Environmentally Responsible Aviation (ERA) Project
Assessing Progress Toward Simultaneous Reductions in Noise, Fuel Burn and NOx

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VSI Systems Analysis Element Lead
Environmentally Responsible Aviation (ERA) Project, NASA
Topics Addressed

- ERA Project Metrics Evolution

- ERA Portfolio Analysis Status
  Measuring Progress Towards our Goal
  (Top down and Bottoms Up)
ERA Project Overview, Flow And Key Decision Point for Phase 2

- Prior Research
- External Input

Flow:
- Formulation
- Phase 1 Investigations
- Initial NRAs
- ERA Systems Analysis Decision Support Task
- Phase 2 Planning
- Phase 2 Investigations

Key Decision Point for Phase 2

Fiscal Years:
- FY09: $60.0M
- FY10: $63.1M
- FY11: $65.1M
- FY12: $61.7M
- FY13: $57.4M
- FY14: $57.4M
- FY15: $57.4M

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

Refer to Title Slide for Distribution Restrictions
### ERA Goals, Objectives & System Level Metrics

<table>
<thead>
<tr>
<th>Era Goal</th>
<th>N+1 = 2015** Technology Benefits Relative To a Single Aisle Reference Configuration</th>
<th>N+2 = 2020** Technology Benefits Relative To a Large Twin Aisle Reference Configuration</th>
<th>N+3 = 2025** Technology Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise (cum below Stage 4)</td>
<td>-32 dB</td>
<td>-42 dB</td>
<td>-71 dB</td>
</tr>
<tr>
<td>LTO NO\textsubscript{x} Emissions (below CAEP 6)</td>
<td>-60%</td>
<td>-75%</td>
<td>better than -75%</td>
</tr>
<tr>
<td>Performance: Aircraft Fuel Burn</td>
<td>-33%</td>
<td>-50%</td>
<td>better than -70%</td>
</tr>
<tr>
<td>Performance: Field Length</td>
<td>-33%</td>
<td>-50%</td>
<td>exploit metro-plex* concepts</td>
</tr>
</tbody>
</table>

**Technology Readiness Level for key technologies = 4-6. ERA will undertake a time phased approach, TRL 6 by 2015 for “long-pole” technologies**

* Concepts that enable optimal use of runways at multiple airports within the metropolitan area
In 2005, market opportunities drove the development of the system level metrics

The market was predicting there would be a single aisle (B737/A320) replacement aircraft by 2015*

- This drove the N+1 focus and metrics to be referenced to SOA single aisle

Also, we projected about 10 years later there would be a large twin aisle (B777) replacement

- This drove the N+2 focus, and metrics to be referenced to the SOA large twin aisle

*Chinese C919, 168-190 seat class and Russian MC-21, 150-212 seat class First Flights in 2014?
Market Opportunities - Current Forecast

• Beyond 2015, before 2020 – New engines (GTF, LEAP-X)
  – A320 New Engine Option
  – Re-engine B737?

• Beyond 2020, before 2025 – CONVENTIONAL THINKING
  – Single Aisle Replacement (B737/A320)
    • High probability tube and wing, adv engine (open rotor)/combustors, advanced structures, plus laminar flow
  – Large Twin Aisle Replacement (B777, etc)
    • High probability tube and wing, advanced engine/combustors, advanced structures, laminar flow, but HWB likely to be evaluated as serious contender

• 2025 and BEYOND – UNCONVENTIONAL THINKING – WHAT IF REPLACEMENTS SLIP TO RIGHT?
  – NASA N+2 and N+3 studies identifying key, time-phased technology roadmaps, and “system ready” unconventional configurations
    • Joined wing, trussed braced wing, double bubble, HWB, etc.
    • Hybrid/JP8/battery, cryo-cooling, low energy nuclear reactors, etc…. 
Assess impacts of technology investments on market opportunities

<table>
<thead>
<tr>
<th>2010 Assessment</th>
<th>Re-engine/Retrofits</th>
<th>Replacement</th>
<th>Replacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re-engine/Retrofits</td>
<td>Replacement Conventional</td>
<td>Replacement Unconventional</td>
<td></td>
</tr>
<tr>
<td>Re-engine/Retrofits</td>
<td>Replacement Conventional</td>
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<tr>
<td>Re-engine/Retrofits</td>
<td>Replacement</td>
<td>Replacement</td>
<td></td>
</tr>
<tr>
<td>2010 Assessment Very Large</td>
<td>Re-engine/Retrofits</td>
<td>Replacement Conventional</td>
<td>Replacement Unconventional</td>
</tr>
</tbody>
</table>

- **Noise** (cum below Stage 4)
- **LTO NO\textsubscript{x} Emissions** (below CAEP 6)
- **Performance:** Aircraft Fuel Burn

TIME NOW → 2025 +
ERA Systems Analysis Overview

ERA systems analysis tasks for measuring progress towards our goal

• “Top Down” Methodology Overview
• Concept Modeling Results Summary
• Large Twin Aisle Class Advanced Tube + Wing and HWB

Georgia Tech’s Aerospace Systems Design Lab (ASDL) is supporting ERA to perform this analysis
ERA Technology Database Development Approach:

- Multiple Data Sources:
  - ERA Phase 1 Project Plans
  - GA Tech JPDO/FAA EDS Database
  - NASA N+3 NRA Reports
  - FAP/SFW Planning Reports
  - ERA Project Engineers
  - ERA Discipline Experts

- Technologies with TRL too low or too high for ERA were removed

Technology Database Analysis Report includes:

- Technology Description
- Current and Projected TRLs
- Technology Compatibility Matrix (interactions for 65 Technologies)
- Summary Spreadsheet (19 airframe technologies; 46 engine technologies)
- Projected benefits and impacts
- Modeling approach in EDS
Initial Technology “Collectors”

Advanced Tube and Wing

Hybrid Wing Body

Engine Options:
Advanced direct drive
Geared Turbofan
Open Rotor

- Potential ERA airframe and engine technology packages installed on both conventional and advanced configurations

- Fuel burn, noise and emissions are estimated using models developed in NASA’s standard toolset (NPSS/WATE, FLOPS, ANOPP) which has been integrated into Ga Tech’s Environmental Design Space (EDS) tool

- EDS can feed global tools in AEDT for fleet level global impact estimates

- Seeking additional technology collector advanced configurations through NRA and in-house efforts
Technology Rankings

• Both deterministic and probabilistic assessments will be performed to determine the ERA technology package that results in the best overall performance (probabilistic assessment will provide a quantified confidence level)

Product

Recommendations for ERA Phase II Portfolio:

Technology Package for Best Overall Performance:

Airframe Tech 1
Airframe Tech 2
Airframe Tech 3
Engine Tech 1
Engine Tech 2
Engine Tech 3
...

Combinatorial Space

Deterministic – Cloud of Point Solutions

Probabilistic – Confidence in meeting a metric
## Concept Modeling Summary

<table>
<thead>
<tr>
<th>Baseline Vehicle</th>
<th>Regional Jet</th>
<th>Single Aisle</th>
<th>Small Twin Aisle</th>
<th>Large Twin Aisle</th>
<th>Very Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>CF34-8</td>
<td>CFM56-7B27</td>
<td>CF6-80</td>
<td>GE90-94B</td>
<td>PW4056</td>
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<tr>
<td>Passengers</td>
<td>86</td>
<td>174</td>
<td>210</td>
<td>301</td>
<td>416</td>
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</table>

### 2025 Tube+Wing

<table>
<thead>
<tr>
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<th>Fuel Burn (%)</th>
<th>Noise (dB cum below Stage 4)</th>
<th>Emissions (%)</th>
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</thead>
<tbody>
<tr>
<td>CRJ900</td>
<td>-42.0%</td>
<td>30.5</td>
<td>-75.0%</td>
</tr>
<tr>
<td>737-800</td>
<td>-40.8%</td>
<td>24.0</td>
<td>-75.0%</td>
</tr>
<tr>
<td>767-300ER</td>
<td>-47.3%</td>
<td>27.1</td>
<td>-75.0%</td>
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<tr>
<td>777-200ER</td>
<td>-44.3%</td>
<td>27.3</td>
<td>-75.0%</td>
</tr>
<tr>
<td>747-400</td>
<td>-41.0%</td>
<td>22.6</td>
<td>-75.0%</td>
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</table>

### 2025 HWB

<table>
<thead>
<tr>
<th></th>
<th>Fuel Burn</th>
<th>Noise (dB cum below Stage 4)</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRJ900</td>
<td>N/A</td>
<td>N/A</td>
<td>TBD</td>
</tr>
<tr>
<td>737-800</td>
<td>N/A</td>
<td>N/A</td>
<td>TBD</td>
</tr>
<tr>
<td>767-300ER</td>
<td>TBD</td>
<td>43.6</td>
<td>TBD</td>
</tr>
<tr>
<td>777-200ER</td>
<td>-50.2%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>747-400</td>
<td>TBD</td>
<td></td>
<td></td>
</tr>
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</table>

### 2025 Concept X

<table>
<thead>
<tr>
<th></th>
<th>Fuel Burn</th>
<th>Noise (dB cum below Stage 4)</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRJ900</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>737-800</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>767-300ER</td>
<td>TBD</td>
<td>43.6</td>
<td></td>
</tr>
<tr>
<td>777-200ER</td>
<td>TBD</td>
<td></td>
<td></td>
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</table>
Trade Space Visualization
Advanced LTA Class Tube and Wing

NOx versus Noise versus Fuel Burn

N+2 Technology Packages
Design Space
(3600 potential solutions)

Notional Corner Point
Trade Space Surface

Noise Margin [EPNL dB - Stage 4]
Optimized Points Comparison to Goals
Advanced LTA Class Tube and Wing

Key Takeaways:

1. ERA Phase I Portfolio makes significant improvements in noise and fuel burn.

2. ERA Phase I plan plus all potential N+2 technologies applied to advanced tube and wing will not meet the goal (noise / fuel burn tradeoff).

3. A configuration change is required (configuration itself is a technology) to meet the ERA goal.
Best Technology Package – LTA Class T+W

Airframe Technologies
- Composite Material Technologies
- Stitched Composites/PRSEUS
- Wing Load Alleviation System
- M.E.A. Electro Mechanical Actuators
- Adaptive Wing - T.E. Variable Camber
- Excrescence Reduction
- HLFC - Wing and Tails
- NLF – Nacelles
- Riblets
- Active Flow Control Rudder
- Continuous Moldline Link for Flaps
- Landing Gear Fairings - Main/Nose
- Slat Inner Surface Acoustic Liner
- Slat-Cove Filler

Engine Technologies
- Active Compressor/Turbine Clearance Control
- Active Compressor/Turbine Flow Control
- Active Film Cooling
- Highly Loaded Compressor/Turbine
- Advanced TBC Coatings
- Advanced Turbine Nickel Based Superalloys
- Ceramic Matrix Composites
- High Temperature Erosion Coating for CMC
- Metal Matrix Composites
- Polymer Matrix Composites
- PMC Fan Blade with Metal Leading Edge
- PMC with High Temperature Erosion Coatings
- Beveled Nozzle
- Combustor Liner
- Herschel-Quincke Tube Liner Integration
- Long-cowl Nacelle Common Nozzle
- Lip Liner
- Over-the-Rotor Metal Foam Liner
- Rotor Sweep
- Soft Vane
- Stator Sweep and Lean
- Variable Geometry Chevrons
- Zero Splice Inlet
- Lightweight CMC Liner
- Advanced Combustor

Green Font = ERA Phase I Technology
# LTA Class Advanced T+W Rankings

## N+2 Best Compromise Fuel Burn

<table>
<thead>
<tr>
<th>Technology</th>
<th>Contribution to Fuel Burn Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced GTF</td>
<td>20%</td>
</tr>
<tr>
<td>High AR Wing</td>
<td>15%</td>
</tr>
<tr>
<td>Composite Technologies</td>
<td>10%</td>
</tr>
<tr>
<td>Hybrid Laminar Flow Control - Wing &amp; Tail</td>
<td>5%</td>
</tr>
<tr>
<td>Riblets</td>
<td>10%</td>
</tr>
<tr>
<td>Stitched Composites</td>
<td>5%</td>
</tr>
<tr>
<td>Wing Load Alleviation System</td>
<td>0%</td>
</tr>
<tr>
<td>Natural Laminar Flow Control - Nacelle</td>
<td>5%</td>
</tr>
<tr>
<td>Excrescence Reduction</td>
<td>0%</td>
</tr>
<tr>
<td>Adaptive Wing/Variable Camber</td>
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<tr>
<td>MEA Electro Mechanical Actuator System</td>
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<tr>
<td>Continuous Moldline Link for Flaps</td>
<td>0%</td>
</tr>
<tr>
<td>Slat Inner Surface Acoustic Liner</td>
<td>5%</td>
</tr>
<tr>
<td>Slat-Cove Filler</td>
<td>0%</td>
</tr>
<tr>
<td>Landing Gear Fairings</td>
<td>5%</td>
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**Chart Notes:**
- **MEA Electro Mechanical Actuator System:** 5%
- **Continuous Moldline Link for Flaps:** 0%
- **Slat Inner Surface Acoustic Liner:** 5%
- **Slat-Cove Filler:** 0%
- **Landing Gear Fairings:** 5%
Optimized Points Comparison to Goals
Advanced LTA Class HWB

Key Takeaways:
1. ERA Phase I Portfolio targeted at HWB
2. ERA Phase I plan plus all potential N+2 technologies plus HWB configuration will meet the ERA goal (noise+ fuel burn+emissions)
**Best Technology Package – LTA Class HWB**

<table>
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<tr>
<th>LTA HWB Airframe Technologies</th>
<th>LTA Engine Technologies</th>
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<td>HLFC - Wing</td>
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<tr>
<td>Slat Inner Surface Acoustic Liner</td>
<td>Polymer Matrix Composites</td>
</tr>
<tr>
<td></td>
<td>PMC Fan Blade with Metal Leading Edge</td>
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Green Font = ERA Phase I Technology
Measuring Progress from the “Bottom Up”

ERA Stitched Composite Airframe Technology Maturation Roadmap

WBS: 2.1 Lightweight Structures
Technology: PRSEUS for the HWB Centerbody
Objective: Reduce primary structural weight

ERA Phase I
Multi-bay Box Test
- Benefit is % weight reduction relative to sandwich composites

NRA Phase II
Subcomponent Tests

ERA Phase I
Pressure Cube Test

Pressure Cube

Compression Panel

Tension Panel

Benefit*

3
FY10

4
FY11

5
FY12

6
FY14

* Note: Not all elements required for full PRSEUS implementation will be TRL=5 at this point
Questions?