National Aeronautics and Space Administration

Advanced Air Transport Technology (AATT) Project

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5th International Workshop on Aviation and Climate Change
University of Toronto Institute for Aerospace Studies
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Toronto, Canada

NASA Aeronautics

NASA Aeronautics Vision for Aviation in the 21st Century

U.S. leadership for a new era of flight

NASA Aeronautics Program Structure

Aeronautics Research Mission Directorate

Mission Programs

- **Advanced Air Vehicles (AAVP)**, Jay Dryer
  - Advanced Air Transport Technology (AATT)
  - Revolutionary Vertical Lift Technology (RVLT)
  - Commercial Supersonic Technology (CST)
  - Advanced Composites (ACP)
  - Aeronautics Evaluation and Test Capabilities (AETC)
- **Integrated Aviation Systems (IASP)**, Ed Waggoner
  - Environmentally Responsible Aviation (ERA)
  - UAS Integration in the NAS
  - Flight Demonstration and Capabilities (FDC)
- **Airspace Operations And Safety (AOSP)**, John Cavolowsky
  - Airspace Technology Demonstration (ATD)
  - SMART NAS – Testbed for Safe Trajectory Operations
  - Safe Autonomous System Operations (SASO)

Seedling Program

- **Transformative Aeronautics Concepts (TACP)**, Doug Rohn
  - Transformational Tools and Technologies (TTT)
  - Convergent Aeronautics Solutions (CAS)
  - Leading Edge Aeronautics Research for NASA (LEARN)

Advanced Air Transport Technology Project

Explore and Develop Technologies and Concepts for Improved Energy Efficiency and Environmental Compatibility for Fixed Wing Subsonic Transports

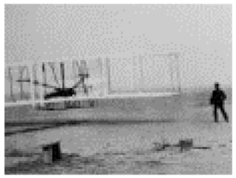
Vision

- Early-stage exploration and initial development of game-changing technology and concepts for fixed wing vehicles and propulsion systems

Scope

- Subsonic commercial transport vehicles (passengers, cargo, dual-use military)
- Technologies and concepts to improve vehicle and propulsion system energy efficiency and environmental compatibility without adversely impacting safety
- Development of tools as enablers for specific technologies and concepts

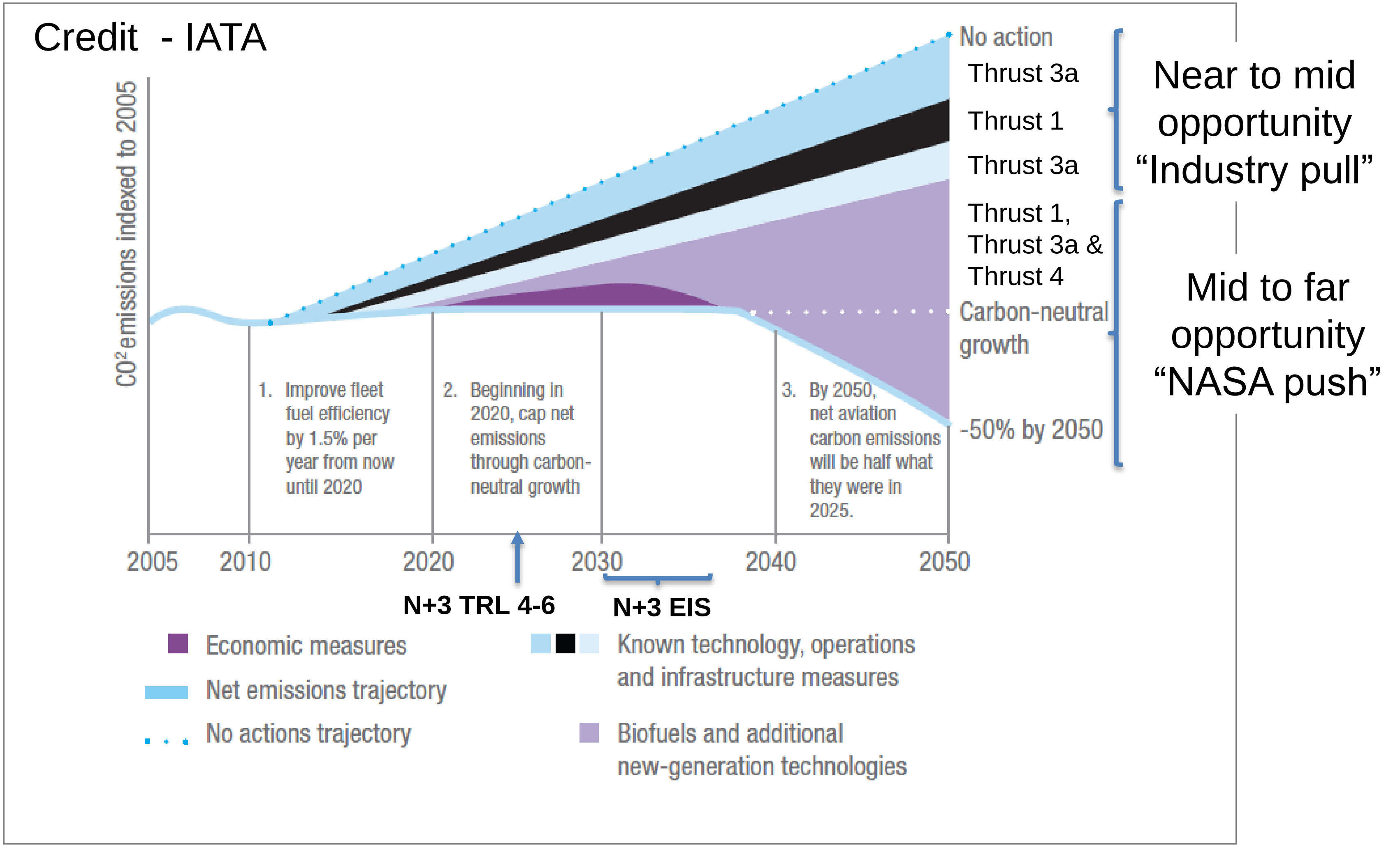
Evolution of Subsonic Transports



1903 — 1930s — 1950s — 2000s

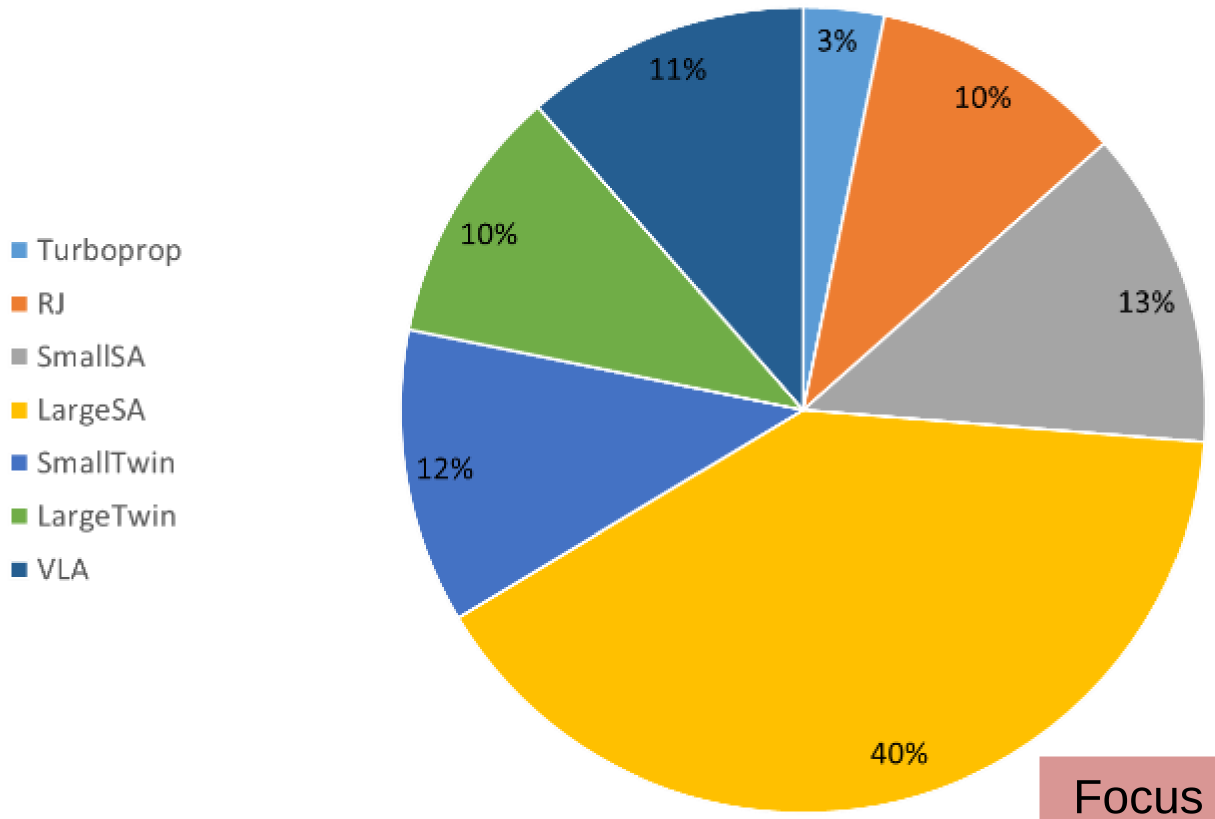
Major Aviation Community "Driver"

Reduce Carbon Footprint by 50% by 2050…



…in the face of increasing demand, and while reducing development, manufacturing and operational costs of aircraft & meeting noise and LTO NOx regulations

Fuel Use by Vehicle Class



Focus on small single-aisle and larger vehicle classes for maximum community impact

40% of fuel use is in 150-210 pax large single aisle class
87% of fuel use is in small single-aisle and larger classes (>100 pax)
13% of fuel use is in regional jet and turboprop classes

Analysis based on FAA US operations data provided by Holger Pfaender of Georgia Tech

NASA Subsonic Transport System-Level Metrics

Strategic Focus

1. Energy Efficiency

2. Environmental Compatibility

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6) v2013.1		
	N+1 (2015)	N+2 (2020**)	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-52 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-33%	-50%	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines. N+2 values are referenced to a 777-200 with GE90 engines.

** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

‡ CO_2 emission benefits dependent on life-cycle CO_2e per MJ for fuel and/or energy source used

N+3 values are referenced to a 737-800 with CFM56-7B engines

Research addressing revolutionary far-term goals with opportunities for near-term impact

AATT Portfolio Development: N+3 Advanced Vehicle Concept Studies Summary

Advanced concept studies for commercial subsonic transport aircraft for 2030-35 Entry into Service (EIS)

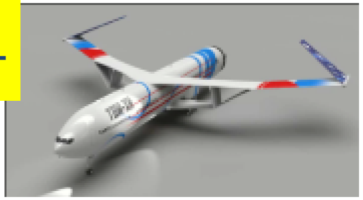
Boeing, GE, GA Tech

NG, RR, Tufts, Sensis, Spirit

GE, Cessna, GA Tech

MIT, Aurora, P&W, Aerodyne

NASA, VA Tech, GT



NASA

Trends:

- Tailored/multifunctional structures
- High aspect ratio/laminar/active structural control
- Highly integrated propulsion systems
- Ultra-high bypass ratio (20+ with small cores)
- Alternative fuels and emerging hybrid electric concepts
- Noise reduction by component, configuration, and operations improvements

Advances required on multiple fronts…

AATT Project Technical Challenges

Near-Term Impact Toward Long-Term Objectives

Goals Metrics (N+3)	Noise Stage 4 – 52 dB cum		Emissions (LTO) CAEP6 – 80%	Emissions (cruise) 2005 best – 80%		Energy Consumption 2005 best – 60%	
Technology Themes	Lighter-Weight Lower-Drag Fuselage	Higher Aspect Ratio Optimal Wing	Quieter Low-Speed Performance	Cleaner, Compact, Higher BPR Propulsion	Hybrid Gas-Electric Propulsion	Unconventional Propulsion-Airframe Integration	Alternative Fuel Emissions

Technical Challenges Near-Term (FY15-21) Project Focus

TC2.1 (FY19) Higher Aspect Ratio Optimal Wing: Enable a 1.5-2X increase in the aspect ratio of a lightweight wing with safe flight control and structures (TRL3).

TC3.1 (FY18) Fan & High-Lift Noise: Reduce fan (lateral and flyover) and high-lift system (approach) noise on a component basis by 4 dB with minimal impact on weight and performance (TRL5)

TC4.1 (FY19) Low NOx Fuel-Flex Combustor: Reduce NOx emissions from fuel-flexible combustors to 80% below the CAEP6 standard with minimal impact on weight, noise, or component life (TRL3).

TC4.2 (FY20) Compact High OPR Gas Generator: Enable reduced size/flow high pressure compressors and high temperature disk/seals that are critical for 50+ OPR gas generators with minimal impact on noise and component life (TRL4).

TC4.3 (FY21) Engine Icing: Predict likelihood of icing events with 90% probability in current engines operating in ice crystal environments to enable icing susceptibility assessments of advanced ultra-efficient engines. (TRL2)

TC5.2 (FY19) Hybrid Gas-Electric Propulsion Concept: Establish viable concept for 5-10 MW hybrid gas-electric propulsion system for a commercial transport aircraft (TRL2)

TC6.1 (FY17) Integrated BLI System: Achieve a vehicle-level net system benefit with a distortion-tolerant inlet/fan, boundary-layer ingesting propulsion system on a representative vehicle (TRL3).

TC6.2 (FY21) Airframe Icing: Enable assessment of icing risk with 80% accuracy for advanced ultra-efficient airframes operating in supercooled liquid droplet environments. (TRL2)

TC7.1 (FY15) Alternative Fuel Emissions at Cruise: Fundamental characterization of a representative range of alternative fuel emissions at cruise altitude (TRL n/a). **COMPLETE**

Note: Reference is best commercially available or best in class in 2005.

TC2.1(FY19): Higher Aspect Ratio Optimal Wing, TRL 3

Objective

Explore and develop aerodynamic, structural, and control technologies to expand the optimal wing system drag vs. weight design trade space for reduced energy consumption

Technical Areas and Approaches

Aerodynamic Shaping

- Low interference external bracing
- Passive wave drag reduction concepts

Active Flow Control

- Transonic drag reduction; mechanically simple high-lift

Adaptive Aeroelastic Shape Control

- Continuous control effector(s) for mission-adaptive optimization

Active Structural Control

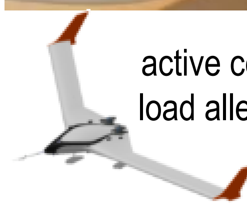
- Distributed control effectors, robust control laws
- Actuator/sensor structural integration

Tailored Load Path Structure

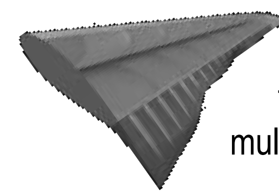
- Passive aeroelastic tailored structures

Benefit/Pay-off

- 20% wing structural weight reduction
- Wave drag benefits tradable for weight or other parameters
- Concepts to control and exploit structural flexibility
- Optimal AR increase up to 50% for cantilever wings, 100% for braced wings



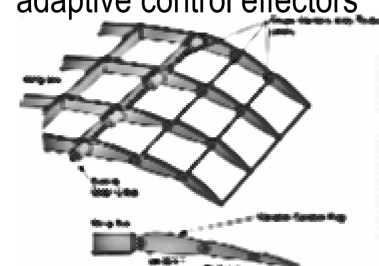
active controls
load alleviation

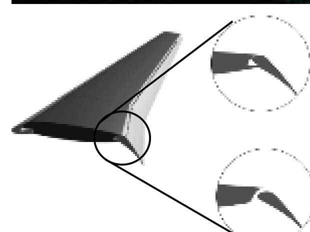


tailored
multifunctional

passive/active
advanced aerodynamics

adaptive control effectors





AFC-based high-lift concepts

TC 3.1(FY18): Fan and High-Lift Noise, TRL 5

Objective

Explore and develop aero-structural-acoustic technologies to directly reduce perceived community noise with minimal or no impact on performance

Technical Areas and Approaches

Airframe Noise

- Flap and slat noise reduction concepts
- Landing gear noise reduction concepts

Acoustic Liners and Duct Propagation

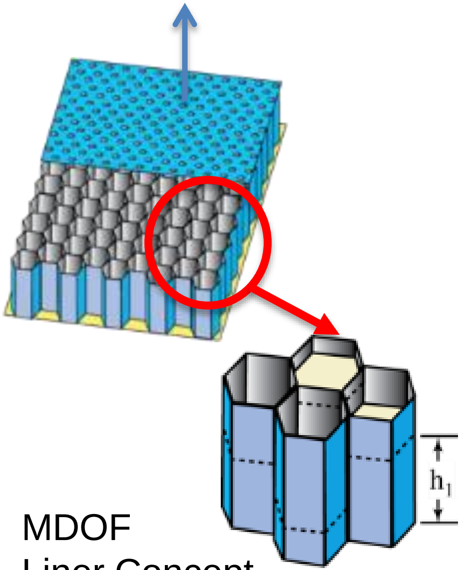
- Multi-degree-of-freedom, low-drag liners

Benefit/Pay-off

- 12 dB cum noise reduction
- Liner and non-active-flow-control high-lift system technology have early insertion potential

flap/slat
noise reduction
concepts

Liner Test Facility (LTF)



MDOF
Liner Concept

TC4.1(FY19): Low NOx Fuel-Flex Combustor, TRL 3

Objective

Explore and develop technologies to directly enable efficient, clean-burning, fuel-flexible combustors compatible with high OPR (50+) gas-turbine generators

Technical Areas and Approaches

Fuel-Flexible Combustion

– Small core injection methods, alternative fuel properties, combustion stability techniques

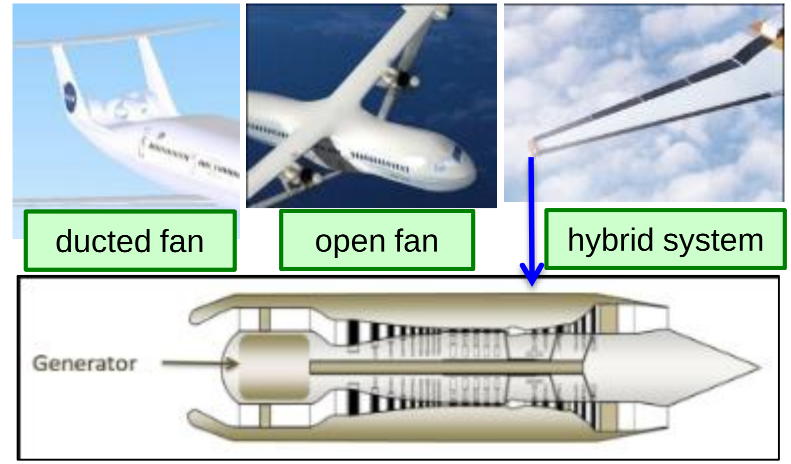
Benefit/Pay-off

– Lower emissions: NOx reduction of 80% at cruise and 80% below CAEP6 at LTO and reduced particulates

– Compatible with thermally efficient, high OPR (50+) gas generators

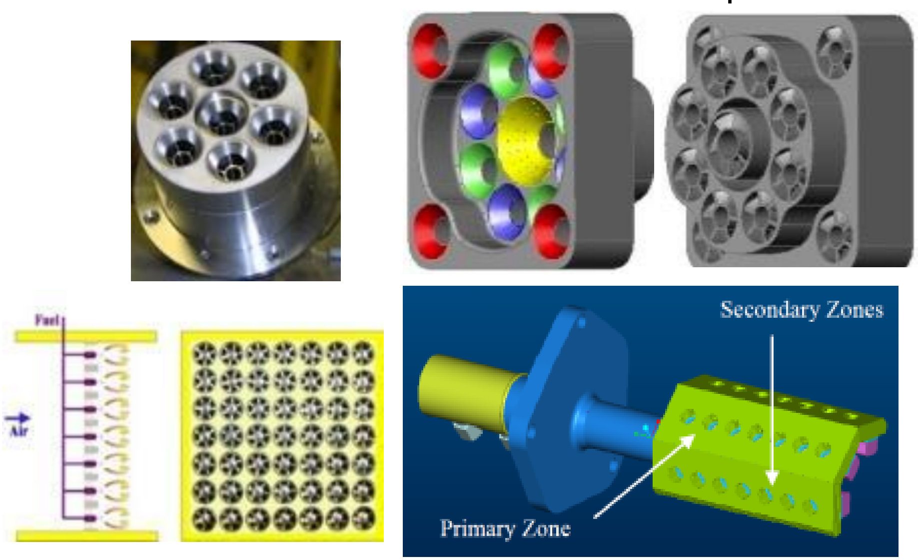
– Compatible with gas-only and hybrid gas-electric architectures and ducted/unducted propulsors

– Compatible with alternative fuel blends



Advanced combustor required for gas-only and hybrid architectures

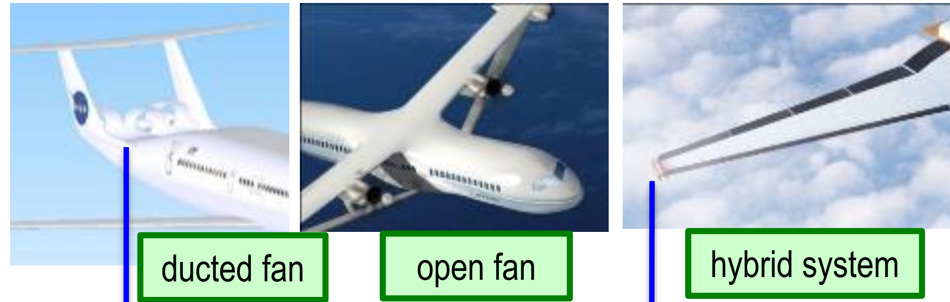
Low-emission flametube concepts

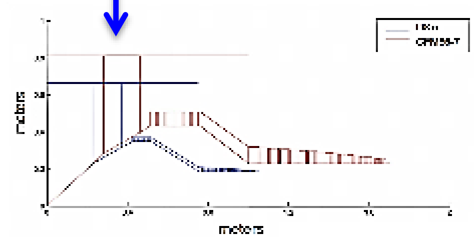


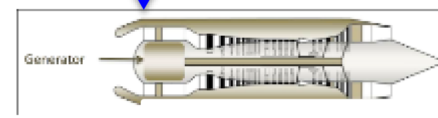
TC4.2(FY20): Compact, High OPR Gas Generator, TRL 4

Objective

Enable reduced size/flow gas generators with 50+ OPR and disk/seal temperatures of 1500F with minimal impact on noise and component life (TRL4).







materials, aerodynamics, and control

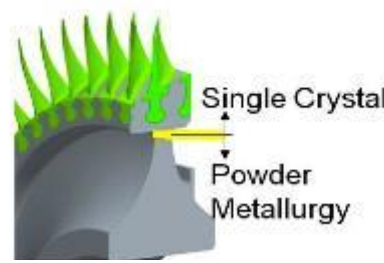
Technical Areas and Approaches

Hot Section Materials

- 1500F hybrid disk and coatings
- 1500F capable non-contacting seal

Reduced Size HPC for High OPR Engines

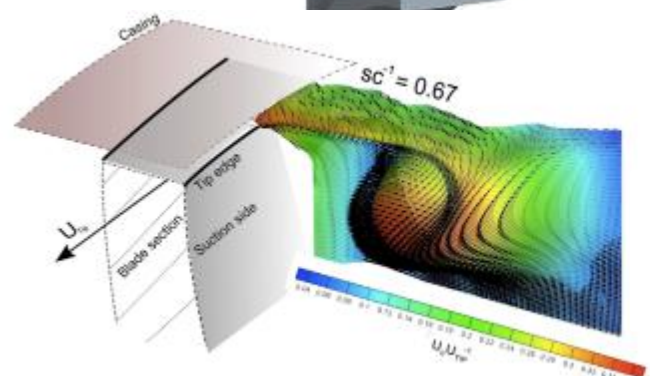
- Minimize losses due to short blades/vanes



1500 F, bonded hybrid disk concept

Benefit/Pay-off

- Advanced compact gas-generator core architecture and component technologies enabling BPR 20+ growth by minimizing core size
- Thermally efficient, high OPR (50+) engines



Tip/endwall aerodynamic loss mitigation

Wu et al. Exp. Fluids, 2010, 1011
Miorini et al., J. Turbomachinery 2012, AIAA Journal 2012

TC4.3(FY21): Engine Icing

Objective

Predict likelihood of icing events with 90% probability in current engines operating in ice crystal environments to enable icing susceptibility assessments of advanced ultra-efficient engines

Technical Areas and Approaches

Icing Prediction Analysis Tool

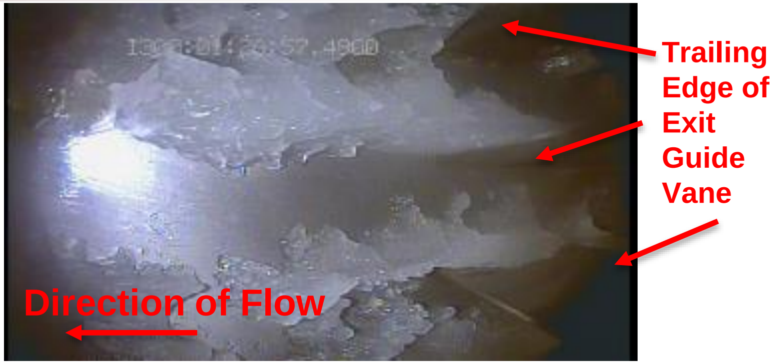
- Engine conditions conducive to ice formation
- Rate of ice growth/engine effects

Fundamental Physics and Engine Icing Tests

- Study ice crystal icing in GRC Propulsion Systems Laboratory to validate tools

Benefit/Pay-off

- Enable analysis of ice crystal icing effects on turbofan engines
- Design tools adapted for N+3, compact core, higher bypass ratio turbofan engines to assess icing impacts during development



Ice Formation inside Engine in PSL

Engine in Propulsion Systems Laboratory for Icing Test

Fundamental Physics Test Ice Accretion

Engine in Ice Crystal Cloud

TC5.2 (FY19): Gas-Electric Propulsion Concept, TRL 2

Objective

Explore and develop concepts and technologies to enable aircraft with hybrid-electric and turboelectric propulsion systems that provide a net vehicle system-level energy efficiency benefit

Technical Areas and Approaches

Propulsion System Conceptual Design

- Early selection of system concepts that allow drill-down in issues of system interaction concept refinement

High Efficiency/Power Density Electric Machines

- Explore conventional and non-conventional topologies
- Integrate novel thermal management
- Advance development of component materials

Flight-weight Power System

- High power electric grid definitions, modeling, simulation
- High voltage power electronics, transmission, protection
- Materials development for lightweight power transmission
- Management & distribution for distributed propulsion

Integrated Subsystems

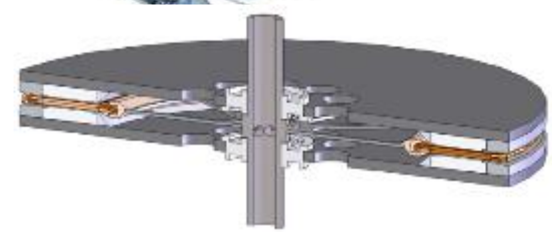
- Component interactions – validate performance and matching during steady-state and transient operation
- Develop control methodology

Benefit/Pay-off

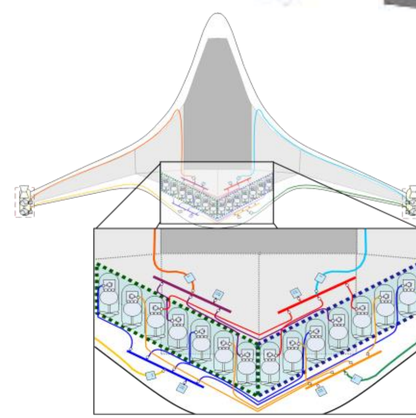
- Enable the paradigm shift from gas turbine to hybrid-electric or turbine-electric propulsion

Gas turbine-battery hybrid

Superconducting turboelectric distributed propulsion



High power density, non-cryogenic motor



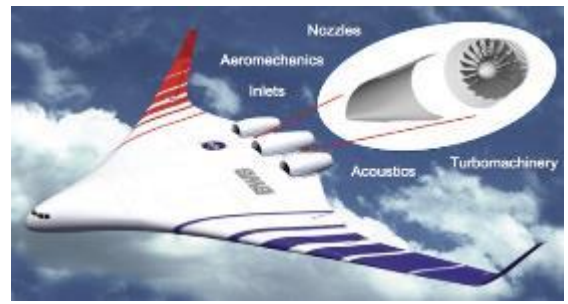
Propulsion power grid architecture

TC6.1(FY16): Integrated BLI System, TRL 3

Objective

Explore and develop technologies to enable highly coupled propulsion-airframe integration that provide a net vehicle system-level energy efficiency benefit

Boundary-layer ingestion for drag reduction



Distortion-tolerant fan required for net vehicle system benefit

Technical Areas and Approaches

Aerodynamic Configuration

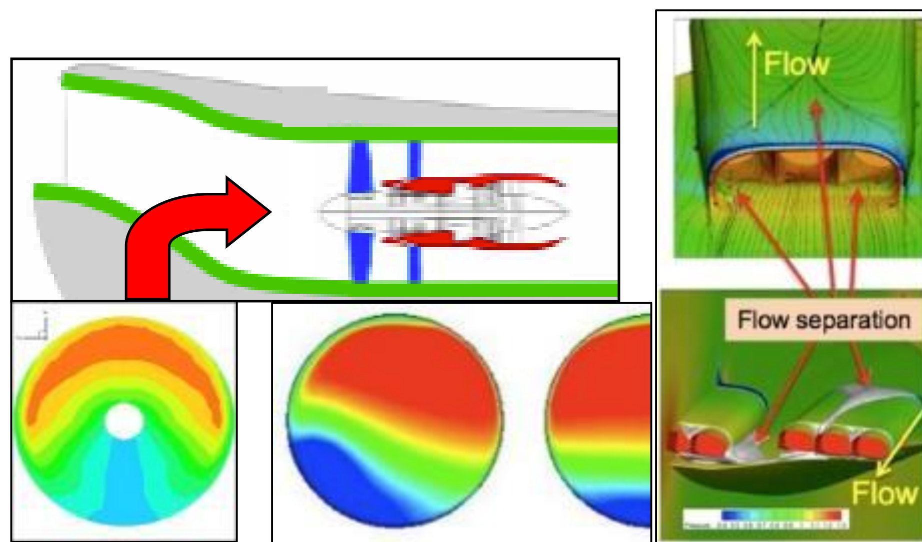
- Novel configurations and installations

Distortion-Tolerant Fan

- Integrated inlet/fan design robust to unsteady and non-uniform inflow

Benefit/Pay-off

- Will demonstrate a net system-level benefit for BLI propulsion system integration that is applicable and beneficial to a variety of advanced vehicle concepts
- Distortion-tolerant fan technology and acoustics characterization is relevant to near-term conventional short-duct installations



TC6.2(FY21): Airframe Icing

Objective

Enable assessment of icing risk with 80% accuracy for advanced ultra-efficient airframes operating in supercooled liquid droplet environments

Technical Areas and Approaches

3D Ice Accretion Prediction Tool

- Develop LEWICE3D to assess ice accretion on complex airframe features

Ice Protection Systems

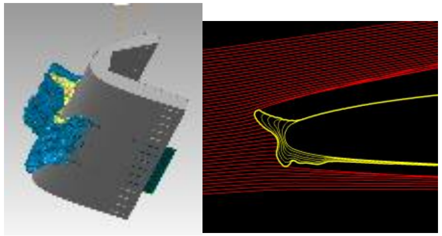
- Integrate assessment of ice protection systems into LEWICE3D as airframe design tool

Benefit/Pay-off

- LEWICE3D validated against experimental data to be used as design tool for advanced N+3 airframes
- Ice protection system evaluation capability to mitigate icing issues for N+3 airframes

Scalloped Ice Shape on Swept Wing

Current NASA Icing Simulation Tools Well Validated and Accepted by Aviation Community



Ice growth on 65% scale CRM wing section model

Straight Wing

Swept Wing

MVD = 18.6 microns

MVD = 215.6 microns

Expanding Current Icing Simulation Tools to Swept Wing and Freezing Rain/Drizzle Icing

NASA Aeronautics 10-Year American Aviation Plan and New Aviation Horizons

NASA Aeronautics Ready for Flight

Accomplishments and Planning

NASA Aero Vision and Strategy Established

Roadmaps Completed

2008-2013	2014/15	2016/17	2018-2026

N+3 Subsonic & Supersonic Concept/Technology Studies

Ground Testing of N+3 configurations and technologies

LBFD PDR Completed

UEST PDR Completed

N+2 Environmentally Responsible Aviation (ERA) Project Initiated

8 Integrated Tech Demos Completed, Tech transitioned to industry. HWB ready for Flight Dem/Val.

Ready for X-Plane Integration & Demonstration

NASA FAA NextGen Research Transition Teams (RTTs) Initiated

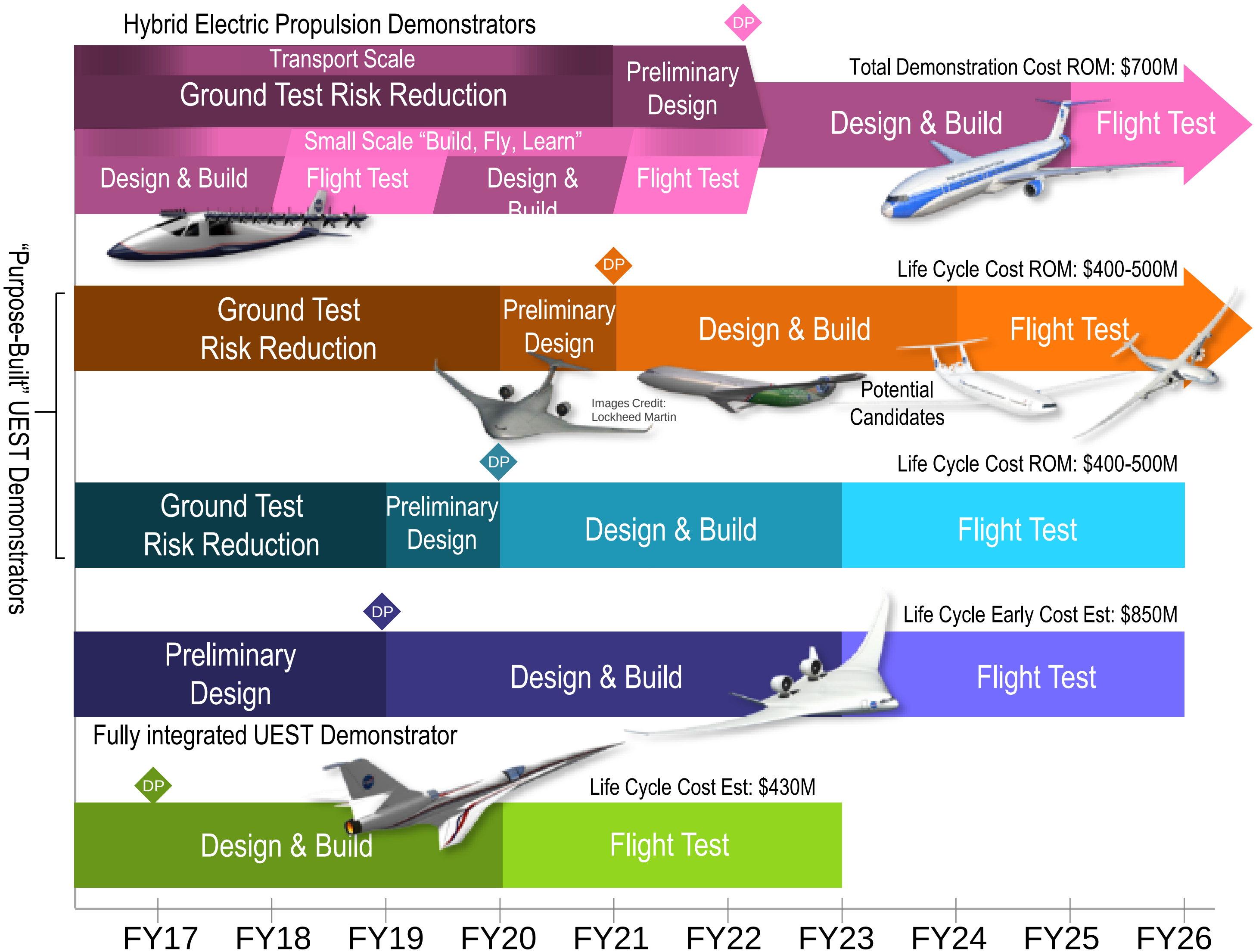
Technology Transitions to FAA: MSP, EDA, PDRC, TSAS

ATD-1 Completed and transferred to FAA

ATD-2, 3 Completed & Transferred to FAA

Ready for NextGen TBO Integration & Demonstration

New Aviation Horizons Flight Demo Plan



Validated HEP Concepts, Technologies And Integration for U.S. Industry to Lead the Clean Propulsion Revolution

Validated ability for U.S. Industry to Build Transformative Aircraft that use 50% less energy and produce less than half of the perceived noise

Enables Low Boom Regulatory Standard and validated ability for industry to produce and operate commercial low noise supersonic aircraft

Ten Year Investment Plan—FY 2017 Budget Accelerates Key Components of NASA Aeronautics Plan

Fund the Next Major Steps to Efficient, Clean and Fast Air Transportation Mobility

New Aviation Horizons

Start a continuing series of experimental aircraft to demonstrate and validate high impact concepts and technologies. Five major demonstrations over the next 10+ years in the areas of Ultra-Efficiency, Hybrid-Electric Propulsion, and Low Noise Supersonic Flight

Major New Initiative within IASP

Enabling Tools & Technologies

Major series of ground experiments to ready key technologies for flight

Research and ground demonstration for an advanced small engine core for very high bypass engines and as a hybrid-electric propulsion enabler

Development of next generation physics-based models needed to design advanced configurations

Increases to AAVP and TACP

Revolutionizing Operational Efficiency

Accelerate demonstration of full gate-to-gate Trajectory Based Operations

Increase to AOSP

Fostering Advanced Concepts & Future Workforce

Increased investment in new innovation through the NASA workforce and Universities

Leverage Non-Traditional Technology Advances

Pursue challenge prizes in areas such as energy storage, high power electric motors, advanced networking and autonomy

Increase to TACP

UAS

Strong continued research leadership in enabling UAS integration into the National Airspace. Extending the UAS in the NAS project for an additional 4 years

Hypersonics

Increased investment to ensure a strong National fundamental research capability

Increases to IASP and AAVP

Build off of major current developments and accomplishments

Continue to incentivize new innovation

AATT Project Research Team

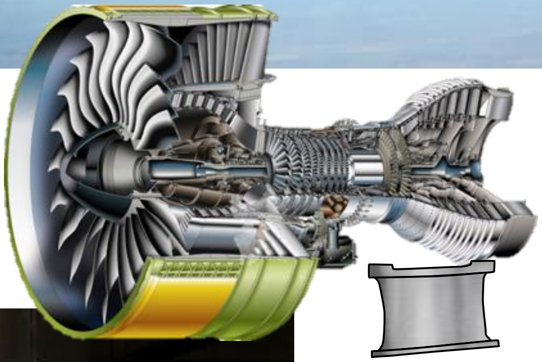
NASA Ames, Armstrong, Glenn, and Langley Research Centers

Three Main Components:

- NASA in-house research
- Collaborations with partners (OGA, Industry, Academia)
- Sponsored research by NASA Research Announcement (NRA)

Concluding Remarks

- Addressing environmental challenges and improving the performance of subsonic aircraft
- Undertaking and solving the enduring and pervasive challenges of subsonic flight
- Understanding and assessing the game changers of the future
- Nurturing strong foundational research in partnership with industry, academia, and other government agencies



Concepts, Technologies, Capabilities, and Knowledge