National Aeronautics and Space Administration

Advanced Air Vehicles Program (AAVP)
Advanced Air Transport Technology Project (AATT)

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Host Center: Glenn Research Center
Partner Centers: Ames Research Center
Armstrong Flight Res. Center
Langley Research Center

Sally Viken, Tech Lead, Higher Aspect Ratio Wing and Integrated BLI Systems

March 25, 2015

NASA Aeronautics Context

Strategic Implementation Plan (SIP)

3 Mega-Drivers

6 Strategic Research & Technology 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 — **FW/AATT**
- Pioneer technologies for big leaps in efficiency and environmental performance

Transition to Low-Carbon Propulsion — **FW/AATT**
- 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

Adapted from Pearce – AIAA Aviation2014

Advanced Air Transport Technology Project

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

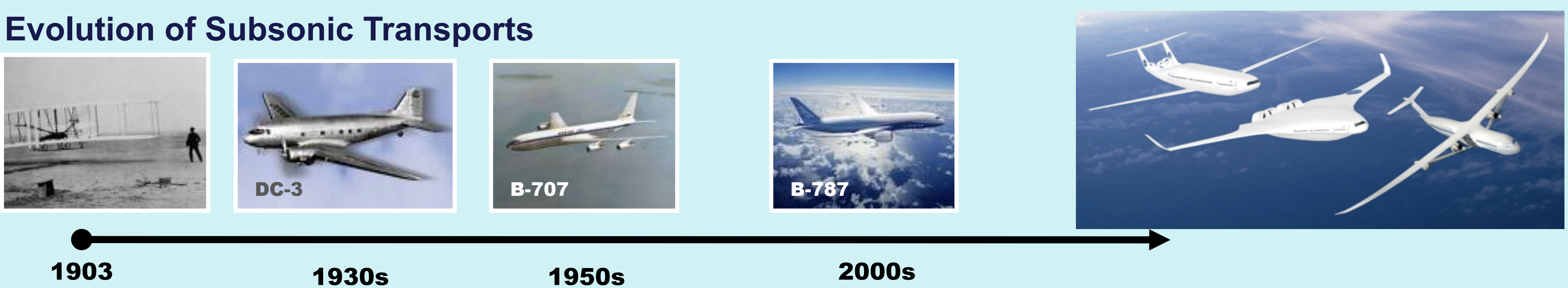
Vision

- 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



AATT Project Research Themes

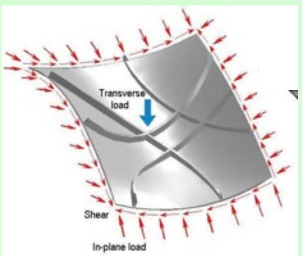
Based on Goal-Driven Advanced Concept Studies

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)

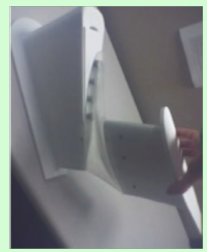




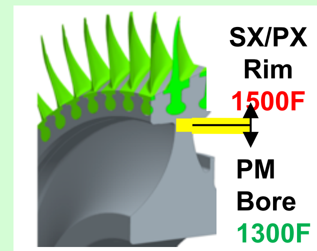


1. Lighter-Weight Lower Drag Fuselage

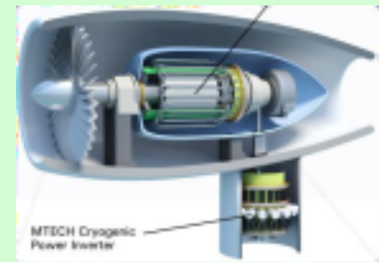
2. Higher Aspect Ratio Optimal Wing



3. Quieter Low-Speed Performance

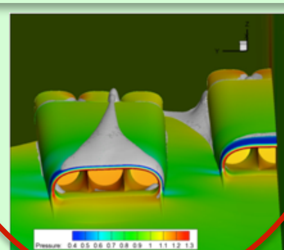


4. Cleaner, Compact Higher BPR Propulsion



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

AATT Project Technical Challenges
(FY13-19 – Near Term)

Goals Metrics (N+3)	Noise Stage 4 – 52 dB cum		Emissions (LTO) CAEP6 – 80%	Emissions (cruise) 2005 best – 80%		Energy Consumption 2005 best – 60%	
Research 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 (FY13-19) 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 (FY18) Low NOx Fuel-Flex Combustor: Reduce NOx emissions from fuel-flexible combustors to 80% below the CAEP6 standard with minimal impacts on weight, noise, or component life (TRL3).

TC4.2 (FY19) Compact High OPR Gas Generator: Enable reduced size/flow gas generators with 50+ OPR and disk/seal temperatures of 1500F with minimal impact on noise and component life (TRL4).

TC5.2 (FY19) **Gas-Electric Propulsion Concept:** Establish a viable 5 MW or greater hybrid gas-electric propulsion system concept 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).

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

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 Challenge Investment Areas

Performance Adaptive Aeroelastic Wing (PAAW)

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

Truss-Braced Wing (TBW)

- Low interference external bracing
- Passive wave drag reduction concepts

Passive Aeroelastic Tailored Wing (PATW)

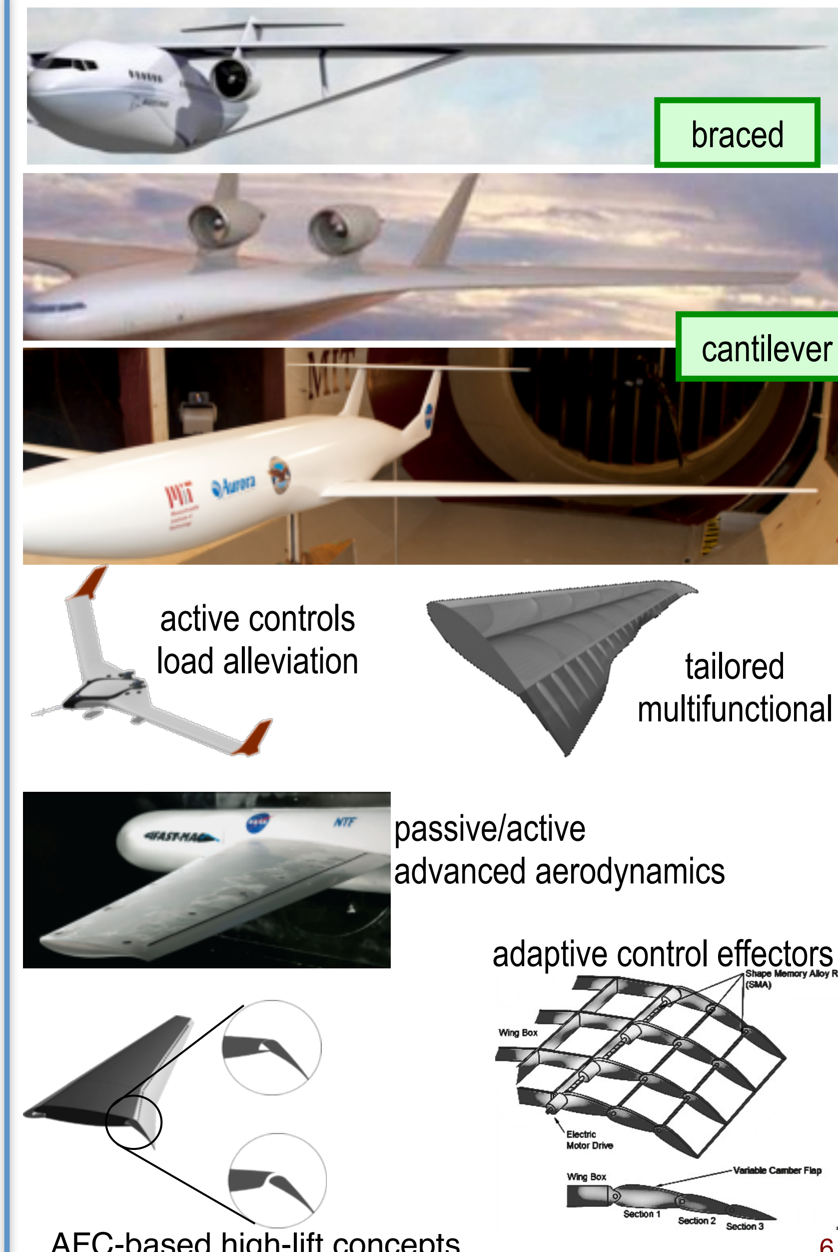
- Passive aeroelastic tailored loadpath structures

Active Flow Control Wing (AFCW)

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

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



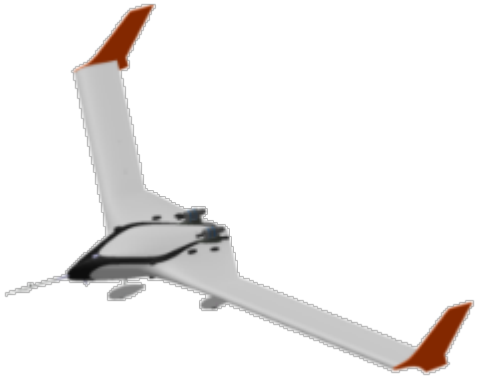
Performance Adaptive Aeroelastic Wing (PAAW)

- **Current and future-generation aircraft wing technology trends toward lightweight, highly flexible, high aspect ratio wing structures**

- **Increasing aspect ratio improves aerodynamic efficiency but can lead to an increase in wing structural flexibility**

- **In practice, wing flexibility can adversely impact aircraft performance, structural integrity, stability and control**
  - Increased drag due to non-optimal loaded wing shapes
  - Reduced flutter margin due to increased wing flexibility
  - Increased load amplification due to gusts and maneuvers
  - Coupled aircraft responses of rigid-body dynamics which can cause poor flying qualities
  - Conventional flight control inadequate to maintain aircraft stability and control

- **Control strategies applied to high aspect ratio wing configurations to optimize aerodynamic efficiency, control flutter, and perform gust load alleviation.**



Performance Adaptive Aeroelastic Wing (PAAW)
Adaptive Aeroelastic Shape Control

Problem
Off-design performance of modern flexible wings can be significantly degraded by aeroelastic deflections that cause increased drag and fuel burn

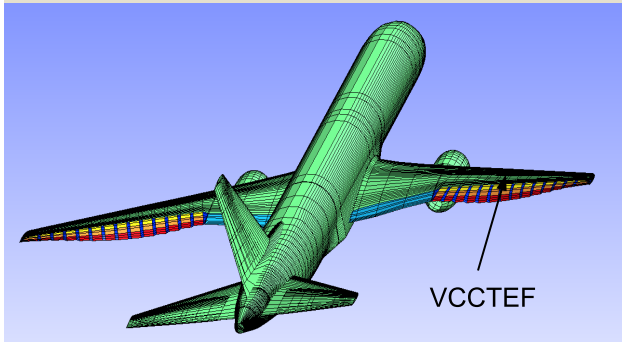
Objective
Develop performance-adaptive aeroelastic wing shaping control technology to achieve improved aerodynamic efficiency

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.

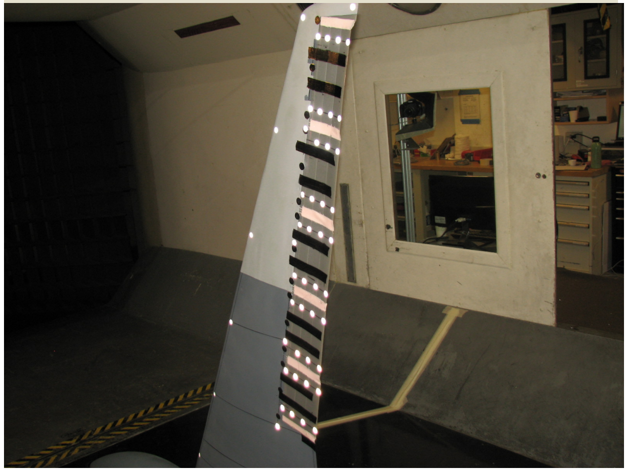
Results
Wind tunnel tests in the University of Washington Aeronautical Laboratory (UWAL) completed. Cruise configuration data has been analyzed and compared with CFD to assess performance. The high-lift test data analysis is continuing.

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)

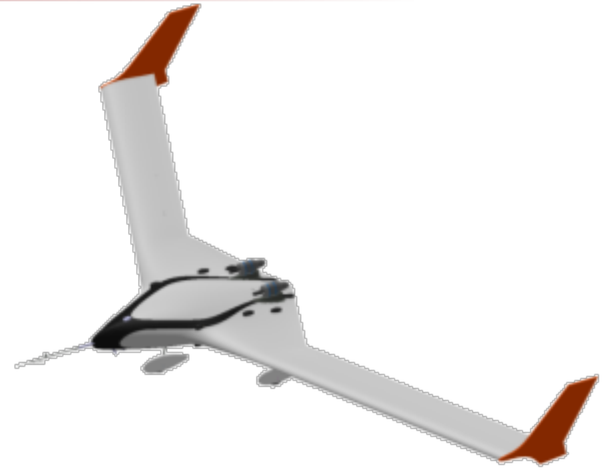
Performance Adaptive Aeroelastic Wing (PAAW)
Aeroelastic Flight Experiment

Problem: Increasing aspect ratio can lead to an increase in wing structural flexibility thus adversely impact aircraft performance, structural integrity, and stability and control

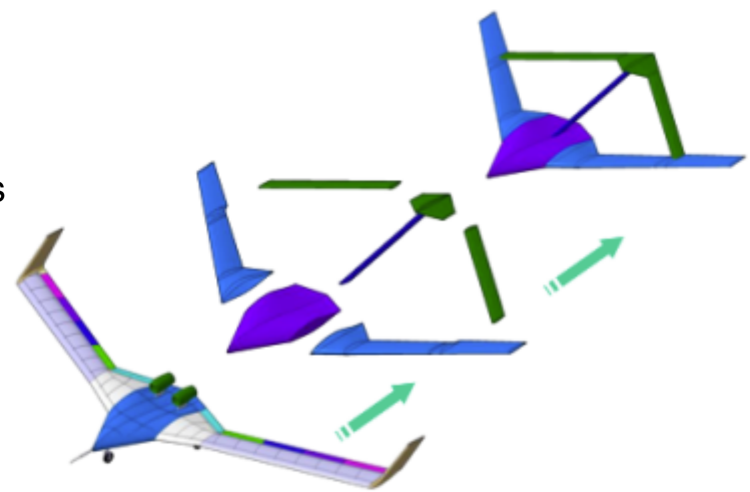
Objective: Demonstrate aeroservoelastic control laws and active flutter suppression through flight testing

Technologies included:
- X-56A modular test bed designed for testing active flutter suppression of multiple flutter modes at the same time
  - Rigid wings enable flight handling and maneuvers
  - Flexible wings intended to induce body freedom flutter, symmetric and antisymmetric bend/torsion flutter in the flight envelope
  - New wings or tail may be designed and added to vehicle for future test points
- Control law development to test using X-56A
  - 1st yr test with rigid wings
  - 2nd & 3rd years test with flexible wings (integrating sensors into the control laws in 3rd yr)
- Partnership with AFRL (vehicle transferred to NASA summer 2014)

Significance:
Establishes the engineering infrastructure (design tools and processes, models, and simulations) necessary for future high aspect ratio, flexible wing flight research. Establishes a flight and ride quality baseline for the X-56A. The resulting non-proprietary controller will be available for open publication.



X-56A (MUTT) testbed for flight testing of control laws.



X-56A modular design allows testing of control theories using stiff and flexible wings.

John Bosworth, Gary Martin

Passive Aeroelastic Tailoring of the AR9 Common Research Model

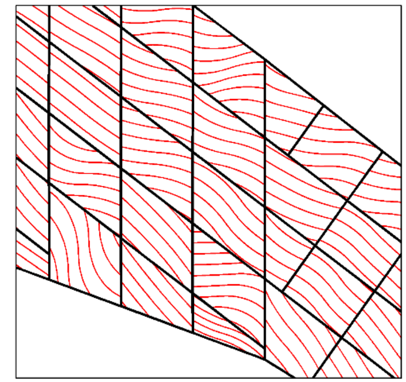
Problem
Structural weight reduction of subsonic transport wings will result in more flexible structures that are susceptible to aeroelastic failure modes.

Objective
Tailor material/structural design in wing skins to minimize structural wing weight while satisfying several design constraints for multiple maneuver loads. Assess the weight-reduction impact of relaxing the flutter constraint by using active control to regain the required margin.

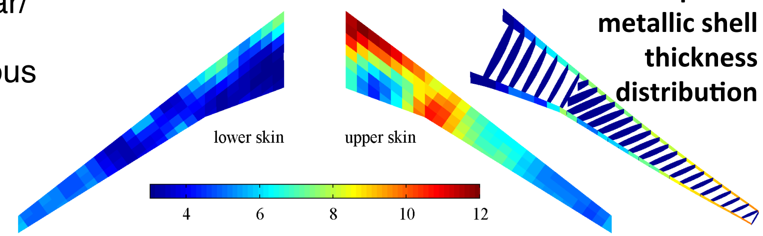
Approach
Gradient-based design optimization of wing skins to minimize weight compared to the baseline aluminum structure. Same baseline internal spar/ rib/ skin/stringer structure used in all combinations (straight-fiber composites, tow-steered composites, functionally-graded metals, continuous trailing edge flaps).

Results
• Tailored ply orientation in wing skins predicts weight reduction of >25% over the all-aluminum baseline wing. Tow-steering within the plies further reduces weight by an additional 3-5%.
• FGM provides very little weight reduction in wing skins, but are expected to play a more significant role in weight reduction for internal structures.
• Use of continuous trailing edge control surfaces enables an additional 5-10% weight reduction by relaxing flutter constraints and regaining the required margin through active flutter suppression.

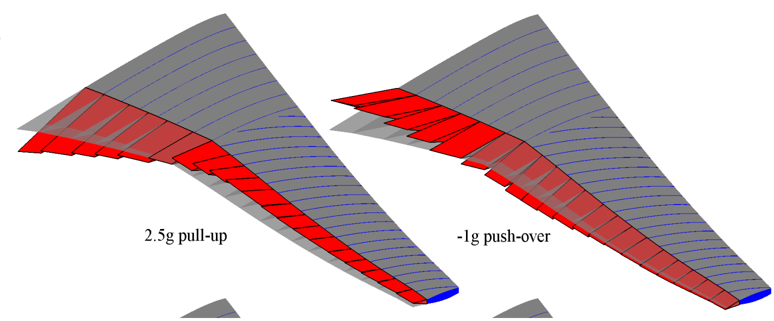
Significance
Initial optimizations indicate tow-steering in composite wing skins can retain stiffness and reduce weight by as much as 30%, with further weight reduction possible through active controls with novel trailing edge control effectors.



optimal composite tow-steering paths around the CRM wing break



optimal metallic shell thickness distribution

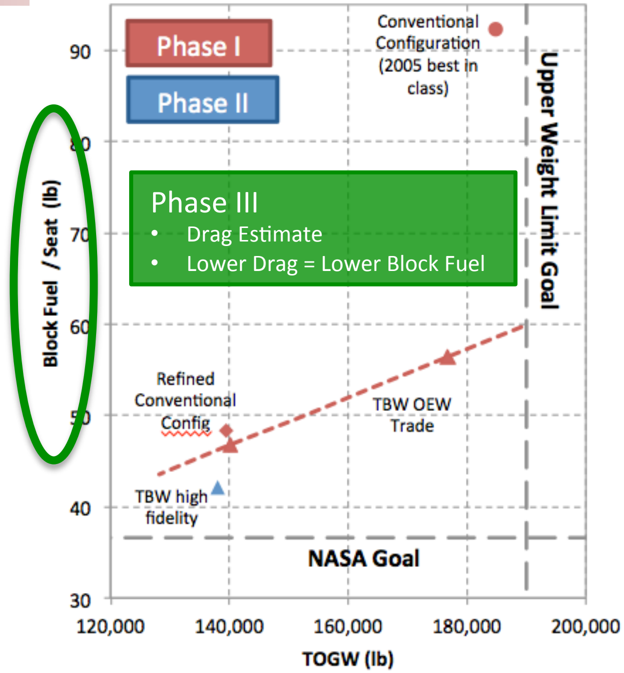


optimal TE control surface deflection profiles

POCs: Bret Stanford (LaRC), Christine Jutte (LaRC), Carol Wieseman (LaRC), Jim Moore (LaRC)

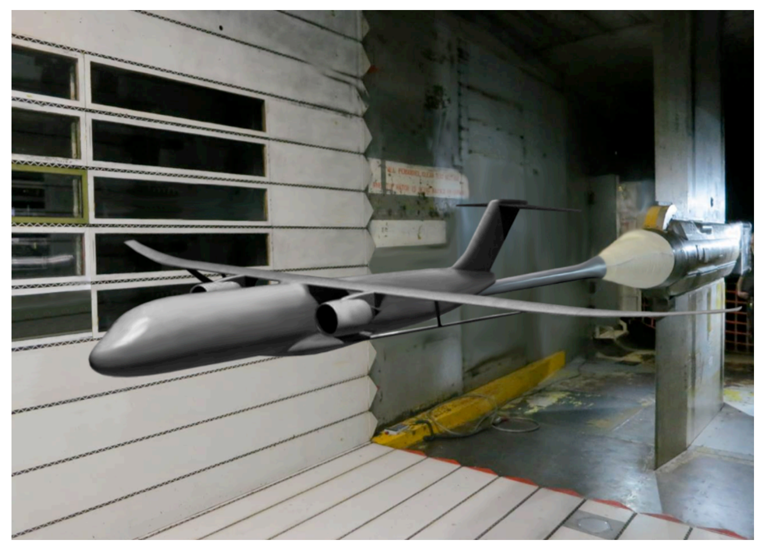
Truss-Braced Wing (TBW)
(Boeing NRA)

Problem
Conceptual design of Truss-Braced Wing (TBW) configuration during the N+3 phase 1 study showed significant potential of this technology to contribute to meeting NASA N+3 goals but also highlighted a significant uncertainty in wing weight estimates.
The TBW N+3 phase 2 study verified the structural estimates of the configuration with flutter constraints.
The next step, Phase 3, in looking at its potential to meet the NASA N+3 goals is to refine the design using higher fidelity tools and verify the performance through a high speed wind tunnel test.



Phase 3 Objectives and Approach
- Refine the design of a Mach 0.7 TBW
- Verify the TBW aircraft aerodynamic performance via wind tunnel test
- Identify challenges that require mitigation for an operational vehicle
- Generate a preliminary Mach 0.8 TBW design
- Exercise the VT TBW MDO environment and understand any differences between VT and Boeing Unlimited Rights Data

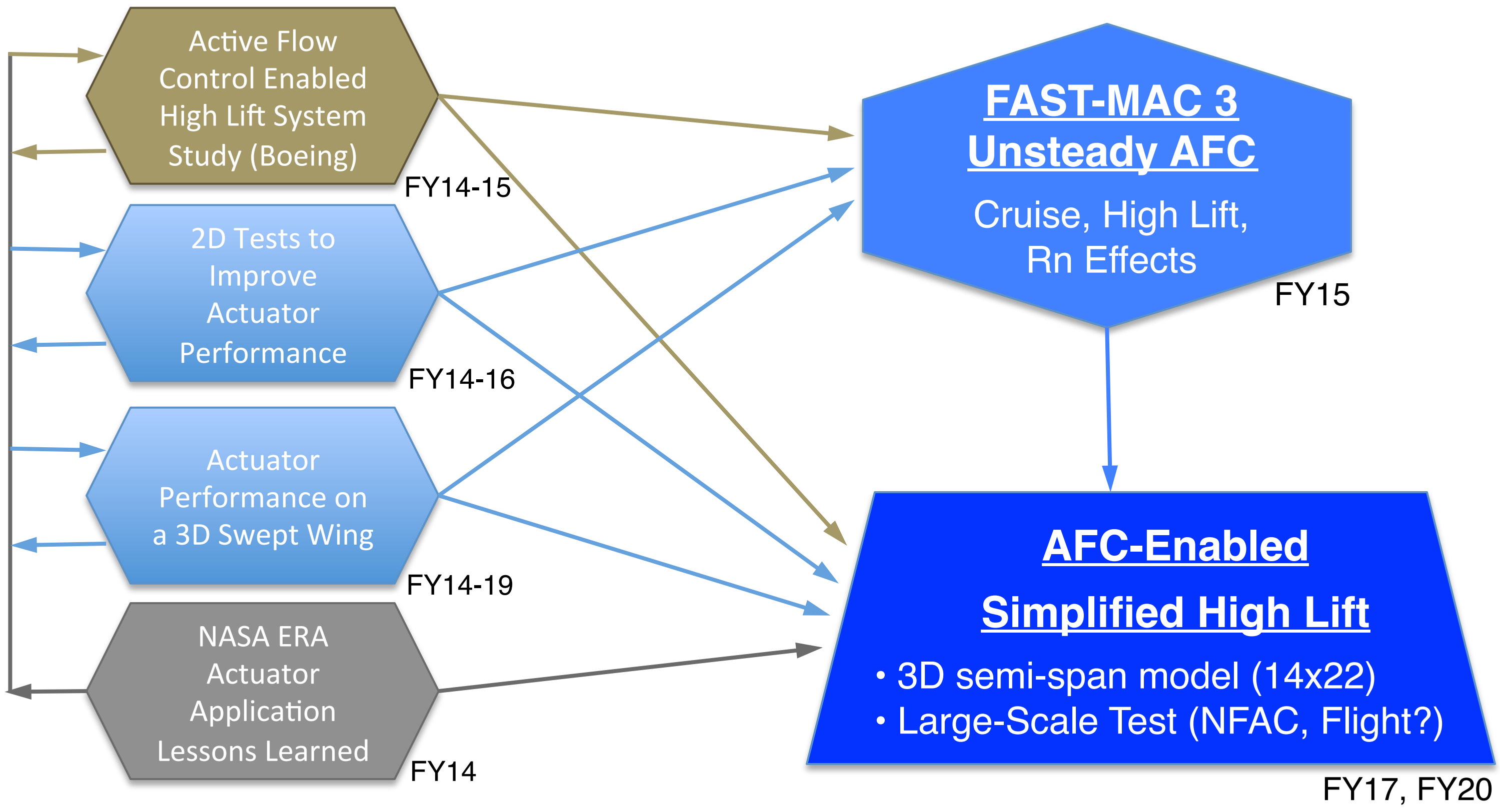
Significance
The TBW configuration remains a viable concept for reducing transport aircraft energy consumption. An aerodynamic performance test and evaluation are required to show that high-order aerodynamic design and analysis tools can be used to predict the performance of a low-interference truss braced wing.



- **Task Order signed 7/22/14 with Boeing**
- **Wind Tunnel Test planned for NASA ARC**
- **Complete by April 2016**

POC: Marty Bradley (Boeing); Eric Olson (NASA, TM); Rob Scott (NASA)

Active Flow Control Wing (AFCW)



Active Flow Control Wing (AFCW)
FAST-MAC

INTRODUCTION

High Reynolds number AFC techniques are being developed at NTF. The FAST-MAC semi-span model is being used to study Reynolds number scaling effects for several high-lift and cruise Circulation Control concepts. Testing is conducted over a wide range of Mach numbers and up to a chord Reynolds number of 30 million.

OBJECTIVES

- Evaluate different blowing geometries associated with a simplified high-lift system (Mach = 0.20)
- Explore the drag reduction potential of the blown flap in the stowed cruise position (Mach = 0.70 – 0.85)

APPROACH

Use a high-pressure air delivery station to supply four onboard model control valves which allow control of the mass flow along the span. Obtain force and moment data with a flow-through side-wall balance and use an ESP system to obtain pressures.

FAST-MAC 2.5 test currently in NTF. Objectives: 1) Evaluate the modifications to the Sidewall Mounted Support System that are necessary for improving the data repeatability and 2) Establish the FAST-MAC baseline without the flow-control plumbing system.

FAST-MAC 3 model with unsteady flow control (sweeping jets) is scheduled to complete by 9/30/15.

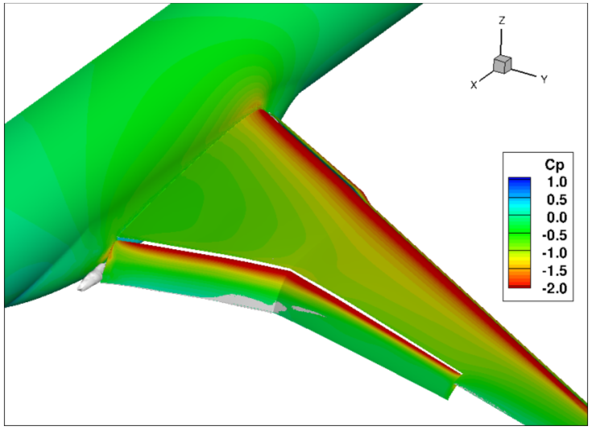
Active Flow Control Wing (AFCW)
AFC-Enabled High-Lift System Integration Study

Problem: High-lift sub-systems necessary to change the wing configuration from cruise to low-speed are complex and employ a significant number of parts to enable safe operation and often protrude into the flow and result in increased cruise drag.

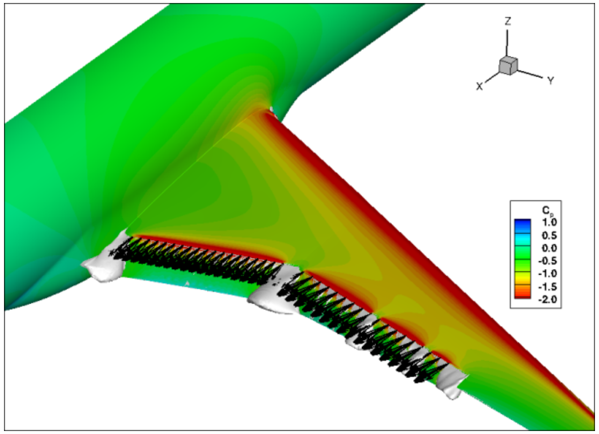
Objective: Demonstrate Active Flow Control (AFC) on a 3D, medium scale, relevant, high-lift system. Demonstrate AFC for <u>performance enhancement</u> on a relevant modern wing; the assessment of AFC <u>effectiveness and interactions</u> with wing components; and the development of a <u>simplified high-lift system</u> that can take advantage of recent advances in AFC.

Approach: Define baseline and AFC-enabled high-lift system semi-span models for wind tunnel testing.

Significance: Potential benefits of reducing complexities and cruise drag associated with a modern high-lift system without sacrificing aerodynamic or acoustic performance could be significant.



Conventional CRM HL, CL=1.68



Refined AFC-based SHL, 37 port system, CL=1.69

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

Objective

Achieve a vehicle-level net system benefit with a distortion-tolerant inlet/fan, boundary-layer ingesting propulsion system on a representative vehicle (TRL3)

Technical Areas and Approaches

Aerodynamic Configuration

– Novel configurations and installations

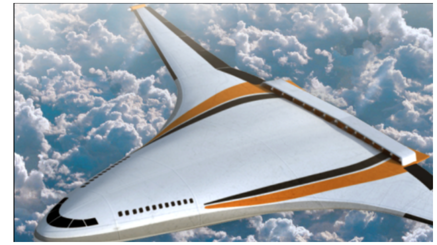
Distortion-Tolerant Fan

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

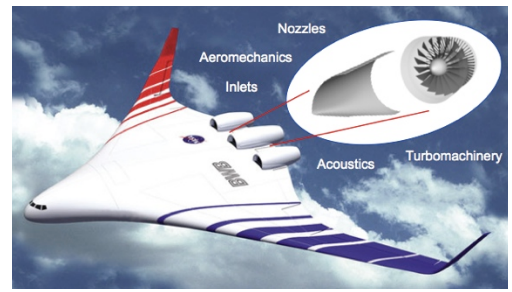
Benefit/Pay-off

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

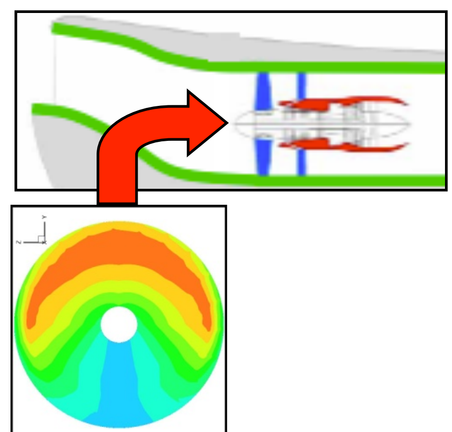
– Distortion-tolerant fan technology to achieve less than 2% fan efficiency & stall margin decrement (translate to fuel burn)

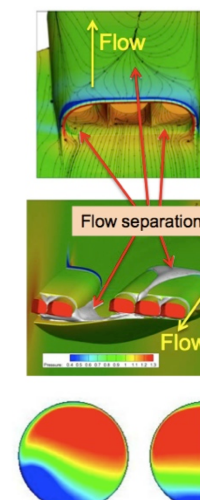


boundary-layer ingestion for drag reduction



distortion tolerance required for net vehicle system benefit





Integrated BLI Test in LaRC 14x22 Foot Subsonic Tunnel

(MIT D8 N+3 Configuration NRA)

Problem

Studies have shown 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 evaluated.

Objective

Experimentally assess the benefits of BLI for propulsive efficiency on the D8 configuration.

Approach

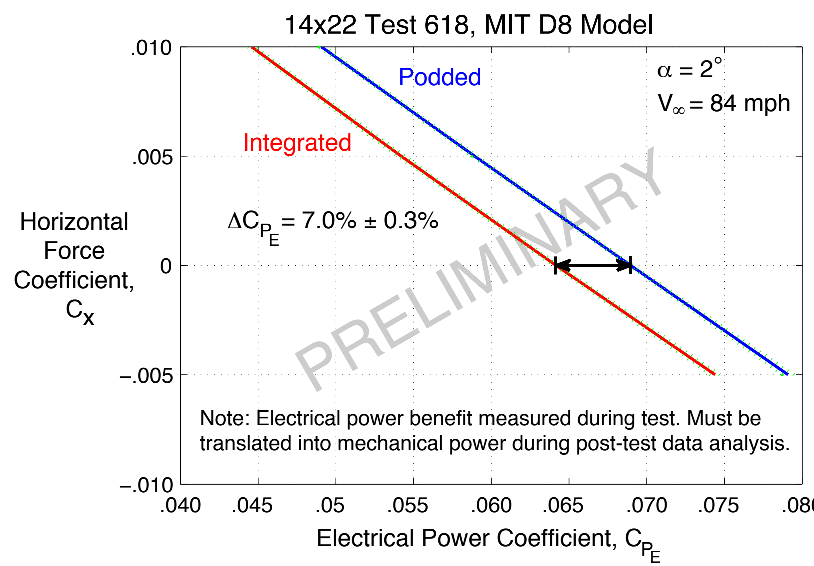
Obtain experimental data at simulated cruise conditions for both podded and integrated powered configurations on a 1/11th scale model and complement that dataset with computational analysis.

Results

Completed five weeks of testing on 9/8/14. Collected force & moment data, total pressure rake & 5-hole probe surveys of engine inlet and exit flows, surface pressures, and surface mini-tuft visualization. Preliminary results indicate a 7% reduction in electrical power required for the integrated configuration when compared with the podded configuration at a simulated cruise condition.

Significance

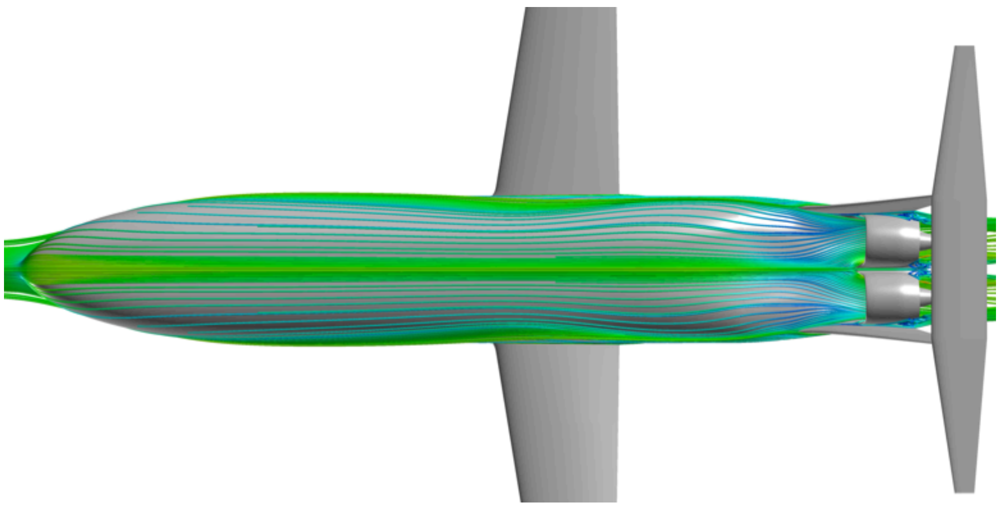
Preliminary analysis of experimental results confirm the potential benefits of BLI for drag/fuel burn reduction.

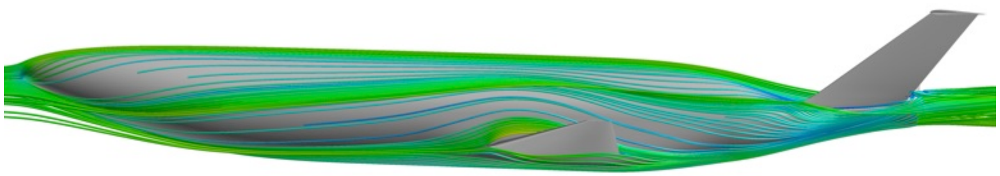


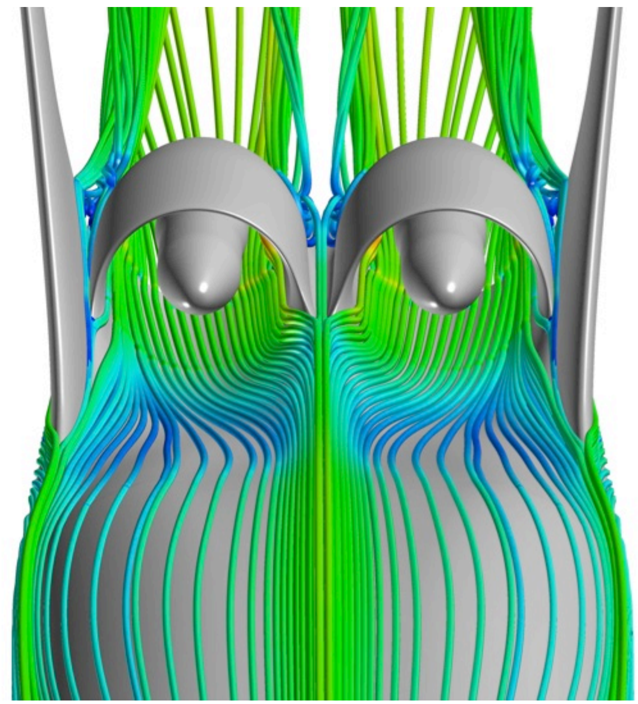
POC: Greg Gatlin (LaRC)

Integrated BLI System, Aerodynamic Configuration

- WT tests
  - Two tests in NASA 14x22
  - Testing at MIT facilities
- CFD
  - Podded & Integrated configurations
  - Wind tunnel wall effects
  - Evaluate config at transonic condition



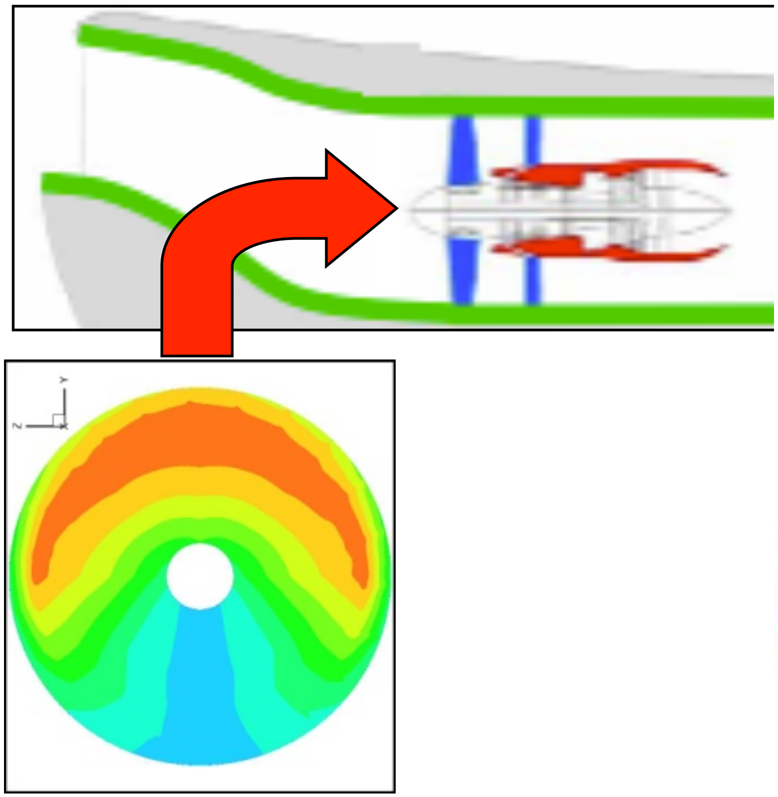




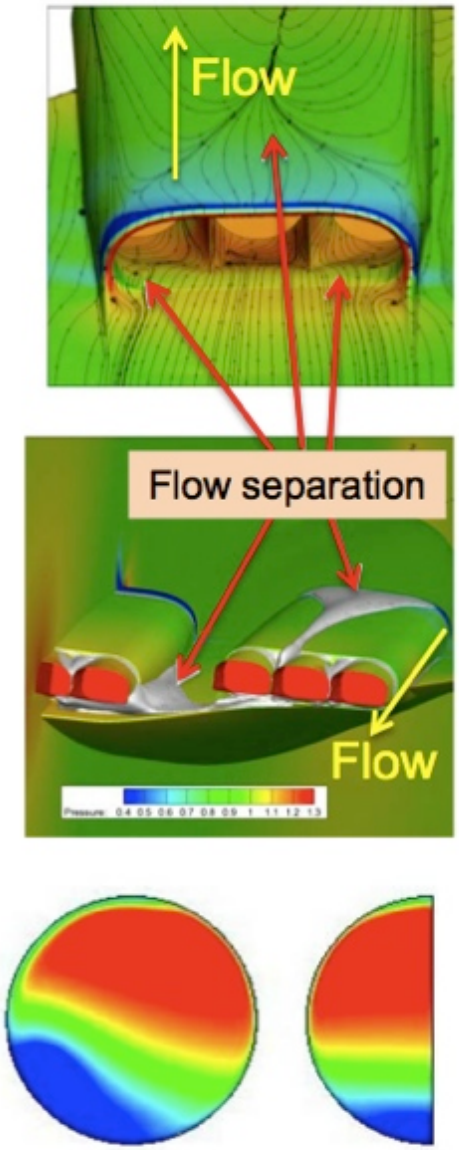
Integrated BLI System, Distortion-Tolerant Fan

Distortion-Tolerant Fan

– Integrated inlet/fan design
– robust design: unsteady and non-uniform inflow
– achieve less than 2% fan efficiency & stall margin decrement



Distortion tolerance required for net vehicle system benefit



Integrated BLI System, Advanced Propulsion Integration

Over the Wing Nacelle (OWN) Test with AFRL

- Annex No. 6 to an existing Interagency Umbrella Agreement for “Collaborative Research and Testing of Cruise-Efficient Advanced Hybrid Wing Body Configuration with Over Wing Nacelle Engine Installation” (signed 5/6/14).
- The annex is “for the purpose of developing technologies and aircraft configurations for efficient transonic cruise.“
  - Concept developed by Lockheed Martin for the AFRL
  - Over Wing Nacelle propulsion integration scheme on an Advanced Hybrid Wing Body (AHWB) platform.
  - The unique AHWB propulsion airframe integration enables installation of ultra-high bypass ducted and unducted propulsion systems.
- Approach: Conduct wind-tunnel test of the AHWB in the National Transonic Facility to validate CFD predictions of the vehicle's performance at transonic cruise conditions and to validate the Over-Wing-Nacelle engine performance.

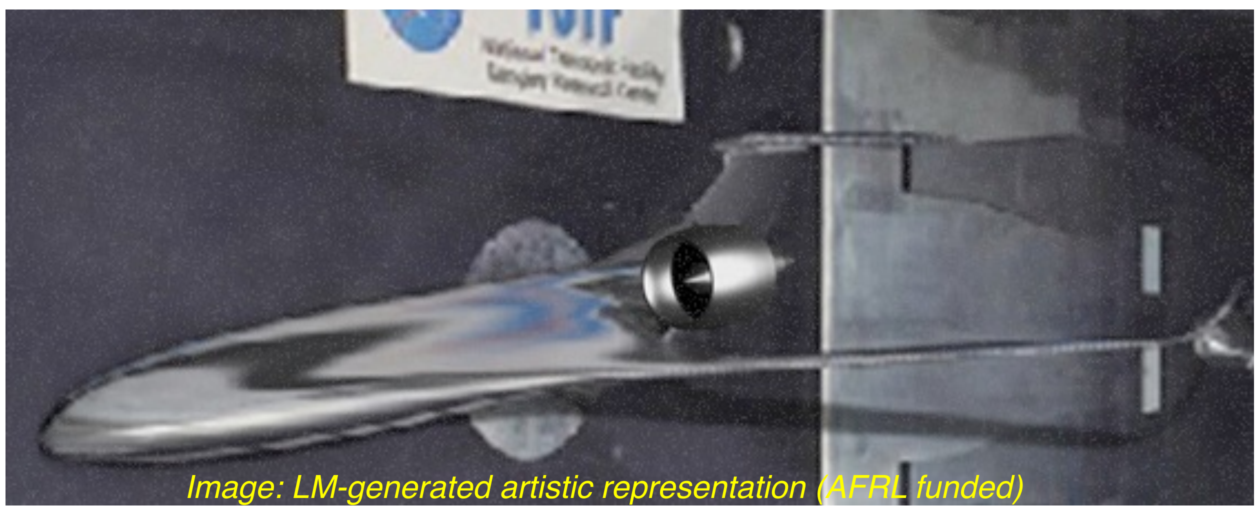


Image: LM-generated artistic representation (AFRL funded)

AATT Project Structure

Project Management

Project Manager	*Rubén Del Rosario, GRC*
Deputy Project Manager	*Scott Anders, LaRC*
Assoc. PM for Project Execution	*Stephen Helland, GRC*
Assoc. PM for Technology,	*Nateri Madavan, ARC*
Assoc. PM for Integrated Testing	*Gary Martin, AFRC*
NRA Manager	*Kimlan Pham, GRC*

ARD Interface

Project management officials will serve as project liaison to their respective Centers

Systems Analysis & Integration

Lead	William Haller, GRC
Assoc. Lead	Mark Guynn, LaRC

Project Planning & Control Team

Business Manager, Lead Resource Analyst	*Susan Crawford, GRC*
Resource Analysts	*Rebecca Miani, AFRC*
	Sandra Ramirez, ARC
	Susan Price, LaRC
Schedulers	*Amanda Eberwine, LaRC*
Risk Manager	*Katherine Harcula, GRC*

Project Level

Subproject Level

High Aspect Ratio Wing
<TC2.1>
Subproject Manager
Susan Wilz, LaRC
Subproject Technical Leads
Sally Viken, LaRC
Karen Taminger, LaRC

Aircraft Noise Reduction
<TC3.1>
Subproject Manager
Hamilton Fernandez, LaRC
Subproject Technical Leads
Douglas Nark, LaRC
Brian Fite, GRC

Integrated BLI
<TC6.1>
Subproject Manager
Craig Robinson, GRC
Subproject Technical Lead
Sally Viken, LaRC
BLI2DTF Task Manager
Tony Shook, GRC

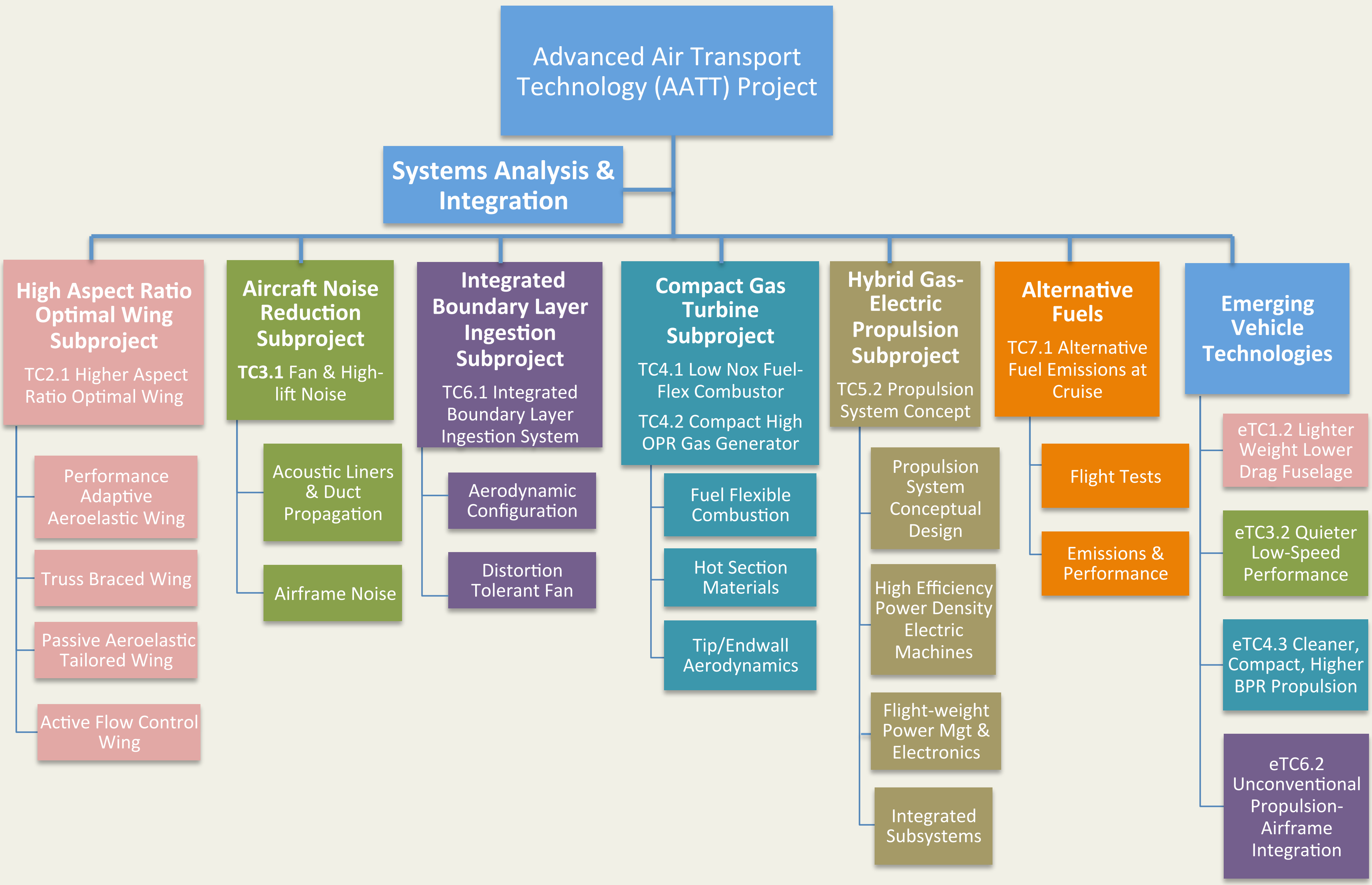
Compact Gas Turbine
<TC 4.1, 4.2>
Subproject Manager
Jim Walker, GRC
Subproject Technical Leads
Michael Hathaway, GRC
Angela Surgenor, GRC
Sue Draper, GRC

Hybrid Gas-Electric Propulsion
<TC 5.2>
Subproject Manager
Amy Jankovsky , GRC
Subproject Technical Lead
Cheryl Bowman, GRC

Alternative Fuels
<TC 7.1>
Subproject Manager
Rubén Del Rosario, GRC
Subproject Technical Lead
Bruce Anderson, LaRC

Sub-project will also provide oversight to key non-TC related activities in the portfolio (work for future TCs)

AATT Project WBS



Performance Adaptive Aeroelastic Wing (PAAW)

Tasks:

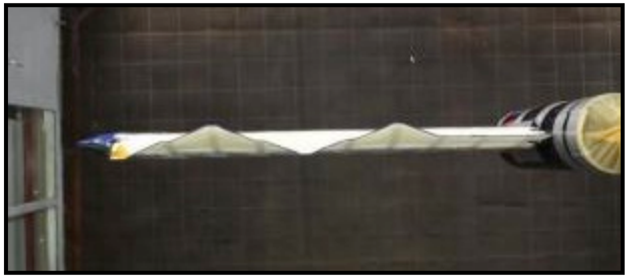
- Develop coupled modeling capability to integrate aerodynamics, aeroelasticity, flight dynamics, and control into a MDAO framework. [ARC]
- Conduct optimization to identify design options for Performance Adaptive Aeroelastic Wing (PAAW) technology that reduce complexity and maintain weight penalty neutral or negative. [ARC, LaRC]
- Develop control solutions for drag reduction guidance, real-time drag minimization during maneuvers, ASE mode suppression and load alleviation control, and aircraft multi-objective flight control. [AFRC, ARC]
- Optimize control effector designs, incorporating structural design, lightweight actuators & sensors, design, build & bench model test [LaRC]
- Conduct wind tunnel testing of flexible wing model with distributed variable camber control effector for cruise CL, high lift, and active control for drag minimization and ASE mode suppression at appropriate speeds [ARC, LaRC]
- Conduct flight testing for 6 dof evaluation of control laws to validate in-flight drag reduction and ASE mode suppression control [AFRC]
- Conduct piloted simulation study to evaluate effectiveness of PAAW flight control technology on closed-loop response of full–scale aircraft and pilot handling quality [ARC]

Distributed Control Effectors

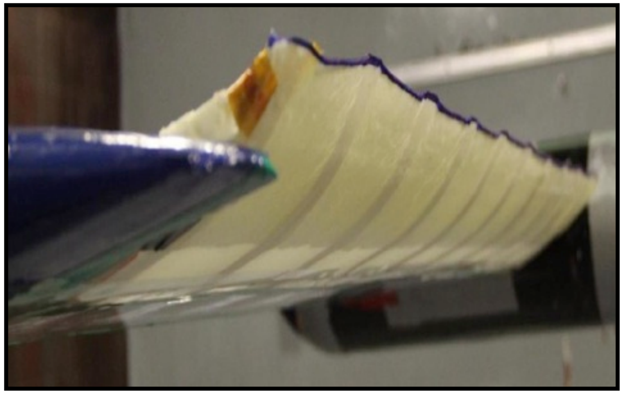
Goal: Optimize control effectors for weight vs. control authority; design bench test article to assess structural performance and integration

Technologies included:

- Control optimization analysis tool development to assess trade-offs between structural weight and control authority, seeking to understand optimal number and size of control effectors along trailing edge of high aspect ratio wings
- Design and fabricate bench model to assess structural design integration of actuators and sensors
  - Piano key (span-wise distribution)
  - Piano key with flexible skins
  - Variable camber (span-wise distribution with multiple joints on each rib)
  - Compliant rib (continuous span-wise and chord-wise distribution)
- Flexible skin development to fill gaps between adjacent flap segments – work on hold until aerodynamic assessment can be completed to quantify drag reduction benefit of skins vs. no skins
- Integrate fiber optics onto bench model to measure flap shape in real time to feed back into control laws



"Piano Key" Design

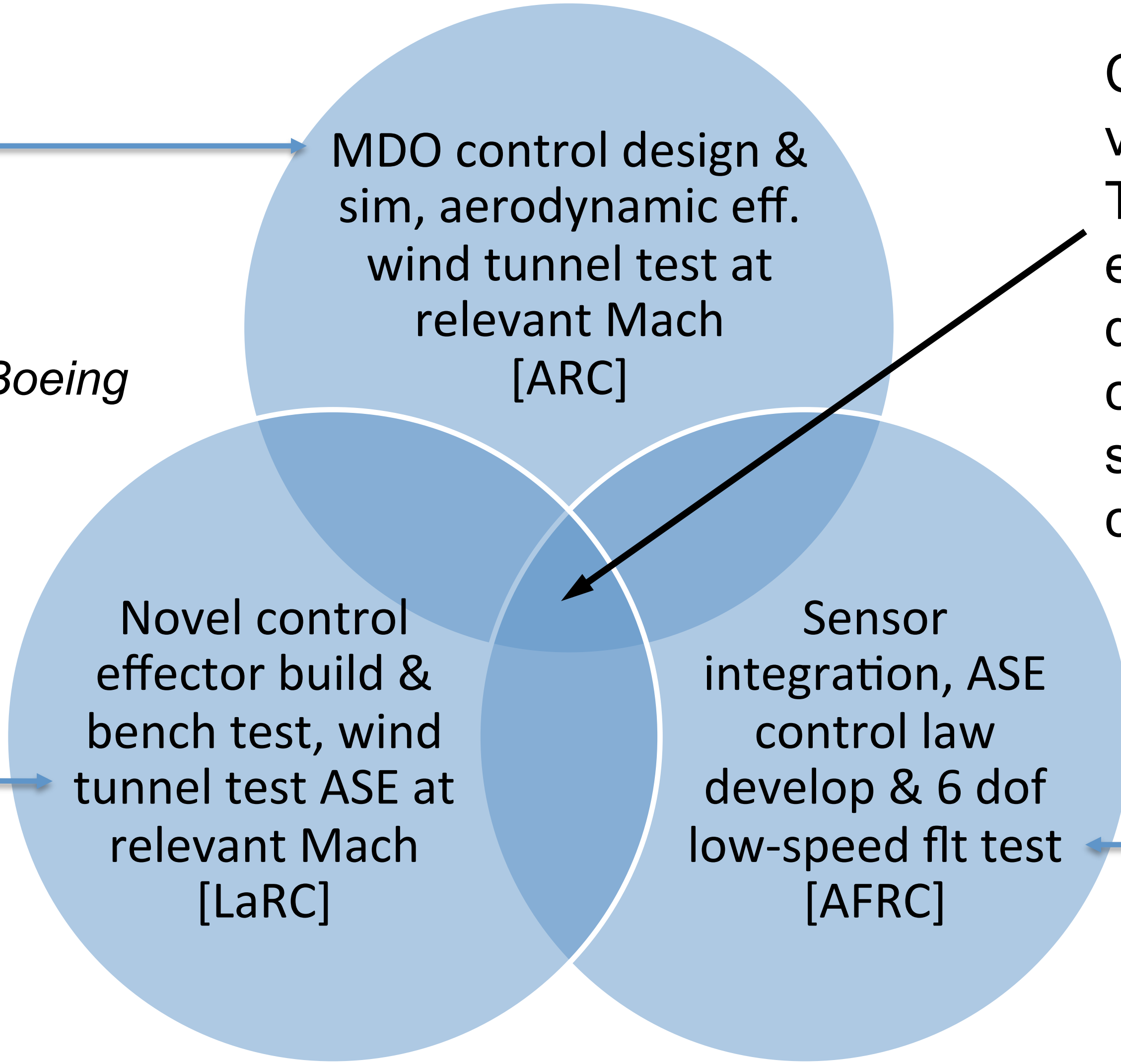


"Compliant Rib" Design

LaRC: Dan Moerder, Ron Busan, Jim Moore, Mia Siochi, Jason Moore

Performance Adaptive Aeroelastic Wing (PAAW)
Areas of Expertise

NRA: Boeing



Common reference vehicles (CRM, TBW) and control effectors (piano key, distributed variable camber); data shared across centers

NRA: Univ. of MN

Lightweight Adaptive Aeroelastic Wing for Enhanced Performance Across the Flight Envelope

(University of Minnesota NRA)

PI: Balas, Gary (U. Minn.)
Co-Is: Danowsky, Brian (Systems Tech., Inc.), Farhat, Charbel (CMSOFT, Inc.), Hollman, Jeremy (Aurora Flt Sciences Corp.), Kapania, Rakesh (VPI & SU), Schmidt, David (D.K. Schmidt & Assoc.)

Key Points of Research:

- 5-year activity, FY15-FY19, involving design, build and low speed flight testing of PAAW concepts.
- Significantly reduces weight through structural design optimization and use of active flutter suppression and gust load alleviation.
- Actively adapts its shape over the entire flight envelope to minimize drag over a range of cruise and off-nominal conditions and provides high-lift performance for takeoff and landing.
- Extends Multidisciplinary Design, Analysis, and Optimization (MDAO) technology to include combined aerodynamic wing shape optimization with optimization of its actively controlled lightweight structure, control laws, and sensor/actuator placement.
- Closed-loop aeroservoelastic dynamics in a formal multidisciplinary design optimization framework. This is a critical requirement for achieving light weight in an aerodynamically efficient wing. Optimization parameters will include aeroelastic control laws and spatial distribution of sensors and conformal actuators, in addition to flight condition-adaptive wing geometry and advanced structural concepts.
- "Research through Development" paradigm drives a sequence of three increasingly complex flight tests in years two through four.
    - Scaled "mini-MUTT" UAV tests at Univ. of Minn.
    - Wind tunnel test in LaRC 12-ft Low Speed Tunnel to test actuators and control surfaces.
    - Flight test of new structurally-optimized wings with active flutter suppression and gust load alleviation on AFRC's X-56 aircraft.

Integrated Adaptive Wing Technology Maturation
(Boeing Inc. NRA)

PI: Kamal Shweyk (Boeing Inc.)
Co-Is: James Urnes, Brian Foist, Ed Whalen, and 5 others from Boeing Inc.

Key Points of Research:

- 4-year activity, FY15-FY18, involving design, build and transonic wind tunnel testing.
- Develops integrated adaptive wing technology solution for real-time drag minimization in-flight by simultaneously controlling spanwise and chordwise wing shape
- Provides integrated ASE flutter suppression and active alleviation control of gust and maneuver loads
- Evaluates concept by transonic aeroelastic wind tunnel test in NASA TDT
- Includes state-of-the-art robust and adaptive control methods with integrated novel control effectors, advanced actuation concepts, and advanced sensor technology
- Potentially utilizes both active flow control and shape morphing devices as advanced novel control effector concepts
- Completes trade study on transonic wing platform at end of first year to down-select to preferred concept
- Provides clear path towards technology transfer and commercialization of NASA research, including EcoDemonstrator flight test of selected concept by 2020
- Leverages Boeing airframe product development expertise in commercial transport applications
- Employs high fidelity CFD analysis to assess concepts and transonic wind tunnel test for validation (3 weeks in NASA TDT)
- Utilizes NASA-sponsored Common Research Model (CRM) modern transonic wing design to ensure relevance
- Leverages NASA FOSS sensor system as potential integrated sensor solution

Passive Aeroelastic Tailoring for Next-Generation High Aspect Ratio Wings

(Aurora Flight Sciences NRA)

PI: Mr. Benjamin Smith (Aurora Flight Sciences)
Co-Is: Dr. Carlos Cesnik (UM), Dr. Joaquim Martins (UM), Dr. Graeme Kennedy (GA Tech)
NASA Tech Monitor: Carol Wieseman (LaRC)

Schedule: Phase 1 – structural optimization – Nov. 2014 – Nov. 2015
Phase 2 – detailed drawings and test article fabrication – Dec. 2015 – Jan. 2017
Phase 3 – GVT & static loads testing – Feb. 2017 – Nov. 2017

Key Points of Research:

- Objective: design, build and test a passive aeroelastic tailored high aspect ratio wing structure optimized for minimum weight without impacting aeroelastic (flutter) performance
- Baseline is a modified Common Research Model (aspect ratio increased by 50% to 13.5)
- Two optimization approaches compared in phase 1: tow steered skins and topology optimized wing box
- Downselected optimization approach will be fabricated into a 10-12 ft. semi-span structural test article
- Jig shape inverse design methods are considered in the design and manufacturing to ensure flight loading correlates with existing high fidelity CFD results
- Test article will be GVT and static load tested and data will be used to validate analytical models

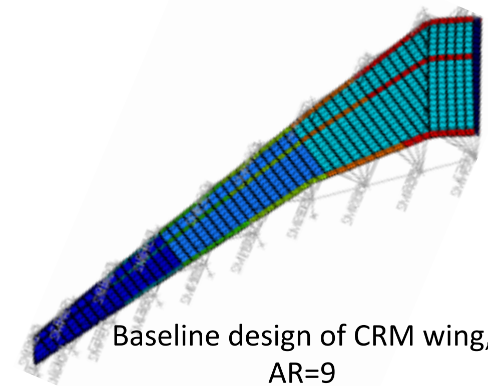
- This effort will substantially improve our understanding of the role nonconventional tailoring schemes can play in improving subsonic transport wing efficiency, and various issues encountered during the manufacturing process.

Passive Aeroelastic Tailored Wing Structural Design

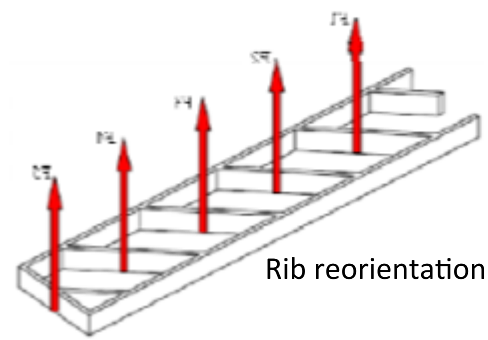
<u>Goal</u>: Explore design space to enable aeroelastically tailored wing structures to increase aspect ratio (from 9 to 14 or 20) and reduce weight by 20-25% without impacting aeroelastic performance

<u>Technologies included:</u>

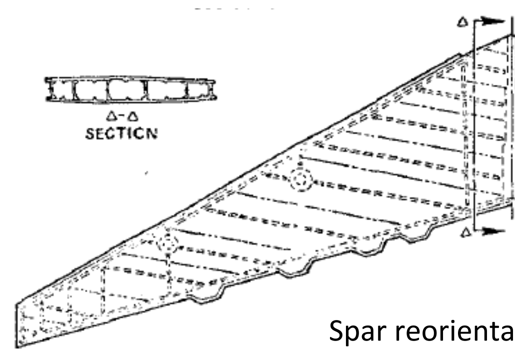
- Gen1 passive aeroelastic tailored wing structure being developed at LaRC based on Common Research Model (AR=9); Gen2 uses same strategy for weight reduction while increasing AR to 14
- Aeroelastic tailoring of materials and structures are being considered for broad design space
  - Bend/twist coupling can be achieved using internal structure reorientation
  - Curvilinear stiffeners, blending of spars and ribs enable modification of moments of inertia (I or J)
  - Functionally graded or tow steered composite engineered materials enables changing moduli (E or G)
- Design/analysis tools
  - Parametric studies (in-house)
  - Topology optimization (in-house/Univ. of Bath, Dr. Alicia Kim)
  - Curvilinear stiffener and SpaRibs (VA Tech, Dr. Rakesh Kapania)
  - Multidisciplinary optimization (Univ. of Michigan, Dr. Quim Martins)
  - Analytical evaluations being performed in NASTRAN
- Next: build structural test article for static loads and ground vibration testing to validate FEM analyses [NRA]



Baseline design of CRM wing, AR=9



Rib reorientation

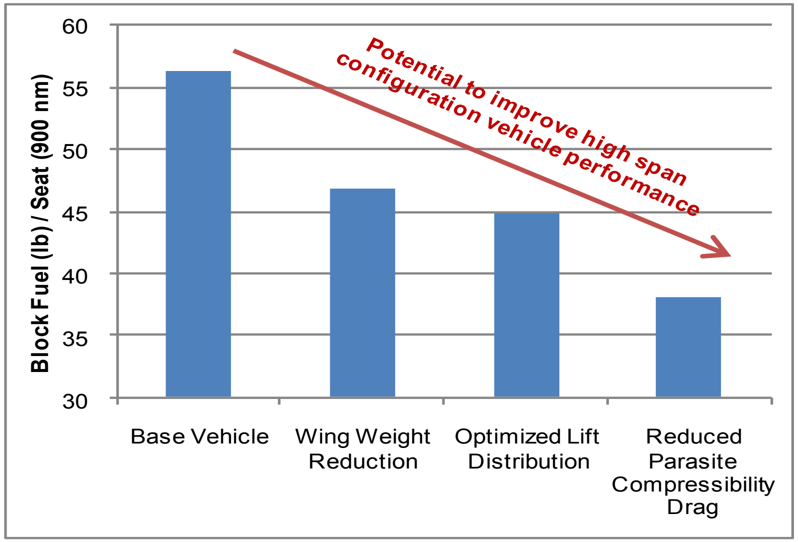


Spar reorientation

Bret Stanford, Carol Wieseman, Christine Jutte, Jim Moore

Truss Braced Wing (TBW)

- Truss braced wings enable very high aspect ratio wings.
- Must account for coupled aerodynamics, structures, materials, propulsion, control, and airport compatibility.
  - Making this wing aerodynamically effective while controlling weight is key to enabling this high L/D configuration.
  - Detailed finite element model that is validated against test data is required.
  - Aerodynamics at the Mach 0.7 cruise condition and off design requires additional optimization and experimental validation.



Active Flow Control Wing (AFCW)
AFC-Enabled High-Lift System Integration Study (Boeing SMAAART Task)

PI: Mr. Peter Hartwich (The Boeing Company)

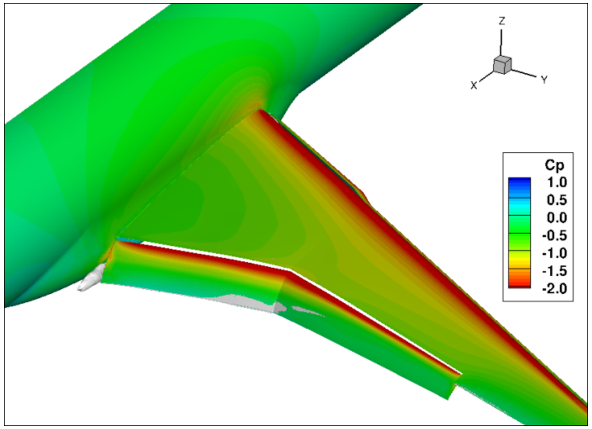
NASA Tech Point of Contact: John Lin (LaRC)

SMAAART Contract Phase 1, AFC-Enabled High-Lift System Integration Study, which completed June 2014 concluded that:

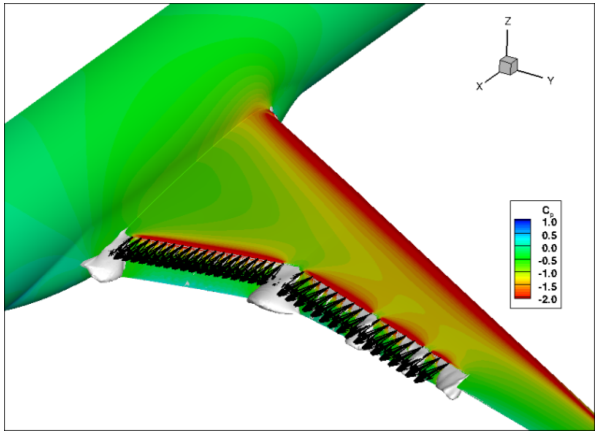
- 0.6% fuel-burn benefit if AFC-enabled SHL is achievable with 16 lbm/s (@80 psia)
- However, it was estimated that the AFC system considered requires 72 lbm/s (@80 psia)

SMAAART Contract Phase 2, Refined AFC-Enabled High-Lift System Integration Study, will use CFD to look for performance gains that are expected by exploring the design space (flap chord, AFC spacing, actuator geometry, etc.). This is a 12-month SMAAART task awarded 9/19/14. Two <u>unrestricted rights</u> geometries will come out of this study:

- A Boeing-funded CRMHL configuration
- A refined AFC-based SHL configuration



Conventional CRM HL, CL=1.68



Refined AFC-based SHL, 37 port system, CL=1.69

TC6.1: Boundary Layer Ingesting Inlet - Distortion Tolerant Fan (BLI^{2}DTF) Aerodynamic Design Finalized

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

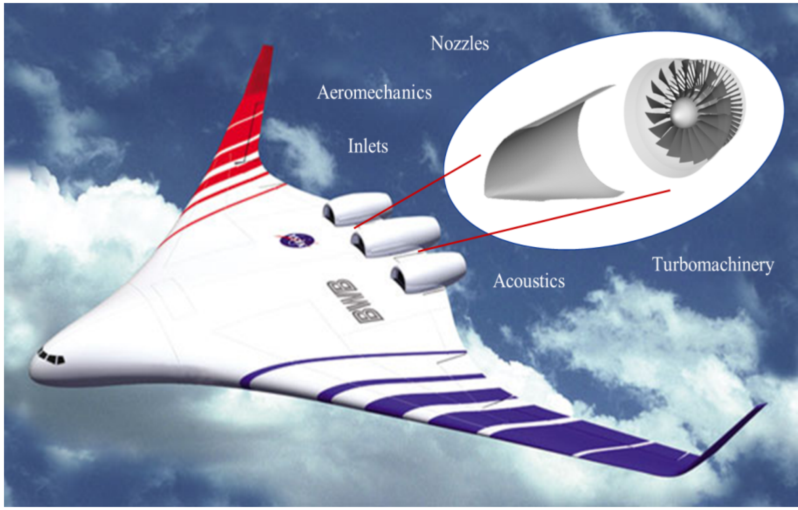
Design, analyze, and fabricate a boundary layer ingesting inlet coupled with a 22" diameter distortion-tolerant fan to test in the NASA GRC 8X6 transonic wind tunnel to demonstrate less than 2% fan efficiency and stall margin and substantiate the system study benefits.

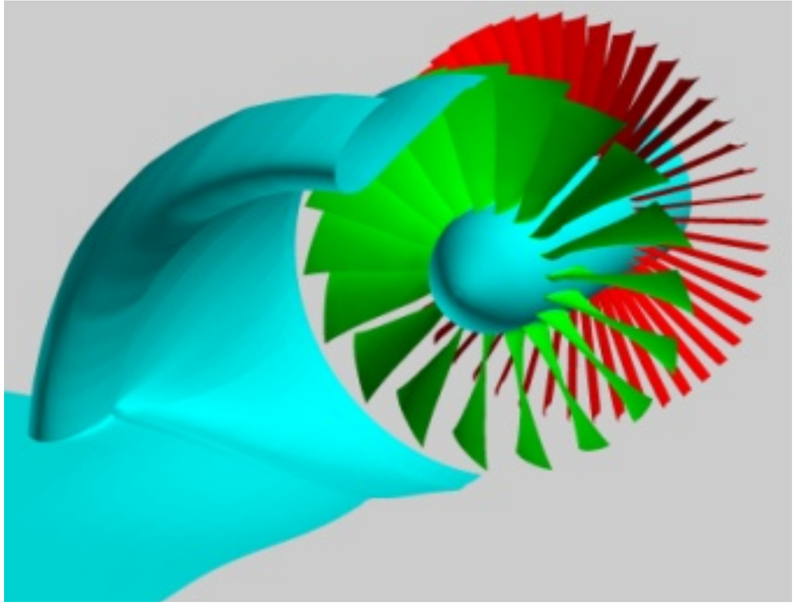
Results

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