Advanced Air Transport Technology (AATT) Project

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5th International Workshop on Aviation and Climate Change
University of Toronto Institute for Aerospace Studies
May 18, 2016
Toronto, Canada
NASA Aeronautics
NASA Aeronautics Vision for Aviation in the 21st Century

Global

Sustainable

Transformative

6 Strategic Thrusts

Safe, Efficient Growth in Global Operations

Innovation in Commercial Supersonic Aircraft

Ultra-Efficient Commercial Vehicles

Transition to Low-Carbon Propulsion

Real-Time System-Wide Safety Assurance

Assured Autonomy for Aviation Transformation

U.S. leadership for a new era of flight
NASA Aeronautics Program Structure

Aeronautics Research Mission Directorate

------------------------------------------------- Mission Programs -------------------------------------------------

Advanced Air Vehicles (AAVP)
Jay Dryer

Integrated Aviation Systems (IASP)
Ed Waggoner

Airspace Operations And Safety (AOSP)
John Cavolowsky

Transformative Aeronautics Concepts (TACP)
Doug Rohn

--------------------------------------------------------------- Seedling Program -----------------------------------------------

Advanced Air Transport Technology (AATT)

Revolutionary Vertical Lift Technology (RVLT)

Commercial Supersonic Technology (CST)

Advanced Composites (ACP)

Aeronautics Evaluation and Test Capabilities (AETC)

Environmentally Responsible Aviation (ERA)

UAS Integration in the NAS

Flight Demonstration and Capabilities (FDC)

Airspace Technology Demonstration (ATD)

SMART NAS – Testbed for Safe Trajectory Operations

Safe Autonomous System Operations (SASO)

Transformational Tools and Technologies (TTT)

Convergent Aeronautics Solutions (CAS)

Leading Edge Aeronautics Research for NASA (LEARN)

-------------------------- Mission Programs --------------------------

Seedling Program

Transformative Aeronautics Concepts (TACP)
Doug Rohn
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
Major Aviation Community “Driver”
Reduce Carbon Footprint by 50% by 2050…

…in the face of increasing demand, and while reducing development, manufacturing and operational costs of aircraft & meeting noise and LTO NOx regulations
Analysis based on FAA US operations data provided by Holger Pfaender of Georgia Tech

**Fuel Use by Vehicle Class**

- **40%** of fuel use is in 150-210 pax large single aisle class
- **87%** of fuel use is in small single-aisle and larger classes (>100 pax)
- **13%** of fuel use is in regional jet and turboprop classes

Focus on small single-aisle and larger vehicle classes for maximum community impact

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Analysis based on FAA US operations data provided by Holger Pfaender of Georgia Tech
## NASA Subsonic Transport System-Level Metrics

### Strategic Focus

1. **Energy Efficiency**
2. **Environmental Compatibility**

### Technology Benefits

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

- *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.

### N+3 Values

N+3 values are referenced to a 737-800 with CFM56-7B engines.

Research addressing revolutionary far-term goals with opportunities for near-term impact.
AATT Portfolio Development:  
N+3 Advanced Vehicle Concept Studies Summary

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

**Boeing, GE, GA Tech**

**NG, RR, Tufts, Sensis, Spirit**

**GE, Cessna, GA Tech**

**MIT, Aurora, P&W, Aerodyne**

**NASA, VA Tech, GT**

**Trends:**
- Tailored/multifunctional structures
- High aspect ratio/laminar/active structural control
- Highly integrated propulsion systems
- Ultra-high bypass ratio (20+ with small cores)
- Alternative fuels and emerging hybrid electric concepts
- Noise reduction by component, configuration, and operations improvements

**Advances required on multiple fronts...**
## AATT Project Technical Challenges

### Near-Term Impact Toward Long-Term Objectives

<table>
<thead>
<tr>
<th>Technology Themes</th>
<th>Noise</th>
<th>Emissions (LTO)</th>
<th>Emissions (cruise)</th>
<th>Energy Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lighter-Weight Lower-Drag Fuselage</td>
<td>Higher Aspect Ratio Optimal Wing</td>
<td>Quieter Low-Speed Performance</td>
<td>Cleaner, Compact, Higher BPR Propulsion</td>
</tr>
<tr>
<td>Goals Metrics (N+3)</td>
<td>Stage 4 – 52 dB cum</td>
<td>CAEP6 – 80%</td>
<td>2005 best – 80%</td>
<td>2005 best – 60%</td>
</tr>
</tbody>
</table>

### 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 (FY19) Low NOx Fuel-Flex Combustor:
Reduce NOx emissions from fuel-flexible combustors to 80% below the CAEP6 standard with minimal impact on weight, noise, or component life (TRL3).

### TC4.2 (FY20) Compact High OPR Gas Generator:
Enable reduced size/flow high pressure compressors and high temperature disk/seals that are critical for 50+ OPR gas generators with minimal impact on noise and component life (TRL4).

### TC4.3 (FY21) Engine Icing:
Predict likelihood of icing events with 90% probability in current engines operating in ice crystal environments to enable icing susceptibility assessments of advanced ultra-efficient engines. (TRL2)

### TC5.2 (FY19) Hybrid Gas-Electric Propulsion Concept:
Establish viable concept for 5-10 MW hybrid gas-electric propulsion system 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).

### TC6.2 (FY21) Airframe Icing:
Enable assessment of icing risk with 80% accuracy for advanced ultra-efficient airframes operating in supercooled liquid droplet environments. (TRL2)

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

Note: Reference is best commercially available or best in class in 2005.
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

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

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

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

Active Structural Control
- Distributed control effectors, robust control laws
- Actuator/sensor structural integration

Tailored Load Path Structure
- Passive aeroelastic tailored structures

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
Objective
Explore and develop aero-structural-acoustic technologies to directly reduce perceived community noise with minimal or no impact on performance

Technical Areas and Approaches
Airframe Noise
- Flap and slat noise reduction concepts
- Landing gear noise reduction concepts

Acoustic Liners and Duct Propagation
- Multi-degree-of-freedom, low-drag liners

Benefit/Pay-off
- 12 dB cum noise reduction
- Liner and non-active-flow-control high-lift system technology have early insertion potential
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
– Small core injection methods, alternative fuel properties, combustion stability techniques

Benefit/Pay-off
– Lower 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 with gas-only and hybrid gas-electric architectures and ducted/unducted propulsors
– Compatible with alternative fuel blends
**Objective**
Enable reduced size/flow gas generators with 50+ OPR and disk/seal temperatures of 1500F with minimal impact on noise and component life (TRL4).

**Technical Areas and Approaches**
- **Hot Section Materials**
  - 1500F hybrid disk and coatings
  - 1500F capable non-contacting seal
- **Reduced Size HPC for High OPR Engines**
  - Minimize losses due to short blades/vanes

**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
TC4.3(FY21): Engine Icing

Objective
Predict likelihood of icing events with 90% probability in current engines operating in ice crystal environments to enable icing susceptibility assessments of advanced ultra-efficient engines.

Technical Areas and Approaches
Icing Prediction Analysis Tool
- Engine conditions conducive to ice formation
- Rate of ice growth/engine effects

Fundamental Physics and Engine Icing Tests
- Study ice crystal icing in GRC Propulsion Systems Laboratory to validate tools

Benefit/Pay-off
- Enable analysis of ice crystal icing effects on turbofan engines
- Design tools adapted for N+3, compact core, higher bypass ratio turbofan engines to assess icing impacts during development
TC5.2 (FY19): Gas-Electric Propulsion Concept, TRL 2

**Objective**
Explore and develop concepts and technologies to enable aircraft with hybrid-electric and turboelectric propulsion systems that provide a net vehicle system-level energy efficiency benefit

**Technical Areas and Approaches**

- **Propulsion System Conceptual Design**
  - Early selection of system concepts that allow drill-down in issues of system interaction concept refinement

- **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 and matching during steady-state and transient operation
  - Develop control methodology

**Benefit/Pay-off**
- Enable the paradigm shift from gas turbine to hybrid-electric or turbine-electric propulsion
Objective
Explore and develop technologies to enable highly coupled propulsion-airframe integration that provide 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
– Will demonstrate a net system-level benefit for BLI propulsion system integration that is applicable and beneficial to a variety of advanced vehicle concepts
– Distortion-tolerant fan technology and acoustics characterization is relevant to near-term conventional short-duct installations
Objective
Enable assessment of icing risk with 80% accuracy for advanced ultra-efficient airframes operating in supercooled liquid droplet environments

Technical Areas and Approaches

3D Ice Accretion Prediction Tool
- Develop LEWICE3D to assess ice accretion on complex airframe features

Ice Protection Systems
- Integrate assessment of ice protection systems into LEWICE3D as airframe design tool

Benefit/Pay-off
- LEWICE3D validated against experimental data to be used as design tool for advanced N+3 airframes
- Ice protection system evaluation capability to mitigate icing issues for N+3 airframes

Current NASA Icing Simulation Tools Well Validated and Accepted by Aviation Community

Scalloped Ice Shape on Swept Wing

Ice growth on 65% scale CRM wing section model

Expanding Current Icing Simulation Tools to Swept Wing and Freezing Rain/Drizzle Icing

TC6.2(FY21): Airframe Icing

MVD = 18.6 microns

MVD = 215.6 microns
NASA Aeronautics 10-Year American Aviation Plan and New Aviation Horizons
NASA Aeronautics Ready for Flight
Accomplishments and Planning

2008-2013

- N+3 Subsonic & Supersonic Concept/Technology Studies
- N+2 Environmentally Responsible Aviation (ERA) Project Initiated

2014/15

- Ground Testing of N+3 configurations and technologies
- 8 Integrated Tech Demos Completed, Tech transitioned to industry. HWB ready for Flight Dem/Val.

2016/17

- LBFD PDR Completed

2018-2026

- UEST PDR Completed

Ready for X-Plane Integration & Demonstration

Ready for NextGen TBO Integration & Demonstration

NASA FAA NextGen Research Transition Teams (RTTs) Initiated

Technology Transitions to FAA: MSP, EDA, PDRC, TSAS

ATD-1 Completed and transferred to FAA
ATD-2, 3 Completed & Transferred to FAA

NASA Aero Vision and Strategy Established

Roadmaps Completed

www.nasa.gov
New Aviation Horizons Flight Demo Plan

Hybrid Electric Propulsion Demonstrators
- Ground Test Risk Reduction
- Preliminary Design
- Design & Build
- Flight Test
- Total Demonstration Cost ROM: $700M

“Purpose-Built” UEST Demonstrators
- Small Scale “Build, Fly, Learn”
- Ground Test Risk Reduction
- Preliminary Design
- Design & Build
- Flight Test
- Life Cycle Cost ROM: $400-500M

Fully integrated UEST Demonstrator
- Preliminary Design
- Design & Build
- Flight Test
- Life Cycle Cost Est: $430M

Life Cycle Cost Est: $430M

Potential Candidates
- Ground Test Risk Reduction
- Design & Build
- Flight Test
- Life Cycle Cost ROM: $400-500M

Life Cycle Early Cost Est: $850M

FY17 FY18 FY19 FY20 FY21 FY22 FY23 FY24 FY25 FY26

Validated ability for U.S. Industry to Build Transformative Aircraft that use 50% less energy and produce less than half of the perceived noise

Validated HEP Concepts, Technologies And Integration for U.S. Industry to Lead the Clean Propulsion Revolution

Enables Low Boom Regulatory Standard and validated ability for industry to produce and operate commercial low noise supersonic aircraft

Validated ability for U.S. Industry to Build Transformative Aircraft that use 50% less energy and produce less than half of the perceived noise

Enables Low Boom Regulatory Standard and validated ability for industry to produce and operate commercial low noise supersonic aircraft

Images Credit: Lockheed Martin

Advanced Air Transport Technology Project
Advanced Air Vehicles Program
Ten Year Investment Plan—FY 2017 Budget Accelerates Key Components of NASA Aeronautics Plan

Fund the Next Major Steps to Efficient, Clean and Fast Air Transportation Mobility

New Aviation Horizons
Start a continuing series of experimental aircraft to demonstrate and validate high impact concepts and technologies. Five major demonstrations over the next 10+ years in the areas of Ultra-Efficiency, Hybrid-Electric Propulsion, and Low Noise Supersonic Flight

Major New Initiative within IASP

Enabling Tools & Technologies
Major series of ground experiments to ready key technologies for flight
Research and ground demonstration for an advanced small engine core for very high bypass engines and as a hybrid-electric propulsion enabler
Development of next generation physics-based models needed to design advanced configurations

Increases to AAVP and TACP

Revolutionizing Operational Efficiency
Accelerate demonstration of full gate-to-gate Trajectory Based Operations

Increase to AOSP

Fostering Advanced Concepts & Future Workforce
Increased investment in new innovation through the NASA workforce and Universities

Increase to TACP

UAS
Strong continued research leadership in enabling UAS integration into the National Airspace. Extending the UAS in the NAS project for an additional 4 years

Increases to IASP and AAVP

Leverage Non-Traditional Technology Advances
Pursue challenge prizes in areas such as energy storage, high power electric motors, advanced networking and autonomy

Hypersonics
Increased investment to ensure a strong National fundamental research capability

Build off of major current developments and accomplishments

Continue to incentivize new innovation
AATT Project Research Team

NASA Ames, Armstrong, Glenn, and Langley Research Centers

Three Main Components:

• NASA in-house research
• Collaborations with partners (OGA, Industry, Academia)
• Sponsored research by NASA Research Announcement (NRA)
Concluding Remarks

• Addressing 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

Concepts, Technologies, Capabilities, and Knowledge