NASA Strategy for Ultra Efficient Propulsion
Full Engine Simulation Workshop

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Advanced Air Transport Technology Project

Vision

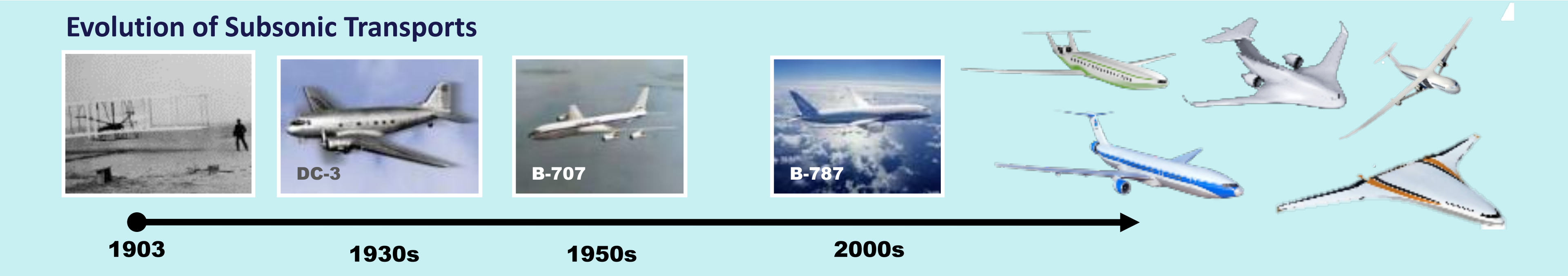
Enable Aircraft with Dramatically Improved Energy Efficiency, Environmental Compatibility, and Economic Impact for the Nation

Mission

Explore and develop viable game-changing concepts, technologies, and tools to improve vehicle and propulsion system energy efficiency and environmental compatibility

Scope

Subsonic fixed-wing commercial transport aircraft



NASA Aeronautics Strategic Thrusts

Safe, Efficient Growth in Global Operations
- Achieve safe, scalable, routine, high-tempo airspace access for all users

Innovation in Commercial Supersonic Aircraft
- Achieve practical, affordable commercial supersonic air transport

Ultra-Efficient Subsonic Transports
- Realize revolutionary improvements in economics and environmental performance for subsonic transports with opportunities to transition to alternative propulsion and energy

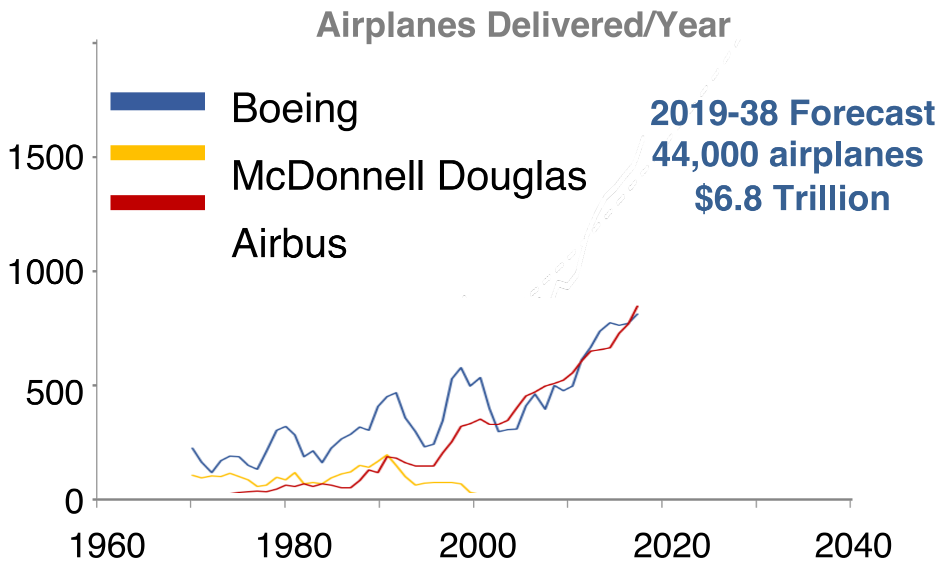
Safe, Quiet, and Affordable Vertical Lift Air Vehicles
- Realize extensive use of vertical lift vehicles for transportation and services including new missions and markets

In-Time System-Wide Safety Assurance
- Predict, detect and mitigate emerging safety risks throughout aviation systems and operations

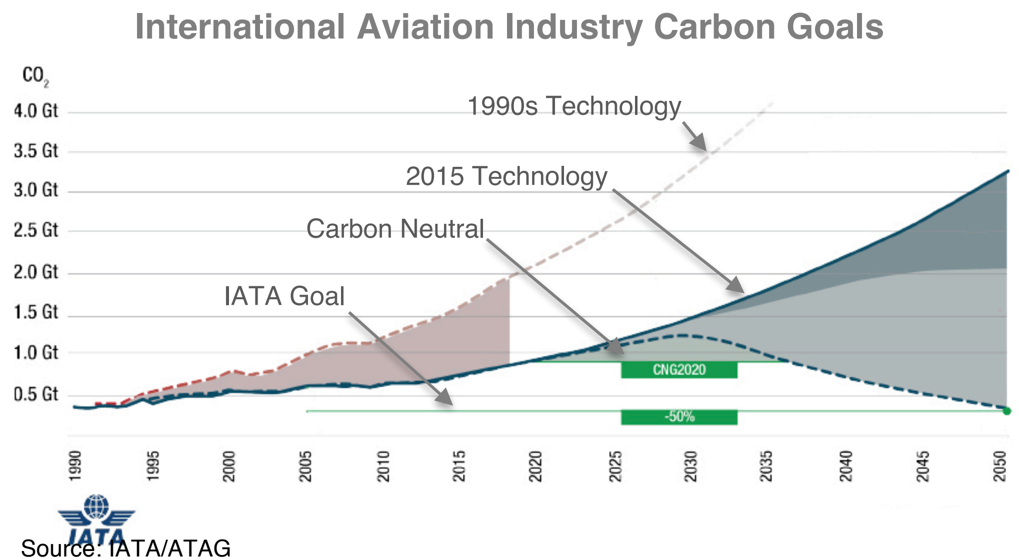
Assured Autonomy for Aviation Transformation
- Safely implement autonomy in aviation applications

Subsonic Transport Airplane Market – COVID-19 not included

Global competition and environmental pressure expanding



Source data: Boeing



Source: IATA/ATAG

- European manufacturers reaching parity
- New competitors in key Asia-Pacific growth market
- U.S. leadership at risk

- Market-based measures in place
- New ICAO CO_2 and nvPM standards starting in 2020
- Social pressure growing, e.g., flight shaming
- U.S. industry must meet global standards

Ultra-efficient subsonic transport technologies address both needs and offer operating cost benefits to airlines

NASA Subsonic Transport System Level Metrics Table Update

v2016.1

TECHNOLOGY BENEFITS	TECHNOLOGY GENERATIONS (Technology Readiness Level = 5-6)		
	Near Term 2015-2025	**Mid Term** 2025-2035	**Far Term** beyond 2035
Noise (cum below Stage 4)	22 – 32 dB	32 – 42 dB	42 – 52 dB
LTO NO_x Emissions (below CAEP 6)	70 – 75%	80%	>80%
Cruise NO_x Emissions (rel. to 2005 best in class)	65 – 70%	80%	>80%
Aircraft Fuel/Energy Consumption (rel. to 2005 best in class)	40 – 50%	50 – 60%	60 – 80%

Recommended Approach:

- AATT has 737MAX-like system model for new reference
- Noise: shift goals to Stage 5 reference, revisit goals
- LTO NOx: shift goals to CAEP 8 reference
- Cruise NOx: eliminate as metric
- nvPM: add as new metric, develop goals
- CO2: add new metric, develop goals
- Fuel/Energy Consumption: update to 2020 best in class, revisit goals

AATT SA&I team working with AAVP/IASP to update table
Original plan to release new table at AIAA Aviation (delayed due to COVID, other factors)
New plan to vet with aviation community and release draft in fall timeframe

Subsonic Transport Technology Prioritization

NASA Aeronautics Vision and Strategy Established

2008-2013 → 2014 - 2019 → 2020-2025

Subsonic Concept/Technology Studies
Electric Aircraft Propulsion, Transonic Truss Braced Wing

Environmentally Responsible Aviation (ERA) Project

Flight Demonstrator Studies

Advanced Composites (ACP)

Next Step

Maturation and Integration of Four Key Technologies that will Create a New "S Curve" for Future Subsonic Transports

FAA CLEEN I	FAA CLEEN II	FAA CLEEN III

ARMD Subsonic Transport Strategy Based on over a Decade of Research, Concept and Technology Development, and NASA-Industry Partnership

Four Key Subsonic Transport Technologies

Create new "S" curve for the next 50 years of subsonic transports

Electrified Aircraft Propulsion

- Improved efficiency/emissions
- Mild hybrid systems promising for early 2030s

Small Core Gas Turbine

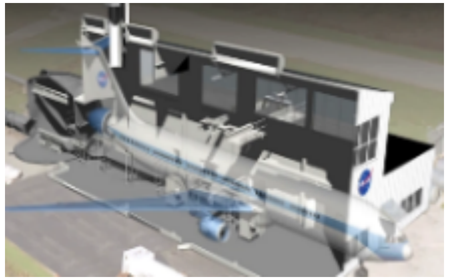
- Increased gas turbine efficiency
- Facilitates airframe integration – conventional or EAP

Transonic Truss-Braced Wing

- Increased aerodynamic and structural efficiency
- Propulsion system integration and high rate production

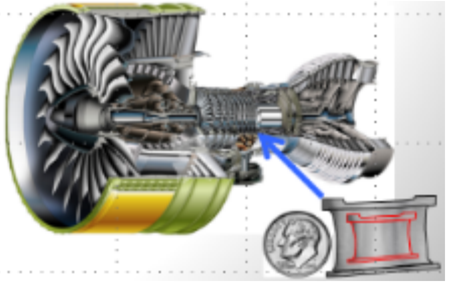
High Rate Composite Manufacturing

- Critical to US competitiveness via reduced delivery time
- Reduced time/cost to market with increased performance

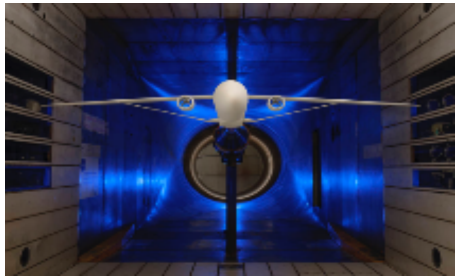


Electrified Aircraft Propulsion

synergistic

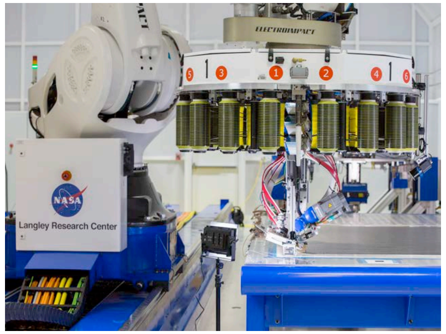


Small Core Gas Turbine



Transonic Truss-Braced Wing

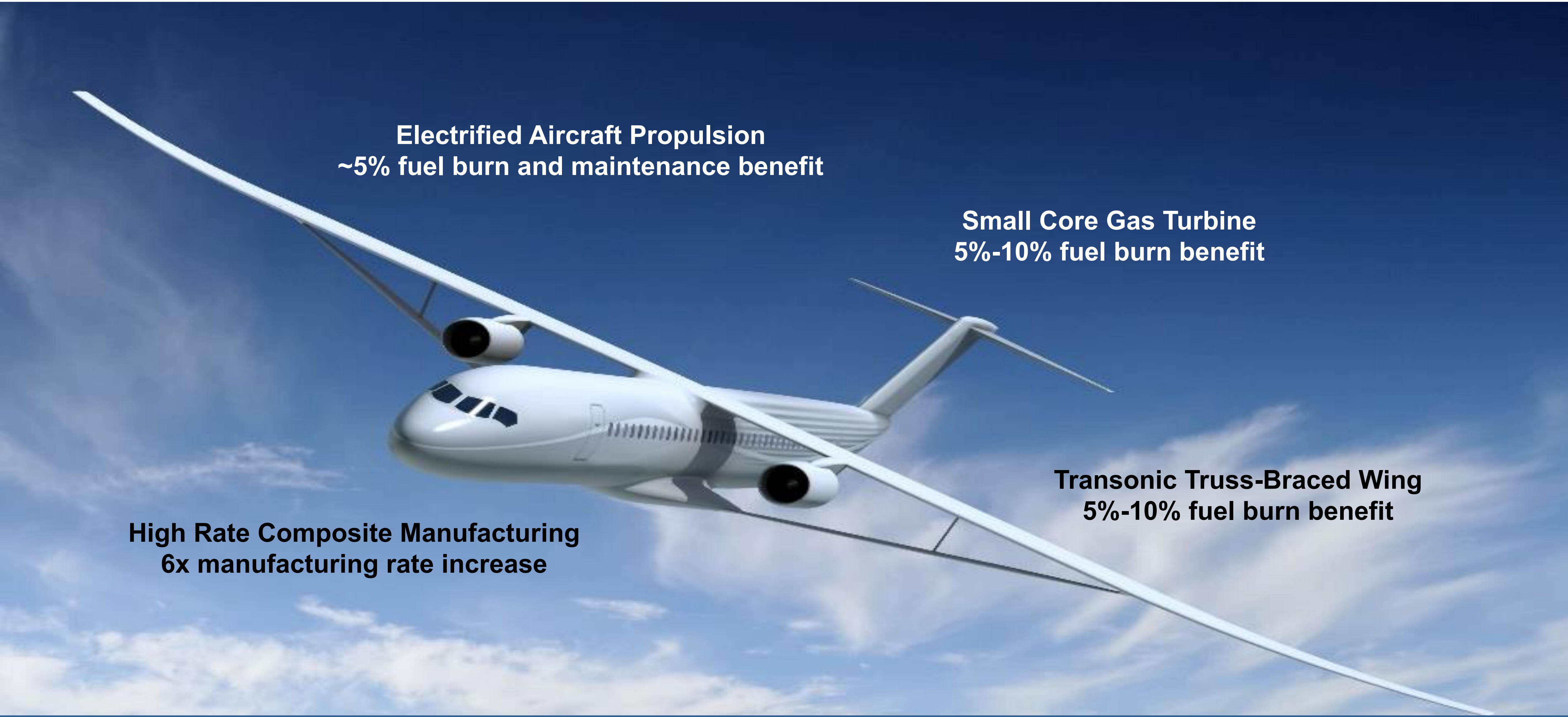
synergistic



High Rate Composites

Advance key technologies to TRL 6 by 2025-28 to create early 2030s market opportunities for US industry

Vision System & Unifying Construct



Ensure U.S. industry is the first to establish the new “S Curve” for the next 50 years of transports

Electrified Aircraft Propulsion

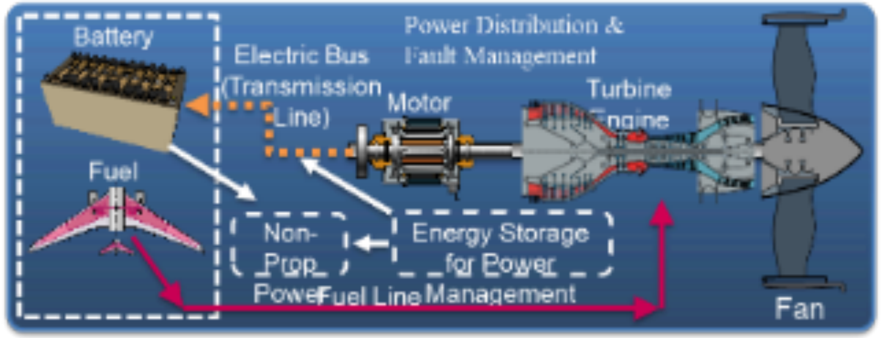
Game-changing architectures and operational schemes offer significant fuel burn benefit

Goals:

- Identify and retire barrier technical and integration risks for MW-class electrified aircraft propulsion systems
- Complement benefits from improved engine cores & airframe efficiencies
- Coordinate system studies, ground tests & flight tests critical to advance to TRL6

Objectives:

- Demonstrate representative hybrid electric powertrain
- Total power of 3X state-of-the-art with large engine power extraction
- Meet fault management, redundancy, and power quality requirements



Technical Challenges:

- High power density and efficiency requirements
- Operation of high voltage components at altitude
- Integration at scale in flight-relevant environment

Approach:

- Partner w/industry on ground and flight test of electrified propulsion architecture
- Leverage prior AATT EAP advances (TRL ~4)

Focus on accelerating MW-class powertrain development through ground and flight test

Small Core Gas Turbine

Game-changing increase in thermal efficiency and reduced size to facilitate hybridization

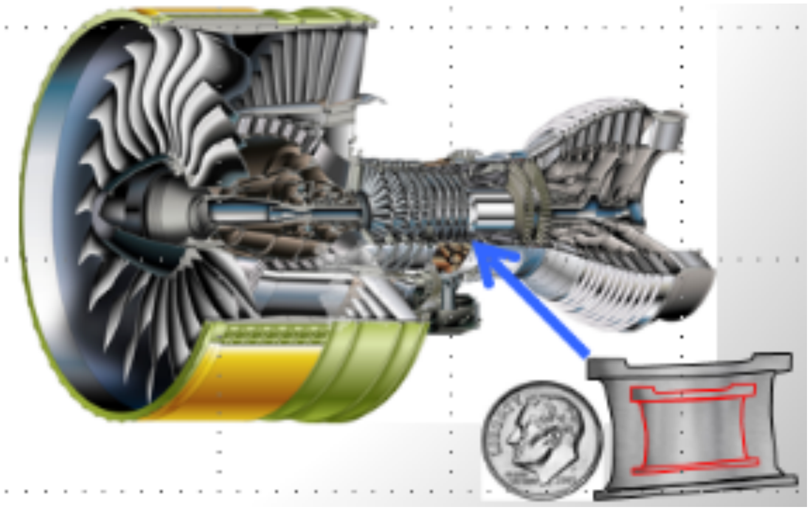
Goal: Establish integrated high power-density hybrid core engine technologies for early 2030s EIS aircraft

Objectives:

- Demonstrate 5-10% fuel burn benefit on representative system to TRL6
- Characterize and validate engine design trade space

Technical Challenges:

- High overall pressure ratio and T4 challenges
- Ultra compact size constraints
- Engine life and maintenance
- Integration challenges for electrical components



Approach:

- Partner with industry for ground test of small core engine, potentia
- Leverage prior small core and hybrid advances (TRL~4)

Large fuel burn benefit enabled by increased thermal efficiency

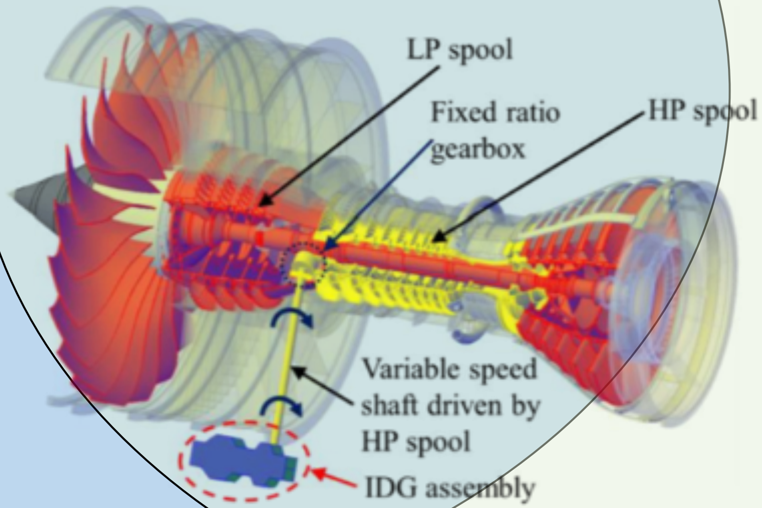
AAVP Supporting ARMD Strategic Plan and IASP

Strategic Thrust 3 Critical Commitment:

Demonstrate technologies for practical vehicle-level integration of high-power (1MW+) electrified aircraft propulsion (EAP) systems with advanced airframe systems for initial applications to small transport aircraft

AAVP

- **Powertrain TC**
- **Power Extraction TC**



IASP/Electrified Aircraft Propulsion (EAP) System Risk Reduction - Ground to Flight Capability:

Identify/Retire "barrier" technical and integration risks associated with MW-class electrified aircraft propulsion systems utilizing NASA ground and flight test assets

TACP :
TTT: crosscutting technologies controls, sensors, materials
CAS: Heather, Maxwell

Subsonic Transport Technology Demonstration Roadmap

Objective: Identify/Retire “barrier” technical and integration risks associated with subsonic transports utilizing NASA ground and flight test assets

Strong alignment of IASP and AAVP plans and timelines

AAVP-led

IASP-led

Year 2019

Near Term
EAP Technology Development/Maturation for Traditional T&W RJ Market Applications

- Ground qualification of flying testbed
- Fly 1 or more hybrid turboprop options
- EAP Powertrain tech. development

Year 2023

Turbo-prop Focused

Mid Term
EAP Technology Development/Maturation for Traditional T&W Single-Aisle Market Applications

HyTEC

- Ground qualification of flying testbed
- Fly Single aisle hybrid turbofan on 747
- Power extraction demo
- Small Core Gas Turbine tech. development
- Small Core Gas Turbine demo
- Turbofan Power Extraction tech. development

Year 2025

Year 2028

Turbo-fan Focused

Far Term
Broad Technology Development/Maturation and Aircraft Configuration Optimization for Maximum Market Benefit/Impact

HiCAM

- Ground Development/Test Campaign – System studies and risk reduction
- Flight Test Spiral Three
- Transonic Truss-Braced Wing tech. development
- High-Rate Composite Manufacturing tech. development
- High-Rate Composite Manufacturing demo

Year 2028

Integrated Multi-Tech Focused

Notional Project Budget Breakout

Refined budget levels to be determined through FY21 planning

- **New HyTEC and HiCAM Finite Duration Projects**
  - FOCUS: NASA collaboration with industry to accelerate technologies to product
  - HyTEC: Core engine demo (TRL 6) in FY26
  - HiCAM: Large composite structural demo (TRL/MRL 5-6) in FY27
  - Engaging prospective industry partners to begin acquisition strategy development
- **AATT Project Restructured**
  - Systems Analysis & Integration (SA&I)
  - Vehicle Systems Integration (VSI) Subproject
    - TTBW TC coordinated with SFD in IASP
    - Additional PAI, aerosciences, aircraft structures research
  - Propulsion & Power (P&P) Subproject
    - EAP TC coordinated with EPFD in IASP
    - Additional propulsion, power, engine materials research

Hybrid Thermally Efficient Core - increase thermal efficiency & facilitate hybridization

Turbofan Engine Power Extraction Demonstration

NEW Technical Challenge:

TC14: Achieve 20% power extraction at altitude from a modern commercial turbofan engine with the **thrust, efficiency, operability, and durability to enable the benefits of electrified aircraft propulsion at a vehicle level.**

Exit Criteria: Demonstrate feasibility of power extraction of at least 20% with sufficient thrust, efficiency, operability, and durability to enable EAP concepts.

Approach: Multidisciplinary approach to demonstrate and evaluate power extraction on a commercial turbofan engine.

Exploration of trade space to validate & enhance controls and engine models

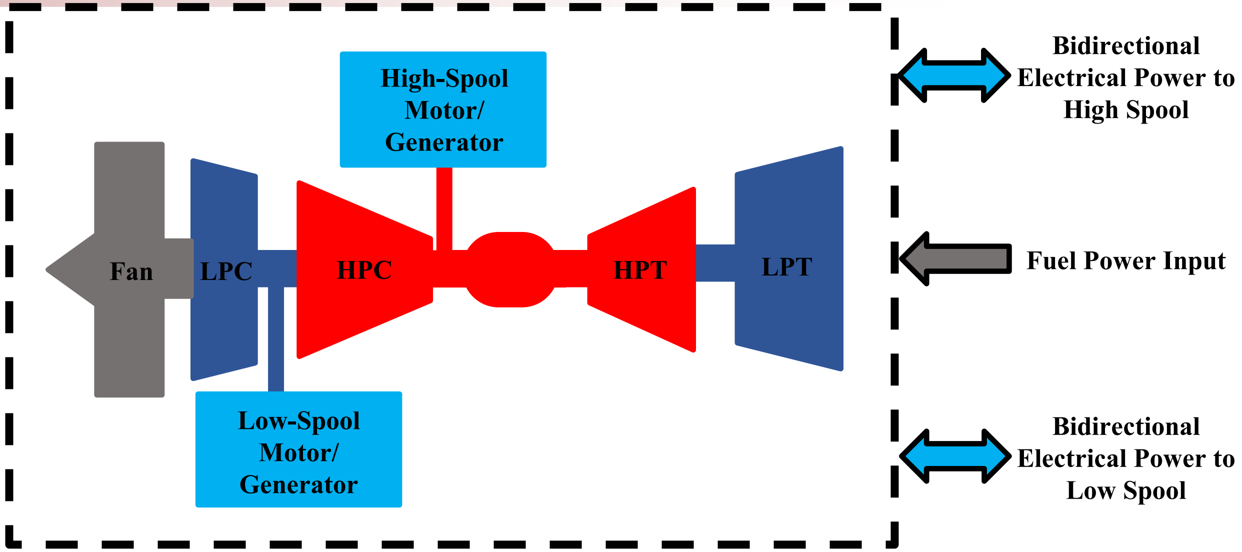
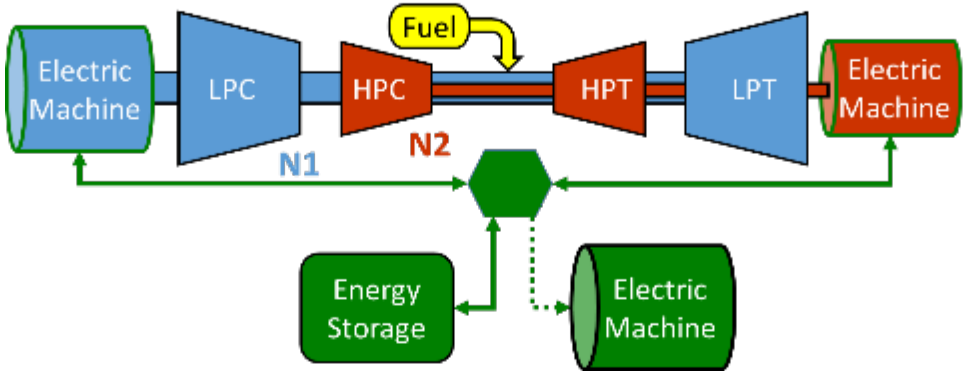


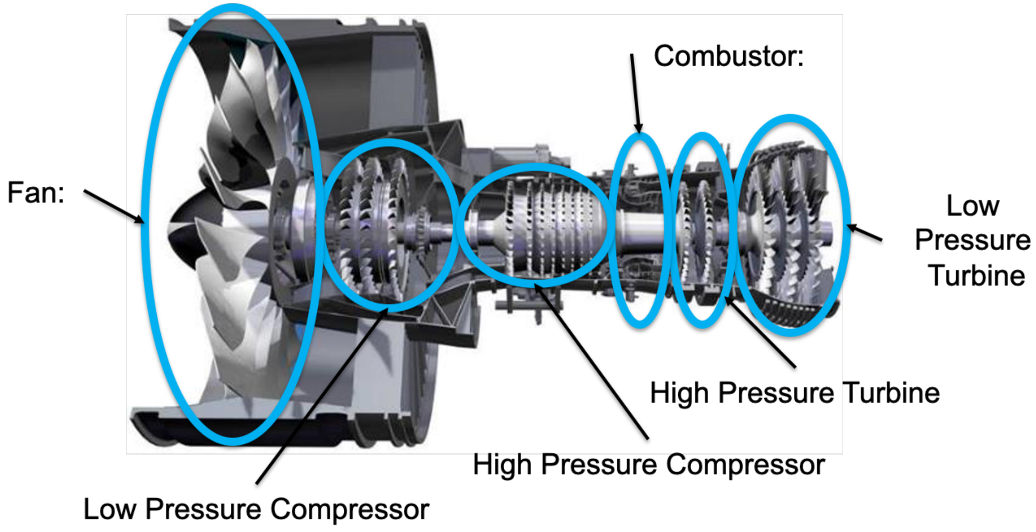
Table 3. Key technology development for turbomachinery - electric machine integration.

Possible EAP Technology Implementations	Potential Impacts	Achievement Level Through Ground Test	Achievement Level Through Altitude Test
Dual spool power extraction/augmentation	Enables operability management – improves idle	Partial	Full
Turbine electric energy management	Energy use and life improvement	Partial	Full
Augmented engine idle conditions	Energy use improvement	Full	Full
Electric fan assist	Energy use improvement	Partial	Full
In-flight battery recharge	Reduced turnaround time – energy use improvement	Partial	Full
Electric taxi	Energy use improvement	Full	N/A

Summary

- ➢ Turbofan Power Extraction (PEx) new Technical Challenge has been identified to be aligned with the Strategic Implementation Plan and address technical barriers to the Electrified Aircraft Propulsion (EAP).
  - Supporting NASA's plans for future ground and flight demonstration of EAP.
  - AAVP, IASP, and TACP efforts to address EAP barriers are well coordinated.
- ➢ HyTEC and HiCAM are 2 new Projects of finite duration to demonstrate TRL 6 technologies in collaboration with industry. Builds upon existing work.
- ➢ HyTEC is expecting to release an RFI and hold industry day prior to Nov 2020.
- ➢ Lower TRL subsonic transport research will continue under the AATT project.





HyTEC - Demonstrate increased thermal efficiency & facilitate hybridization

NASA

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Component Coupling / Simulation & Design Process Improvements

- **Coupled CFD Analysis of Propulsion-Airframe Integration**
  Shishir Pandya, ARC / Wai-Ming To, GRC

- **Numerical Study of Combustor-Turbine Interaction**
  Kenji Miki / Thomas Wey

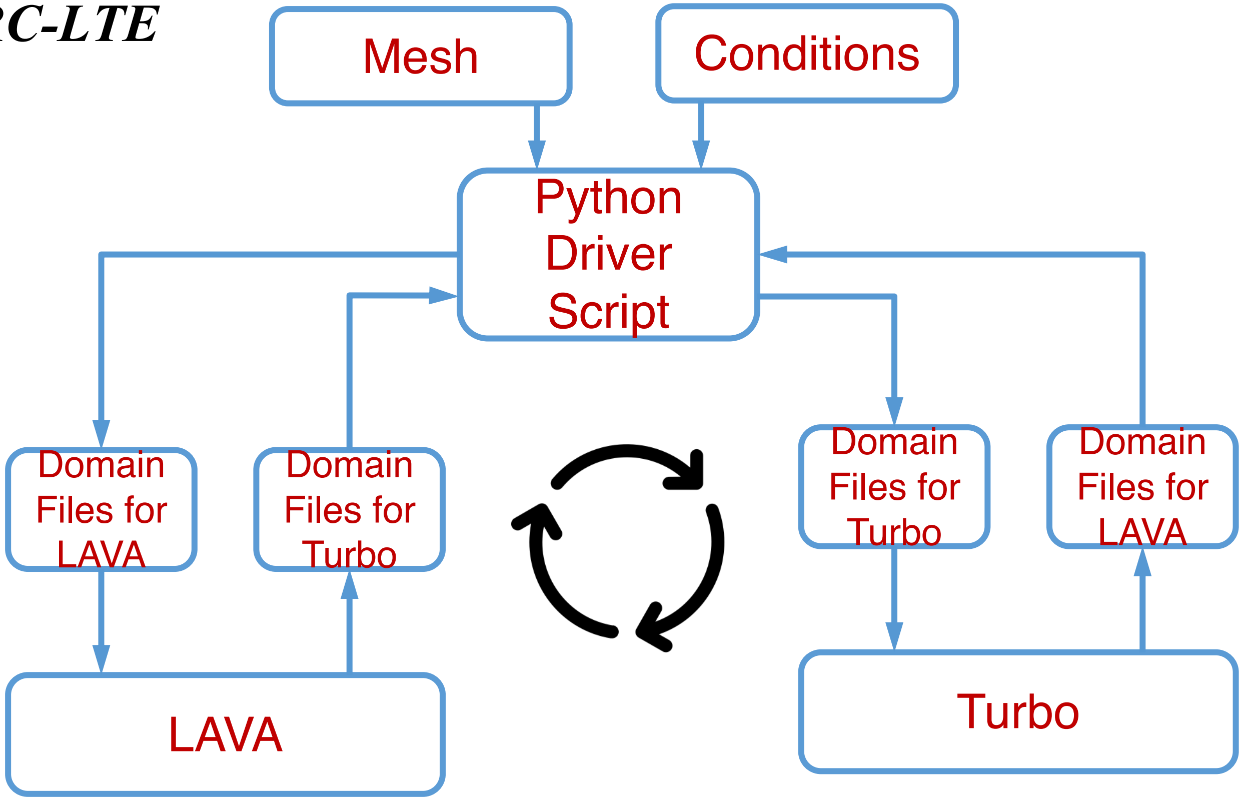
- **Turbomachinery Machine Learning Master Plan**
  Paht Juangpanich / Vikram Shyam

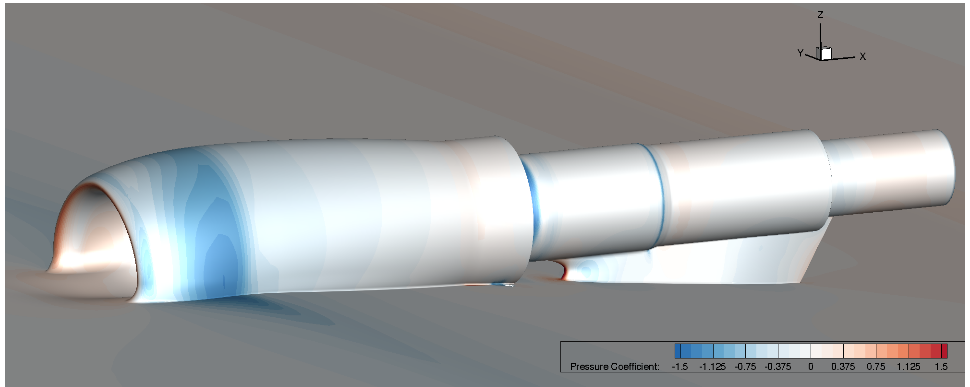
- **Turbulent Heat Flux Experiments**
  Mike Borghi / Nick Georgiadis / Mark Wernet / Randy Locke / Phil Poinsatte
  Doug Thurman / Seth Spiegel

Coupled CFD Analysis of Propulsion-Airframe Integration

Shishir Pandya, ***ARC-TNA*** **/ Waiming To,** ***GRC-LTE***

- **Motivation: Need for coupled capability**
- **Plan: Get LAVA and Turbo to talk to each other**
  - Validate the coupled capability with BLI2DTF data (8x6 and W8)
  - Validate LAVA for tail cone thruster nacelle with the NTF test



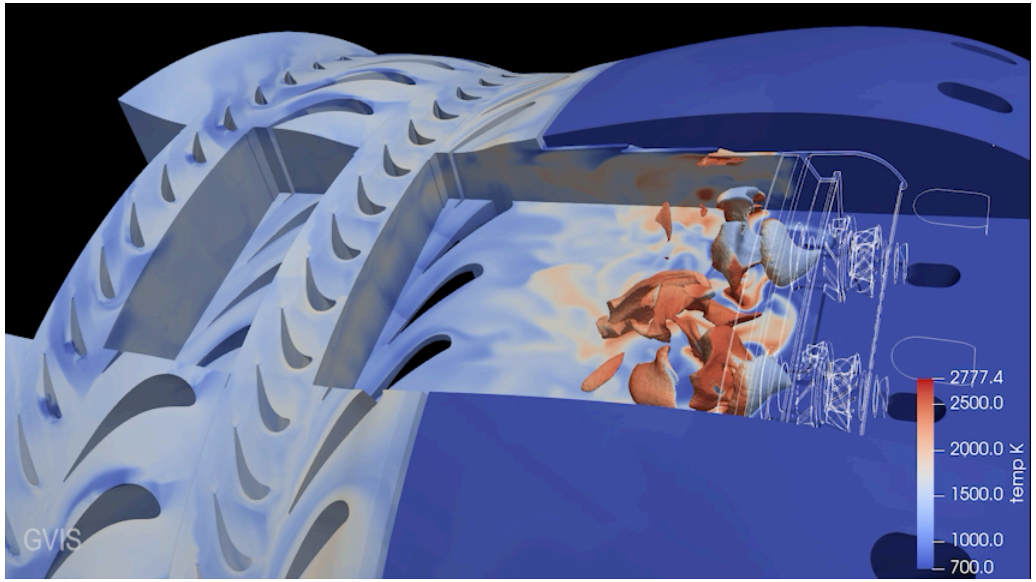


Numerical Study of Combustor-Turbine Interactions With OpenNCC

Kenji Miki ***GRC-LTE*** **/ Thomas Wey** ***GRC-LTC***

➢ Summary of work

Combustor-turbine interactions (CTIs) are investigated by modeling the unsteady flow-fields inside a realistic combustor and HPT from the E^3 Program. 3D unsteady simulations with a liquid-spray fuel/air chemistry including a relative motion between the combustor and HPT were performed using the Open National Combustion Code (OpenNCC).



➢ CPU

~1.5 million CPU-hours (initial transients and sufficient time to get meaningful time-averaged and time-history results) for the fully-coupled simulation

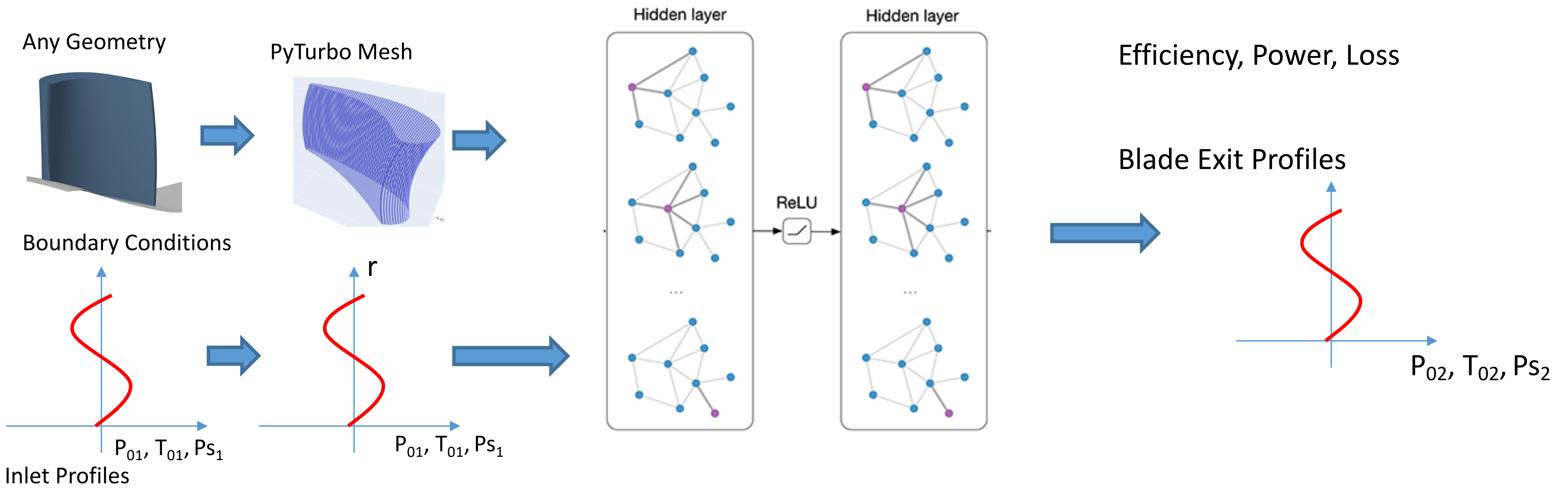
➢ Key results

The results demonstrate that fully-coupled combustor-turbine simulations are possible and can produce significant differences in predicted HPT efficiency, hot-streak distributions and dynamics behavior in the HPT.

Turbomachinery Machine Learning Master Plan

Paht Juangpanich & Vik Shyam *GRC LTE*

Inputs | Graph Neural Networks | Predict Performance of any design

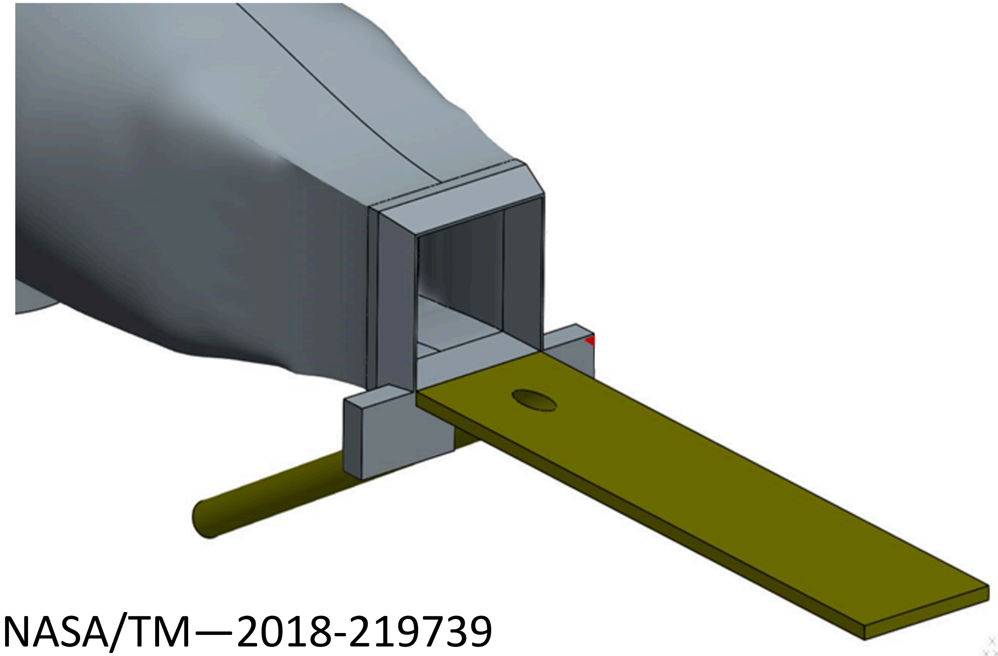


Robust Performance Prediction Framework

Turbulent Heat Flux (THX) Experiments

- Turbulent Heat Flux (THX) Experiments – have completed 5 phases.
- THX3 (2017) and THX4 (2018) were experiments run in GRC AAPL, same nozzle, stainless steel hardware.
- THX Goal: Take measurements of velocities and temperatures, mean and rms (turbulent) for flows where turbulent transport of heat is important.
- These measurements are needed to improving modeling of propulsion flows & and all flows where turbulent transport of heat is important.

THX 3: Single Cooling Hole – fundamental aerodynamic & thermodynamic scientific study



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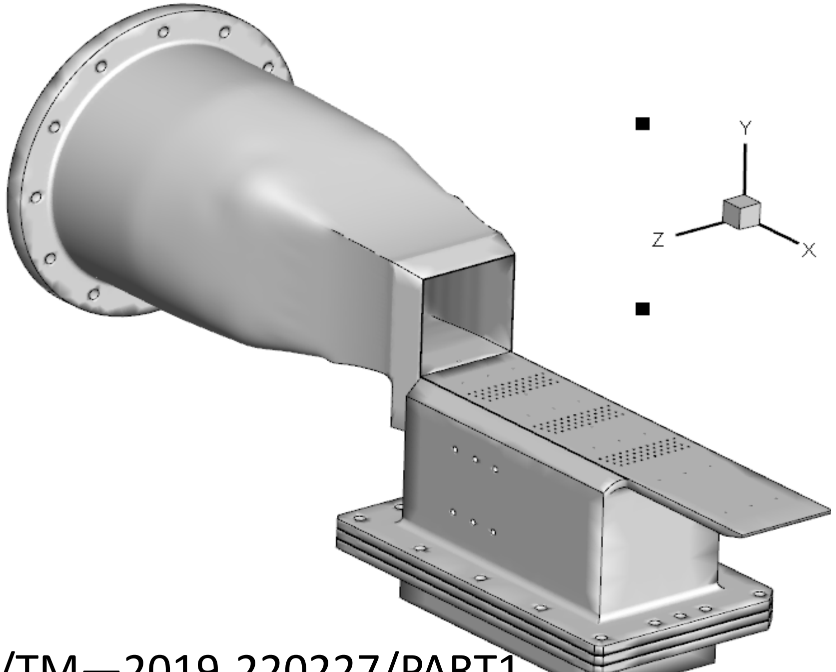
THX 4: Porous Plate – also detailed in-flow measurements, but more of an engineering configuration.



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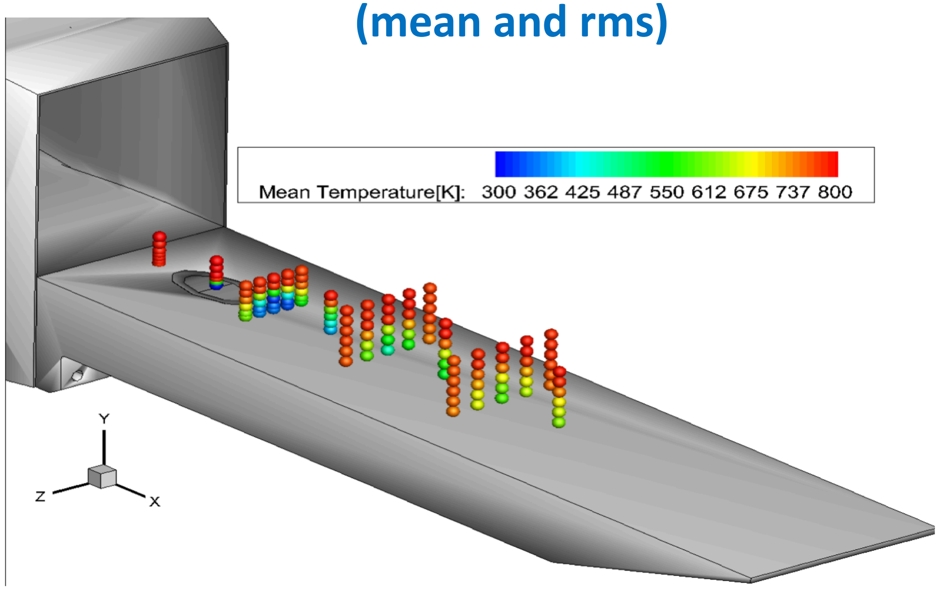
Turbulent Heat Flux (THX) Experiments

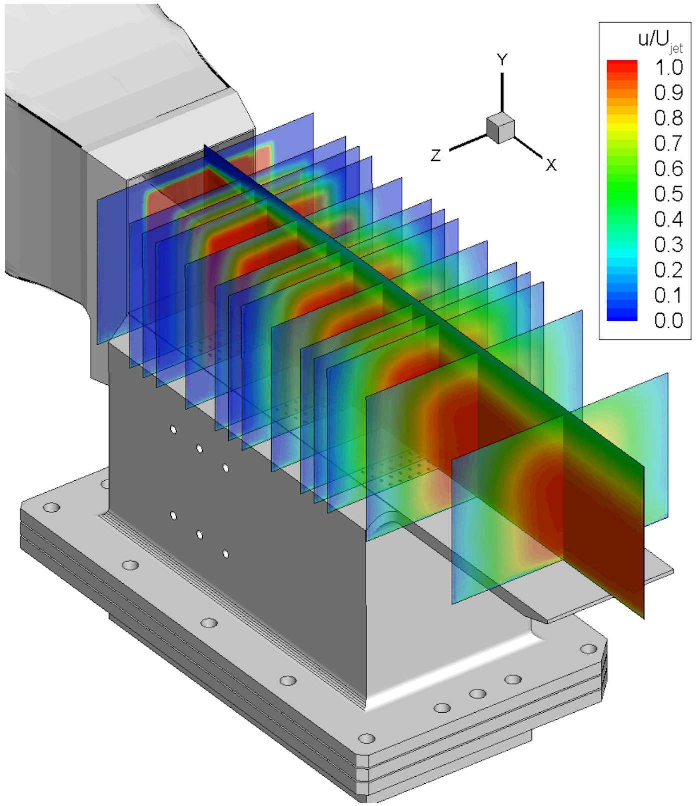
- **Sample experimental measurements:**

THX 3: Raman temperature measurements (mean and rms)

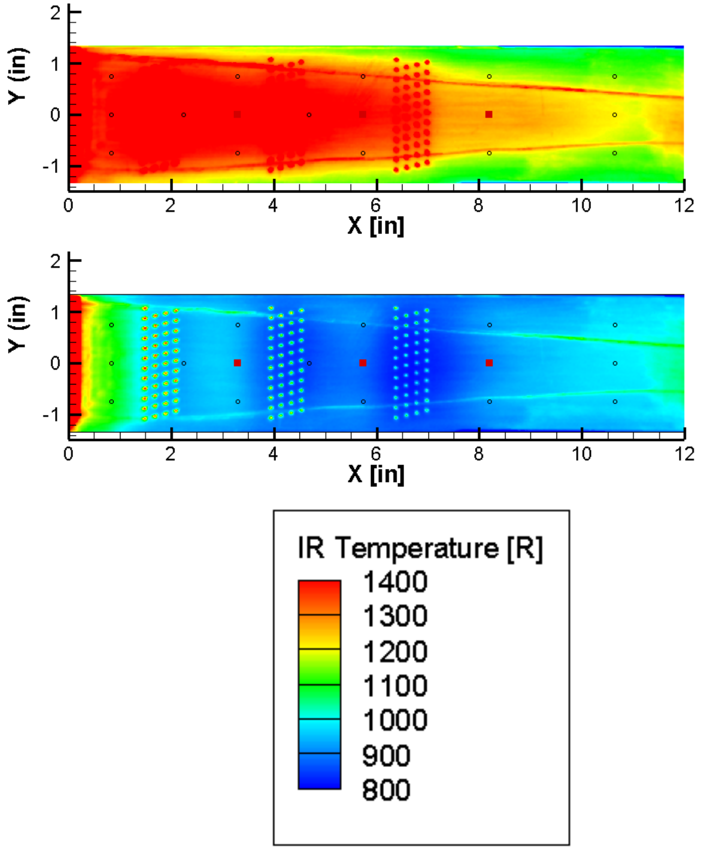


	PIV	Raman	Surface IR
THX 3	✓	✓	
THX 4	✓	✓	✓

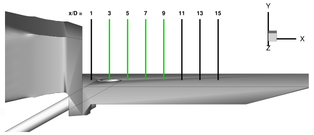
THX 4: PIV velocity measurements (mean and rms)



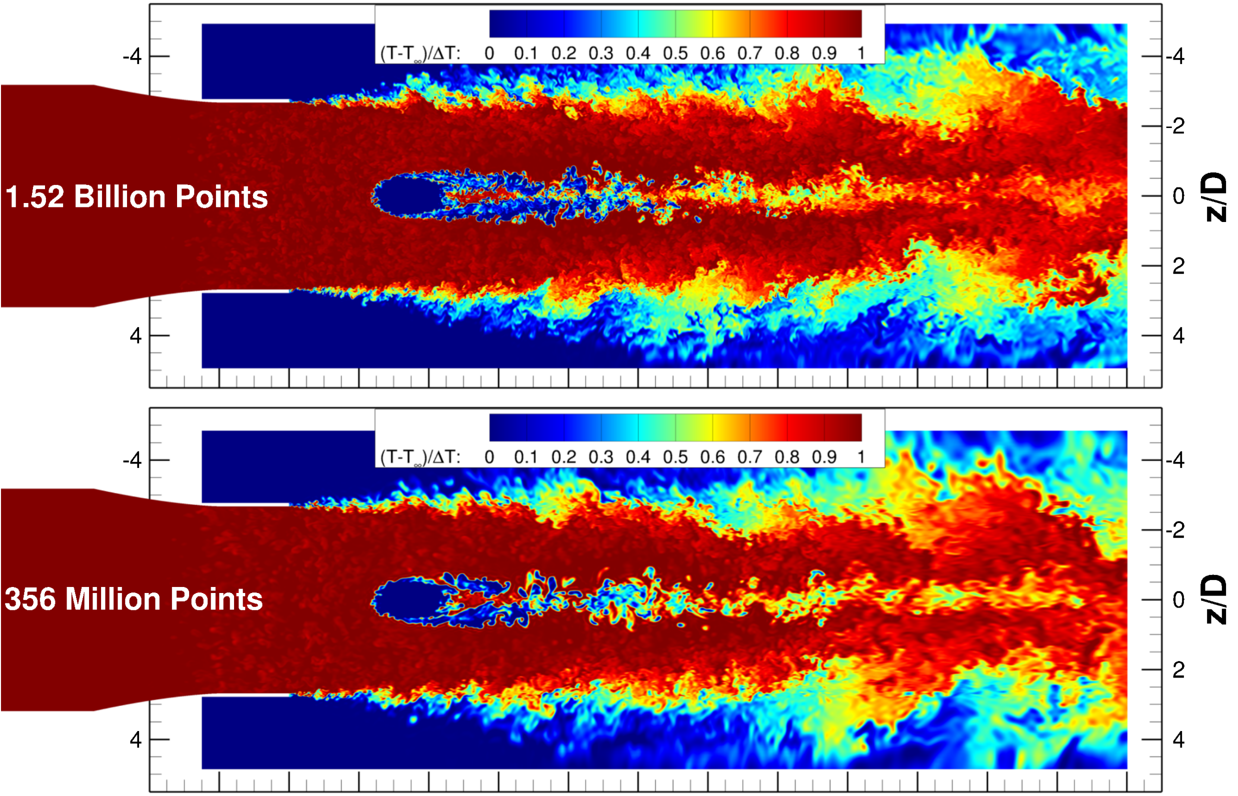
THX 4: Surface IR temperature measurements



THX Phase 3: Very High-Fidelity Studies

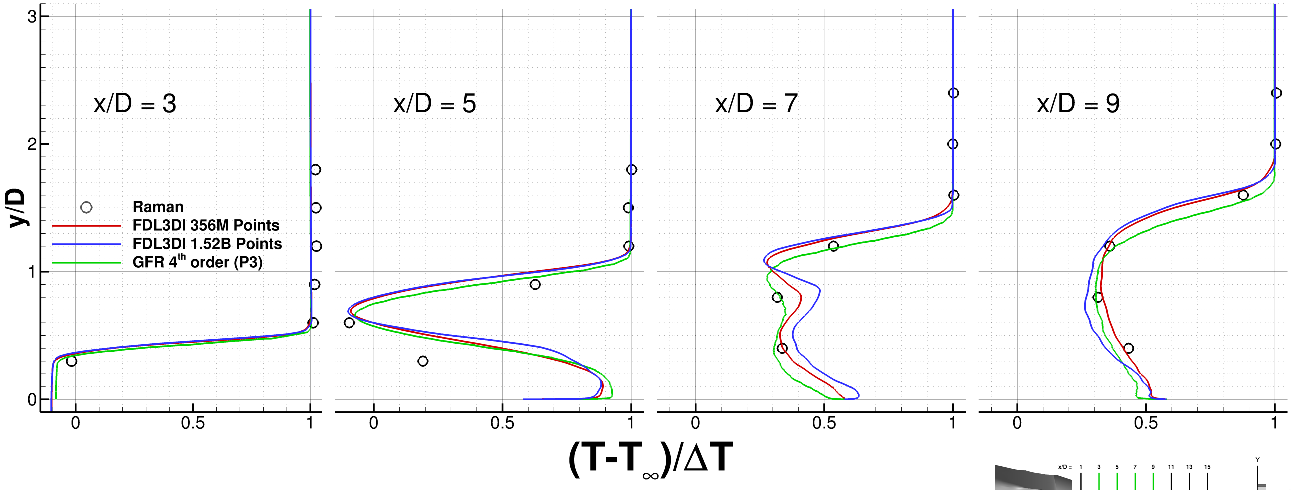


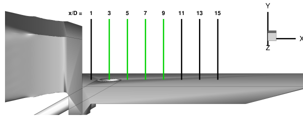
- Higher fidelity BR=2.0 case using FDL3DI
  - Increased grid resolution from **356M to 1.52B points**.
- Higher fidelity BR=1.0 case using GFR
  - Increased solution accuracy from 4th order (P3) to 5th order (P4),
    increasing DoF from **839M to 1.64B total effective points.**



Comparison of structures resolved at y/D=0.2 by FDL3DI on higher fidelity grid (top) and base grid (bottom)

BR=2.0 including higher fidelity FDL3DI case





BR=1.0 including higher fidelity GFR case