National Aeronautics and Space Administration

Fixed Wing Project: Technologies for Advanced Air Transports

Dr. Rubén Del Rosario, Project Manager
Mr. John Koudelka, Deputy Project Manager
Dr. Rich Wahls, Project Scientist
Dr. Nateri Madavan, Deputy Project Scientist

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The Fixed Wing Project

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

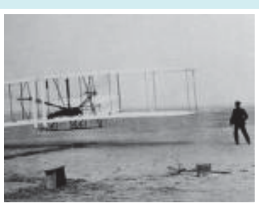
Vision

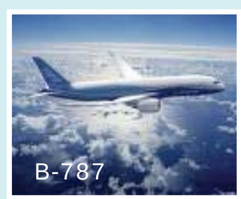
- Early-stage exploration and initial development of game-changing technology and concepts for fixed wing vehicles and propulsion systems

Scope

- Subsonic commercial transport vehicles (passengers, cargo, dual-use military)
- Technologies and concepts to improve vehicle and propulsion system energy efficiency and environmental compatibility
- Development of tools as enablers for specific technologies and concepts

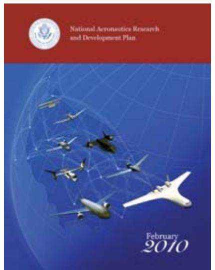
Evolution of Subsonic Transports





1903 — 1930s — 1950s — 2000s

NASA Subsonic Transport System Level Metrics



Strategic Thrusts

1. Energy Efficiency

2. Environmental Compatibility

v2013.1

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		
	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

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

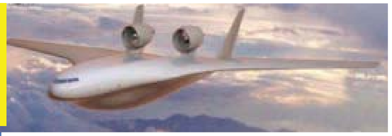
N+3 Advanced Vehicle Concept Studies Summary

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

Technology 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

Boeing, GE, GA Tech



NG, RR, Tufts, Sensis, Spirit

GE, Cessna, GA Tech

MIT, Aurora, P&W, Aerodyne

NASA, VA Tech, GT

NASA

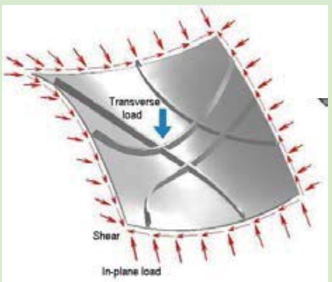
Advances required on multiple fronts…

Fixed Wing Project Research Themes

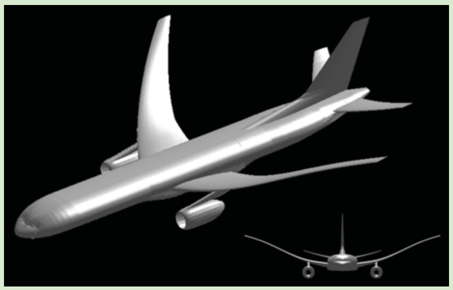
Based on Goal-Driven Advanced Concept Studies

Goals Metrics (N+3)	**Noise**	**Emissions (LTO)**	**Emissions (cruise)**	**Energy Consumption**
	Stage 4 – 52 dB cum	CAEP6 – 80%	2005 best – 80%	2005 best – 60%

Goal-Driven Advanced Concepts (N+3)

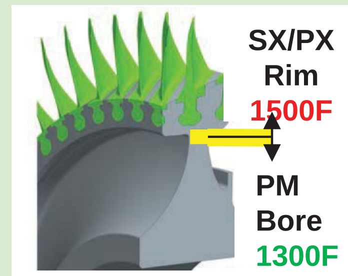


1. Lighter-Weight Lower Drag Fuselage

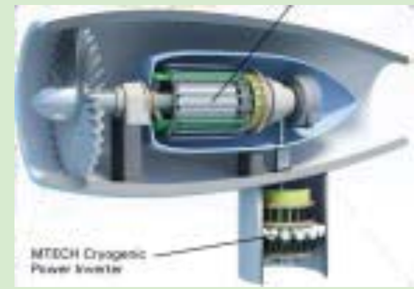


2. Higher Aspect Ratio Optimal Wing

3. Quieter Low-Speed Performance

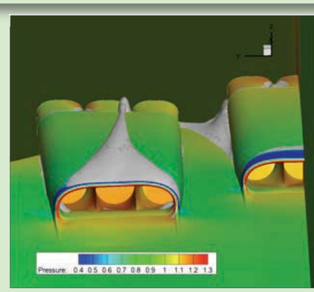


4. Cleaner, Compact Higher BPR Propulsion

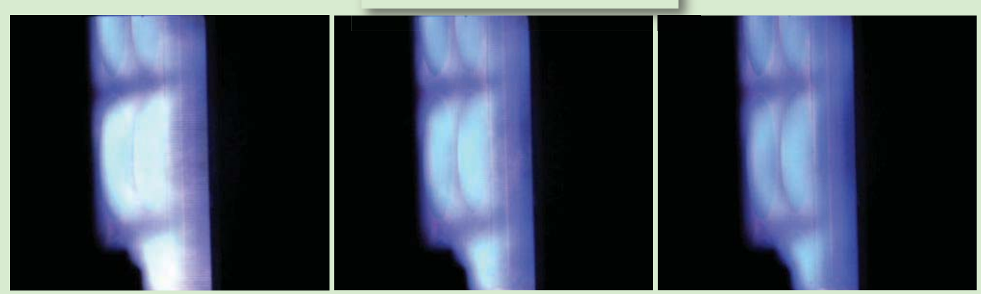


5. Hybrid Gas-Electric Propulsion

6. Unconventional Propulsion Airframe Integration



7. Alternative Fuel Emissions



Research Themes with Investments in both Near-Term Tech Challenges and Long-Term (2030) Vision

Higher Aspect Ratio Optimal Wing

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

Tailored Load Path Structure

- Passive aeroelastic tailored structures

Active Structural Control

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

Aerodynamic Shaping

- Low interference external bracing
- Passive wave drag reduction concepts

Active Flow Control

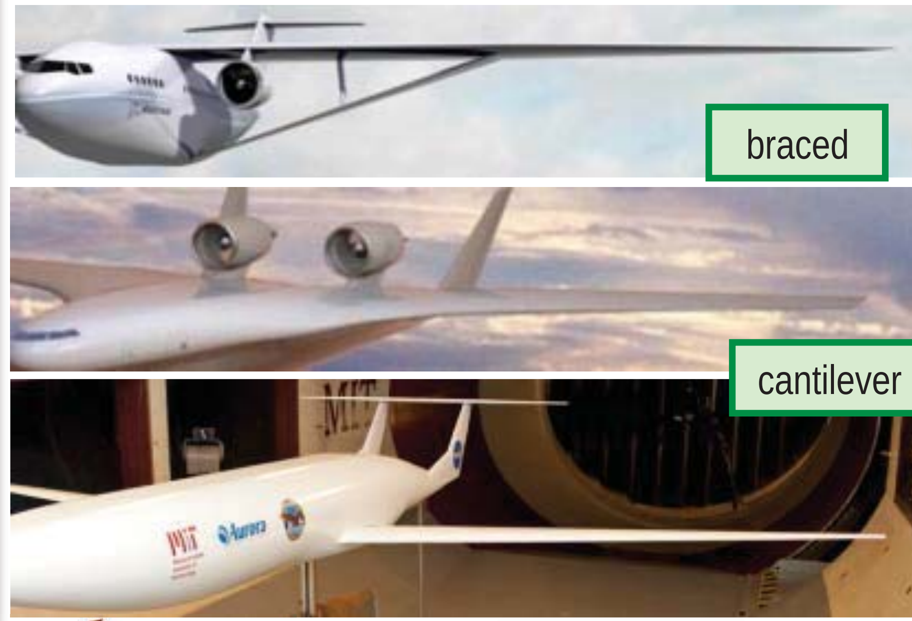
- Transonic drag reduction; mechanically simple high-lift

Adaptive Aeroelastic Shape Control

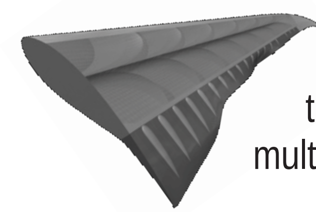
- Continuous control effector(s) for mission-adaptive optimization

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



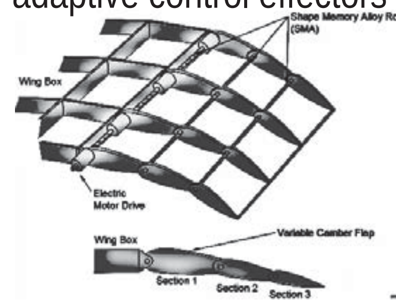
active controls
load alleviation

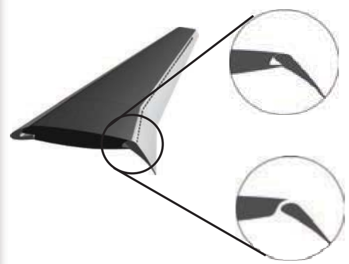


tailored
multifunctional

passive/active
advanced aerodynamics

adaptive control effectors





AFC-based high-lift concepts

Truss-Braced Wing: Wing Weight Uncertainty

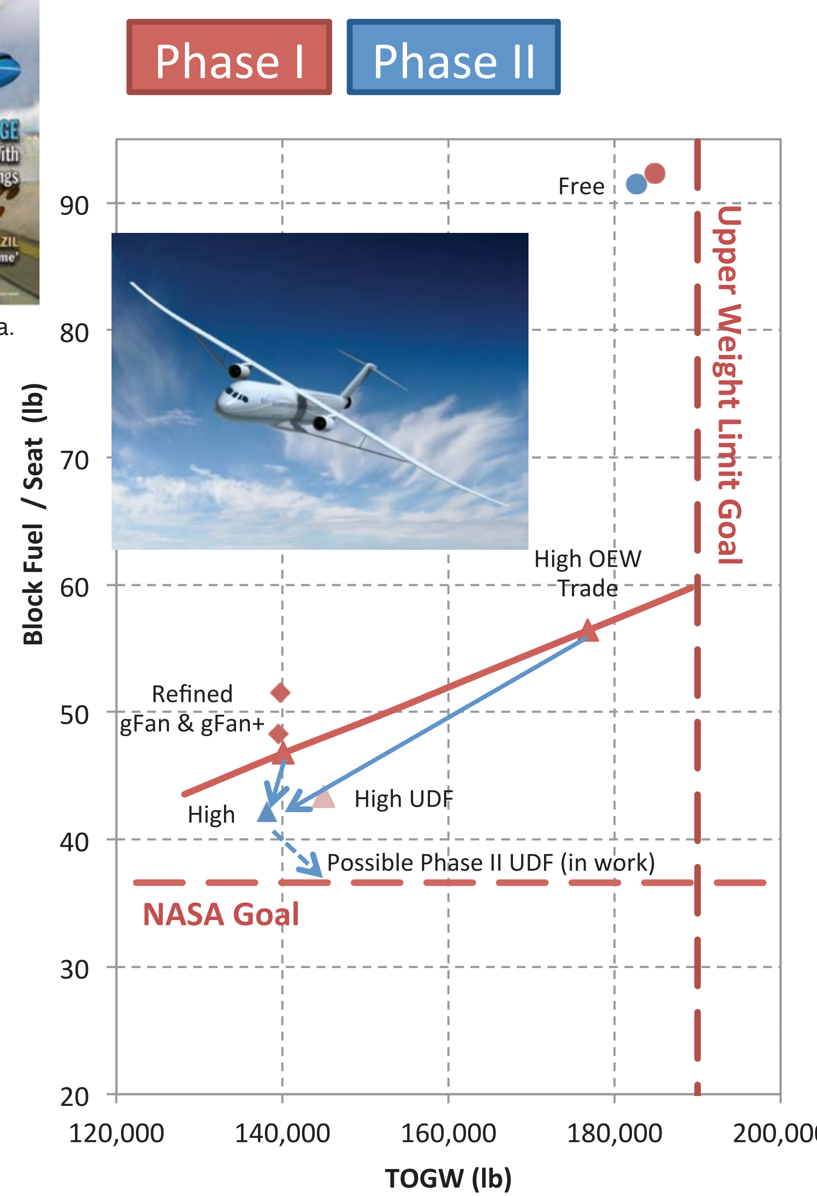
(Boeing SUGAR N+3 Phase 2 NRA)

Objective

Refine the SUGAR High configuration and reduce the uncertainty in estimates of the potential benefits of TBW technology with specific focus on reducing wing weight uncertainty

Approach

Create a detailed finite element model (FEM) of SUGAR High configuration to provide a higher fidelity weight estimate of the concept and validate the FEM via a transonic aeroservoelastic test in the LaRC/Transonic Dynamics Tunnel (TDT)



Status

- FEM completed to provide the desired higher fidelity wing weight estimates. 1) SUGAR High fuel burn significantly improves, 2) SUGAR High fuel burn over Refined SUGAR gets better, and 3) Unducted fan variant of SUGAR High may approach the N+3 goal
- Wind tunnel testing of 15% scale model completed. Flutter boundaries identified with successful demonstration of flutter suppression for this model. Additional new control laws were also tested at more aggressive conditions

POCs: Marty Bradley (Boeing), Erik Olson (LaRC)

Truss-Braced Wing: Testing

(Boeing SUGAR N+3 Phase 2 NRA)

POCs: Marty Bradley (Boeing), Erik Olson (LaRC)

Cleaner, Compact, Higher Bypass Ratio Propulsion
Low NOx, Fuel Flexible Combustors

Objective

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

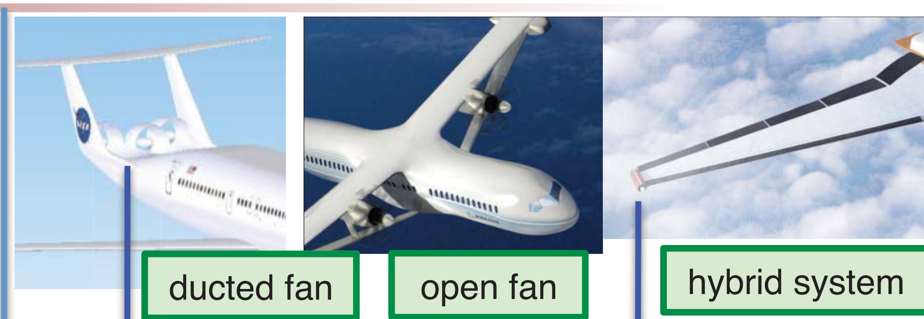
Technical Areas and Approaches

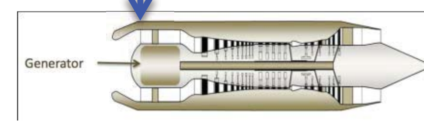
Fuel-Flexible Combustion

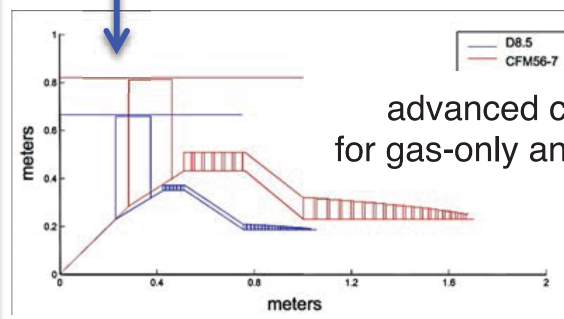
– Injection, mixing, stability

Benefit/Pay-off

– Low 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 for gas-only and hybrid gas-electric architectures
– Compatible with ducted or unducted propulsors

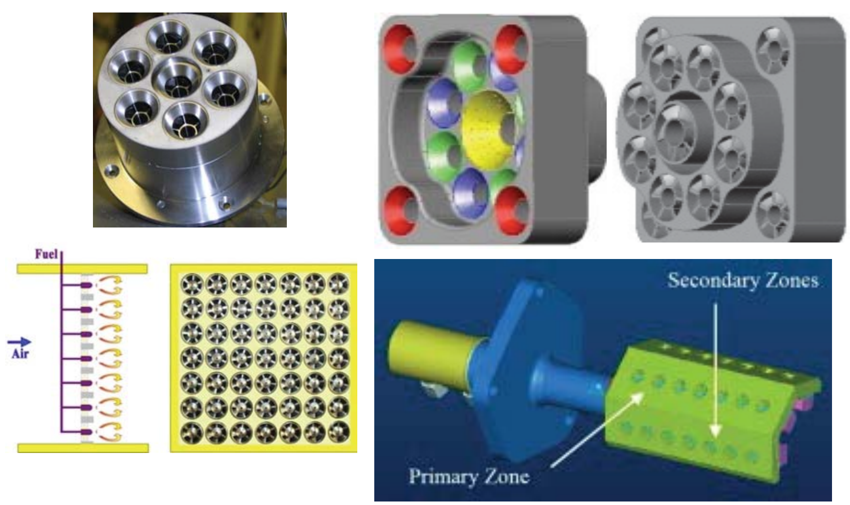






advanced combustor required for gas-only and hybrid architectures

low emission flametube concepts



Cleaner, Compact, Higher Bypass Ratio Propulsion
Compact, High OPR Gas Generator

Objective

Explore and develop material, aerodynamic, and control technologies to enable compact gas-turbine generators with high thermal efficiency to directly reduce fuel consumption

Technical Areas and Approaches

Hot Section Materials

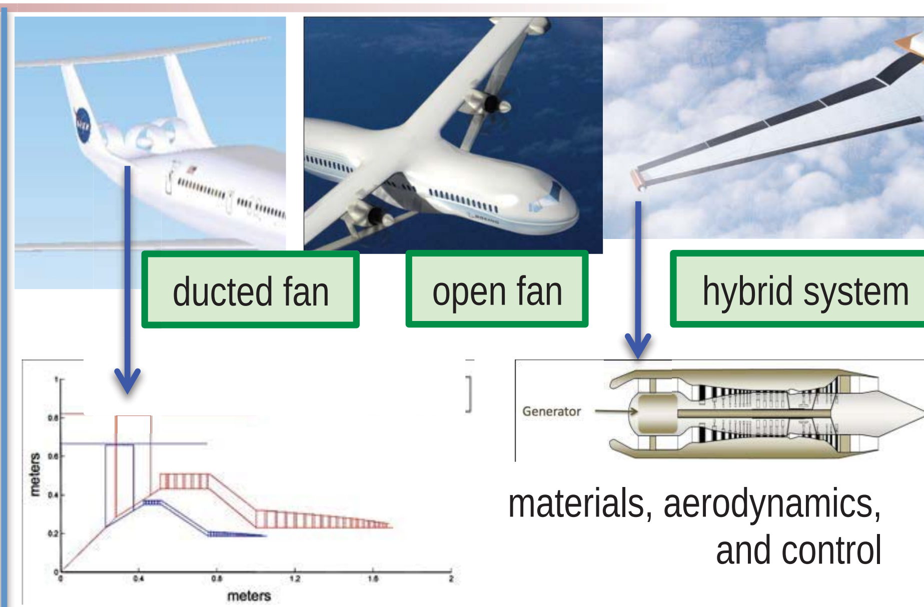
– 1500F disk & coatings
– 1500F capable non-contacting seal

Tip/Endwall Aerodynamics

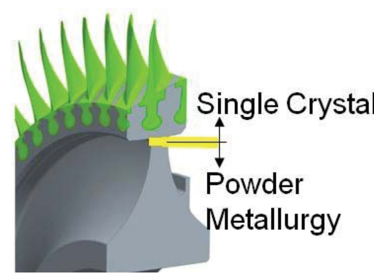
– Minimize losses due to short blades/vanes
– Minimize cooling/leakage losses

Benefit/Pay-off

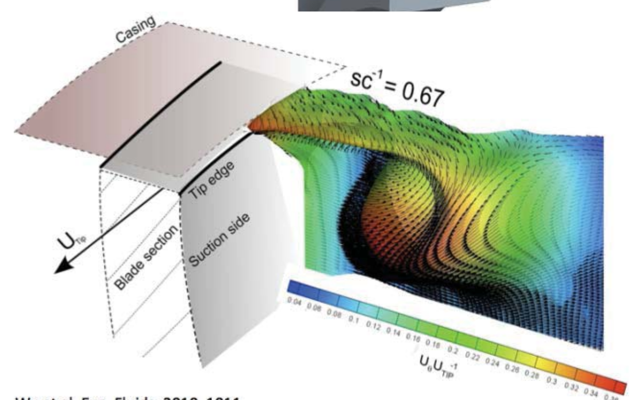
– Advanced compact gas-generator core architecture and component technologies enabling BPR 20+ growth by minimizing core size
– Thermally efficient, high OPR (50+) engines



materials, aerodynamics, and control



1500 F, bonded hybrid disk concept



Tip/endwall aerodynamic loss mitigation

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

Compressor Tip Clearance/Endwall Flow Research (Johns Hopkins U. & Purdue U.)

Objective

Gain physical insights into loss mechanisms associated with large compressor tip clearance gaps by experiments and simulations of loss mitigation concepts.

Approach

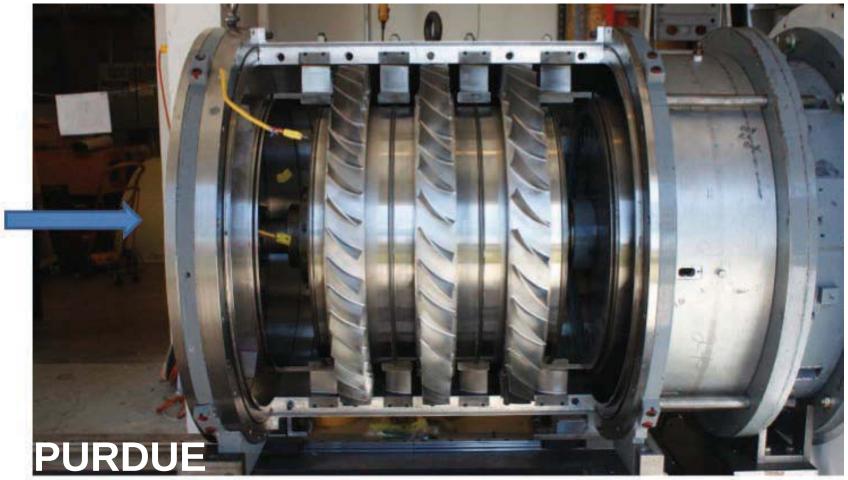
Obtain detailed data and CFD simulations for tight and increased tip clearance gaps to measure performance impact and loss mechanisms. Johns Hopkins University (JHU) rig made of acrylic operating in Sodium Iodide (NaI) mixture renders casing and blades optically transparent. This is a unique capability.

Status

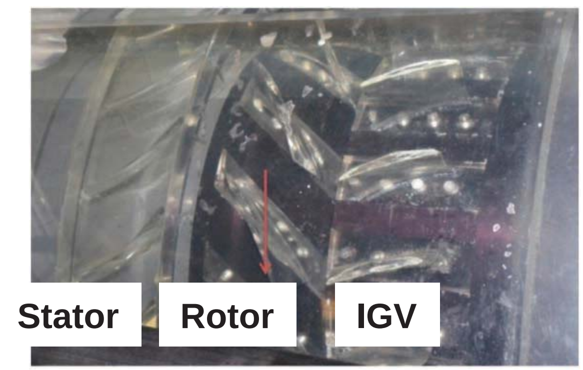
JHU: Obtaining unsteady 3-D tip clearance flow data at low speed compressor test rig. Tomographic PIV validated.

Purdue: Stall inception testing and compressor stability characterization completed. PIV measurement progressing well.

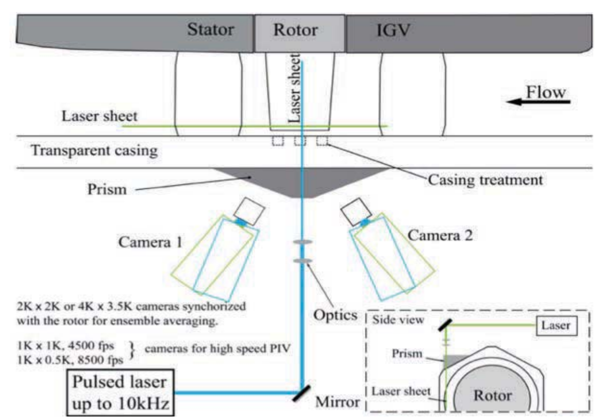
Research team: Prof. Nicole Key (Purdue), Mark Celestina (GRC), Prof. Joe Katz (JHU), Chunill Hah (GRC)



JHU (optically transparent)



3D PIV



Turbine Tip Clearance/Endwall Flow Research (Honeywell, Pratt & Whitney, Naval Academy)

Objective

Gain physics insight into large tip clearance gap leakage flow losses and hub seal cavity hot-gas re-ingestion to minimize loss and cooling flow requirements.

Approach

Obtain detailed data and CFD simulations with increasing tip clearance gaps and novel tip treatments to measure performance impact and loss mechanisms. Understand impact of seal cavity design parameters on minimizing hot gas re-ingestion and cooling requirements.

Status

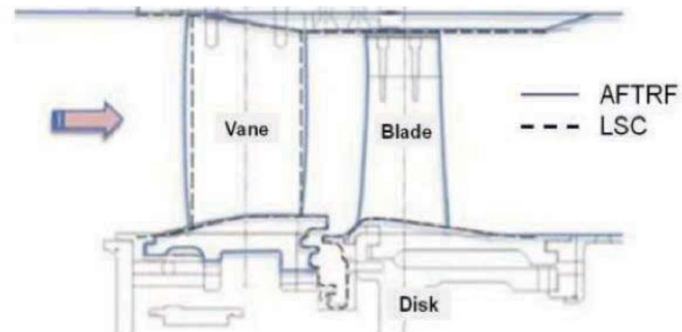
P&W: Testing at PSU in low-speed cascade facility underway. Axial Flow Turbine Rig will also be used for measuring blade exit relative total pressure.

USNA: Passive flow control to reduce tip leakage with winglets, with and without gaps, measured. Tip vortex reduced but losses not affected.

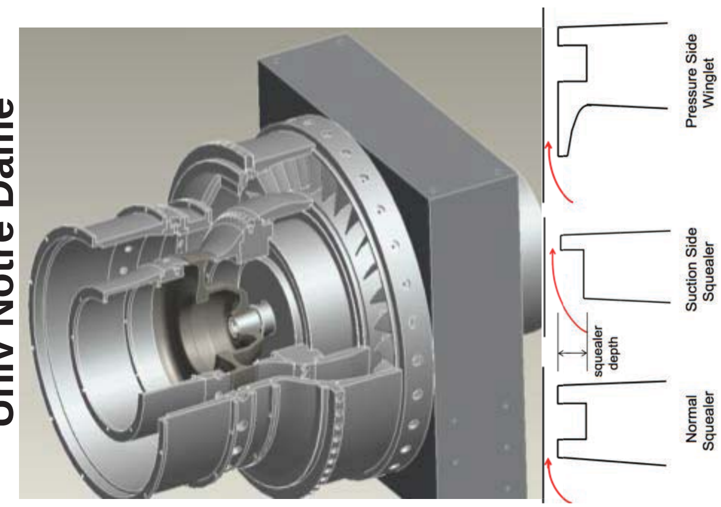
Honeywell: CFD simulations and test article fabrication completed. Testing at U of Notre Dame underway.

Research team: J. Christophel (P&W), Ashlie McVetta (GRC), M. Malak (Honeywell), Phil Poinsatte (GRC), R. Volino (Naval Academy), David Ashpis (GRC)

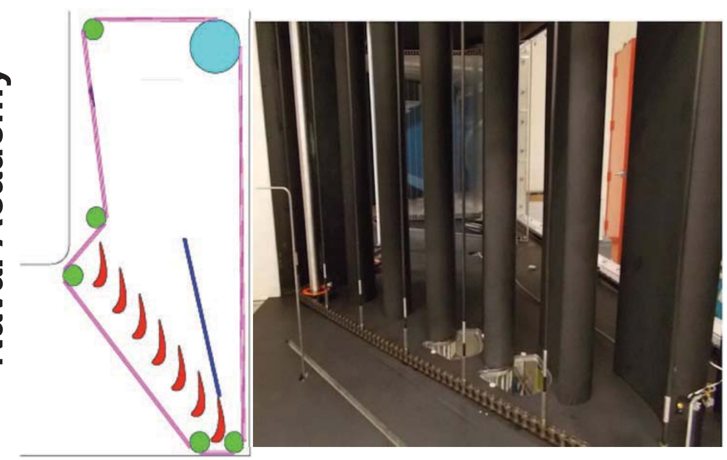
Pratt & Whitney
Penn State Univ



Honeywell
Univ Notre Dame



Naval Academy



Hybrid Gas-Electric Propulsion

Objective

Explore and develop electric system materials and increase the power density of an electric motor contributing to game-changing hybrid gas-electric propulsion

Technical Areas and Approaches:

Electric System Materials

- Low ac loss superconducting materials
- Multifunctional structures integrating power system

Electric Components

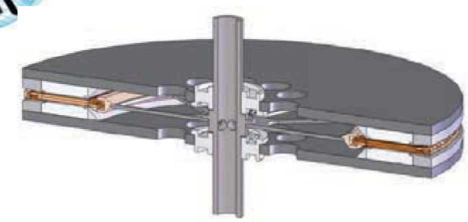
- High power density superconducting motor
- High power density non-cryogenic motor

Benefit/Pay-off:

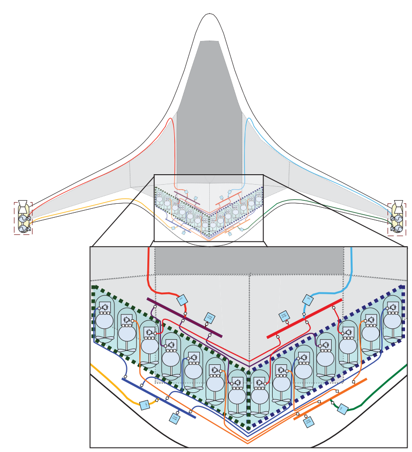
- Will help enable the paradigm shift from gas to hybrid gas-electric propulsion
- Hybrid gas-electric propulsion will help reduce energy consumption, emissions, and noise

Gas turbine-battery hybrid

Superconducting turboelectric distributed propulsion



High Power Density, Non-cryogenic Motor



Propulsion power grid architecture

Unconventional Propulsion Airframe Integration
Integrated BLI Systems

Objective

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

Technical Areas and Approaches

Aerodynamic Configuration

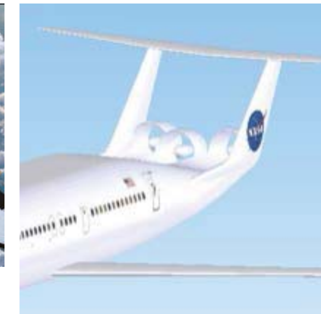
- Novel configurations and installations

Distortion-Tolerant Fan

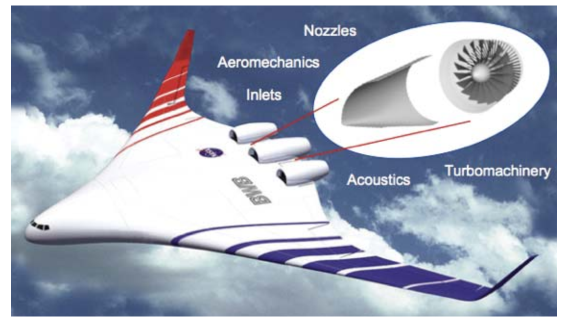
- Integrated inlet/fan design robust to unsteady and non-uniform inflow

Benefit/Pay-off

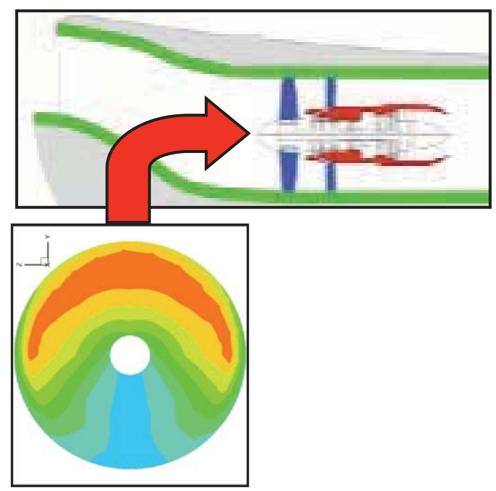
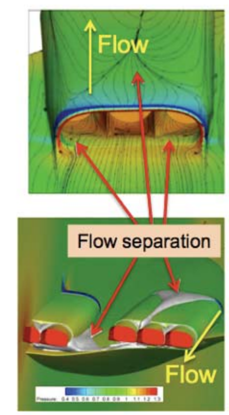
- Demonstrates a net system-level benefit for BLI propulsion system integration; applicable and beneficial to a variety of advanced vehicle concepts
- Distortion-tolerant fan technology and acoustics characterization relevant to near-term, conventional short-duct installations

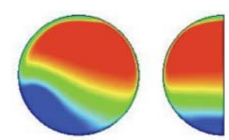



boundary-layer ingestion for drag reduction



distortion tolerance required for net vehicle system benefit



MIT D8 Model Test in the 14x22 SWT

Objective
Experimentally assess the benefits of boundary layer ingestion (BLI) for the D8 configuration.

Approach
Obtain experimental data at simulated cruise conditions for the podded and integrated configurations and conduct complementary numerical simulations.

Status

- Collected force and moment data, rake surveys of the engine inlet and exit, surface pressures, and surface tuft visualization. Results indicate a 20-25 drag count reduction for the integrated configuration relative to the podded configuration. This translates to an electrical power savings on the fans of about 5-8%.

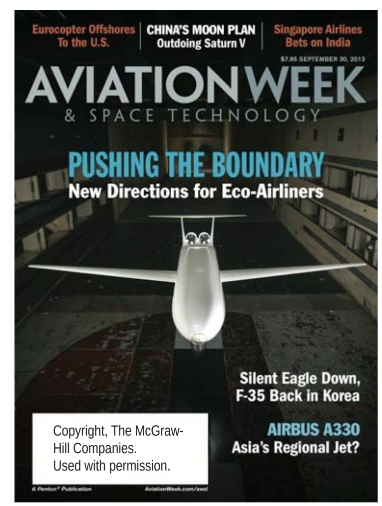
- Results are aligned with design assumptions of D8 configuration.

Research Team: MIT/PW/Aurora Team; Greg Gatlin (LaRC) Shishir Pandya (ARC)

Direct comparison of podded and integrated configurations

Aviation Week Article

September 30, 2013



Alternative Fuel Emissions at Cruise

Objectives

Explore the potential of alternative fuels to reduce the impact of aviation on air quality and climate, and their impact on performance

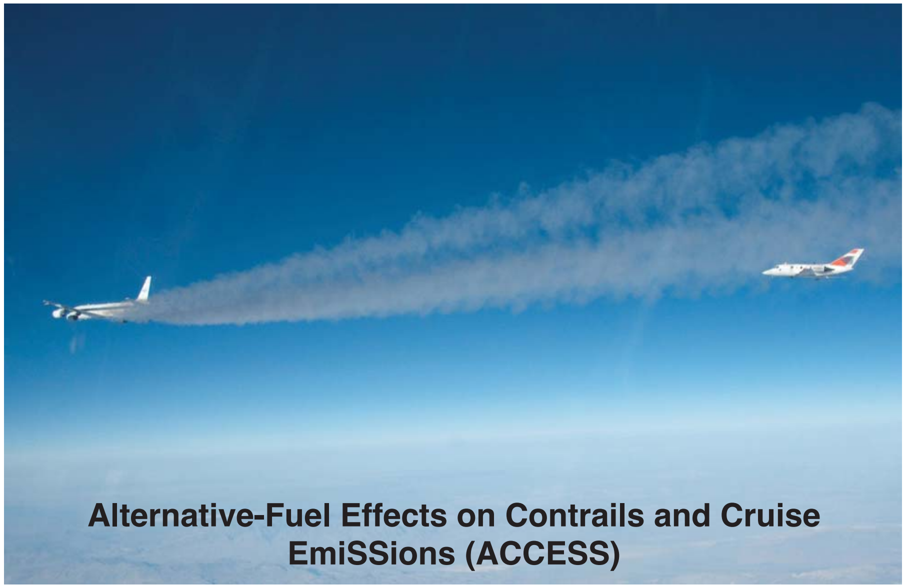
Technical Areas & Approaches

Emission & Performance Characterization

- Flight tests
- Ground tests
- Laboratory tests

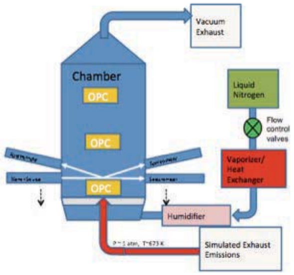
Benefit/Pay-off

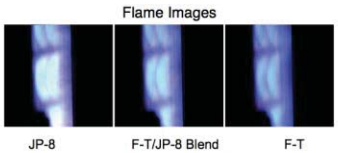
- Will dramatically reduce the impact of aviation on the environment (gaseous, particulates, and contrails)
- Will support standard-setting organizations by providing important and timely data



leverage ground tests from prior years

lab studies





ACCESS Flight Tests

ACCESS 2 flight test campaign on-going (May 5-30, 2014)

- Establish effects of alternative fuels on engine emissions and thrust at cruise and examine the impact of aerosols on contrail formation
- In partnership with DLR (Germany), NRC (Canada), FAA (USA)

Team Leads: Brian Beaton (Integ. Mgr, LaRC); POCs: Bruce Anderson (LaRC); Dan Bulzan (GRC); Gary Martin (DFRC)

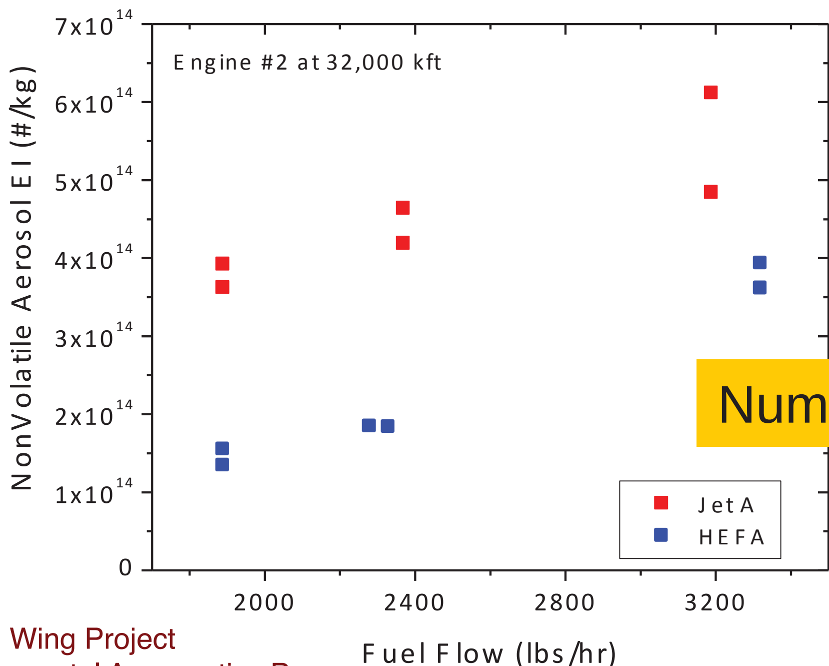

NASA
N525NA

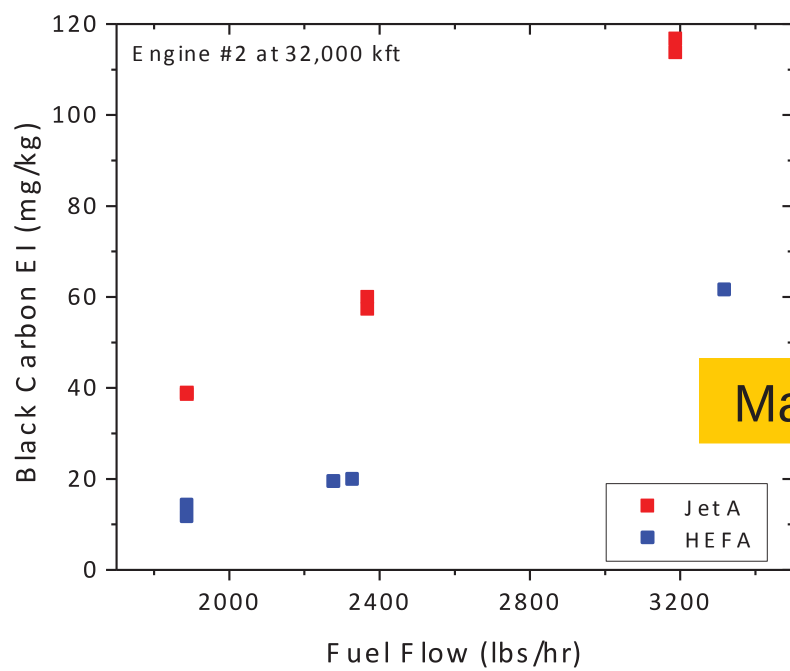
ACCESS: Multi-Platform, Multi-Fuels Sampling

Test	JP-8	JP-8 Hi S	Blend
Sulfur (ppm)	<10 ppm	1000 ppm	<5 ppm
Aromatics (%vol)	18	18	9
Density (kg/L)	0.81	0.81	0.79
End Point (degC)	275	275	279

Preliminary Results from ACCESS II Flight Campaign

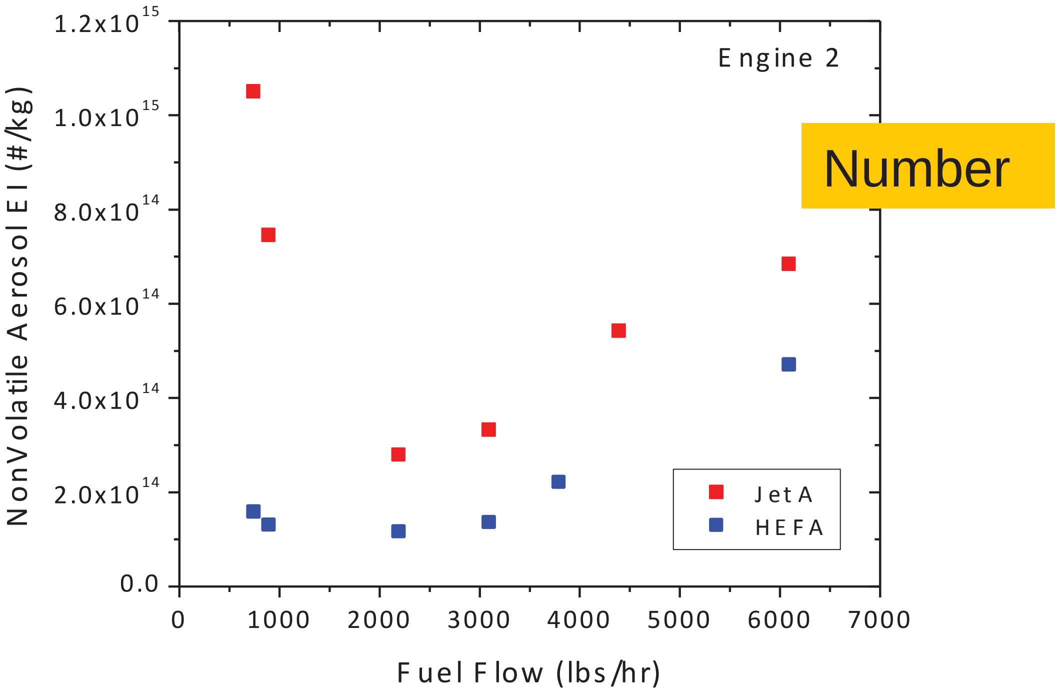
HEFA Blend Reduces Black Carbon Number and Mass Emissions by 30 to 60% at Cruise

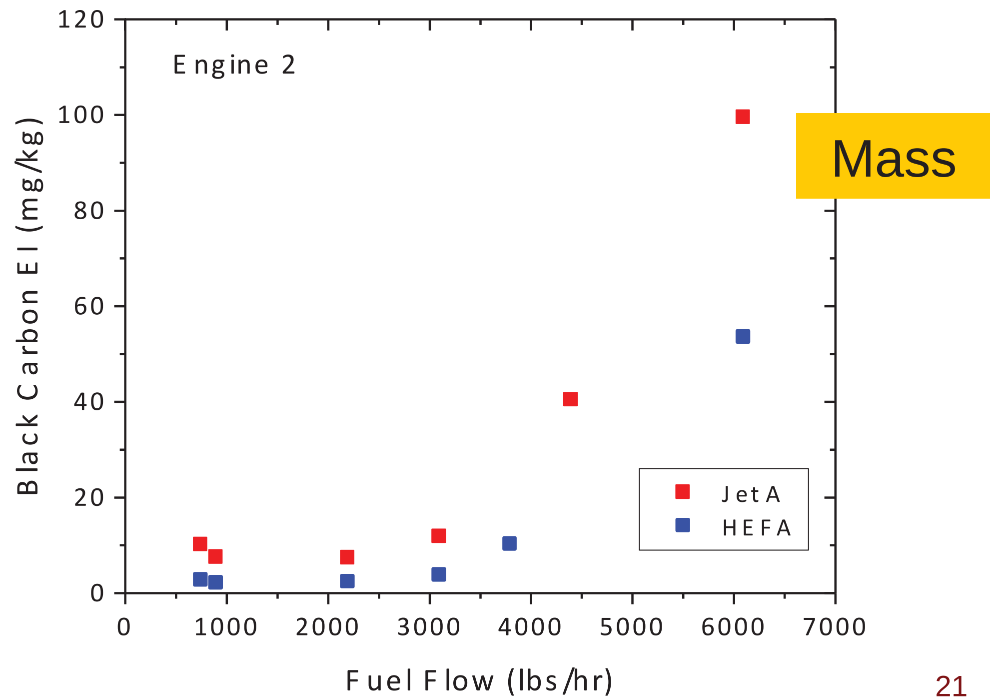




Preliminary Results from ACCESS II Ground Emissions Test

HEFA Blend Reduces Black Carbon Number and Mass Emissions by 30 to 80% during Ground Ops





Concluding Remarks

- Addressing the 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

Technologies, Concepts, and Knowledge

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