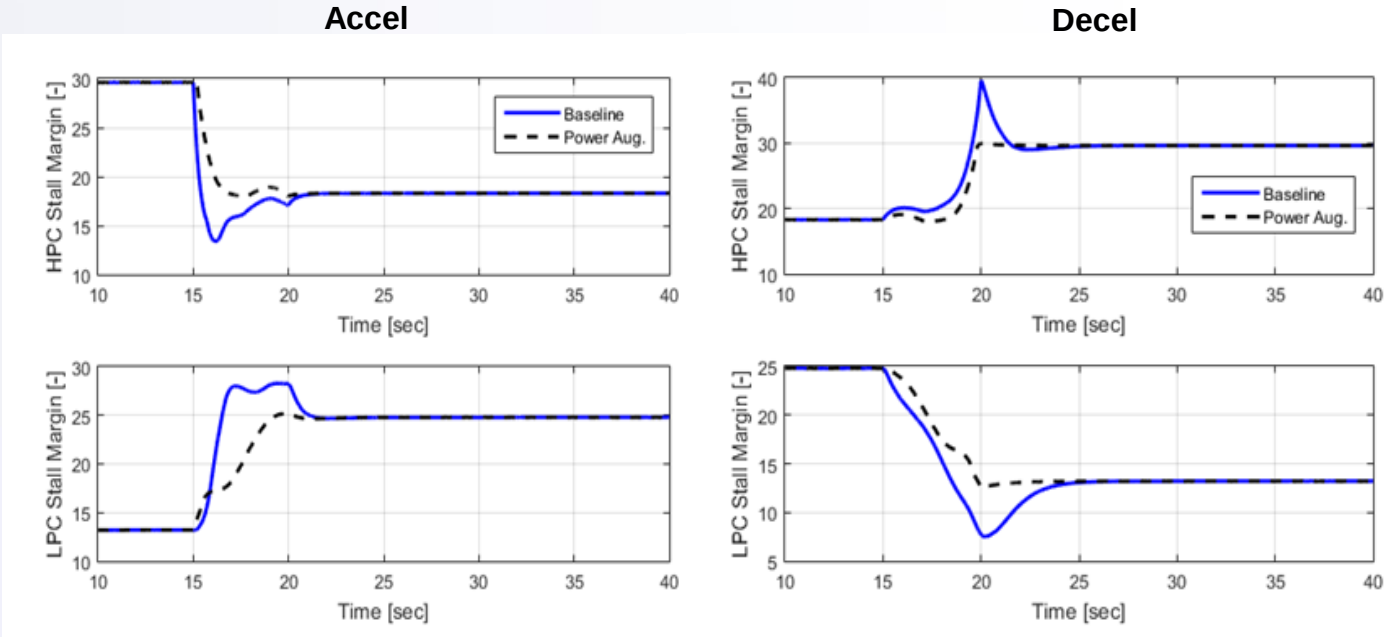
Accomplished Build Complete – Facility Operational (T^3 and HyTEC Collaboration)

- An agile testbed specifically for propulsion dynamics, control, operability, and energy management technology development.
- All classes of propulsion architecture accommodated using a ***novel method*** of scaling power and inertia via software.
- Includes power extraction and thrust augmentation with supercapacitor energy storage and dynamically variable loading.
- Operates in the 100kW power flow class and is instrumented to capture turbine - power system interactions and propulsion dynamics ***in a flexible, low-cost environment***.

Importance

- Addresses the increased complexity of Electrified Propulsion Systems and energy flows across the vehicle, especially dynamic interactions.
- Provides opportunity for injecting controls into the conceptual design process – *Operability Influenced Design*.
- Agile platform for collaboration with external partners.

Risk reduction platform for investigating advanced concepts, fault management, and real-time model performance



Overview of MDAO Research Area

ARMD Alignment

Integrated Multi-Center Aircraft Design & Mission Analysis Code Development

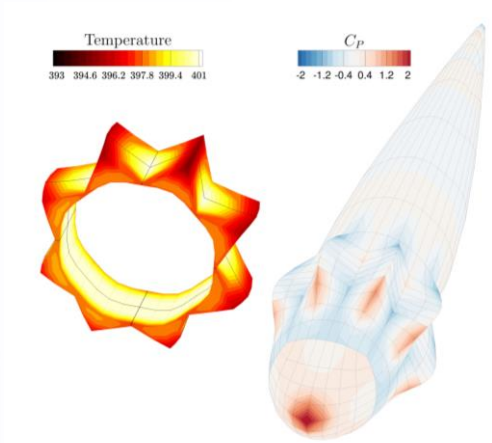
Problems: MDAO state of the art has advanced beyond the state of adoption; Existing aircraft design capabilities are severely limited in their ability to provide meaningful trends for hybrid-electric and all-electric aircraft

Project Goals: Develop Next Generation Aircraft Design Tools for RVLT, EPFD, AATT and other stakeholders. 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.

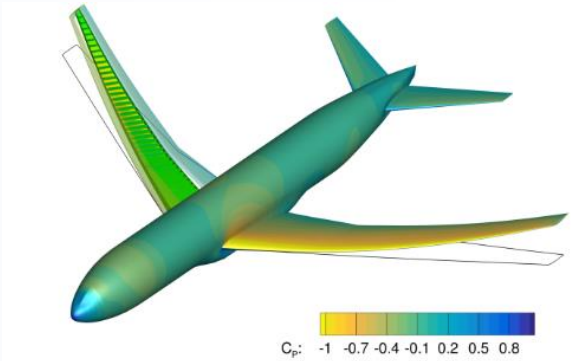
Details: Reimplemented legacy aircraft sizing codes using state of the art numerical methods

Impact: Expanded “toolbox”. Highly integrated into AATT MBSA/E efforts

Partners: Academia, Industry, Government Labs

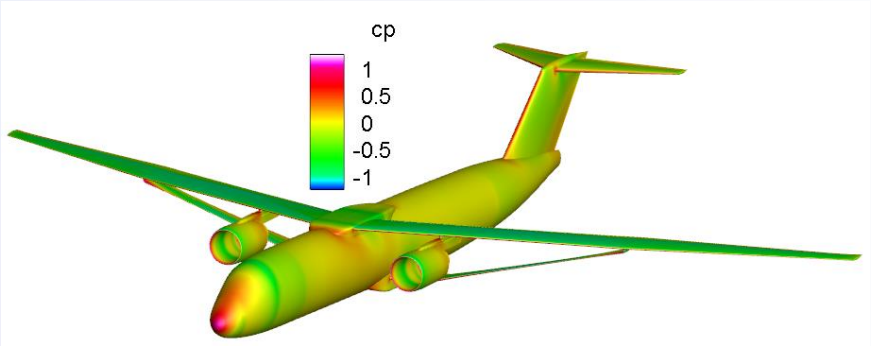


Aerothermal design of X57 high lift motor fairing



Tightly Coupled Aerostructural Optimization

Co-funding activities with AATT, EPFD & SFD. Laying the foundation for SFNP’s Model-based Systems Analysis and Engineering effort



Unconventional Vehicle Design and Analysis

TTT MDAO Supported Toolsets ANOPP2, GASPy, LEAPS, VSPAero, Cart3D, FUN3D, Mphys, pyCycle, OpenMDAO, Dymos, UQPCE, etc.

Battery System Architecture Design and Testing

Rapid design, fabrication, and experimentation to collect data for safely integrating batteries in electric aircraft

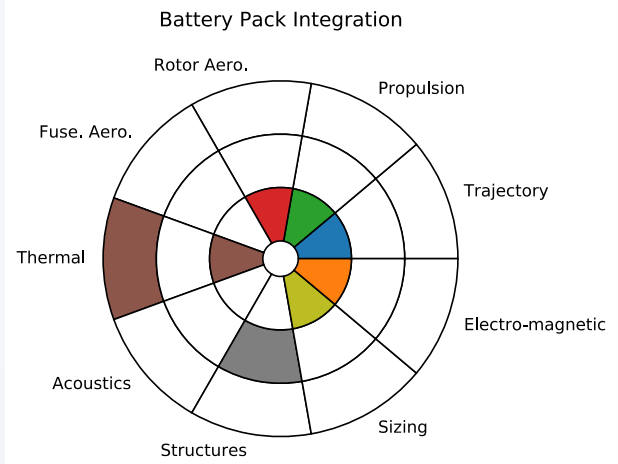
Results

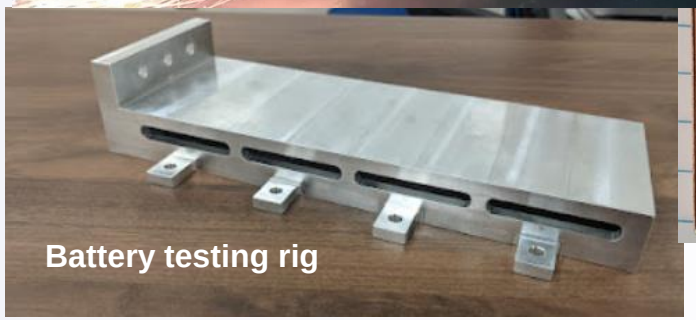
- Amprius silicon nanowire anode cells used at 5.2Ah and 410 Wh/kg
- Required thermal runaway (TR) data to finalize geometry, specify a phase change material (PCM), and validate aerogel
- Aerogel reduced max cell surface temperature compared to no aerogel
- Max temperature on opposite side of aerogel was 38˚C
    - *Good option for preventing heat spread to adjacent cells*

Impact

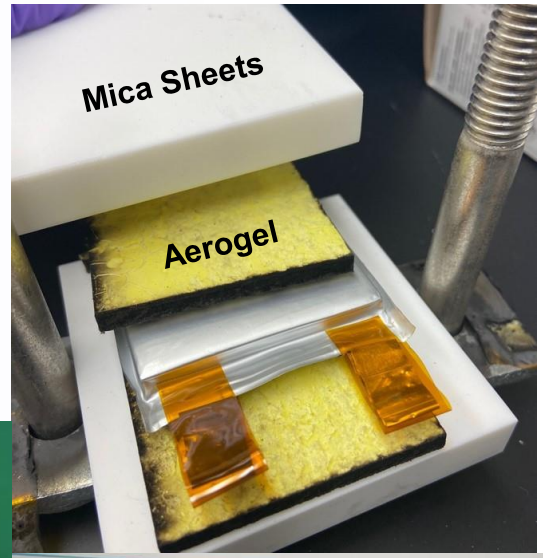
- Leverages T^3 developed tools and methods from enduring disciplines (Mphys, OpenMDAO)
- Rapid design, fabrication, experimentation, and iteration. Multiple design and test cycles complete yearly
- Develop relationships for thermal management weight as a function of battery architecture, size, and composition
- Provide fundamental data needed on battery system architecture for UAM/AAM aircraft.

Tests provided unique, previously unavailable data on thermal runaway for these cells





Test setup for TR



Cu-Mo-Cu enclosure for TMS system testing

University Innovation Project

Inspiring and supporting the next generation of researchers and entrepreneurs.
Growing a diverse pipeline of future leaders.

Join the NASA research family and collaborate with peers to contribute to the evolving field of aeronautics!

NASA is seeking creative ideas/concepts relevant to NASA Aeronautics from interdisciplinary University faculty and student teams

ULI targets Faculty Proposals	USRC seeks Student Ideas	Competitions are for Student Groups
• Propose to solve major, system-level technical challenges in aeronautics	• Students propose their novel ideas for aviation	• New competition topic each year • As a team work on a future aviation concept
• Receive $1-2M/year for 3-5 years	• Receive up to $80K	• Winning team receives NASA internships
• Two-step proposal submission and evaluation process	• 3-page technical proposal	• A 5-to-7-page paper/design study and an infographic • Top 8 teams present to NASA
• 1 solicitation per year, typically solicitation opens in March	• 3 proposal cycles per/year, proposals due around February, June, November	• Submissions typically due March
• Opportunities for undergraduate and graduate students to participate in aeronautics research • Promote diversity in aeronautics with inclusion of minority-serving institutions and underrepresented university faculties	• Gain technical and entrepreneurial skills • Teams use crowdfunding • Interface with NASA experts • Open to all majors and interdisciplinary teams	• To increase college students' interest in climate friendly aviation research • Gain systems-level thinking • Open to all majors and interdisciplinary teams

Diverse ULI Teams Addressing Aviation Challenges

5 rounds of ULI solicitations
$157M of awards

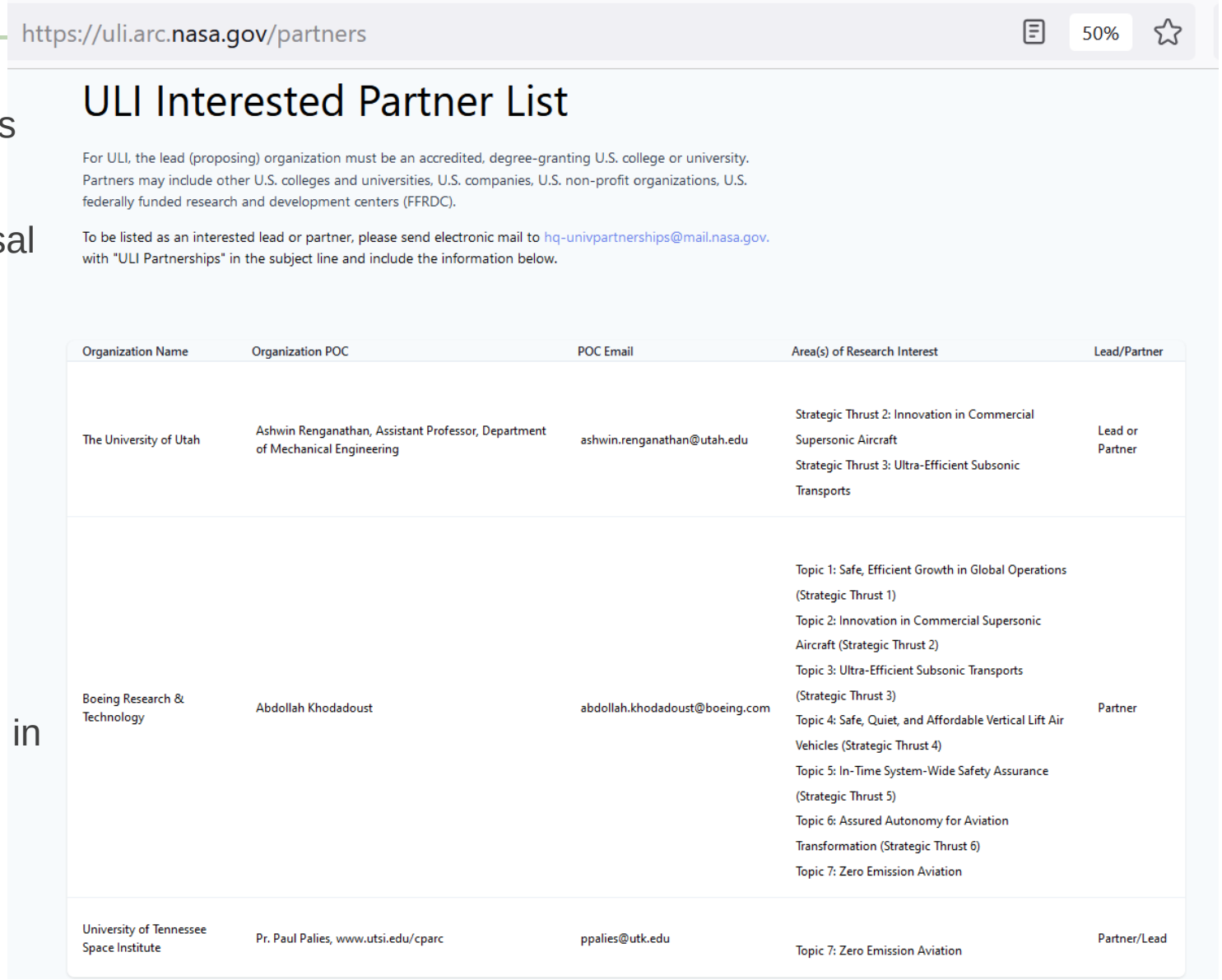
Seeking and awarding proposals addressing a variety of topics

- 406 proposals submitted
- 23 awards with 65 universities
- 9 HBCUs and 13 other MSIs
- 20–50 students per team

Awards @ https://uli.arc.nasa.gov/

ULI Proposal Tips

- Sign up in NSPIRES, receive ARMD notifications
- Do read the ULI solicitation
- Clear communication of focus in how the proposal will make a difference to aviation, and how it is linked to outcomes in ARMD's Strategic Implementation Plan https://www.nasa.gov/aeroresearch/strategy
- Plan integrated work that enables your goal
- Describe technology transition options
- Seek out partners or leads
  - ULI Interested Partners List – https://uli.arc.nasa.gov/partners
  - Broad participation but do not dilute effort
  - Ensure strong HBCU and/or MSI participation in the proposal
- Do not forget about education and workforce development



https://uli.arc.nasa.gov/partners 50%

ULI Interested Partner List

For ULI, the lead (proposing) organization must be an accredited, degree-granting U.S. college or university. Partners may include other U.S. colleges and universities, U.S. companies, U.S. non-profit organizations, U.S. federally funded research and development centers (FFRDC).

To be listed as an interested lead or partner, please send electronic mail to hq-univpartnerships@mail.nasa.gov. with "ULI Partnerships" in the subject line and include the information below.

Organization Name	Organization POC	POC Email	Area(s) of Research Interest	Lead/Partner
The University of Utah	Ashwin Renganathan, Assistant Professor, Department of Mechanical Engineering	ashwin.renganathan@utah.edu	Strategic Thrust 2: Innovation in Commercial Supersonic Aircraft Strategic Thrust 3: Ultra-Efficient Subsonic Transports	Lead or Partner
Boeing Research & Technology	Abdollah Khodadoust	abdollah.khodadoust@boeing.com	Topic 1: Safe, Efficient Growth in Global Operations (Strategic Thrust 1) Topic 2: Innovation in Commercial Supersonic Aircraft (Strategic Thrust 2) Topic 3: Ultra-Efficient Subsonic Transports (Strategic Thrust 3) Topic 4: Safe, Quiet, and Affordable Vertical Lift Air Vehicles (Strategic Thrust 4) Topic 5: In-Time System-Wide Safety Assurance (Strategic Thrust 5) Topic 6: Assured Autonomy for Aviation Transformation (Strategic Thrust 6) Topic 7: Zero Emission Aviation	Partner
University of Tennessee Space Institute	Pr. Paul Palies, www.utsi.edu/cparc	ppalies@utk.edu	Topic 7: Zero Emission Aviation	Partner/Lead

My Story

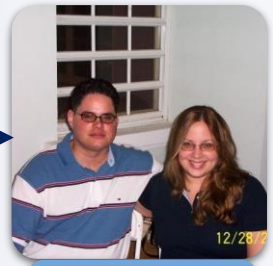
From Puerto Rico to Cleveland, OH

- *PR-LSAMP Fellowship*
- *NASA Space Grant Scholarships*
- *IFN Fellowship*

1995
- Graduated from HS
- Academia del Perpetuo Socorro

1999
- BS in Chemistry
- UPR-RUM
- Started Medical School (UPR-RCM)

2001
- Left Medical School
- Started Physics courses UPR-RP



2002
- Met my husband ☺

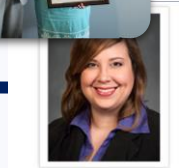
2003
- Started Ph.D. in Chemical Physics
- Cathodoluminescence of Nanocrystalline Silicon for Field Emission Displays

2007
- Got married!

2008
- Ph.D in Chemical Physics

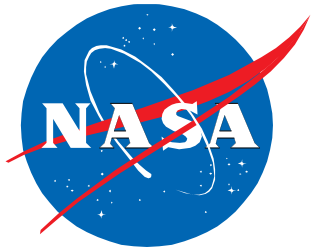
2009
- Moved to Cleveland, OH
- Started work at NASA GRC

2011
- We became parents!



2018
- Stage 4 rectal cancer diagnosis
- Cancer free for almost 2 years!

Present
- SPM for TTT
- Living and enjoying life to the fullest!


NASA