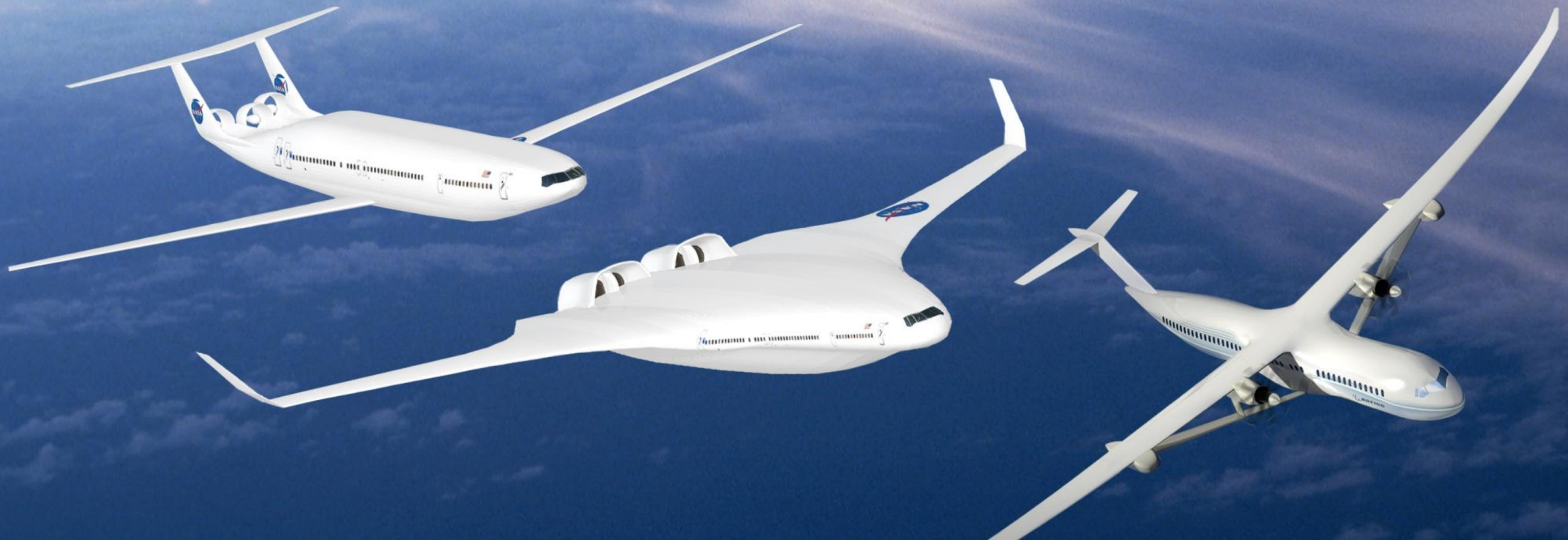
National Aeronautics and Space Administration

Overview of Subsonic Fixed Wing Project: Technical Challenges for Energy Efficient, Environmentally Compatible Subsonic Transport Aircraft

Mr. Bill Haller, Technical Lead
Systems Analysis & Integration Sub-project
Subsonic Fixed Wing Project



3rd NASA Glenn Propulsion Control & Diagnostics Workshop
Cleveland, OH
February 28, 2012

Outline

- Project Context within NASA Aeronautics
- Project Mission and Objectives
- Goals/Metrics
- Goal-Driven Advanced Concept Studies
- Subsystem Concepts and Enabling Technologies
- Concluding Remarks

NASA Aeronautics Programs

and where the Green Aviation emphasis is



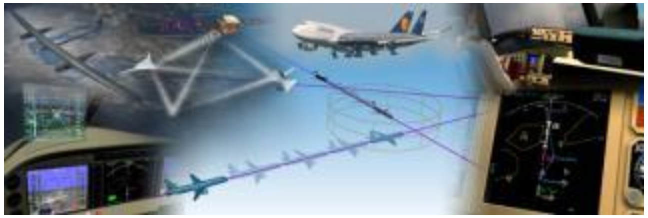

Fundamental Aeronautics Program

Conduct fundamental research that will produce innovative concepts, tools, and technologies to enable revolutionary changes for vehicles that fly in all speed regimes.

Integrated Systems Research Program

Conduct research at an integrated system-level on promising concepts and technologies and explore/assess/demonstrate the benefits in a relevant environment



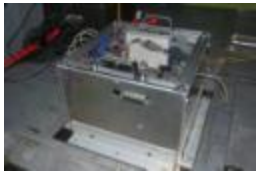


Airspace Systems Program

Directly address the fundamental ATM research needs for NextGen by developing revolutionary concepts, capabilities, and technologies that will enable significant increases in the capacity, efficiency and flexibility of the NAS.


Aviation Safety Program

Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to improve the intrinsic safety attributes of current and future aircraft.





Aeronautics Test Program

Preserve and promote the testing capabilities of one of the United States' largest, most versatile and comprehensive set of flight and ground-based research facilities.


The NASA Subsonic Fixed Wing Project

Explore and Develop Tools, Technologies, and Concepts for Improved Energy Efficiency and Environmental Compatibility for Sustained Growth of Commercial Aviation

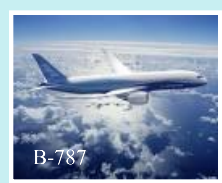
Objectives

- Prediction and analysis tools for reduced uncertainty
- Concepts and technologies for dramatic improvements in noise, emissions and performance

Relevance

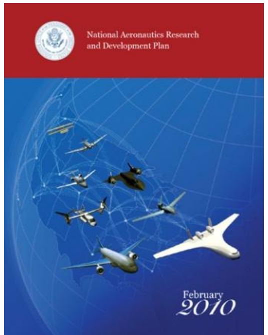
- Address daunting energy and environmental challenges for aviation
- Enable growth in mobility/aviation/transportation
- Subsonic air transportation vital to our economy and quality of life

Evolution of Subsonic Transports

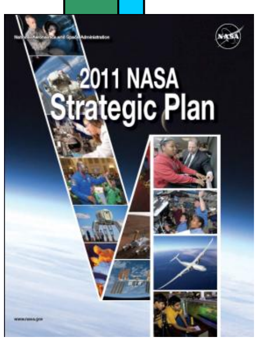


1903 — 1930s — 1950s — 2000s

SFW Strategic Framework/Linkage



Strategic Thrusts	Strategic Goals	System Level Metrics
1. Energy Efficiency	1.1 Reduce the energy intensity of air transportation	• Fuel Burn • Energy Efficiency
2. Environmental Compatibility	2.1 Reduce the impact of aircraft on air quality around airports 2.2 Contain objectionable aircraft noise within airport boundaries 2.3 Reduce the impact of aircraft operations on global climate	• LTO NO_X Emissions • Other LTO Emissions • Aircraft Certification Noise • Cruise NO_X Emissions • Life-cycle CO_2e per Unit of Energy Used



NASA Subsonic Transport System Level Metrics

…. technology for dramatically improving noise, emissions, & performance

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	-71 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-33%	-50%	-60%

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

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

‡ CO_2 emission benefits dependent on life-cycle CO_{2e} per MJ for fuel and/or energy source used

FAA/CLEEN → NASA/ERA → NASA/SFW

SFW Strategic Thrusts & Technical Challenges

Energy Efficiency Thrust *(with emphasis on N+3)*
Develop economically practical approaches to improve aircraft efficiency

Environmental Compatibility Thrust *(with emphasis on N+3)*
Develop economically practical approaches to minimize environmental impact

Cross-Cutting Challenge *(pervasive across generations)*

Energy & Environment

TC1 - Reduce aircraft drag with minimal impact on weight (aerodynamic efficiency) — Drag

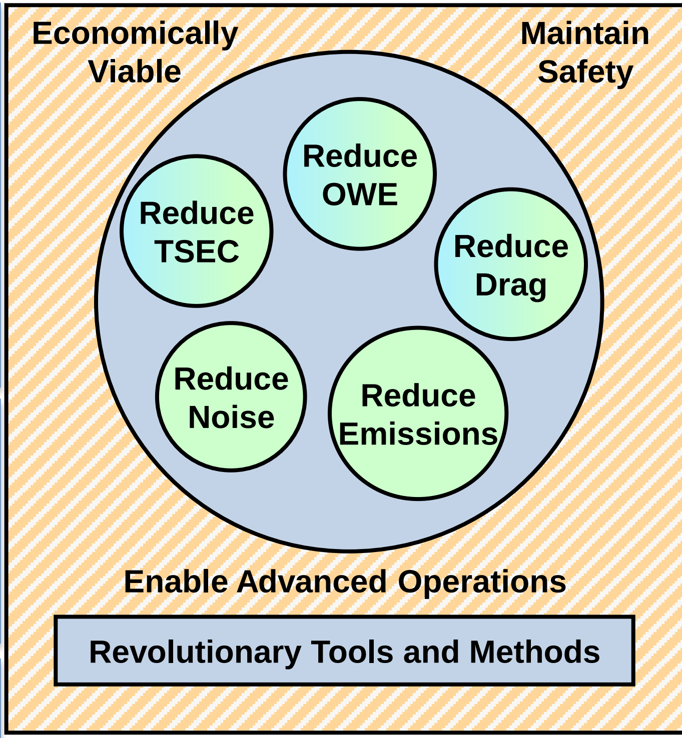
TC2 - Reduce aircraft operating empty weight with minimal impact on drag (structural efficiency) — Weight

TC3 - Reduce thrust-specific energy consumption while minimizing cross-disciplinary impacts (propulsion efficiency) — TSEC

TC4 - Reduce harmful emissions attributable to aircraft energy consumption — Clean

TC5 - Reduce perceived community noise attributable to aircraft with minimal impact on weight and performance — Noise

TC6 - Revolutionary tools and methods enabling practical design, analysis, optimization, & validation of technology solutions for vehicle system energy efficiency & environmental compatibility — Tools



Goal-Driven Advanced Vehicle Concept Studies (N+3)
purpose/approach

- Leverage external and in-house expertise
- Stimulate thinking to determine potential aircraft solutions to address significant performance, environmental, and operations issues of the future
- Identify advanced airframe and propulsion concepts and corresponding enabling technologies for commercial aircraft anticipated for 2030-35 EIS (market conditions permitting)
- Identify key driving technologies (traded at the system level)
- Prime the pipeline for future, revolutionary aircraft technology developments
- Use to inform and define SFW research portfolio and investments

Goal-Driven Advanced Vehicle Concept Studies (N+3)
summary

Advanced concept studies for commercial subsonic transport aircraft for 2030-35 EIS

Boeing, GE, GA Tech

154Pax
3500nm
M.70

NG, RR, Tufts, Sensis, Spirit

120Pax
1600nm
M.75

GE, Cessna, GA Tech

20Pax
800nm
M.55

MIT, Aurora, P&W, Aerodyne

354Pax
7600nm
M.83

180Pax
3000nm
M.74

Trends:

- *Tailored/Multifunctional Structures*
- *High AR/Active Structural Control*
- *Highly Integrated Propulsion Systems*
- *Ultra-high BPR (20+ w/ small cores)*
- *Alternative fuels and emerging hybrid electric concepts*
- *Noise reduction by component, configuration, and operations*

NASA, VA Tech, GT

305Pax
7730nm
M.85

NASA

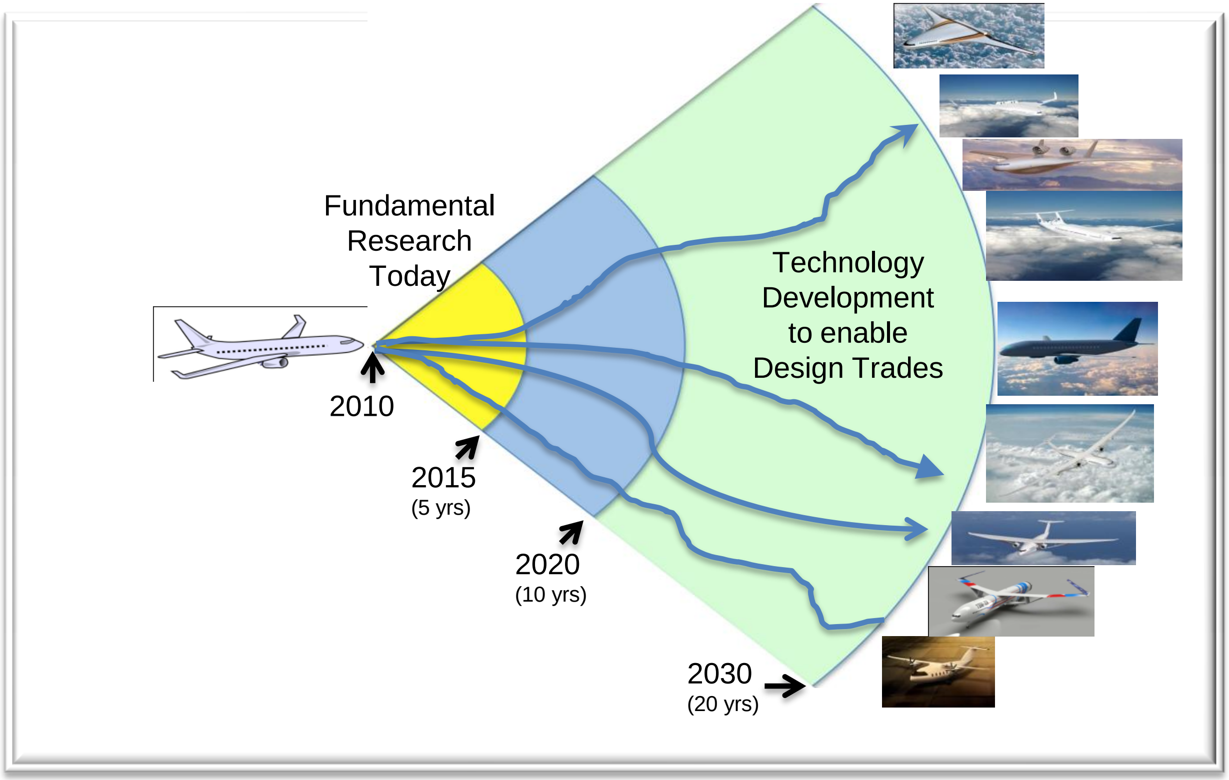
300Pax
7500nm
M.84

Advances on multiple fronts are required to meet national goals – many broadly applicable features, some uniquely enabling.

N+3 Subsystem Concepts and Enabling Technologies

many broadly applicable, some uniquely enabling

- N+3 Subsystem Concepts to guide Fundamental Research
  - Informed by technology trends identified from advance vehicle concepts
  - Technology collectors provide vision and focus for fundamental research needed today to enable far-term outcomes/products
  - Far-term outcomes/products will change with time
  - Fundamental Research portfolio robust to many possible futures
  - Outcomes/products along the way may have near/mid-term impact



SFW N+3 Subsystem Concepts

broadly applicable . . . .






<u>N+3 Opportunities from Goal-Driven Advanced Concepts</u>

1. Tailored Fuselage
2. High AR Elastic Wing
3. Quiet, Simplified High-Lift
4. High Efficiency Small Gas Generator
5. Hybrid Electric Propulsion
6. Propulsion Airframe Integration

<u>Near Term/Cross-cutting</u>

7. Alternative Fuels
8. Tool Box (MDAO, Systems Modeling, Physics-Based)



Tailored Fuselage

opportunity to reduce large structural weight, large wetted area

Objective

Drag | Weight | TSEC | Clean | Noise

Explore and develop technologies to enable direct structural weight and skin friction reduction

Approach/Challenges

Tailored Load Path Concepts & Design

- Curvilinear metallic stiffeners
- Tow-steered carbon fibers

Designer Materials

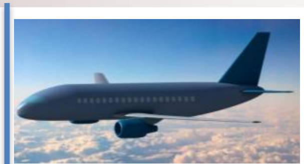
- Functionally graded metallics
- CNT hybrid composites

Turbulent Skin Friction Drag Reduction

- Direct skin friction drag reduction
- Fuselage wetted area reduction via flow control

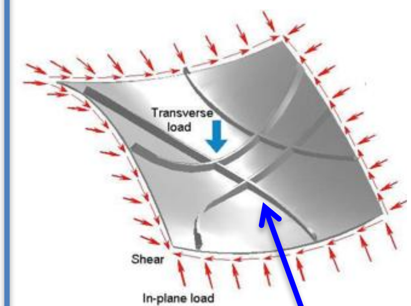
Benefit/Pay-off

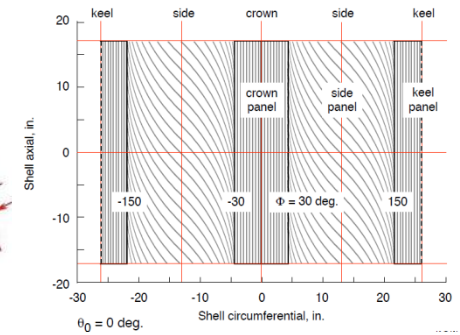
- 25% fuselage structural weight reduction
- 10% fuselage turbulent boundary-layer drag reduction



large structure
large area

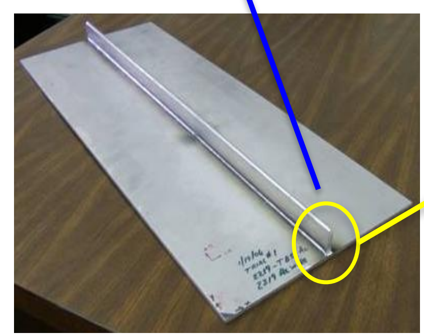
conventional and unconventional

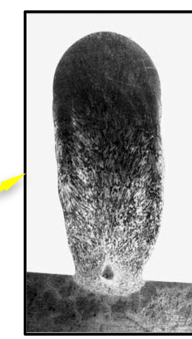




metallic & composites

tailored load path design/build
tailored materials





High Aspect Ratio Elastic Wing

changing the drag/weight trade space

Objective

Drag | Weight | TSEC | Clean | Noise

Explore and develop technologies to enable lightweight high aspect ratio wings

Approach/Challenges

Tailored Load Path Concepts & Design

Designer Materials

Active Structural Control

- Structural adaptation to reduce loads, suppress flutter, and maintain optimal aerodynamics

Aerodynamic Shaping

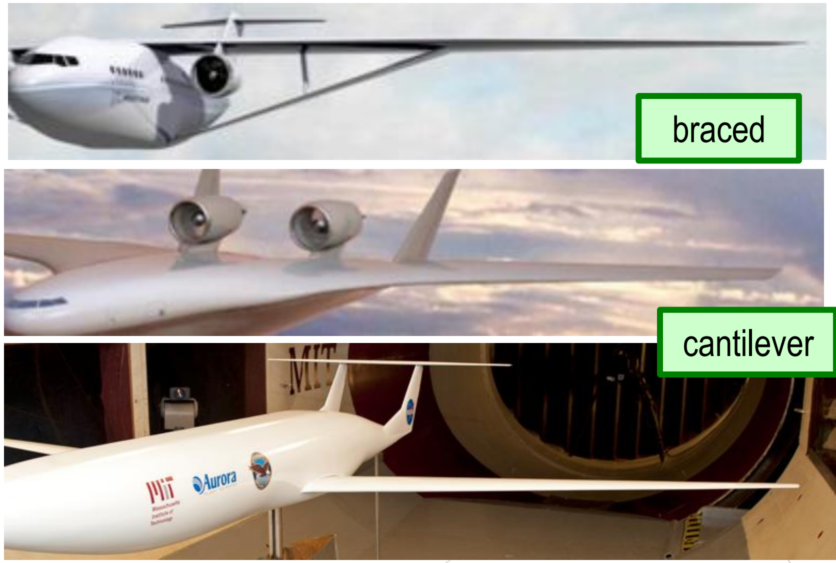
- Low interference external bracing
- Passive/Active concept to reduce wave drag

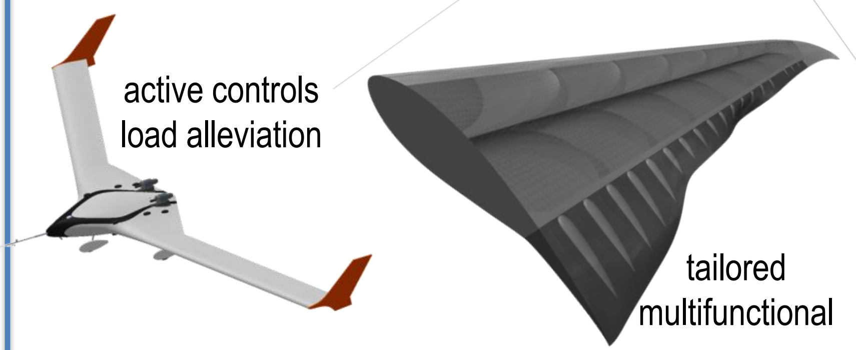
Elastic Aircraft Flight Control

- Control concepts, aeroservoelastic optimization

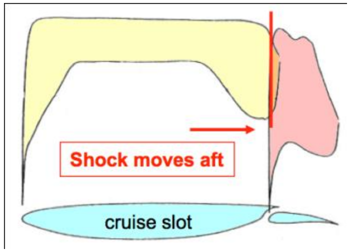
Benefit/Pay-off

- 25% wing structural weight reduction
- AR increase of 30-40% for cantilever wings, 2X+ for braced





passive/active
advanced aerodynamics



Quiet, Simplified High-Lift

quiet systems with improved performance

Objective

Drag | Weight | TSEC | Clean | Noise

Explore and develop technologies to enable high performance, low noise high-lift systems

Approach/Challenges

High-lift System Noise

- Slat cove/gap fillers
- Flap edge treatments

Landing Gear Noise

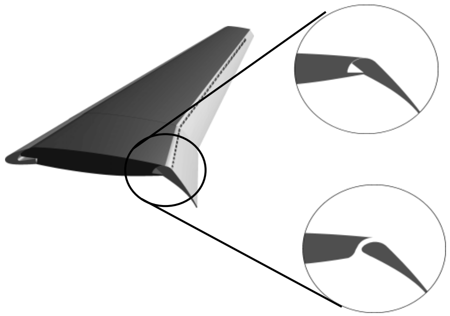
- Unsteady flow physics
- Noise reduction concept development

Active Flow Control

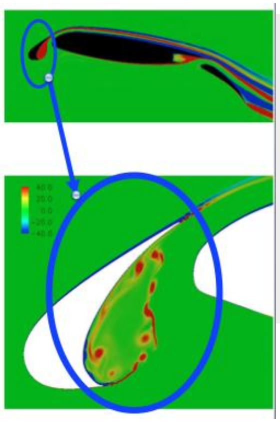
- Mechanically simple high-lift systems
- Acoustic evaluation and alleviation

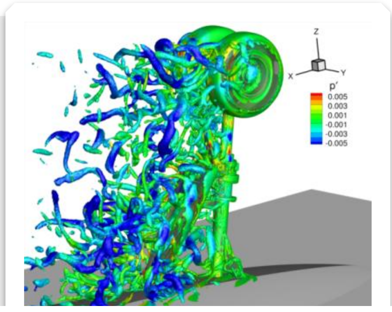
Benefit/Pay-off

- 8-10 dB airframe noise reduction
- Reduced part count, reduced weight/drag



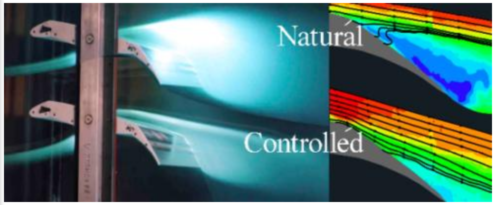
high-lift system concepts





noise source physics
noise reduction concepts

active flow control
performance & acoustics



High Efficiency Small Gas Generator

versatile core applicable to variety of propulsion systems/installations

Objective

Drag	Weight	TSEC	Clean	Noise

Explore and develop technologies to enable advanced, small, gas-turbine generators with high thermal efficiency

Approach/Challenges

Hot Section Materials

– 1500F HPC, 2700/3000F HPT blade/vane

Tip/Endwall Aerodynamics

– Minimizing losses due to short blades/vanes

Fuel-Flexible Combustion

– Fuel/Air Mixing/Stability Controls

Decentralized Control

– FADEC to networked to wireless

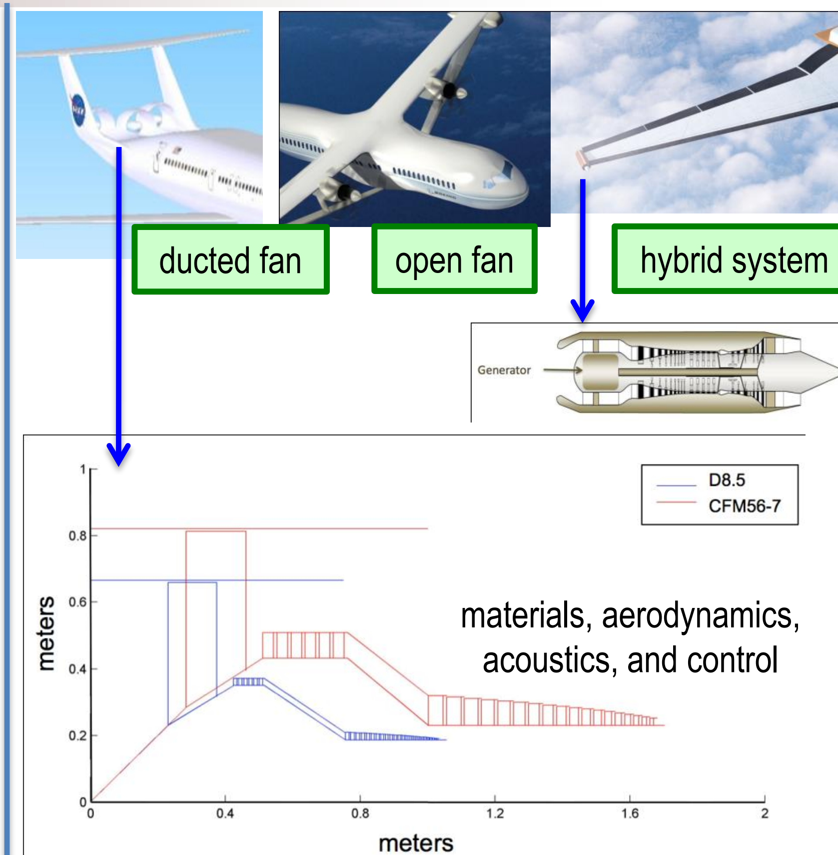
Core Noise

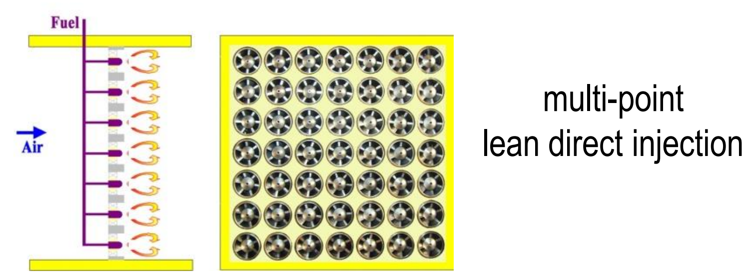
– Understand and mitigate source noise (e.g., liners)

Benefit/Pay-off

– BPR 20+ growth by minimizing core size

– Low emission, fuel-flexible combustors with NOx reduction of 80% below CAEP6





Hybrid Electric Propulsion
changing the paradigm

Objective

Drag | Weight | **TSEC** | Clean | Noise

Explore and develop technologies to enable hybrid gas-turbine/electric propulsion architectures

Approach/Challenges

Transmission and Winding Materials

- Room Temperature
- Superconducting

Gas-Turbine/Electric Hybrids

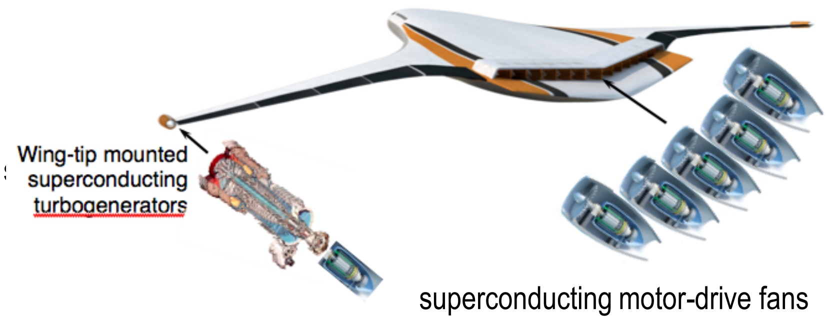
- Dual power source to single propulsor (coupled)
- Single power source to multiple propulsor (decoupled)

Aircraft Power Distribution

- Stable wide-area electrical power distribution

Benefit/Pay-off

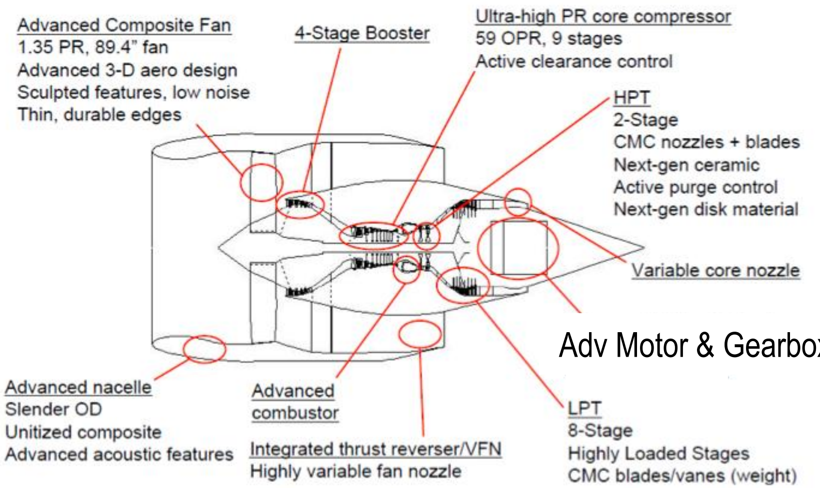
- Low noise and zero emission (onboard) electric drives
- Renewable energy sources for aviation use
- Electric transmission to enable decoupled distributed propulsion for higher effective BPR and improved TSEC



single power source to multiple, decoupled fans

stable, wide area power transmission

dual power to single fan



adv conventional to hybrid to (eventually) all electric

Propulsion Airframe Integration
increasingly synergistic integration

Objective

Drag	Weight	TSEC	Clean	Noise

Explore and develop technologies to enable highly coupled, synergistic aero-propulsive-control

Approach/Challenges

Aerodynamic Configuration

– Novel configurations and installations (e.g. BLI, DP)

Adaptive, Lightweight Fan Blade

– SMA to twist blade (10 deg at tip)

– Nano-toughened composite blade

Distortion-Tolerant Fan

– Robust to unsteady and non-uniform inflow

Acoustic Liners

– Low drag, multi-degree-of-freedom

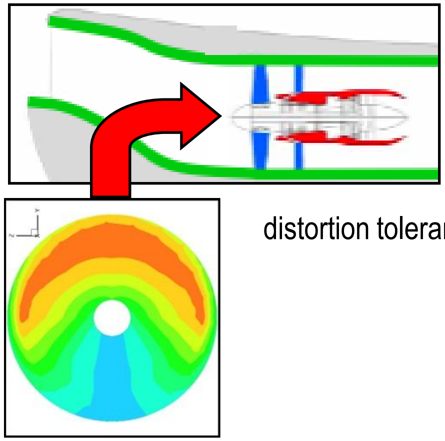
Propulsion Airframe Aeroacoustics

– Inlet distortion, jet-flap/surface interaction

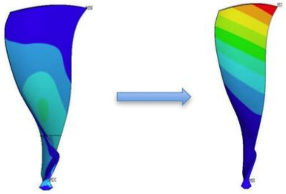
Benefit/Pay-off

– Improved multidisciplinary performance and noise characteristics; benefits tradable for specific missions

boundary-layer ingesting concepts
thrust vectoring

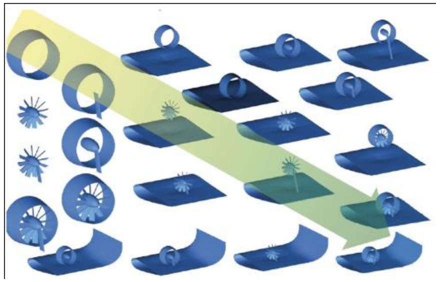


distortion tolerance



adaptive fan blades

jet/surface interaction acoustics



Alternative Fuels
characterization of alternative fuels in the near and mid term

Drag | Weight | TSEC | **Clean** | Noise

Objective

Fundamental characterization of alternative fuel properties and emissions to reduce impact of aviation on the environment

Approach/Challenges

Fuel Property Characterization

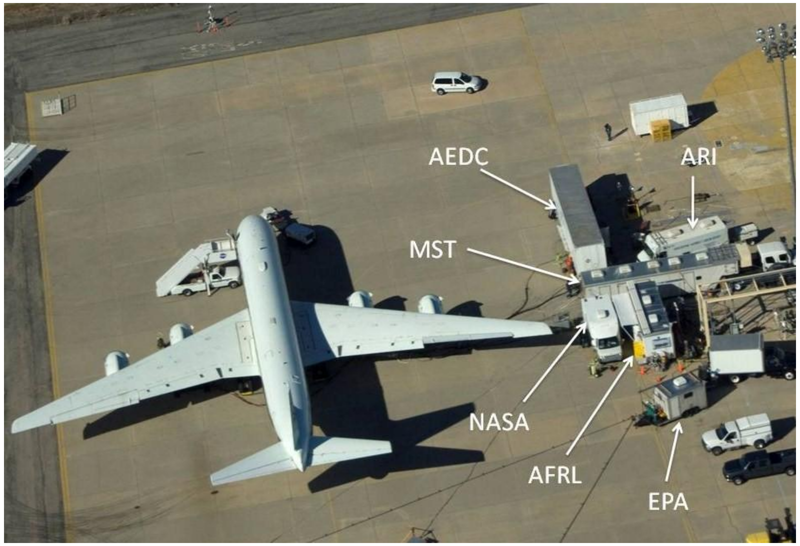
- Thermal stability, chemical kinetics, ignition energy

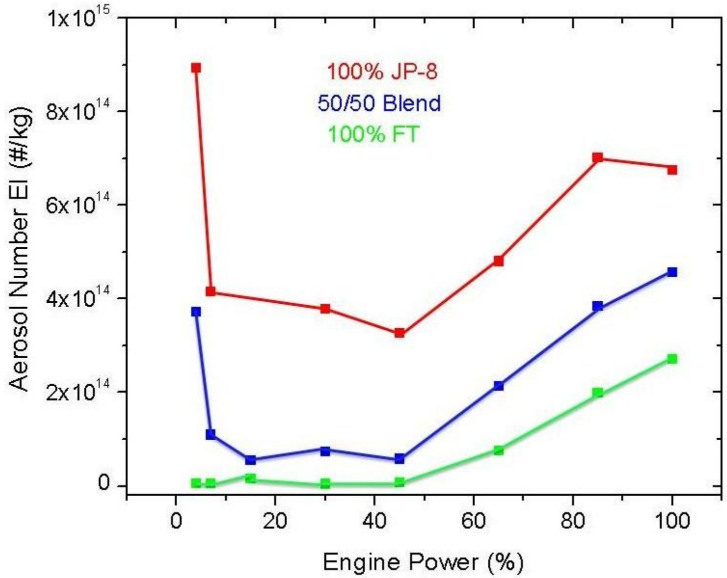
Emission & Performance Characterization

- Laboratory tests
- Ground tests of full-scale engines
- Flight tests

Benefit/Pay-off

- Broad use and understanding of alternative aviation fuels
- Low emission, fuel-flexible combustors with NOx reduction of 80% below CAEP6
- Reduce aircraft engine particulate matters and gas phase emissions





Tool Box
cross-cutting foundation

Objective

Drag | Weight | TSEC | Clean | Noise

Explore and develop tools for the practical design, analysis, optimization, and validation of technology solutions for components and vehicle systems

Approach/Challenges

MDAO
- OpenMDAO framework

Systems Analysis/Conceptual Design
- Higher Order Design Environment (HOrDE), ANOPP2
- Specific System Models (e.g., open rotor)

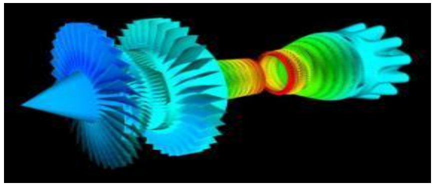
Physics-based
- Turbulence Modeling/Advanced CFD
- Fast Scattering Acoustics
- Composite Uncertainty (crack onset/progression)
- Many others . . .

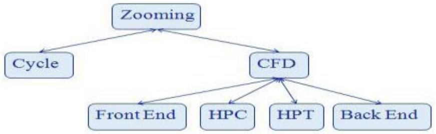
Benefit/Pay-off

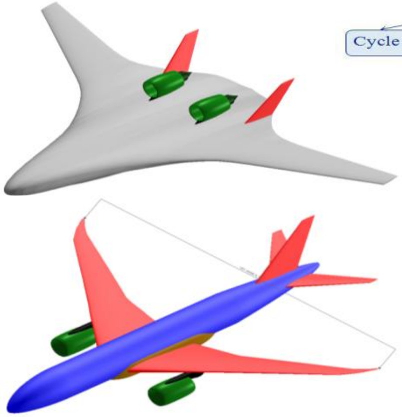
- High confidence, cost-effective variable-fidelity tools available for analysis and design from subcomponents to full vehicle systems

open source python OpenMDAO.org

open Source MDAO engineering framework

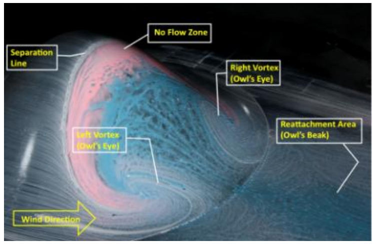


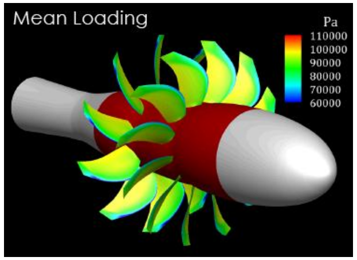




Vehicle Sketch Pad geometry

high-fidelity tools/models and validation experiments

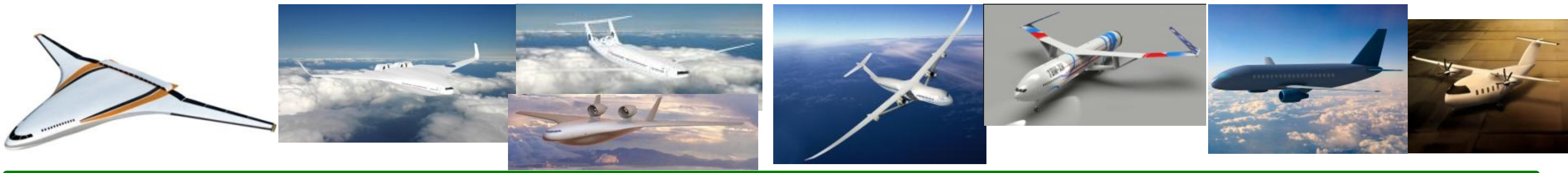




Diversified Portfolio Addressing N+3 Goals

broadly applicable subsystems and enabling technologies

N+3 Vehicle Concepts



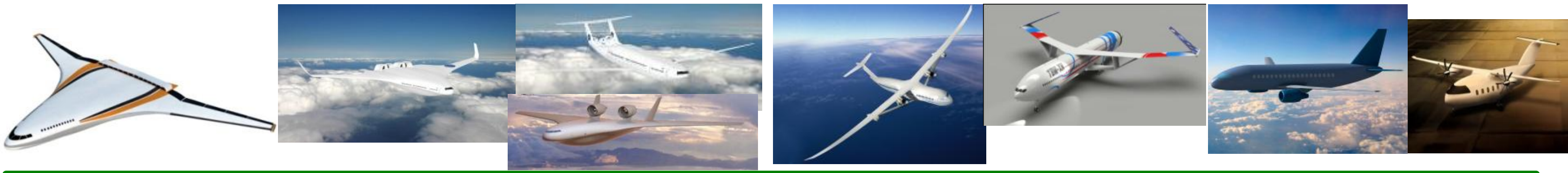
N+3 Subsystem Concepts

Tailored Fuselage	High AR Elastic Wing	Quiet, Simplified High-Lift	High Eff. Small Gas Generator	Hybrid Electric Propulsion	Propulsion Airframe Integration	Alternative Fuels

Diversified Portfolio Addressing N+3 Goals

broadly applicable subsystems and enabling technologies

N+3 Vehicle Concepts



N+3 Subsystem Concepts / Technical Areas

Tailored Fuselage	High AR Elastic Wing	Quiet, Simplified High-Lift	High Eff. Small Gas Generator	Hybrid Electric Propulsion	Propulsion Airframe Integration	Alternative Fuels
Turbulent CF Drag Reduction	Aerodynamic Shaping	Active Flow Control	Hot Section Materials	Gas-Turbine/Electric Hybrids	Aerodynamic Configuration	Fuel Properties
Tailored Load Path Structure	Elastic Aircraft Flight Control	High-Lift System Noise	Tip/Endwall Aerodynamics	Transmission and Winding Materials	Adaptive, Lt Wt Fan Structure	Emission & Performance
Designer Materials	Tailored Load Path Structure	Landing Gear Noise	Decentralized Control	Aircraft Power Distribution	Distortion Tolerant Fan	
	Designer Materials		Fuel-Flexible Combustion		Acoustic Liners	
	Active Structural Control		Core Noise		Propulsion Airframe Aeroacoustics	

Drag
Weight
TSEC
Clean
Noise
Tools

Tool Box – MDAO, System Modeling, Physics-Based Tools

Structure/ Aeroelastic/ Materials	Aerodynamics	Acoustics	Combustion	Propulsion	MDAO	Systems Analysis/ Conceptual Design

Concluding Remarks

- Strong NASA Aeronautics programs for addressing challenges of aviation
- Goals driven by National Plan for Aeronautics R&D
- SFW metrics informed by systems analyses
- Broad technical challenges to define fundamental research needed to meet the strategic thrusts of Energy Efficiency and Environmental Compatibility
- Goal-driven advanced concepts to inform SFW research portfolio and investments
- Broadly applicable N+3 subsystem concepts provide far-term focus to guide near-term research needs
- Robust fundamental research portfolio to enable design trades with many possible futures