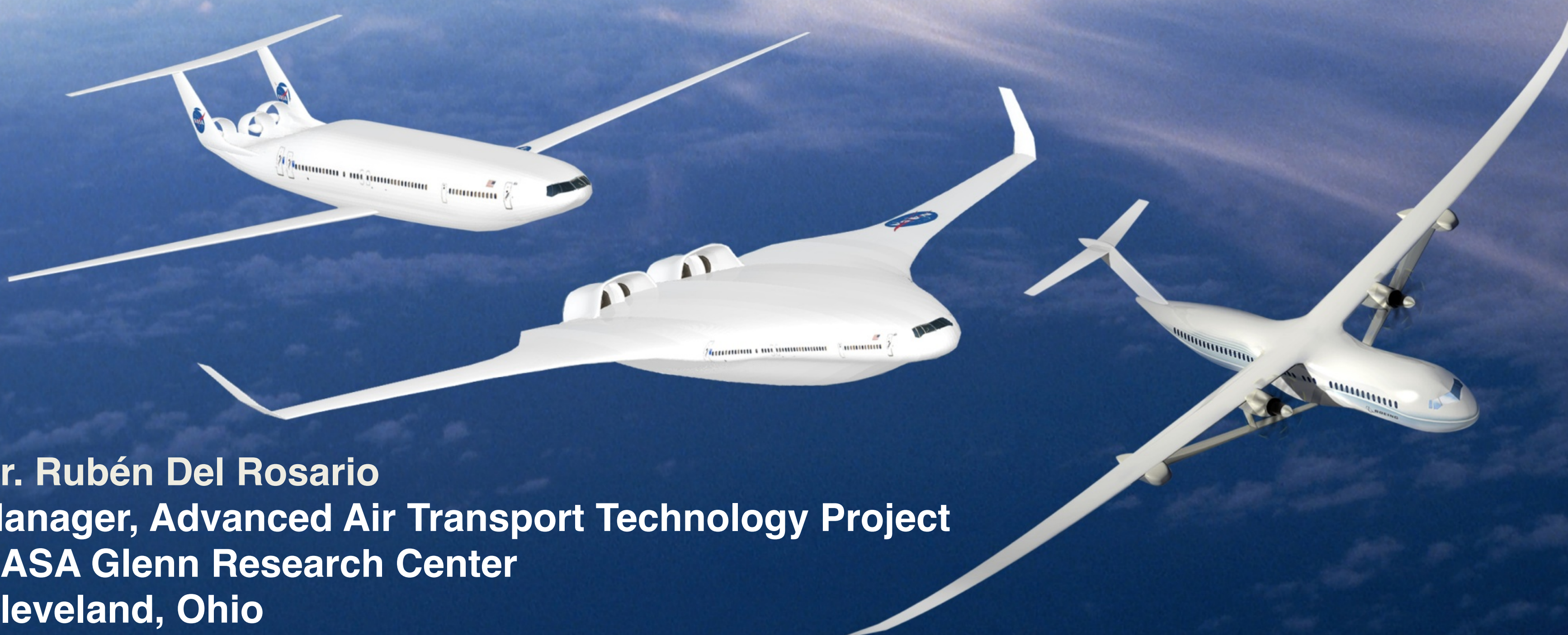
National Aeronautics and Space Administration

NASA Aeronautics
Advanced Air Transport Technology (AATT)



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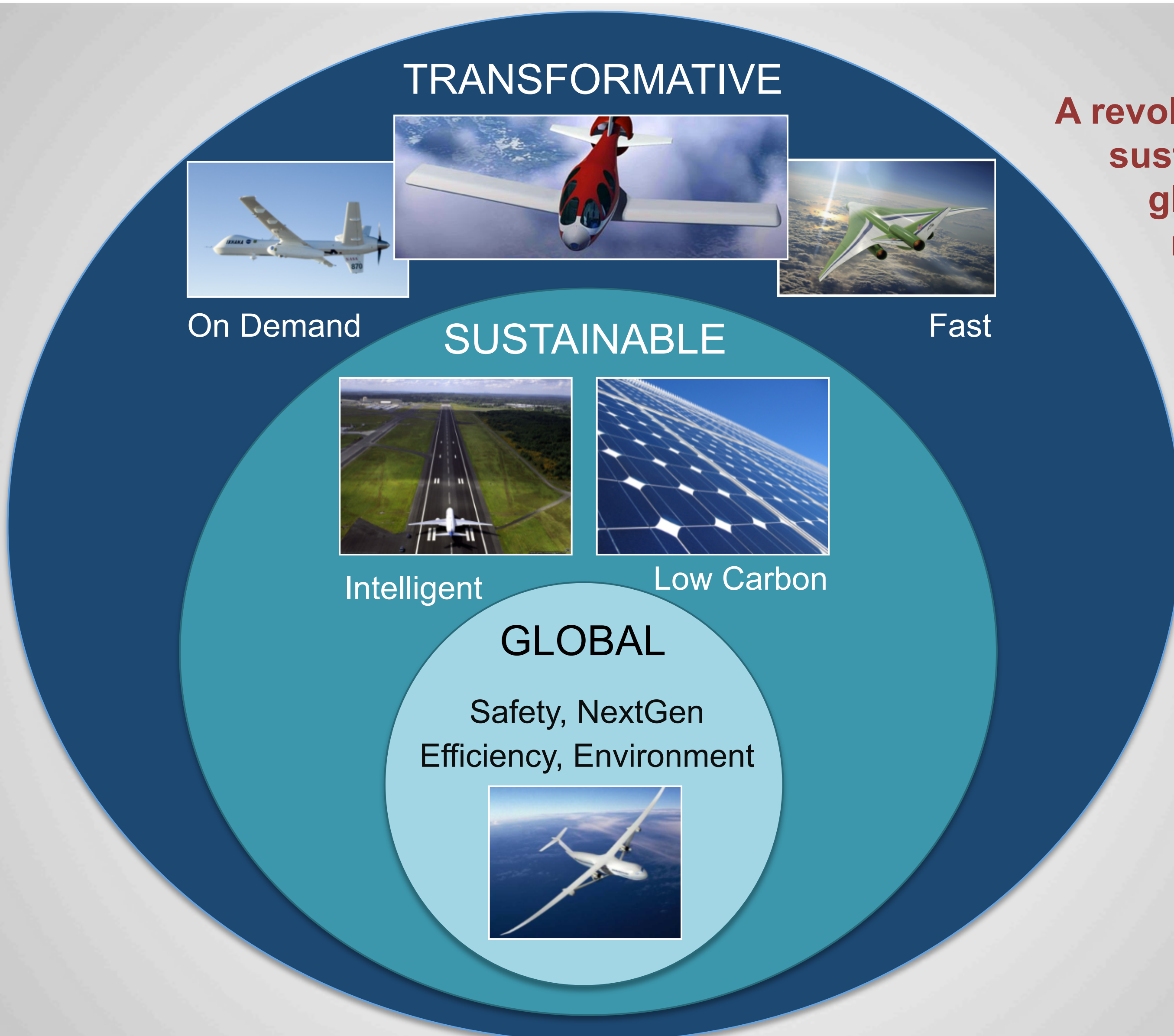
www.nasa.gov

Applied Modeling & Simulation (AMS) Seminar Series
NASA Ames Research Center, May 21, 2015

Outline of Presentation

- The New Strategy for NASA Aeronautics
- The AAVP Program
- The AATT Project
- The AATT Project Research and Technology Portfolio
- Concluding Remarks

NASA Aeronautics Vision for the 21st Century



A revolution in sustainable global air mobility

NASA Aeronautics Research Six Strategic Thrusts

Safe, Efficient Growth in Global Operations

- Enable full NextGen and develop technologies to substantially reduce aircraft safety risks

Innovation in Commercial Supersonic Aircraft

- Achieve a low-boom standard

Ultra-Efficient Commercial Vehicles

- Pioneer technologies for big leaps in efficiency and environmental performance

Transition to Low-Carbon Propulsion

- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

Real-Time System-Wide Safety Assurance

- Develop an integrated prototype of a real-time safety monitoring and assurance system

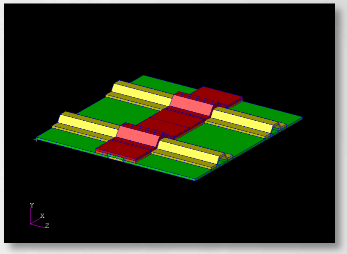
Assured Autonomy for Aviation Transformation

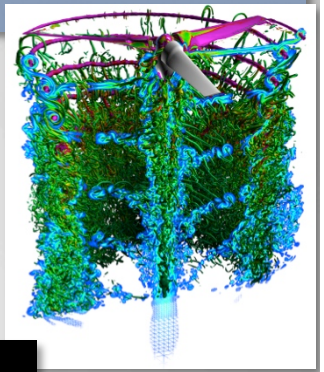
- Develop high impact aviation autonomy applications

NASA Aeronautics Programs

The Advanced Air Vehicles Program

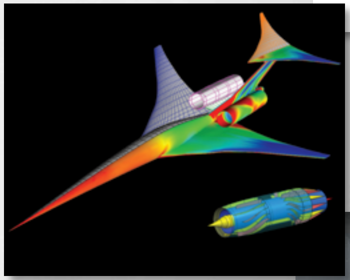
Cutting-edge research that will generate innovative concepts, technologies, capabilities & knowledge to enable revolutionary advances for a wide range of air vehicles.





Advanced Air Transport Technology Project (AATT)
Conducts fundamental research to improve aircraft performance and minimize environmental impacts from subsonic air vehicles

Revolutionary Vertical Lift Technology Project (RVLT)
Develops and validates tools, technologies & concepts to overcome key barriers, including noise, efficiency, & safety for vertical lift vehicles



Advanced Composites Project (ACP) Conducts research to reduce the timeline for certification of composite structures for aviation

Commercial Supersonics Technology Project (CST) Explores theoretical research for potential advanced capabilities & configurations for low boom supersonic aircraft.

Aeronautical Evaluation & Test Capabilities Project (AETC)
Ensures the strategic availability, accessibility, & capability of a critical suite of aeronautics ground test facilities to meet Agency & national aeronautics testing needs

Advanced Air Transport Technology Project

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

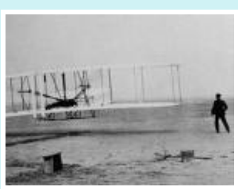
Vision

- 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



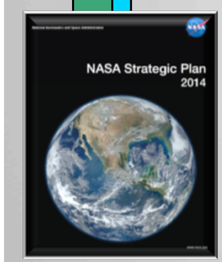
1903 | 1930s | 1950s | 2000s

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

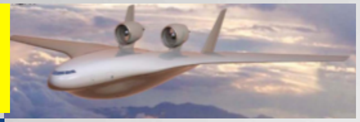
N+3 Advanced Vehicle Concept Studies

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

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

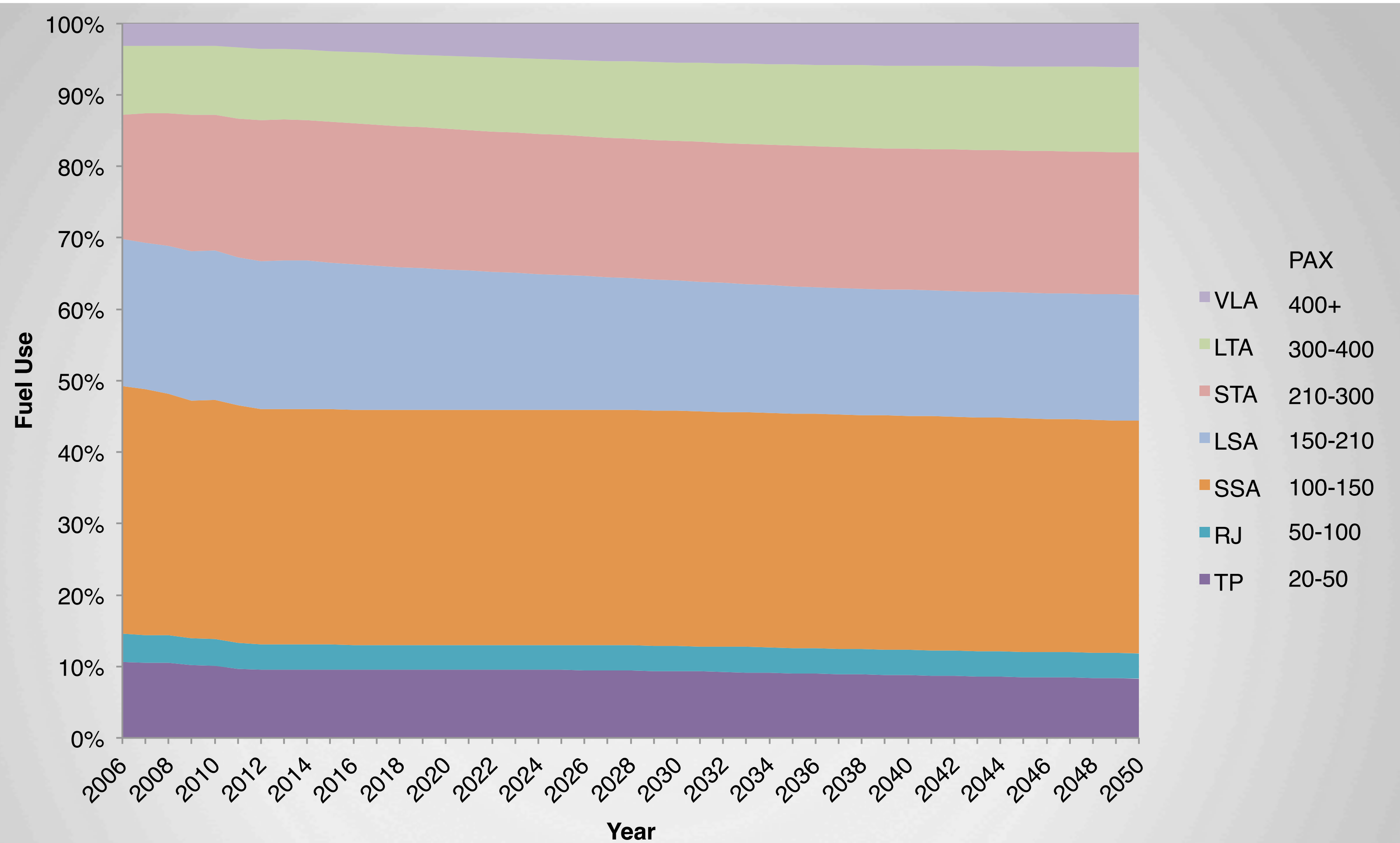
MIT, Aurora, P&W, Aerodyne

NASA, VA Tech, GT

NASA

Advances required on multiple fronts…

AATT Scope: Fuel Use by Vehicle Classes



85% of fuel use is in small single-aisle (100-150 pax) and larger classes; regional jets and turboprops account for only 15% of fuel use

Based on FAA Terminal Area Forecast (TAF) for US Operations; Courtesy of Ga Tech

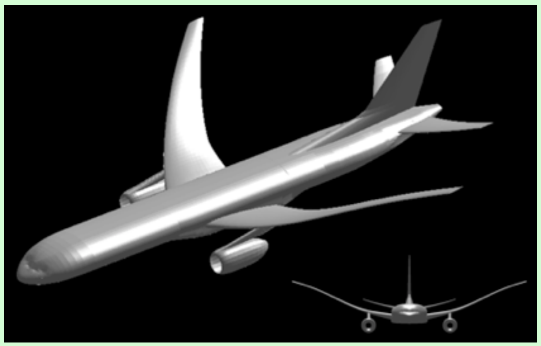
AATT Project Research Themes

Based on Goal-Driven Advanced Concept Studies

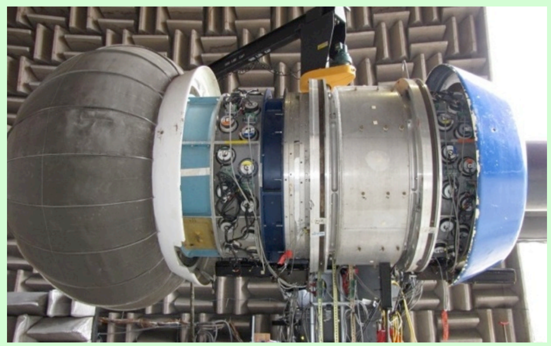
Goals Metrics (N+3)	Noise Stage 4 – 52 dB cum	Emissions (LTO) CAEP6 – 80%	Emissions (cruise) 2005 best – 80%	Energy Consumption 2005 best – 60%

Goal-Driven Advanced Concepts (N+3)

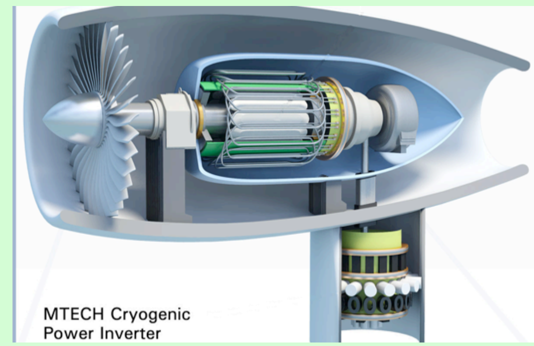
Research Themes with Investments in both Near-Term Tech Challenges and Long-Term (2030) Vision



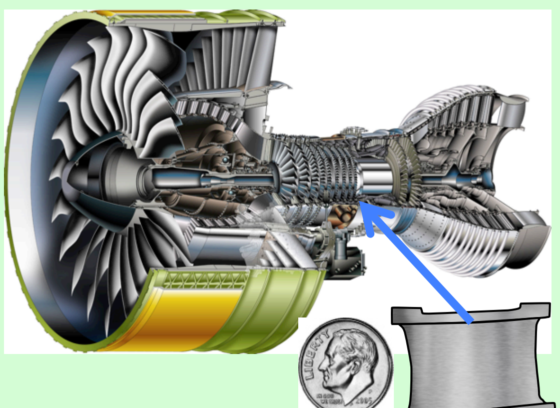
Higher Aspect Ratio Optimal Wing



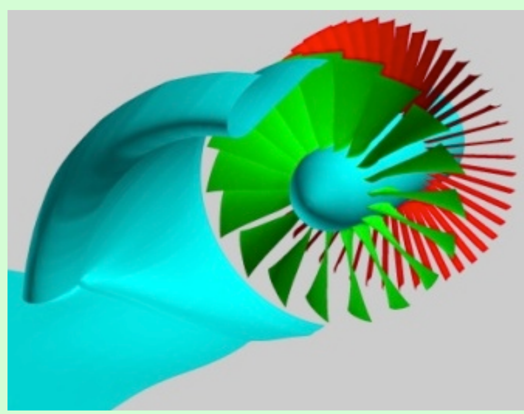
Quieter Low-Speed Performance



Hybrid Gas Electric Propulsion



Cleaner, Compact Higher BPR Propulsion



Unconventional Propulsion Airframe Integration

Alternative Fuel Emissions

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

Passive Aeroelastic Tailored Wing (PATW)

- Passive aeroelastic tailored loadpath structures

Performance Adaptive Aeroelastic Wing (PAAW)

- Distributed control effectors, robust control laws
- Actuator/sensor structural integration
- Continuous control effector(s) for mission-adaptive optimization

Active Flow Control Wing (AFCW)

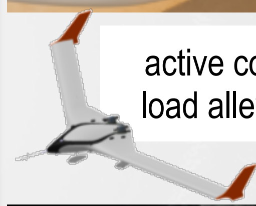
- Light weight mechanically simple high-lift system
- Transonic drag reduction

Truss-Braced Wing (TBW)

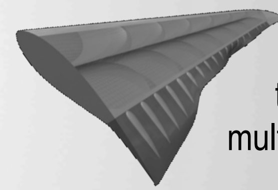
- Low interference external bracing
- Passive wave drag reduction concepts

Benefit/Pay-off

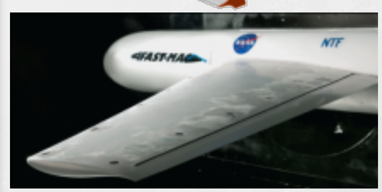
- 20% wing structural weight reduction
- Wave drag benefits tradable for weight or other parameters
- Concepts to control and exploit structural flexibility
- Optimal wing AR increase up to 50% for cantilever wings, 100% for braced wings



active controls
load alleviation

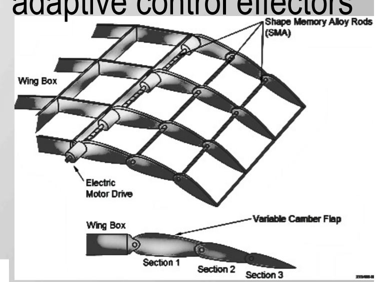


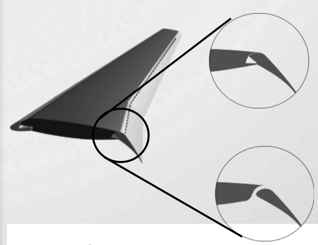
tailored
multifunctional



passive/active
advanced aerodynamics

adaptive control effectors





AFC-based high-lift concepts

Truss-Braced Wing Weight Uncertainty

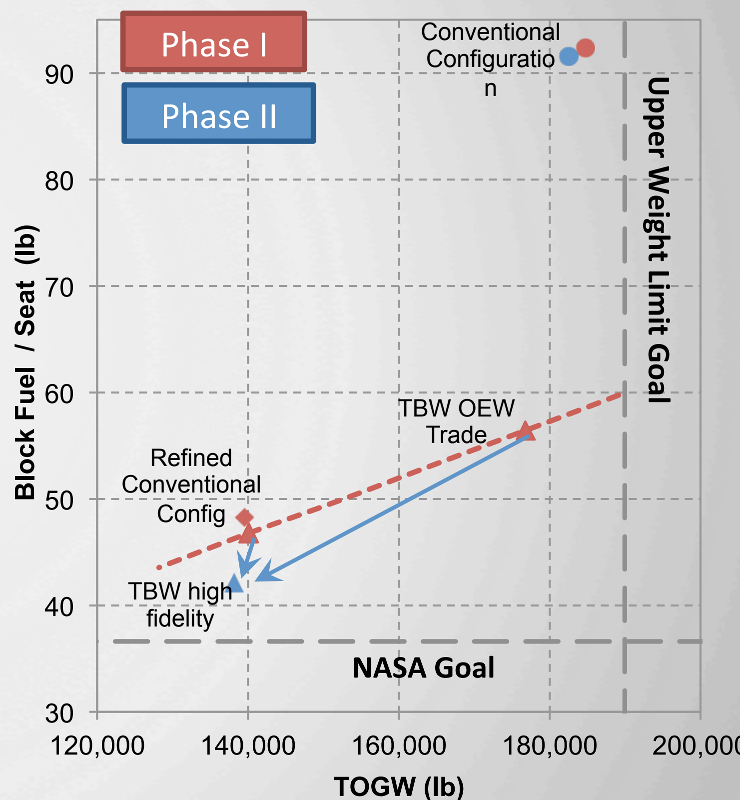
Problem
Truss-Braced Wing (TBW) configuration shows significant potential to contribute to meeting NASA N+3 goals but also present significant uncertainty in wing weight estimates.

Objective
Refine the TBW configuration and reduce the uncertainty in the potential benefits with specific focus on reducing the uncertainty of the wing weight.

Approach
Create a detailed finite element model (FEM) of the TBW configuration to provide a higher fidelity weight estimate of the concept; validate the FEM via a transonic aeroservoelastic (ASE) test in the NASA Transonic Dynamics Tunnel (TDT).

Results
A high fidelity weight estimate was completed that showed favorable wing weights and significant improvement in fuel burn. The ASE test was used to validate and update the wing weight estimate that increased 463 lbs (12,577 lb wing).

Significance
The TBW configuration is a viable concept for reducing transport aircraft energy consumption. The validated detailed FEM enables credible weight and fuel burn estimates. Further investigations of the TBW concept are clearly justified. Based on these results, an aerodynamic performance test and evaluation is planned to show that high-order aerodynamic design and analysis tools can be used to predict the performance of a low-interference truss braced wing.

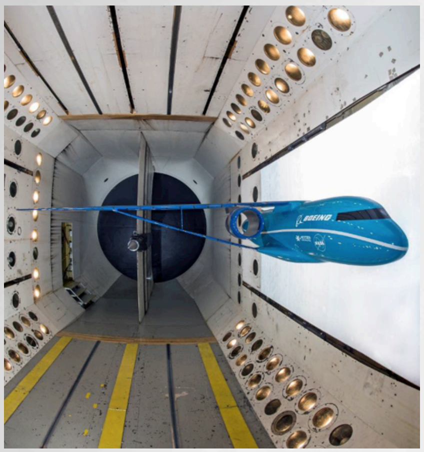


POC: Marty Bradley (Boeing PI); Erik Olson (NASA TM); Rob Scott (NASA)

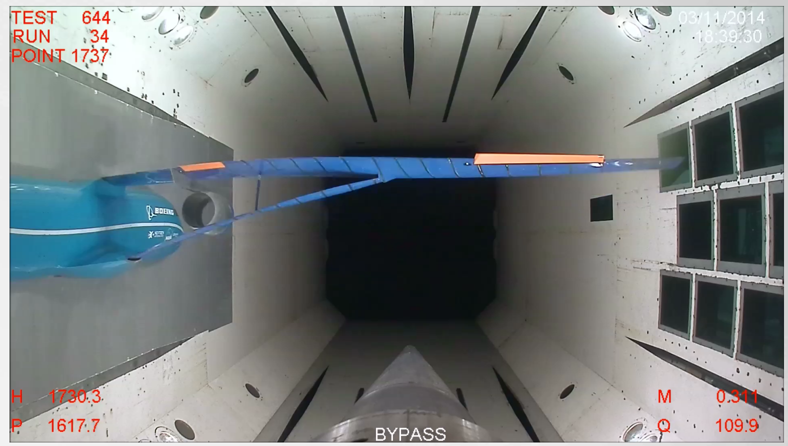
Truss-Braced Wing Aeroservoelastic Test in Transonic Dynamics Tunnel

Identify open loop flutter boundaries and compare to predictions

Investigate active controls on truss braced wing and demonstrate flutter suppression and assess effect of control laws effect on gust loads and ride quality

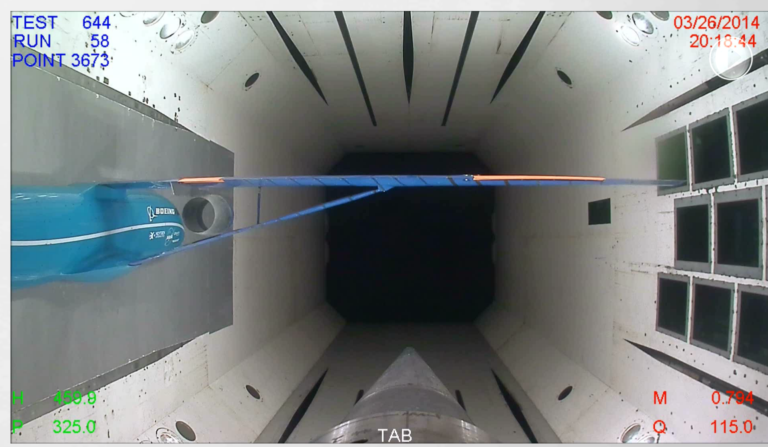


Model Installed in TDT



Control Surface Flutter

Hard Flutter



Flutter Suppression

POC: Rob Scott (LaRC)

Adaptive Aeroelastic Shape Control

Problem

Off-design performance of flexible wings can be significantly degraded by aeroelastic deflections that cause increased drag.

Objective

Develop performance-adaptive aeroelastic wing shaping control technology to achieve improved aerodynamic efficiency.

Approach

Use Variable Camber Continuous Trailing Edge Flap (VCCTEF) on representative flexible wing to tailor spanwise lift distribution and chordwise pressure distribution to achieve optimum aerodynamic efficiency throughout the flight envelope. VCCTEF consists of three chordwise segments to enable variable camber and multiple spanwise segments connected by elastomers to form an unbroken trailing edge.

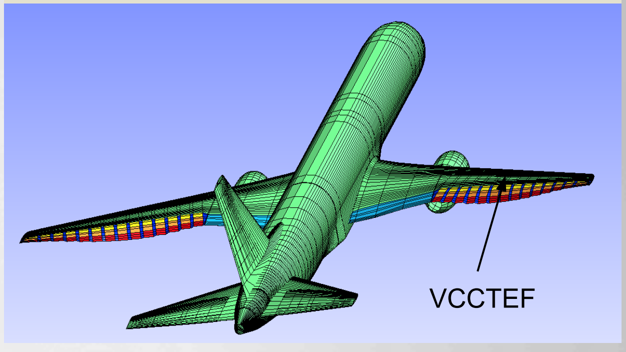
Results

Wind tunnel tests in the University of Washington Aeronautical Laboratory (UWAL) completed. Data are being analyzed and compared with CFD to assess performance.

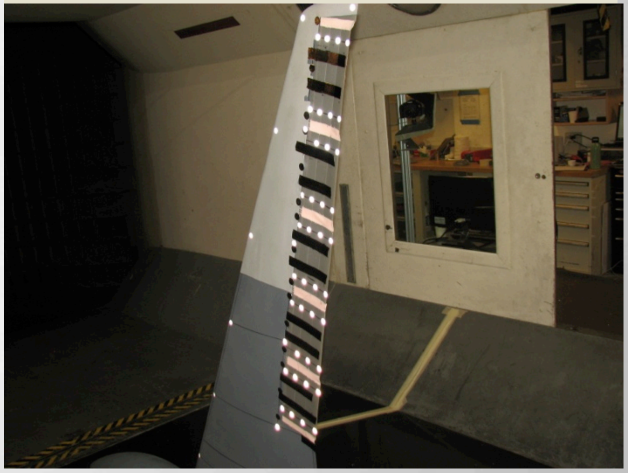
Significance

VCCTEF-based performance-adaptive aeroelastic wing technology can potentially improve aerodynamic performance of current- and next-generation transports by in-flight aerodynamic wing shape optimization.

B757-Derivative Generic Transport with VCCTEF



Flexible Wing Wind Tunnel Model with VCCTEF



POC: Nhan Nguyen (ARC)

TC 3.1(FY18): Fan & 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

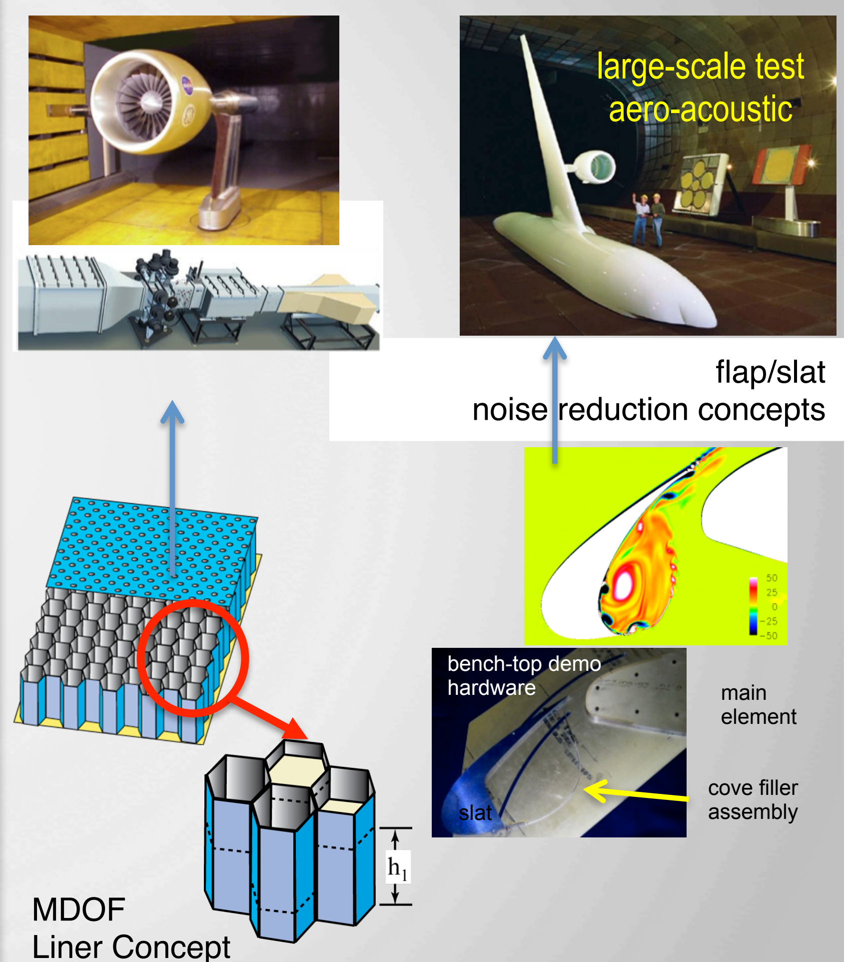
Acoustic Liners and Duct Propagation

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

Benefit/Pay-off

Component noise reduction with minimal impact on weight and performance

- Aft fan noise reduction over relevant frequency range: 4 dB at both sideline and cutback
- High-lift system noise reduction: 4 dB at approach
- Liner and non-active-flow-control high-lift system technology have early insertion potential



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

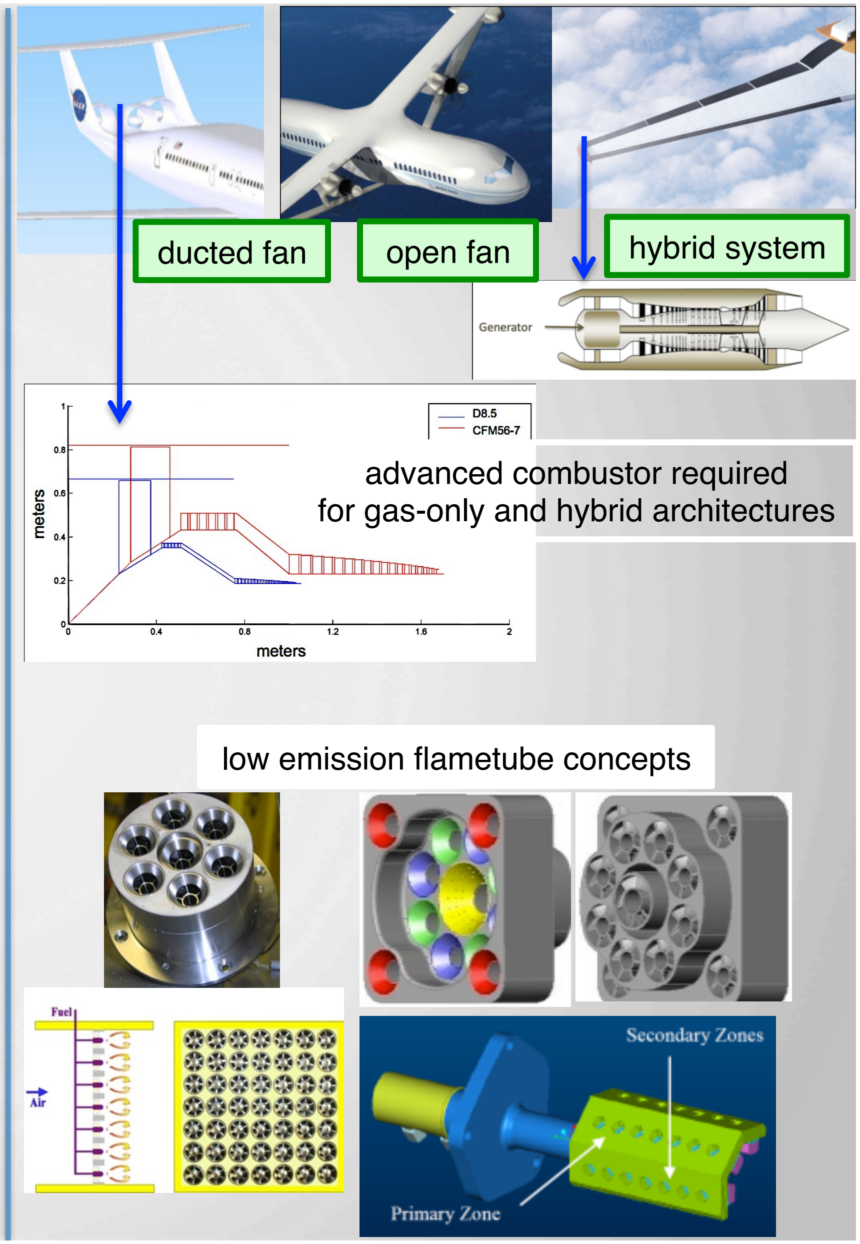
Technical Areas and Approaches

Fuel-Flexible Combustion

- 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



TC4.2 (FY19): Compact, High Overall Pressure Ratio (OPR 50+) Gas Generator, TRL 4

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

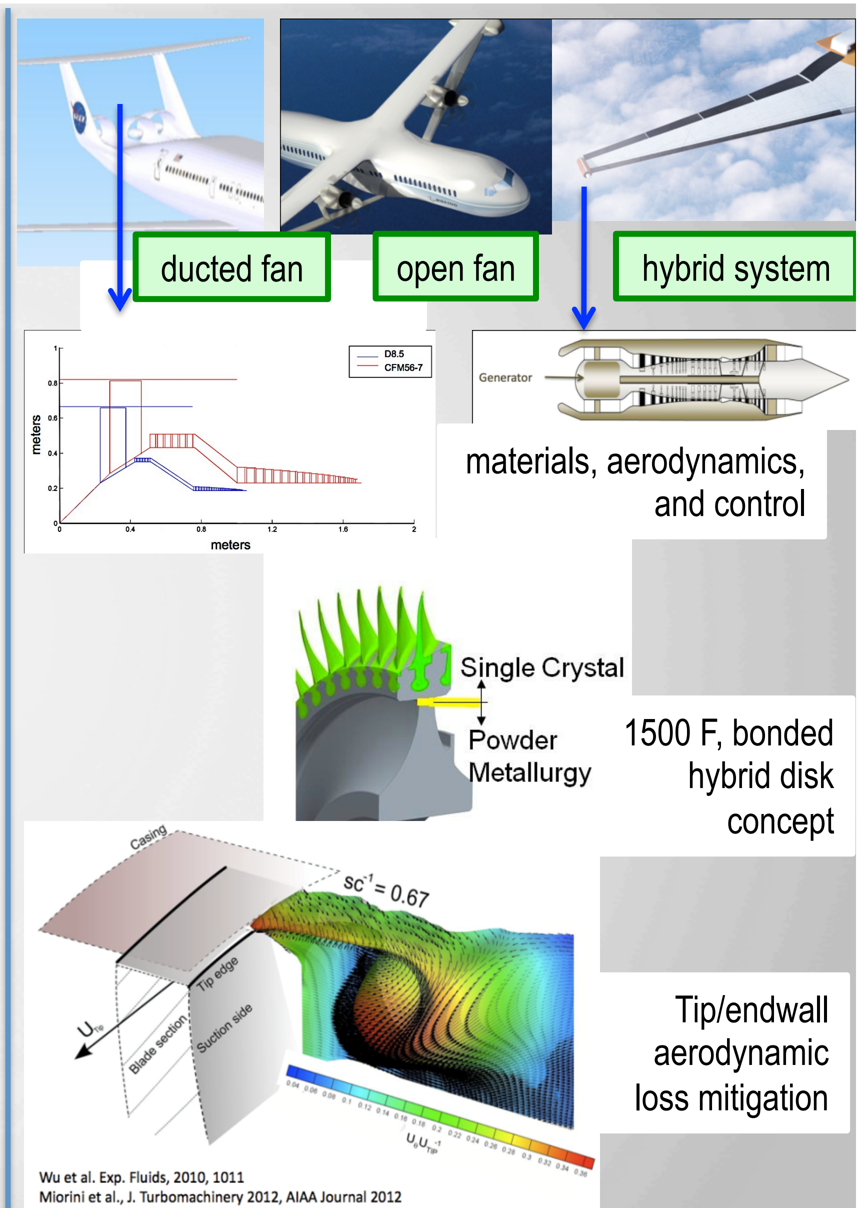
- 1500F disk & coatings
- 1500F capable non-contacting seal

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



Small Core Size Design Challenge for High OPR Engine

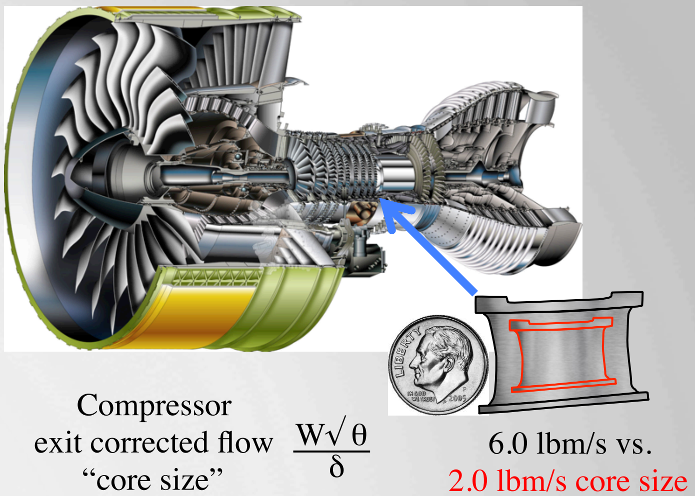
Problem
Enable high OPR (40+) gas generator core for improved thermal efficiency and fuel burn reduction.

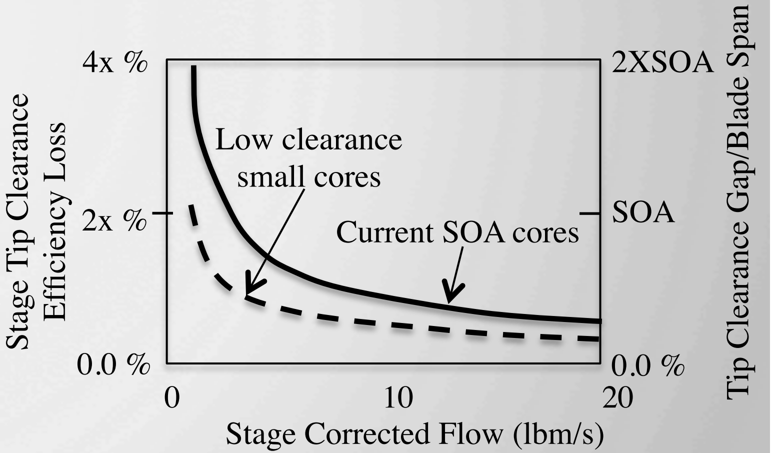
Objective
Mitigate aerodynamic losses and resulting decrements in high OPR core compressor and turbine efficiencies due to larger tip clearance and under-platform seal cavity gaps associated with small core size.

Approach
Solicit proposals for N+3 relevant system studies of high OPR core to assess benefits and develop concepts, approaches, and roadmaps to substantiate potential performance and fuel burn benefits of proposed technologies, and then down-select most promising concept(s) for TRL 4 testing.

Results
Awards to GE for an advanced casing treatment concept applied to an advanced HPC aft block, and to P&W for a conceptual and preliminary design of a HPC tied to N+3 relevant system studies, followed by low and high speed tests of candidate blade design and technology concepts in a scaled HPC aft block commensurate with manufacturing limitations of small core blade.

Significance
TRL 4 demonstration of benefits afforded by high OPR small core engine concept anchored by N+3 relevant system studies will enable significantly higher engine BPRs due to smaller/compact cores.





Research team: Chunill Hah (P&W NRA COTR, GRC) , Vikram Shyam (GE NRA COTR, GRC)

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

Objective

Key performance parameters and threshold level requirements for gas turbine, electric machine, power system and thermal systems to guide research investment

Technical Areas and Approaches:

Propulsion System Conceptual Design

– System concepts for assessment of benefits

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

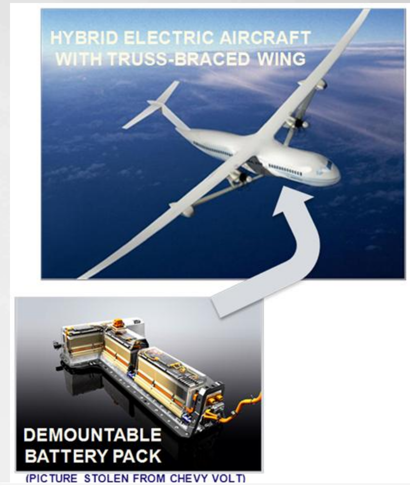
– High power electric grid definitions, modeling, simulation
– High voltage power electronics, transmission, protection
– Materials development for lightweight power transmission
– Management & distribution for distributed propulsion

Integrated Subsystems

– Component interactions – validate performance & matching at steady-state and transient operation

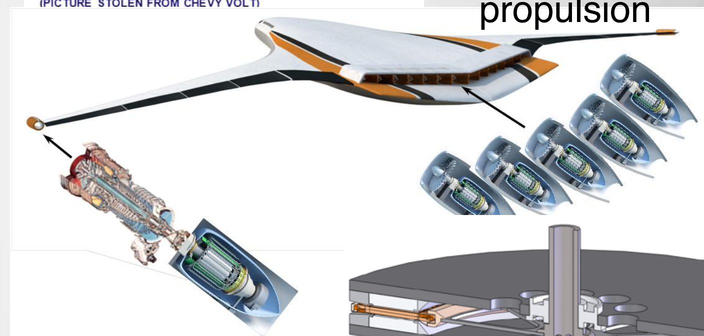
Benefit/Pay-off:

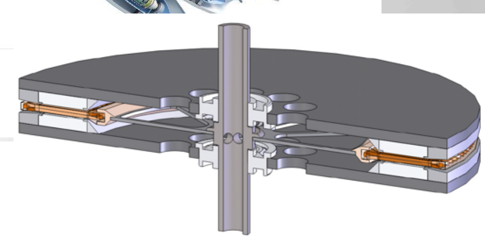
– Will enable the paradigm shift from gas turbine to hybrid-electric or turbine-electric propulsion



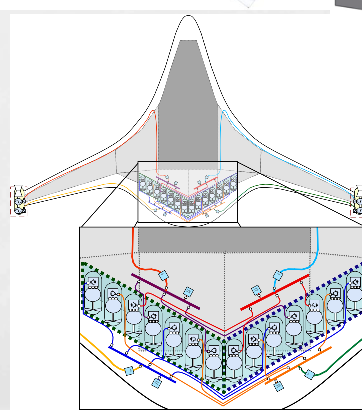
Emphasizing technologies supporting both:

- Gas turbine-battery hybrid
- Superconducting turboelectric distributed propulsion





High Power Density, Non-cryogenic Motor



Propulsion power grid architecture

Fully Superconducting Electric Generator Design

Problem
Hybrid or turboelectric propulsion offers revolutionary benefits, but requires development of light-weight and efficient electric machines.

Objectives
Use state-of-the-art as well as near-term, cutting-edge component technology expectations to develop a conceptual design of a fully superconducting (SC) motor with specific power greater than 10 horse-power/pound.

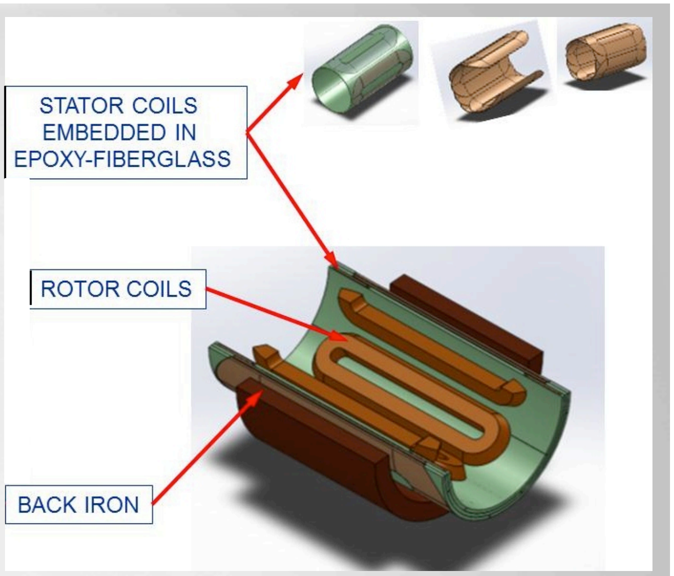
Approach
- Establish design requirements for flight-weight, fully superconducting motor.
- Establish technical requirements for fully superconducting motor.
- Develop basic motor sizing based on conventional and expected technology.
- Perform parametric studies on design alternatives.
- Perform high fidelity motor sizing on select options.
- Produce SolidWorks design for concept physical details.

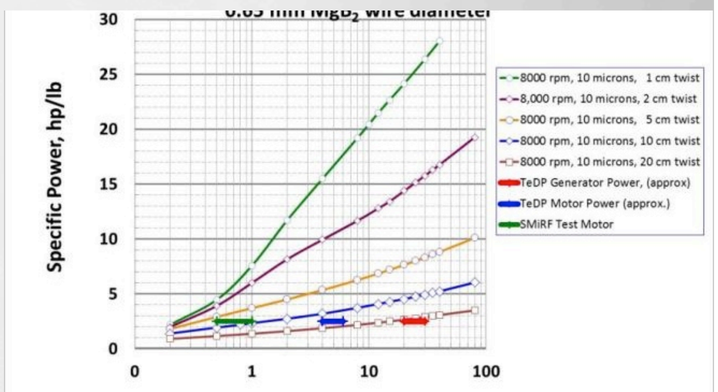
Results
- Extensive parametric designs surveying power, speed, poles, phases, SC material, SC wire configuration, and structural materials
- Down-selection of design parameters: 12 MW, 8,000 rpm, 3 poles, 3 phases, 10 μm filament MgB_2 wire
- Detailed calculation of electromagnetic field/torque, mechanical design, rotordynamics, and thermal analyses
- Full conceptual design of electric machine with the following:

Generator speed - 8,000 rpm
Power - 12 MW (16,086 hp)
Weight - 288 kg (635 lb)
Efficiency - 99.8 %
Specific Power - 25 hp/lb

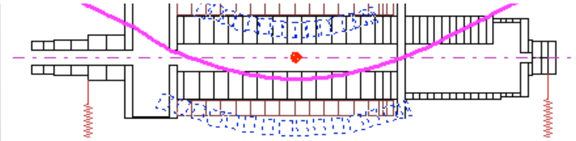
Significance
Parametric studies and detailed subsystem analysis provide conceptual design that exceeds initial targets for a flight-weight, fully superconducting, motor/generator

POCs: Gerald Brown & Jeffrey Trudell (GRC)





Specific power as a function of MgB_2 twist pitch



Rotordynamics modeling from DyRoBeS

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

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

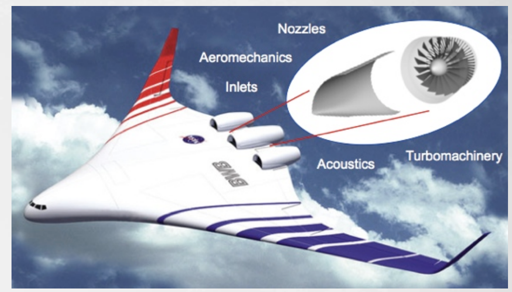
Distortion-Tolerant Fan

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

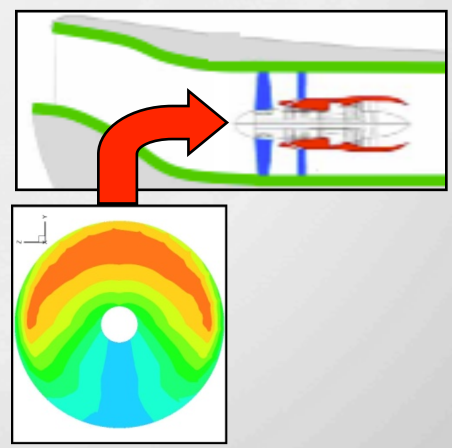
Benefit/Pay-off

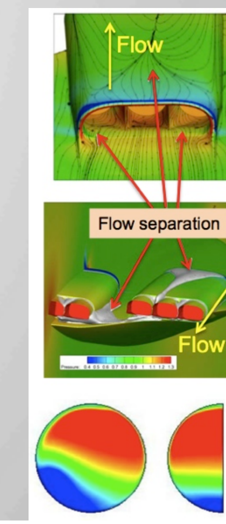
- Demonstrates a net system-level benefit for BLI propulsion system integration; applicable and beneficial to a variety of advanced vehicle concepts
- Distortion-tolerant fan technology and acoustics characterization relevant to near-term, conventional short-duct installations

boundary-layer ingestion for drag reduction



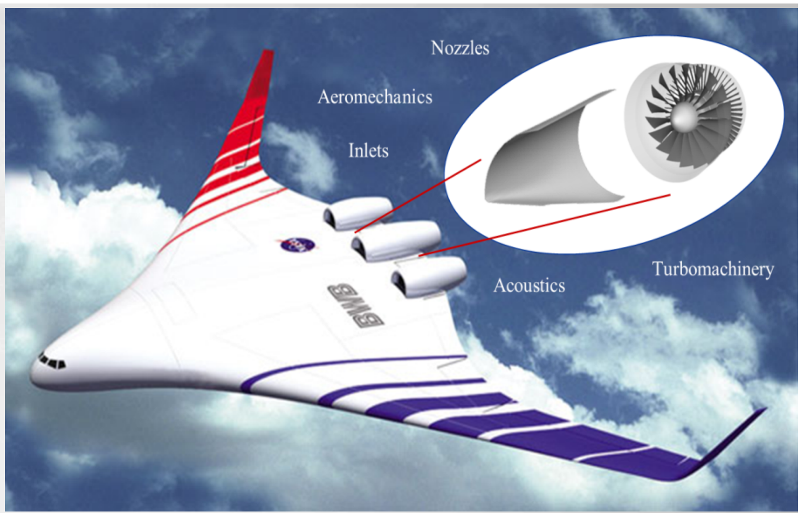
distortion tolerance required for net vehicle system benefit





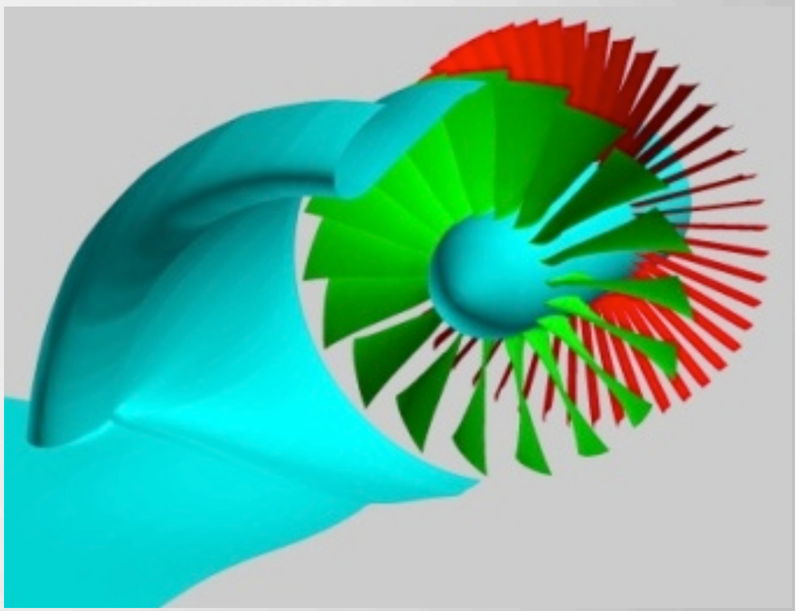
Boundary Layer Ingesting Inlet - Distortion Tolerant Fan (BLI^{2}DTF) Aerodynamic Design

Problem
The benefits of propulsion systems more highly integrated with the aircraft are offset by the decrement in fan performance due to ingesting the aircraft boundary layer.



Objective
Demonstrate less than 2% reduction in efficiency and stall margin for a boundary layer ingesting distortion tolerant fan.

Approach
Design, analyze, and fabricate a boundary layer ingesting inlet coupled with a 22” diameter distortion-tolerant fan to test in the NASA GRC 8X6 transonic wind tunnel to demonstrate less than 2% fan efficiency and stall margin and substantiate the system study benefits.



Results
Aerodynamic design was completed by UTRC in July 2014. Design reviews were completed in August with recommendation to proceed to final design. The final design has low vibratory stresses and acceptable structural margin at the 100% aerodynamic design point.

Significance
The aerodynamic design constitutes the first credible fully coupled inlet-distortion tolerant fan candidate for enabling identified BLI propulsor benefits.

Research team: Dave Arend (PI/COTR); United Technologies Research Center; Virginia Tech (NRA); NASA Researchers

Computational Validation of Wind Tunnel Experiments of Integrated BLI on MIT D8

Problem
Studies have shown that the D8 configuration provides a substantial performance benefit, a large part of which is attributed to boundary layer ingestion (BLI). These study results need to be experimentally and computationally validated.

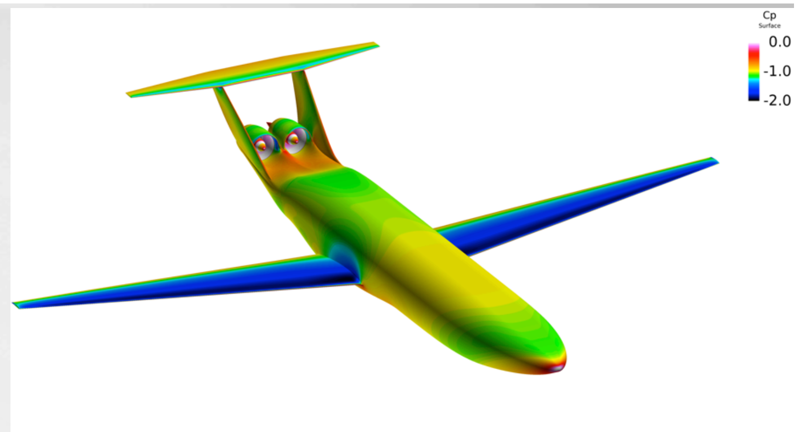
Objective
Computationally and experimentally assess the benefits of BLI for improving the propulsive efficiency of the D8 configuration.

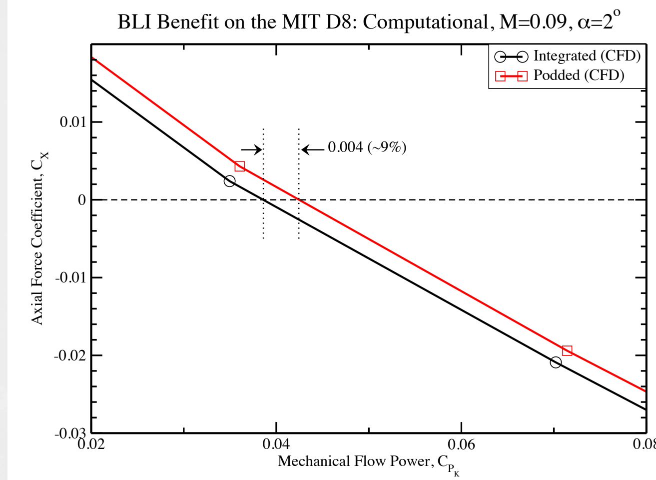
Approach
Perform CFD simulations at a simulated cruise condition for both podded and integrated powered configurations on a 1:11 scale model and compare results to experimental data.

Results
Completed CFD simulations indicate a 4-9% reduction in mechanical flow power required for the integrated configuration when compared with the podded configuration at a simulated cruise condition. Compared force/moment data to experimental measurements. Total pressure at extracted planes from the CFD simulations compared to rake surveys of engine inlet and exit flows. Near-surface flow compared to experimental mini-tuft visualizations. Good agreement between experiments and CFD.

Significance
Computational and experimental results confirm the potential benefits of BLI for power/fuel-burn reduction measured in the experiments.

POC: Shishir Pandya (ARC)





TC7.1(FY15): Alternative Fuel Emissions at Cruise,TRL-N/A

Objectives

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

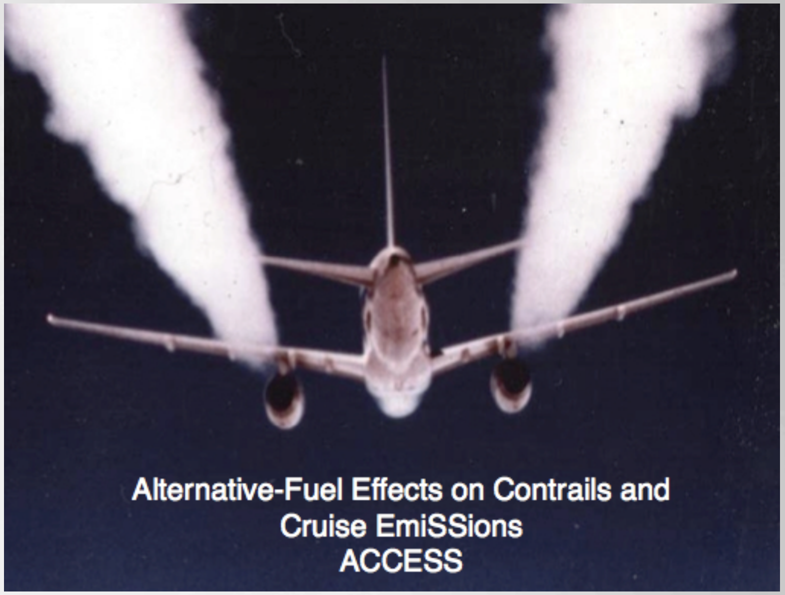
Technical Areas & Approaches

Emission & Performance Characterization

- Flight tests
- Ground tests
- Laboratory tests

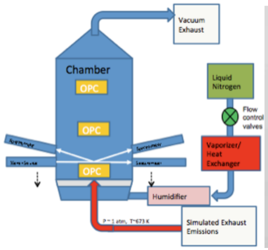
Benefit/Pay-off

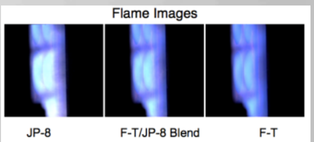
- Will dramatically reduce the impact of aviation on the environment (gaseous, particulates, and contrails)
- Will support standard-setting organizations by providing important and timely data



leverage ground tests from prior years

lab studies





ACCESS 2 (Alternative fuel effects on Contrails and Cruise EmiSSions) Flight Test

Participants: NASA, DLR, NRC-Canada, JAXA

Details: 7 flights (26 hours) and one ground test (4 hours) between May 5-30, 2014, in Palmdale, CA

Fuels: Low S JP-8, High S JP-8, Low S HEFA/JP-8 Blend

Source Aircraft: DC-8 w/CFM56-2C engines; Sampling Aircraft: NASA HU-25 Falcon, DLR Falcon 20, NRC Canada T-33

Team Leads: Brian Beaton (LaRC), Bruce Anderson (LaRC), Angela Sugenor (GRC), Gary Martin (DFRC)

Major Activities for FY2015

- Acquire **X-56A** flight vehicle from AF, conducting flight test of stiff-wing controller, and work on developing advanced and open (non-proprietary) flexible wing control capability
- Conduct **FAST-MAC 2.5 and 3.0** NTF test
- Optimize passive aeroelastically-tailored **CRM** wing with AR 14
- Complete final design and fabrication of **distortion-tolerant fan** for embedded engines and prepare for testing in GRC 8x6 tunnel in FY16
- Complete high-fidelity aerodynamic design, initiate model fabrication, and prepare for **TBW Performance** test (planned for FY16) in the ARC 11’ tunnel
- Conduct TRL 5 **MDOF liner** test in conjunction with reimbursable **Honeywell fan** test in GRC 9x15 tunnel
- Complete **contrail formation** studies using ground APU emission source in the Particulate Aerosol Laboratory
- Complete documentation of ACCESS 2 (**FY15 API**)
- Initiate Phase 1 activities of ten newly awarded **NRA**s

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

AAV Program webpage:
http://www.aeronautics.nasa.gov/programs-aavp.htm
AATT Project webpage:
http://www.aeronautics.nasa.gov/aavp/aatt/index.html