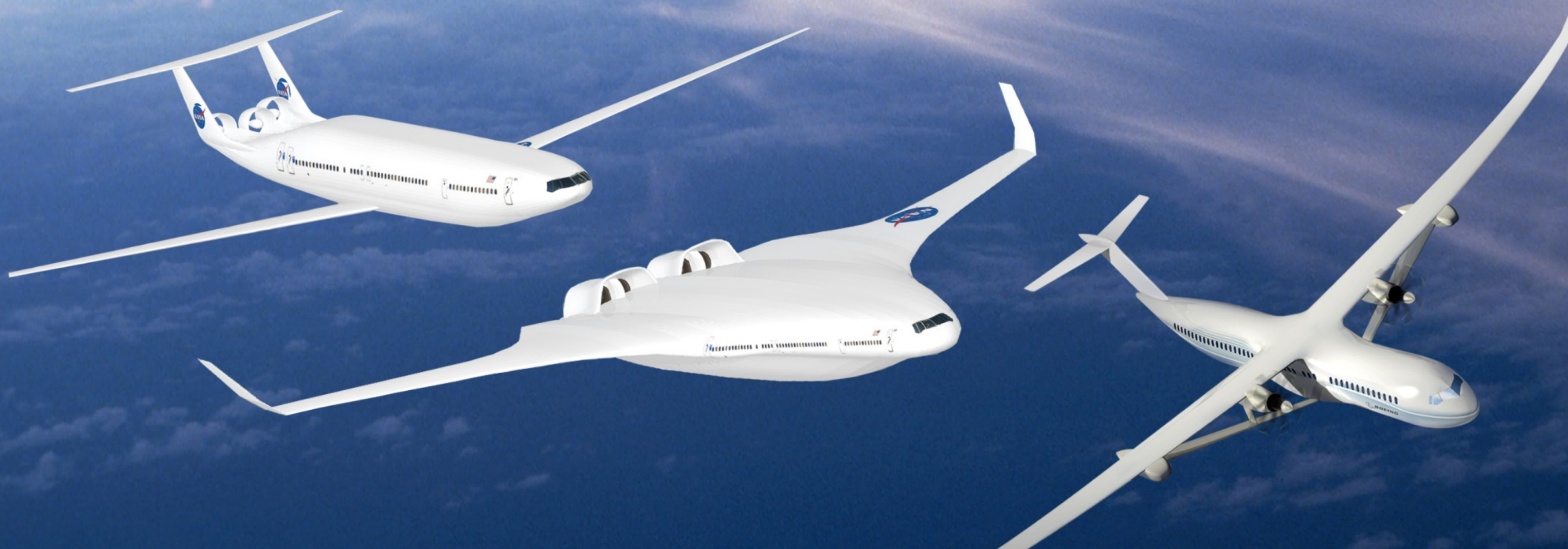
National Aeronautics and Space Administration

NASA Fixed Wing Project:
Green Technologies for Future Aircraft Generations

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



Progress Towards N+3 Technologies in NASA's Fixed Wing Project
AIAA SciTech 2014
January 12-17, 2014
National Harbor, MD

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

‡ CO2 emission benefits dependent on life-cycle CO2e 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)

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…

Fixed Wing Project Research Themes

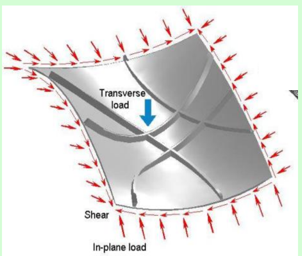
Based on Goal-Driven Advanced Concept Studies

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

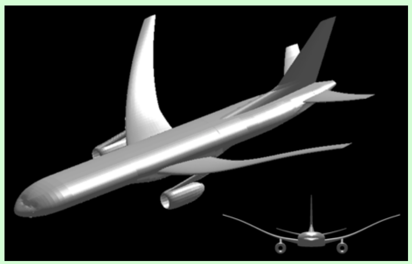
Goal-Driven Advanced Concepts (N+3)





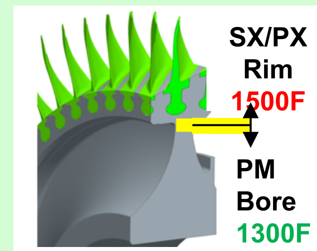


1. Lighter-Weight Lower Drag Fuselage

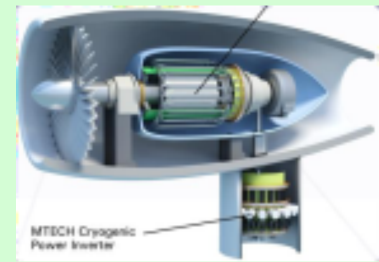


2. Higher Aspect Ratio Optimal Wing

3. Quieter Low-Speed Performance

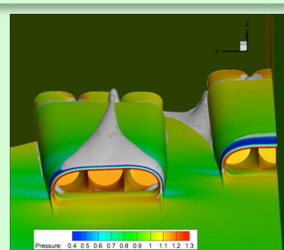


4. Cleaner, Compact Higher BPR Propulsion

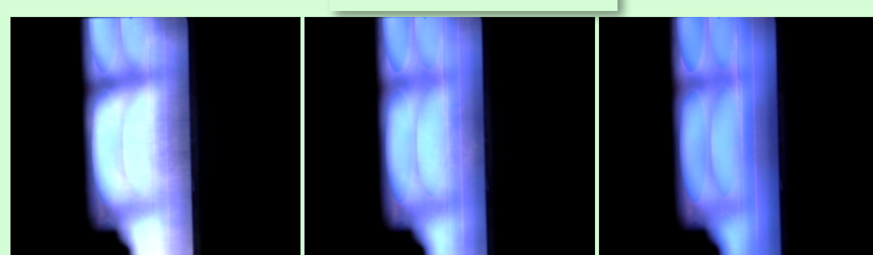


5. Hybrid Gas-Electric Propulsion

6. Unconventional Propulsion Airframe Integration



7. Alternative Fuel Emissions



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

Lighter-Weight, Lower-Drag Fuselage

Objective

Explore and develop structural technology concepts enabled by emerging advanced manufacturing capability to directly reduce aircraft operating empty weight

Technical Areas and Approaches

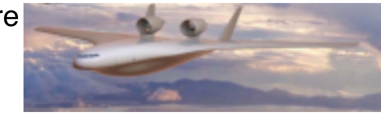
Tailored Load Path Structure

- Curvilinear, metallic stiffeners
- Tow-steered carbon fiber

Benefit/Pay-off

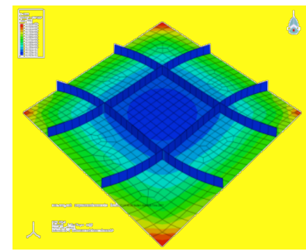
- 15% fuselage structural weight reduction relative to conventional composite structure
- Validated design methodology can be applied immediately and will be applicable to future designer materials for greater benefit

large structure
large area

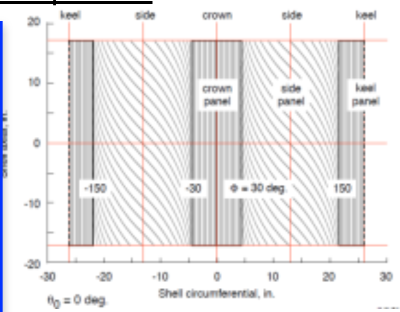


conventional and unconventional

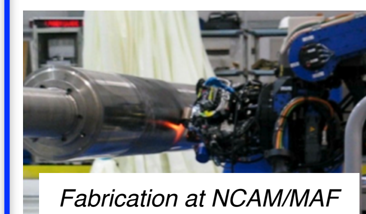
metallic and composites



Design

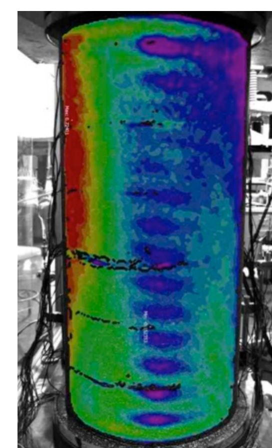


Build



Fabrication at NCAM/MAF

Test



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

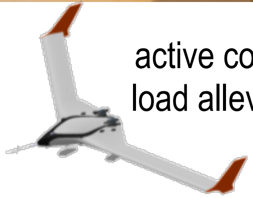
Aerodynamic Shaping
- Low interference external bracing
- Passive wave drag reduction concepts

Active Flow Control
- Transonic drag reduction; mechanically simple high-lift

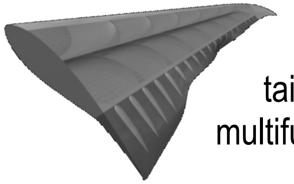
Adaptive Aeroelastic Shape Control
- Continuous control effector(s) for mission-adaptive optimization

Benefit/Pay-off

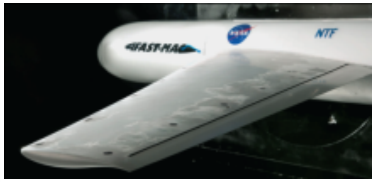
- 20% wing structural weight reduction
- Wave drag benefits tradable for weight or other parameters
- Concepts to control and exploit structural flexibility
- Optimal AR increase up to 50% for cantilever wings, 100% for braced wings



active controls
load alleviation

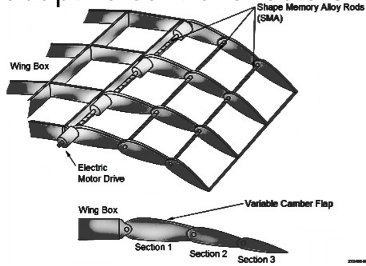


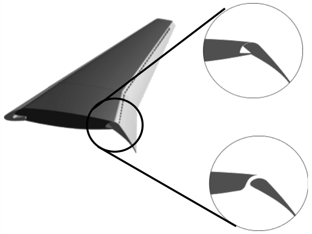
tailored
multifunctional



passive/active
advanced aerodynamics

adaptive control effectors





AFC-based high-lift concepts

TC2.1: Truss-Braced Wing: Wing Weight Uncertainty
(Boeing SUGAR N+3 Phase 2 NRA)

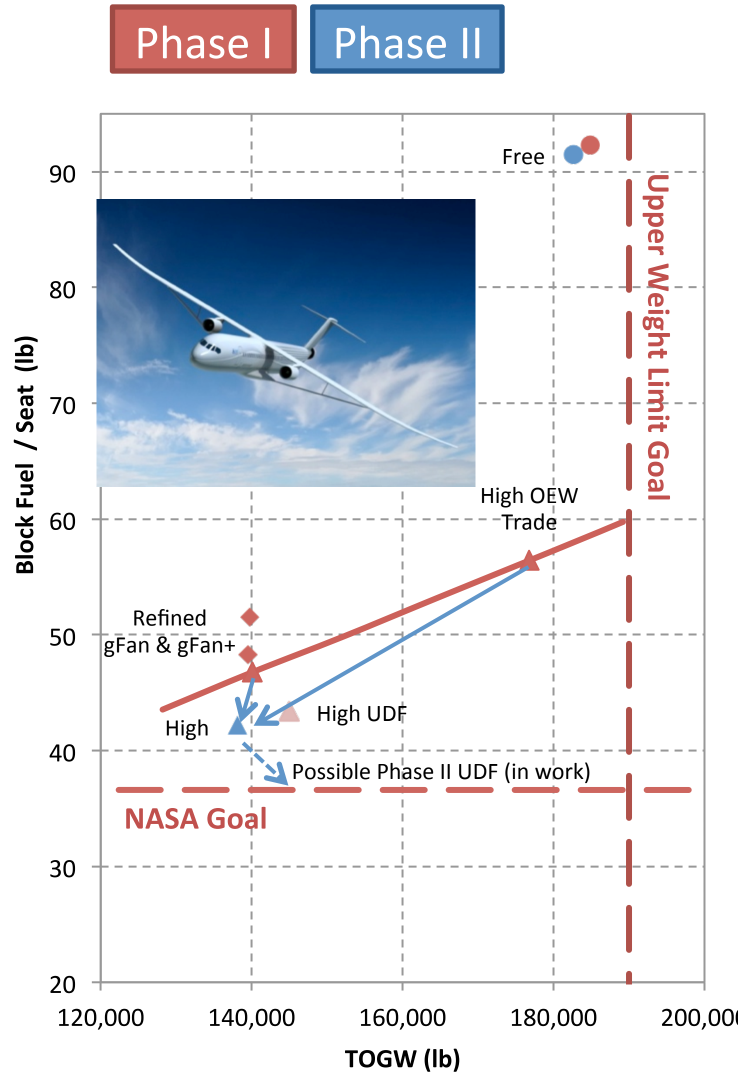
Problem
Conceptual design of Truss-Braced Wing (TBW) SUGAR High configuration during the N+3 phase 1 study showed that the TBW had significant potential to contribute to meeting NASA N+3 goals but also highlighted a significant uncertainty in the wing weight estimate.

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)

Results
FEM completed and provides the higher fidelity wing weight estimates desired. 1) SUGAR High fuel burn significantly improves, 2) SUGAR High fuel burn over Refined SUGAR gets better, and 3) an unducted fan variant of SUGAR High may approach the N+3 goal.

Significance
The TBW concept remains a viable, multidisciplinary concept to reduce transport aircraft energy consumption. The FEM provides the basis for a TDT test to validate the structural model and gives confidence to begin planning for a high-fidelity aerodynamic design/ analysis targeted at a low-interference truss integration.



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

Quieter Low-Speed Performance

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

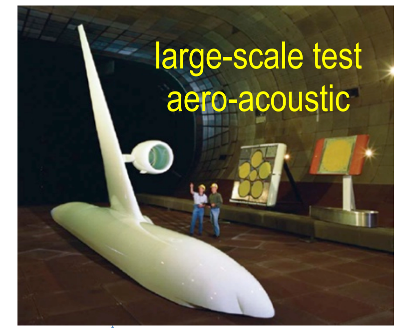
- Flap and slat noise reduction concepts
- Landing gear noise reduction concepts

Acoustic Liners and Duct Propagation

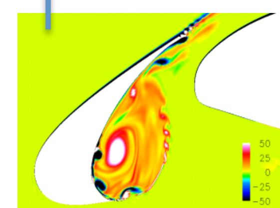
- Multi-degree-of-freedom, low-drag liners

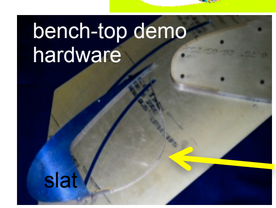
Benefit/Pay-off

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



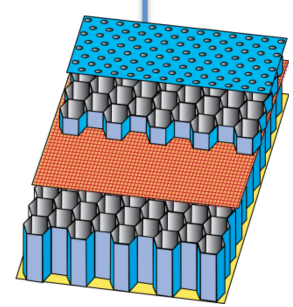
flap/slat noise reduction concepts





main element

cove filler assembly



two-layer liner concept

Test of Advanced MDOF Liner

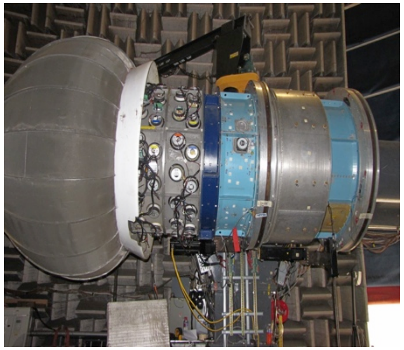
Objective
Develop design processes and liner technology implementations to address aft directed broadband noise.

Approach
A novel variable impedance and variable depth liner designed at LaRC and tested in GRC's Advanced Noise Control Fan (ANCF) rig. Liner manufactured by Hexcel Corporation. A conventional two-degrees of freedom liner served as the benchmark.

Results
Results indicate improved broadband performance for the variable impedance liner. Valuable insights have been gained for follow-on high-speed testing (TRL 5).

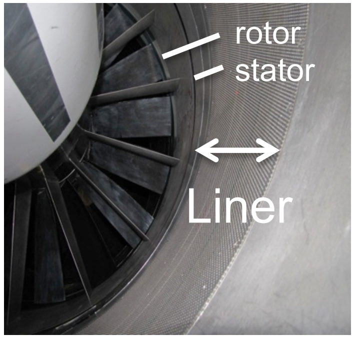
Significance
Increased confidence in design tools and the efficacy of the variable depth liner concept.

Research Team: Dan Sutliff (GRC), Michael Jones (LaRC), Douglas Nark (LaRC)

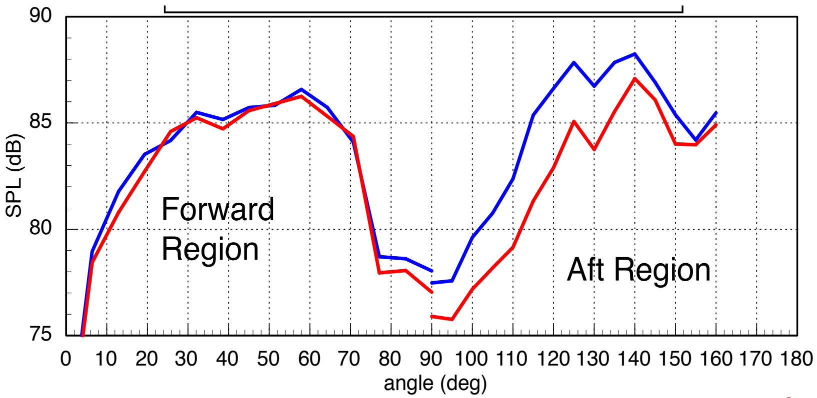


ANCF Rig with Advanced Multiple-Degrees of Freedom (MDOF) Aft-Duct Liner installed downstream of the stator.

Aft-Duct View



Preliminary Far-field Directivity Results
Broadband SPL (2.5 to 3.5 BPF)
Adv. MDOF Liner Follows Anticipated Trends in Aft Noise Reduction Compared To Hard-Wall



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

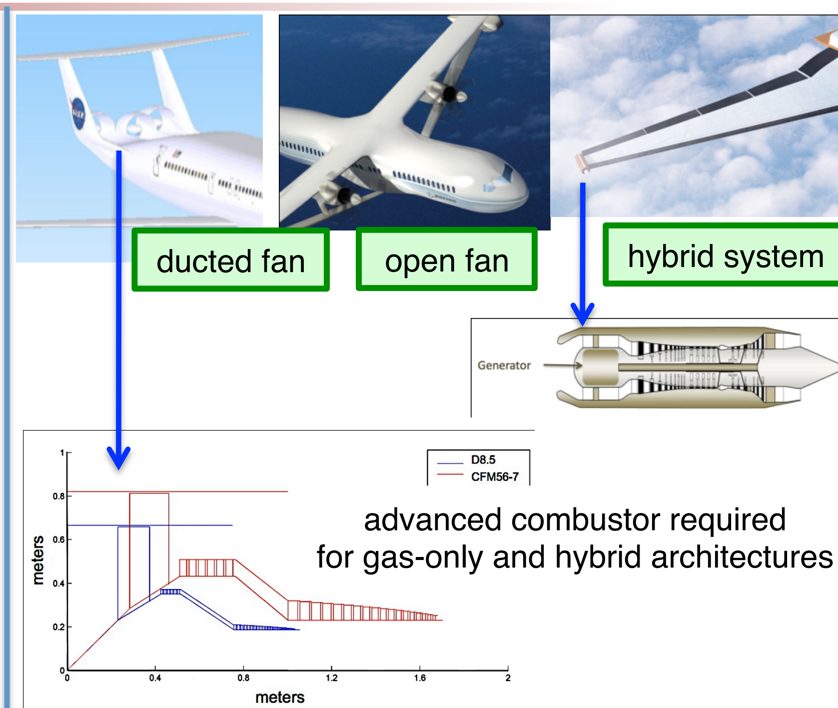
Technical Areas and Approaches

Fuel-Flexible Combustion

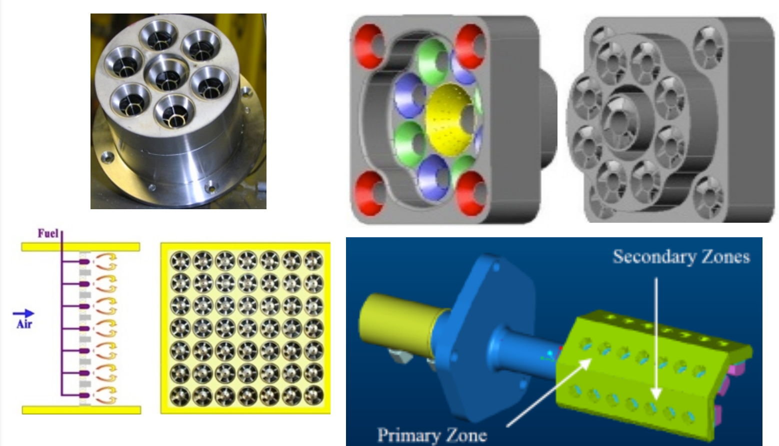
- Injection, mixing, stability

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



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

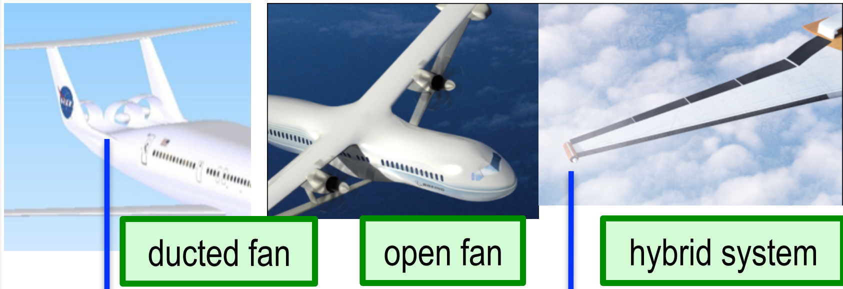
- 1500F disk & coatings
- 1500F capable non-contacting seal

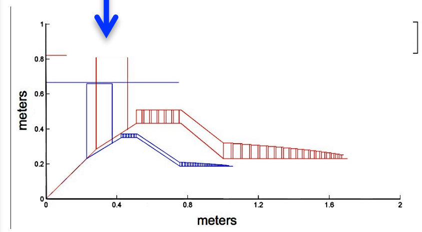
Tip/Endwall Aerodynamics

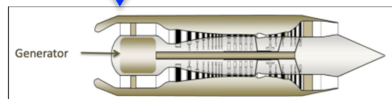
- Minimize losses due to short blades/vanes
- Minimize cooling/leakage losses

Benefit/Pay-off

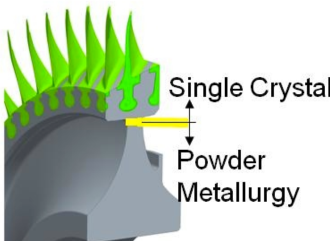
- Advanced compact gas-generator core architecture and component technologies enabling BPR 20+ growth by minimizing core size
- Thermally efficient, high OPR (50+) engines



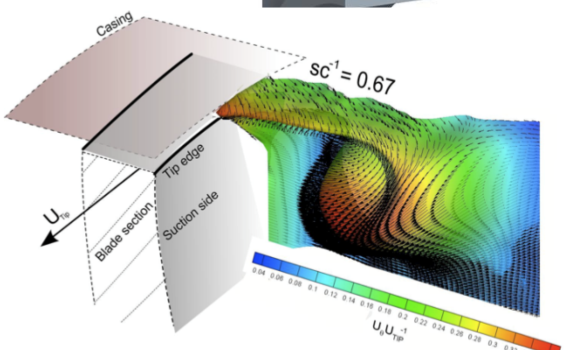




materials, aerodynamics, and control



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 to guide and test loss mitigation concepts.

Approach

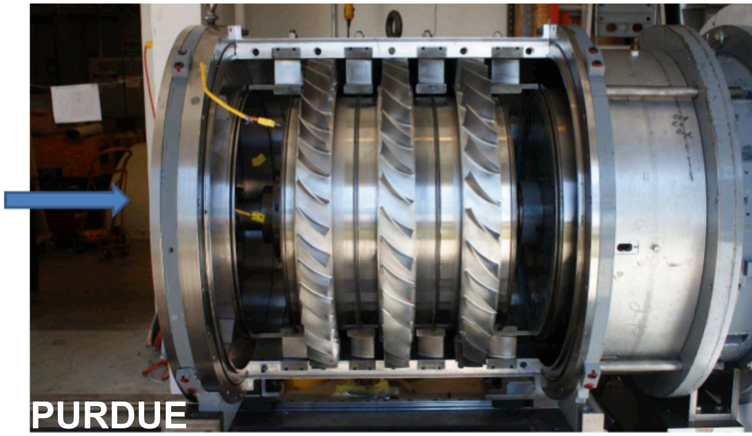
Obtain detailed data and CFD simulations for tight and increased tip clearance gaps to measure performance impact and loss mechanisms. Johns Hopkins University (JHU) rig made of acrylic operating in NaI mixture renders casing and blades optically transparent. This is a unique capability.

Results

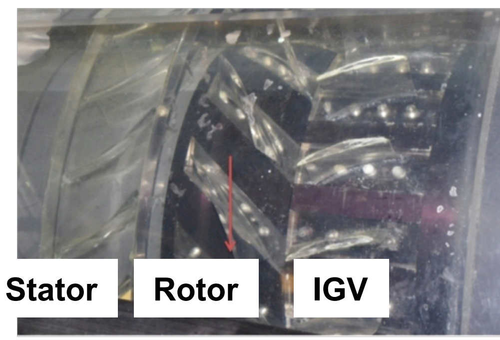
All hardware fabricated and installed. Data acquisition in progress.

Significance

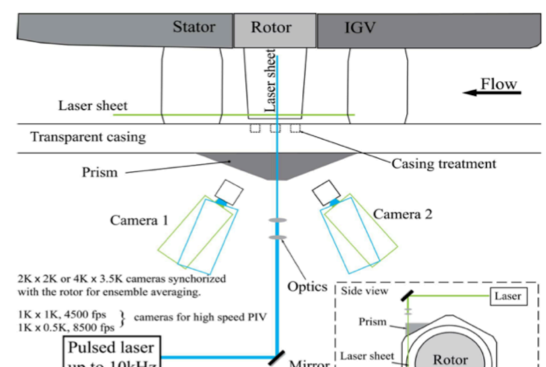
Mitigating tip clearance loss of aft stages of small high pressure compressor will enable higher bypass ratio fans and increased thermal efficiency.



JHU (optically transparent)



3D PIV



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

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

Objective

Gain physics insight of 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 for increasing tip clearance gaps and tip treatments to measure performance impact and loss mechanisms. Understand impact of seal cavity design parameters on minimizing hot gas reingestion and cooling requirements.

Results

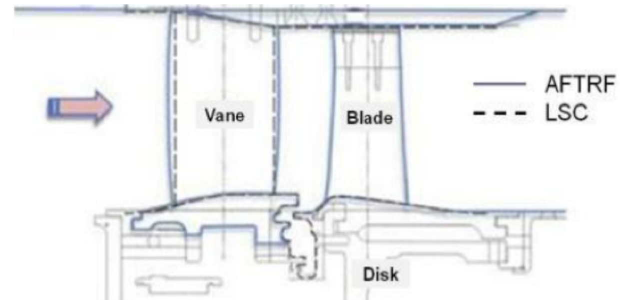
All hardware fabricated and installed. Data acquisition in progress.

Significance

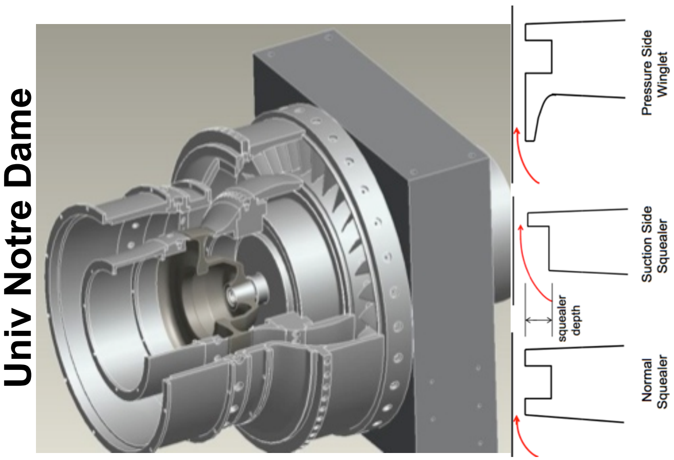
Mitigating tip clearance/endwall loss of smaller gas generator turbine stages will enable increased fan bypass ratio and improved thermal efficiency.

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

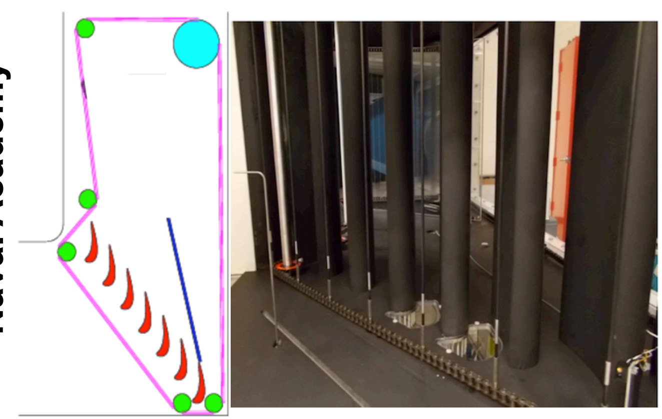
Pratt & Whitney
Penn State Univ



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

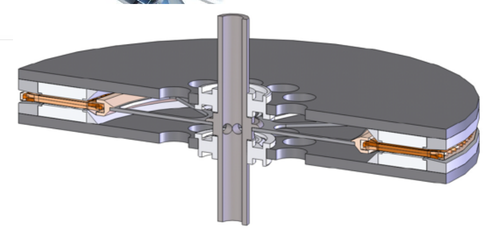
- High power density superconducting motor
- High power density non-cryogenic motor

Benefit/Pay-off:

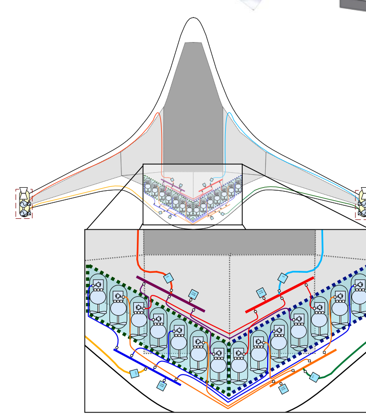
- Will help enable the paradigm shift from gas to hybrid gas-electric propulsion
- Hybrid gas-electric propulsion will help reduce energy consumption, emissions, and noise

Gas turbine-battery hybrid

Superconducting turboelectric distributed propulsion



High Power Density, Non-cryogenic Motor



Propulsion power grid architecture

High Fidelity Sizing Model for Superconducting Rotating Machines for Turboelectric Propulsion Design" (AML NRA)

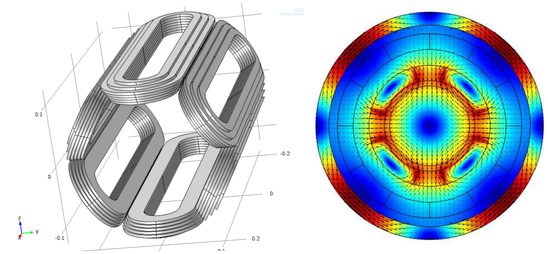
Objectives
- Accurate predictions of weights and efficiencies of superconducting machines
- Higher fidelity AC loss models for superconducting stators

Approach
- Replace current sheet field approximations with exact field calculations
- Develop AC loss models for combined pulsating and rotating magnetic fields
- With DoE, build new AC loss facility at CAPS/FSU to validate the loss models

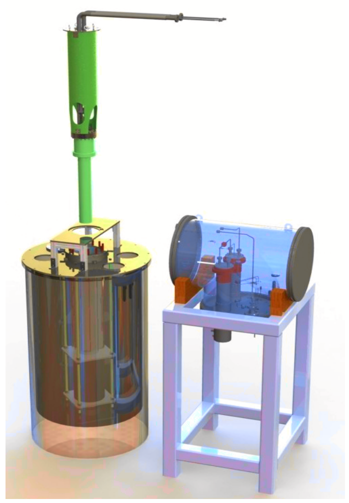
Results
New fully superconducting motor model developed incorporating AC losses from rotating fields, pulsating fields and transport current

Significance
Much greater confidence in the design of fully superconducting motors. New loss models and AC loss facility will guide future superconductor motor development

Research team: Gerald Brown (Lead) & Jeff Trudell (GRC); Advanced Magnet Lab (AML); Univ. of Houston (Partners)
Other Partners: Center for Advanced Power Systems (CAPS); Department of Energy (DoE); Florida State University (FSU)



MOTOR WINDINGS & FIELD CALCULATIONS



AC LOSS RIG (Jan. 2014 completion)

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

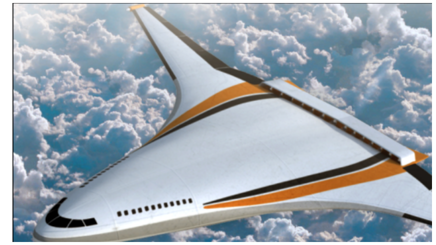
Propulsion Airframe Aeroacoustics

– Noise shielding of integrated installations

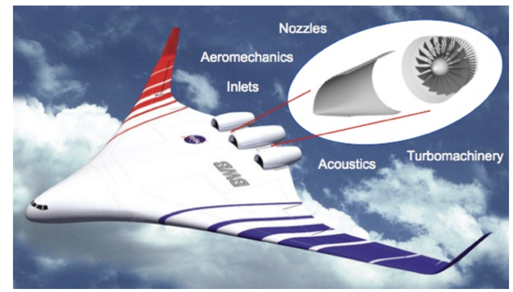
Benefit/Pay-off

– Demonstrates a net system-level benefit for BLI propulsion system integration; applicable and beneficial to a variety of advanced vehicle concepts

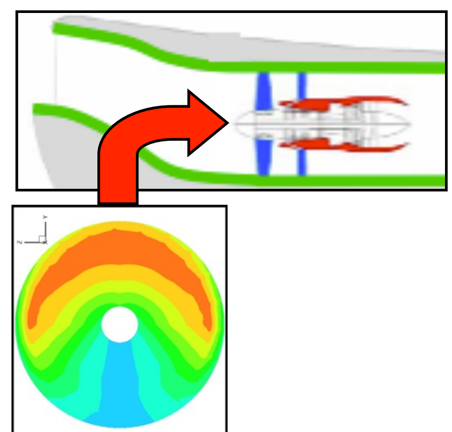
– Distortion-tolerant fan technology and acoustics characterization relevant to near-term, conventional short-duct installations

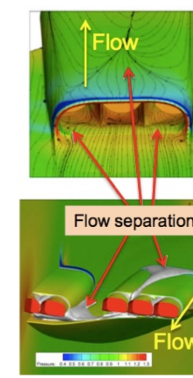


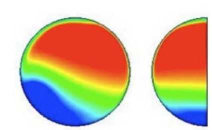
boundary-layer ingestion for drag reduction



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 complement that dataset with computational analysis.

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

Significance
Preliminary 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

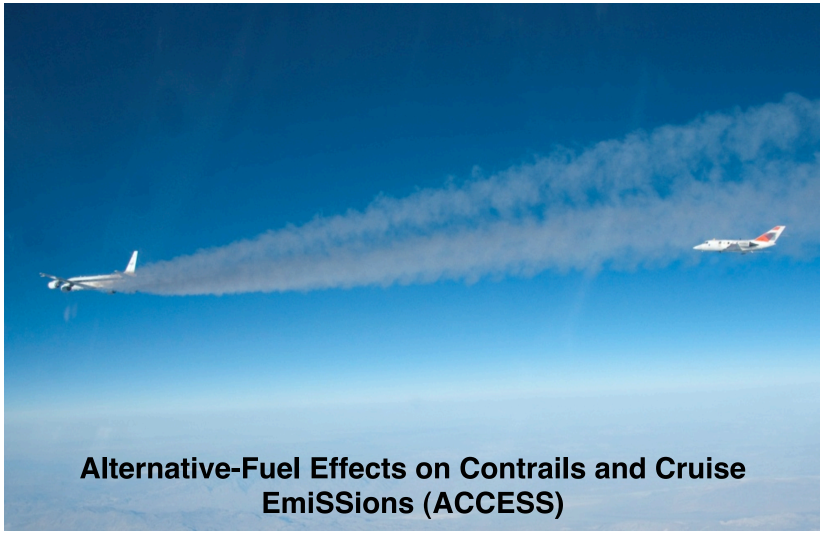
Technical Areas & Approaches

Emission & Performance Characterization

- Flight tests
- Ground tests
- Laboratory tests

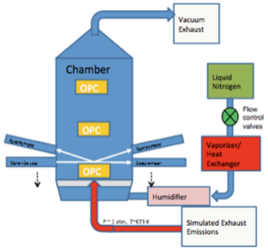
Benefit/Pay-off

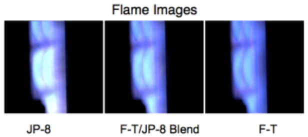
- Will dramatically reduce the impact of aviation on the environment (gaseous, particulates, and contrails)
- Will support standard-setting organizations by providing important and timely data



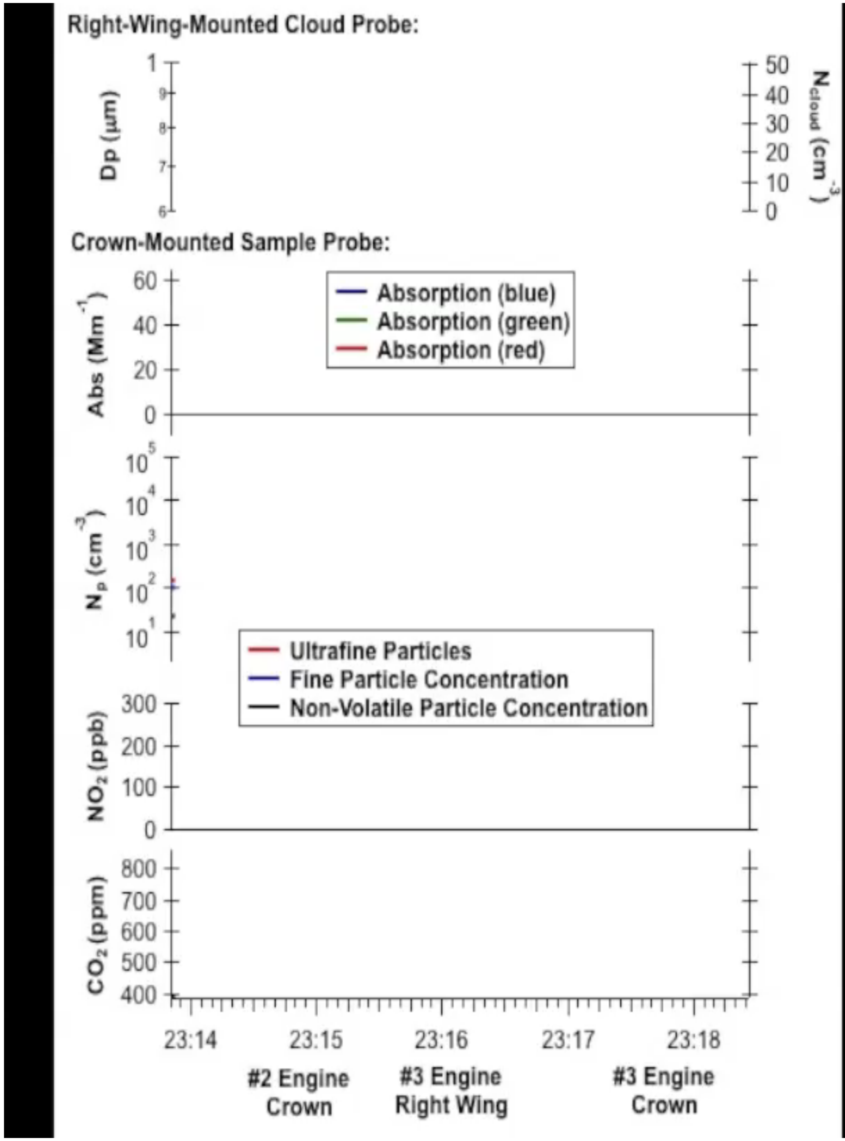
leverage ground tests from prior years

lab studies





ACCESS 1 Flight Test



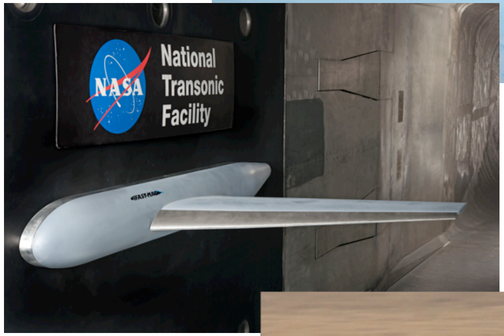
Team Leads: Brian Beaton (Integ. Mgr, LaRC); POCs: Bruce Anderson (LaRC); Dan Bulzan (GRC); Gary Martin (DFRC)

Major Fixed Wing Activities for FY2014

- Acquire **X-56A** flight vehicle from AF after shakedown flight tests and work on developing advanced and open (non-proprietary) control capability
- Conduct **ACCESS-2** flight tests using biofuels and International Partnership
- Conduct **FAST-MAC 2.5** NTF test
- Conduct **Truss-Braced Wing Aeroservoelastic Test** with Boeing at LaRC TDT
- Conduct additional **PAI/BLI Aerodynamic Tests** on MIT/D8 concept at LaRC 14x22
- Optimize passive aeroelastically-tailored CRM wing with AR 14
- Complete final design of **distortion-tolerant fan** for embedded engines and prepare for testing in GRC 8x6 tunnel in FY15
- Solicit and award next round of **NRA** awards

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

Electron Beam Freeform Fabrication: Changing the way we build airplanes