Environmentally Responsible Aviation: Propulsion Research to Enable Fuel Burn, Noise and Emissions Reduction

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and

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Acknowledgements to:
ERA Project Manager
Fayette Collier, Ph.D., M.B.A.
Open Rotor technologies were studied during ERA Phase 1 in partnership with GE and FAA."
### Introduction – System Level Metrics - Subsonic Transports!

<table>
<thead>
<tr>
<th>Date for Technology Readiness Level=6</th>
<th>N+1 2015 Timeframe</th>
<th>N+2 2020 Timeframe</th>
<th>N+3 2025+ Timeframe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise (rel. to Stage 4)</td>
<td>-32 EPNdB</td>
<td>-42 EPNdB</td>
<td>-52 EPNdB</td>
</tr>
<tr>
<td>LTO NO\textsubscript{x} Emissions (rel. to CAEP 6)</td>
<td>-60%</td>
<td>-75%</td>
<td>better than -75%</td>
</tr>
<tr>
<td>Aircraft Fuel Burn/ Energy Use (rel. 2005 Best in Class)</td>
<td>-33%</td>
<td>-50%</td>
<td>better than -50%</td>
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</tbody>
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<thead>
<tr>
<th>FAA CLEEN I FOCUS</th>
<th>FAA CLEEN II FOCUS</th>
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<tbody>
<tr>
<td>NASA ERA FOCUS</td>
<td>NASA FIXED WING FOCUS</td>
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<thead>
<tr>
<th>AFRL AEROSPACE SYSTEMS DIRECTORATE RESEARCH FOCUS</th>
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<tbody>
<tr>
<td>EUROPEAN FRAMEWORK RESERACH FOCUS</td>
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Introduction – Environmentally Responsible Aviation
Vision/Mission/Scope Aimed at N+2 Timeframe!

• Vision
  – expand the viable and well-informed trade space for commercial transport design decisions
  – enable simultaneous realization of national noise, emissions, and performance goals

• Mission
  – Execute integrated technology demonstrations
  – Partner w/Industry and transfer knowledge

• Scope
  – Mature technology for application in the 2020+ time frame
    • Advance the state-of-the-art, reduce risk of application
  – Perform system/subsystem research in relevant environments
Introduction"  
ERA Project Flow with Key Decision Points!

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY09</td>
<td>Formulation</td>
</tr>
<tr>
<td>FY10</td>
<td>KDP 1</td>
</tr>
<tr>
<td>FY11</td>
<td>Phase 1 Investigations</td>
</tr>
<tr>
<td>FY12</td>
<td>Initial NRAs</td>
</tr>
<tr>
<td>FY13</td>
<td>Phase 2 Planning</td>
</tr>
<tr>
<td>FY14</td>
<td>Integrated Technology Demonstrations (8)</td>
</tr>
<tr>
<td>FY15</td>
<td></td>
</tr>
</tbody>
</table>

Technical input from Fundamental Programs, NRAs, Industry, Academia, Other Gov’t Agencies
Outline!

- Introduction"
- ERA Technical Challenges"
  - ERA Phase II Integrated Technology Demonstrations"
    - Propulsion Integrated Technology Demonstrations"
- Potential Fleet Impacts"
- Concluding Remarks"

CMC mixer nozzle work in ERA Phase 1 in partnership with Rolls-Royce and AFRL."
Innovative Flow Control Concepts for Drag Reduction
  – Demonstrate drag reduction of 8 percent

Advanced Composites for Weight Reduction
  – Demonstrate weight reduction of 10 percent

Advanced UHB Engine Designs for Specific Fuel Consumption and Noise Reduction
  – Demonstrate UHB efficiency improvements to achieve 15% TSFC reduction

Advanced Combustor Designs for Oxides of Nitrogen Reduction
  – Demonstrate reductions of LTO NOx by 75 percent from CAEP6 and cruise NOx by 70 percent

Airframe and Engine Integration Concepts for Community Noise and Fuel Burn Reduction
  – Demonstrate reduced component noise signatures leading to 42 EPNdB to Stage 4
ERA Phase 1 combustor sector test in ASCR with partners GE and P&W.
Goal Decomposition and Technology Selection!

Fuel Burn
-50%

NO\textsubscript{x}
-75%

Noise
-42EPNdB

Innovative Flow Control Concepts
TC 1: 8% Drag Reduction

Advanced Composites
TC 2: 10% Structural Weight Reduction

Advanced UHB Engines
TC 3: 15% TSFC and 15 EPNdB Noise Reduction

Advanced Combustors
TC 4: 75% LTO NOx Reduction

Airframe & Engine Integration
TC 5: 42 EPNdB Cum Noise Reduction and 50% Fuel Burn Reduction

P2 Integrated Technology Demonstrations (TRL 4-6)

12A+
AFC VT & Advanced Wing
KPP\textsubscript{2025}
• Cruise Drag Reduction"

21A
PRSEUS
KPP\textsubscript{2025}
• Structural Weight Reduction"

21C
ACTE
KPP\textsubscript{2025}
• Wing Weight Reduction"

30A
Front Block Compressor
KPP\textsubscript{2025}
• TSFC"

35A
UHB Propulsor
KPP\textsubscript{2025}
• TSFC"
• Cumulative Noise Reduction"

40A
Low LTO NOx, Fuel Flex Combustor
KPP\textsubscript{2025}
• LTO NOx"

50A
Low Noise Flap Edge & Landing Gear
KPP\textsubscript{2025}
• Airframe Component Noise Reduction"

51A
UHB Engine Integration on HWB
KPP\textsubscript{2025}
• Fuel Burn Reduction"
• Cumulative Noise Reduction"

P1 Technology Development & Maturation
Airframe Technology"
Integrated Technology Demonstrators!

21A PRSEUS Assembled multi-bay box in C-17 factory

21C Adaptive Compliant Trailing Edge Flight Demonstration

12A+ AFC Vertical Tail and Advanced Wing Flight Test
Vehicle Systems Integration"
Integrated Technology Demonstrators!

50A Landing Gear & Flap Edge Noise Reduction Flight Test

51A UHB Integration on a Hybrid Wing Body
Propulsion Technology!
Integrated Technology Demonstrators!

30A: Highly Loaded Front Block Compressor (GE)!
35A: 2nd Gen UHB Propulsor Integration (P&W and FAA)!
40A: Low NOx, Fuel Flexible Combustor Integration (P&W)!
## Integrated Technology Demonstrator"
Highly Loaded Front Block Compressor Demonstration!"![NASA logo]

### Key Performance Parameters!
- Reduce TSFC by 2.5 percent"

### Technology Insertion Challenges Addressed!
- Front block aerodynamic losses limit efficiency"
- Identify loss mechanisms and interaction effects of highly-loaded compressor stages"
- Trade-off OPR, Efficiency, and operability to optimize fuel burn"
- Establish part-speed operability margin"
- Integrated 1st 3 stages of HPC"

### Timeline:

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<th>FY12!</th>
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<th>FY14!</th>
<th>FY15!</th>
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<tbody>
<tr>
<td>Mechanical checkout test 1</td>
<td>Two stage HS HPC Phase 1 test in W7</td>
<td>NASA Adaptive Hardware Delivered</td>
<td>Build 2 three stage rig test in W7</td>
</tr>
<tr>
<td>Mechanical checkout test 2</td>
<td>Single stage HS HPC Phase 1 test in W7</td>
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Unsteady Interactions Predicted by CFD: Entropy Plot – From Gorrell et al, 2005
ITD30A had supply chain and hardware challenges.!
The intent of minimum success is still achievable as is the goal of 2.5% TSFC reduction for the technology.!
Integrated Technology Demonstrator"
2nd Generation UHB Propulsor Integration!

Key Performance Parameters!
- Reduce noise by 15 EPNdB"
- Reduce TSFC by 9 percent"

Technology Insertion Challenges Addressed!
- Noise reduction & aero performance of advanced liners validated: 1 – 2 EPNdB"
- Comprehensive- modern database of propulsor multi-discipline performance characteristics for sys analysis created."
- Integrated performance of modern fan + advanced FEGVs + short inlet verified"

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<tr>
<td>SMA VAN Prototype Demo</td>
<td>UHB OTR Perf. Risk Mitigation Test</td>
<td>UHB OTR/SV Noise Reductions Validation Test</td>
<td>Integrated System LS Test</td>
</tr>
<tr>
<td>UHB Gen 2 Test</td>
<td>Integrated Systems Design Task Start</td>
<td>UHB Integ. System DDR</td>
<td>UHB Low Loss FEGVs Test</td>
</tr>
<tr>
<td>Sys Analysis/Tech Mat Complete</td>
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End TRL: 5"
Integrated Technology Demonstrator''
2nd Generation UHB Propulsor Integration!

Pressure & temperature sensitive paint utilized over range of operating lines

ITD35A validated performance and acoustics for the propulsor that exceeded the goals of 9% TSFC reduction and 15 EPNdB noise reduction for the technology.
Integrated Technology Demonstrator"  
Fuel Flexible, Low NOX Combustor Integration!

Key Performance Parameters!

- Reduce LTO NOx by 75 percent"

Technology Insertion Challenges Addressed!

- Lean burn system operability concerns"
  - Auto-ignition"
  - Flame stability"
  - Acoustic resonance"
- Durability for lean burn configuration"
- 50/50 jet/alt fuel mixture"

End TRL: 5"
ITD40A was fully successful in validating greater than 75% NOx reduction re/CAEP6 with a durable lean-lean combustor system that is compatible with alt fuel blends.
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  — Propulsion Integrated Technology Demonstrations"
• Potential Fleet Impacts"
• Concluding Remarks"

Propulsion Airframe Aeroacoustics research during ERA Phase 1 in partnership with Boeing."
The project is delivering technology that is relevant to next generation aircraft designs and will impact the *carbon footprint* of the fleet.

Through 2050 the cumulative delta between RTC to ITD is 88 B gal = 264B dollars

**BAU** - Business as usual, no technology insertion  
**RTC** - Potential impact of technology available prior to ERA  
**ITD** - Potential impact of ERA Integrated Technology Demo’s
Outline!

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  – Propulsion Integrated Technology Demonstrations"
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• Concluding Remarks"

2nd Gen UHB Propulsor Integrated Systems Test in the Glenn 9x15 LSWT (P&W and FAA CLEEN)"
• ERA was a finite length technology development project that, in partnership with industry and other government agencies, advanced technologies for the simultaneous reduction of aircraft fuel burn, noise and emissions."

• The Propulsion Technology ITDs were successful at maturing compressor, propulsor and combustor technologies for next generation engines."