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

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Subsonic Fixed Wing Project

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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.

**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.

**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.

**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

DC-3  B-707  B-707
SFW Strategic Framework/Linkage

Strategic Thrusts

1. Energy Efficiency
   - 1.1 Reduce the energy intensity of air transportation

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

Strategic Goals

1.1 Reduce the energy intensity of air transportation
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

System Level Metrics

- Fuel Burn
- Energy Efficiency
- LTO NOₓ Emissions
- Other LTO Emissions
- Aircraft Certification Noise
- Cruise NOₓ Emissions
- Life-cycle CO₂e per Unit of Energy Used
## NASA Subsonic Transport System Level Metrics

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

<table>
<thead>
<tr>
<th>TECHNOLOGY BENEFITS*</th>
<th>TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Noise (cum margin rel. to Stage 4)</td>
<td>-32 dB</td>
<td>-42 dB</td>
</tr>
<tr>
<td>LTO NOx Emissions (rel. to CAEP 6)</td>
<td>-60%</td>
<td>-75%</td>
</tr>
<tr>
<td>Cruise NOx Emissions (rel. to 2005 best in class)</td>
<td>-55%</td>
<td>-70%</td>
</tr>
<tr>
<td>Aircraft Fuel/Energy Consumption† (rel. to 2005 best in class)</td>
<td>-33%</td>
<td>-50%</td>
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* 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.
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)*

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

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

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

**TC4** - Reduce harmful *emissions* attributable to aircraft energy consumption

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

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

GE, Cessna, GA Tech

NG, RR, Tufts, Sensis, Spirit

MIT, Aurora, P&W, Aerodyne

NASA, VA Tech, GT

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


Great 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
N+3 Opportunities from Goal-Driven Advanced Concepts

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

Near Term/Cross-cutting

7. Alternative Fuels
8. Tool Box (MDAO, Systems Modeling, Physics-Based)
Tailored Fuselage
opportunity to reduce large structural weight, large wetted area

Objective

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
High Aspect Ratio Elastic Wing
changing the drag/weight trade space

**Objective**

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
Quiet, Simplified High-Lift
quiet systems with improved performance

**Objective**

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
**Objective**

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

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**Subsonic Fixed Wing Project**
**Fundamental Aeronautics Program**
**Objective**

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

**Adv Motor & Gearbox**
- Superconducting motor-drive fans
- Single power source to multiple, decoupled fans
- Stable, wide area power transmission
- Dual power to single fan

**Clean Weight**
- Drag
- Weight
- TSEC
- Noise

**Adv conventional to hybrid to (eventually) all electric**
**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

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Subsonic Fixed Wing Project
Fundamental Aeronautics Program
Alternative Fuels
characterization of alternative fuels in the near and mid term

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
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

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