The Environmentally Responsible Aviation (ERA) Project – A technology development project

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NASA Glenn Research Center

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Advanced Air Transport Technology Project

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Currently, Associate Director for Flight Strategy
Integrated Aviation Systems Program
New Aviation Horizons

Turbine Engine Technology Symposium
Dayton, OH
September 2016
NASA Aeronautics Six Strategic Thrusts

ERA - Ultra Efficient Commercial Vehicles

6 Strategic Research and Technology Thrusts

Safe, Efficient Growth in Global Operations
- Enable full NextGen and develop technologies to substantially reduce aircraft safety risks

Innovation in Commercial Supersonic Aircraft
- Achieve a low-boom standard

Ultra-Efficient Commercial Vehicles
- Pioneer technologies for big leaps in efficiency and environmental performance

Transition to Low-Carbon Propulsion
- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

Real-Time System-Wide Safety Assurance
- Develop an integrated prototype of a real-time safety monitoring and assurance system

Assured Autonomy for Aviation Transformation
- Develop high impact aviation autonomy applications


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Grand Challenge for Commercial Aviation (1 of 2)
Reduce carbon footprint by 50 percent by 2050

.... in the face of increasing demand, and while reducing development, manufacturing and operational costs of aircraft & meeting noise and LTO NOx regulations

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Change in noise “footprint” area (within 85 dB) for a landing and takeoff

Contour area for aircraft meeting the Stage 4 rule

N: Stage 4 - 10dB CUM (= to 777 cert level)
Area-SEL = 49.5%

HWB N+2:
(Stage 4 – 42 EPNdB)
Area-SEL = 10.4%

N+1: Stage 4 – 32 EPNdB
Area-SEL = 13.2%

80% Reduction in Noise Footprint Area

• All contours are for a 777-like aircraft weight and mission, N+2 achieved with HWB aircraft for same 777-like mission

• N and N+2 areas are rigorous predictions using analytical tool (ANOPP) with measurements for key installation effects

• Stage 4 and N+1 areas are computed from N aircraft to meet required EPNL
  • Source levels changed, assumed even distribution between three certification points

• Effects of source component directivity and aircraft configuration are included

• Auralizations of ANOPP predictions for straight and level flight at conditions of takeoff and approach


Environmentally Responsible Aviation
Vision, Mission, & Scope

• Vision
  – expand the viable and well-informed trade space for commercial transport design decisions
  – enable **simultaneous** realization of national noise, emissions, and performance goals (N+2 timeframe)

• Mission
  – Execute integrated technology demonstrations
  – Partner w/Industry/Academia/OGA 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

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Environmentally Responsible Aviation Project Flow

Prior Research
External Input

Formulation

KDP 1

Phase 1 Investigations

Adv. Vehicle Concept Study

KDP 2

Phase 2 Planning

Integrated Technology Demonstrations (ITD)

FY09: $56.9M
FY10: $65.1M
FY11: $74.2M
FY12: $70.5M
FY13: $70.1M
FY14: $69.7M
FY15:

- GE/NASA/FAA Open Rotor Integration
- Boeing/AFRL/NASA BWB X-48B/C Low Speed Flight Controls Development/Validation
- HWB Acoustics Database Established
- Lockheed, Northrop Grumman, Boeing, P &W, Liberty Works
- 3 Vehicle Concepts Studied
- Critical Technologies Identified
- RR UltraFan Concept Introduced

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

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Open Rotor technologies were studied during ERA Phase 1 in partnership with GE and FAA. (Aeronautical Journal, Oct 2014)

+ CMC turbine vanes, CMC combustor liner, active combustion control, lean direct injection, boundary layer ingesting propulsor.

CMC mixer nozzle work in ERA Phase 1 in partnership with Rolls-Royce and AFRL.
• Noise measurements were obtained from Tower and Truss microphones, and from Microphone Phased Array at key streamwise locations.
HWB AIRFRAME MODEL

5.8% scale (12.35 ft span)
Modular components (control surfaces and landing gear)
High fidelity of geometric details
Designed by a team led by Boeing under a NASA Research Announcement

Detailed characterization of:
- Jet noise and its shielding
- Airframe noise
- Broadband noise shielding

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Measuring Progress in ERA Phase 2
Goal Decomposition and Technology Selection

2025 Vehicle System Level Goals

Technical Challenge

Progress Indicators

Fuel Burn
-50%

NOx
-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

21A PRSEUS

21C ACTE

30A Front Block Compressor

35A UHB Propulsor

40A Low LTO NOx, Fuel Flex Combustor

50A Low Noise Flap Edge & Landing Gear

51A UHB Engine Integration on HWB

KPP2025

KPP2025

KPP2025

KPP2025

KPP2025

KPP2025

KPP2025

KPP2025

Cruise Drag Reduction

Structural Weight Reduction

Wing Weight Reduction

TSFC

TSFC

Cumulative Noise Reduction

LTO NOx

Airframe Component Noise Reduction

Fuel Burn Reduction

Cumulative Noise Reduction

ERA Technology Development & Maturation Plans – Phase 1 and 2

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Innovative Flow Control Concepts for Drag Reduction
- Demonstrate drag reduction of 8 percent, contributing to the 50 percent fuel burn reduction goal at the aircraft system level, without significant penalties in weight, noise, or operational complexity

Advanced Composites for Weight Reduction
- Demonstrate weight reduction of 10 percent compared to SOA composites, contributing to the 50 percent fuel burn reduction goal at the aircraft system level, while enabling lower drag airframes and maintaining safety margins at the aircraft system level

Advanced UHB Engine Designs for Specific Fuel Consumption and Noise Reduction
- Demonstrate UHB efficiency improvements to achieve 15% TSFC reduction, contributing to the 50 percent fuel burn reduction goal at the aircraft system level, while reducing engine system noise and minimizing weight, drag, NOx, and integration penalties at AC system level

Advanced Combustor Designs for Oxides of Nitrogen Reduction
- Demonstrate reductions of LTO NOx by 75 percent from CAEP6 and cruise NOx by 70 percent while minimizing the impact on fuel burn at the aircraft system level, without penalties in stability and durability of the engine system

Airframe and Engine Integration Concepts for Community Noise and Fuel Burn Reduction
- Demonstrate reduced component noise signatures leading to 42 EPNdB to Stage 4 noise margin for the aircraft system while minimizing weight and integration penalties to enable 50 percent fuel burn reduction at the aircraft system level
Airframe Technology
Integrated Technology Demonstrators

ITD 21A: Damage Arresting Composite Demonstration
ITD 21A: Damage Arresting Composite Demonstration
Overall Approach – Technology Maturation Plan

Key Performance Parameters
• Reduce structural weight by 20 percent for LTA Class Aircraft w/GTF Engine

Technology Insertion Challenges Addressed
• Damage tolerance
• Post-buckled composite structure
• Integrated system weight
• Large scale flight weight infused composite parts

Weight | Drag | TSFC | Noise | NOx | End TRL: 5

Assembled Multi bay Box in C-17 Factory

Baseline
Completed

FY12 | FY13 | FY14 | FY15

Multibay Box Assembly Start

Testing Complete

Published for Public Release
NASA Super Guppy Aircraft picked up the MBB at the Long Beach Airport in Calif. and delivered it to NASA LaRC where it was moved to COLTS and installed between the platens for testing.
ITD 21A: Damage Arresting Composites Demonstration Summary Technical Highlight

Requirements
• Fabricate an aerospace-quality large-scale pultruded rod stitched efficient unitized structural (PRSEUS) test article representative of a HWB centerbody.
• Demonstrate that the pristine PRSEUS multi-bay pressure box could support design ultimate load in five critical loading conditions.
• Demonstrate that the damaged PRSEUS multi-bay pressure box could support design ultimate load in five critical loading conditions.
• Demonstrate that analytical tools and modeling techniques are adequate for predicting structural response of complex PRSEUS structures.

Accomplishments
• A high-quality 30-ft long, 6.5-ft wide, 13.5-ft tall multi-bay pressure box test article was fabricated from 11 PRSEUS panels, 4 sandwich panels, fasteners, metal fittings and load-introduction elements.
• The test article was installed in the NASA Langley Research Center Combined Loads Test System facility and loaded to design ultimate load in up-bending, down-bending, internal pressure and combinations of pressure and mechanical load in the pristine condition, with barely visible impact damage and with discrete source damage.
• Finite element analysis predictions showed good agreement with test data.
Propulsion Technology
Integrated Technology Demonstrators

30A: Highly Loaded Front Block Compressor (GE)
35A: 2\textsuperscript{nd} 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

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

Approved for Public Release
ITD30A validated a 2.9% 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

Weight Drag TSFC Noise NOx

End TRL: 5

<table>
<thead>
<tr>
<th>FY12</th>
<th>FY13</th>
<th>FY14</th>
<th>FY15</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMA VAN</td>
<td>UHB OTR Perf. Risk Mitigation Test</td>
<td>UHB OTR/SV Noise Reductions Validation Test</td>
<td>Integrated System LS Test</td>
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<tr>
<td>Prototype Demo</td>
<td></td>
<td></td>
<td></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 Approved for Public Release</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Integrated Technology Demonstrator
2nd Generation UHB Propulsor Integration

Pressure & temperature sensitive paint utilized over range of operating lines

Oil pigmentation gave insight into aerodynamic behavior

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**

<table>
<thead>
<tr>
<th>Weight</th>
<th>Drag</th>
<th>TSFC</th>
<th>Noise</th>
<th>NOx</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>End TRL: 5</td>
</tr>
</tbody>
</table>

#### 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

![Image](https://via.placeholder.com/150)

**ERA Phase 2 Sector Rig**

<table>
<thead>
<tr>
<th>FY12</th>
<th>FY13</th>
<th>FY14</th>
<th>FY15</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASCR Upgraded</td>
<td>PW Gen 1 ASCR Test</td>
<td>Phase 2 Concept downselect</td>
<td>Full annular Rig Test</td>
</tr>
<tr>
<td>Single-injector flame tube screening</td>
<td>GE Gen 1 ASCR Test</td>
<td>MSR NOx Correlation</td>
<td>MSR ASCR Test</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Approved for Public Release</td>
</tr>
</tbody>
</table>

**Sys Analysis/ Tech Mat Complete**
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.
## Integrated Technology Demonstrators

### Summary Performance

<table>
<thead>
<tr>
<th></th>
<th>Integrated Technology Demonstrators</th>
<th>Partner(s)</th>
<th>Min Success</th>
<th>Full Success</th>
<th>Plan/Actual Impact (2025)</th>
</tr>
</thead>
</table>
| 12A+ | AFC Enabled Vertical Tail and Advanced Wing Flight Test | Boeing | | | -1.5 / -0.92+% Tail Drag  
-3 / -3.3% Wing Drag (NLF) |
| 21A | Damage Arresting Composites Demonstration | Boeing | | | -20 / - 20+ % Structural Weight |
| 21C | Adaptive Compliant Trailing Edge Flight Test | AFRL/FlexSys | | | -5 / -8+% Wing Weight |
| 30A | Highly Loaded Front Block Compressor Demonstration | General Electric | | | -2.5 / -2.94% TSFC |
| 35A | 2nd Generation UHB Propulsor Integration | Pratt & Whitney/FAA | | | -9 / -10.9% TSFC  
-15 / -20.9 EPNdB |
| 40A | Fuel Flexible, Low NOX Combustor Integration | Pratt & Whitney | | | -75 / -81% LTO NOX |
| 50A | Landing Gear and Flap Edge Noise Reduction Flight Test | Gulfstream | | | LG -1.0 / -1.0+ EPNdB  
FE -3.0 / -3+ EPNdB |
| 51A | UHB Integration on Hybrid Wing Body Aircraft | Boeing | | | -42 / -40+ EPNdB  
-50 / -47+% Fuel Burn |
Potential Impacts
Vehicle Level – AIAA 2016-1030 & 0863

Assessment of the Noise Reduction Potential of Advanced Subsonic Transport Concepts for the NASA Environmentally Responsible Aviation Project

Russell H. Thomas, Casey L. Burley, and Craig L. Nickol
NASA Langley Research Center

AIAA SciTech 2016
San Diego, California
January 5, 2016
AIAA Paper 2016-0863
Potential Impacts
Vehicle Level – AIAA 2016-1030 & 0863

Assessment of the Performance Potential of Advanced Subsonic Transport Concepts for NASA’s Environmentally Responsible Aviation Project

Craig Nickol
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Bill Haller
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AIAA SciTech 2016
San Diego, California
January 6, 2016

AIAA Paper 2016-1030

Approved for Public Release
Potential Impacts
Vehicle Level – AIAA 2016-1030 & 0863

**RJ**
- T+G98-DD (2) Small DD
- OWN98-DD (2) Small DD

**SA**
- T+G160-GTF (2) Small GTF
- OWN160-GTF (2) Small GTF

**STA**
- T+G216-GTF (2) Medium GTF
- HWB216-GTF (2) Medium GTF

**LTA**
- T+G301 (2) Large DD
- HWB301 (2) Large HWB GTF
- MFN301-GTF (2) Large GTF

**VLTA**
- T+G400-GTF (4) Medium GTF
- HWB400-GTF (3) Medium HWB GTF
# Potential Impacts

## Vehicle Level - Best Performers

### 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>

**Table 15. N+2 HWB-GTF Concept Performance Summary**

<table>
<thead>
<tr>
<th>ERA Target</th>
<th>Noise</th>
<th>Fuel Burn</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-42 dB Cumulative Margin to Stage 4</td>
<td>-50% Block Fuel Burn Relative to 2005 Best-in-Class</td>
<td>-75% LTO Nox relative to CAEP/6</td>
</tr>
<tr>
<td>HWB301-GTF</td>
<td>-40.3</td>
<td>-47</td>
<td>-79</td>
</tr>
<tr>
<td>HWB400-GTF</td>
<td>-40.3</td>
<td>-49.4</td>
<td>-79</td>
</tr>
</tbody>
</table>
Potential Impacts
US Fleet Level – Carbon Footprint

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

Notes – (1) This “what-if” scenario assumes ITD technology finds it way into the fleet in 2025.
(2) ITD wedge above based on transition of ITD techs to tube and wing only in 2025.
Technical Accomplishments - Summary

- It is feasible that Open Rotor Systems will meet current noise standard
- Laminar flow applications have been applied by Boeing to B787
  - Main wing, high Rn applications are the final challenge
- Active flow control applications are still being investigated
- Compliant wing technology is feasible. Large impact on tube & wing
  - Aviation Partners has teamed with FlexSys
- A scalable low NOX, fuel-flexible combustor that exceeds the current regulation with an engine w/advanced fan blade system is feasible
  - Application to future engine products are being explored
- Highly loaded compressor blading is feasible
  - Application to future engine products are being explored
- The Rolls Royce UltraFan engine concept shows great promise
- Feasible noise reduction technologies for engine and airframe emerged
- The NASA/Boeing HWB / GTF configuration was matured further
  - Low speed aero, structures, and operability issues solved
- Less mature, over the wing configurations also show promise toward goals

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Future work/Collaboration opportunities

Propulsion specific

- Advanced Air Transport Technology Project (AATT)
  - Next Generation Propulsors – ducted/unducted propulsors and PAI
  - Boundary Layer Ingesting Propulsors – distortion tolerant
  - Advanced combustors – compact and low NOx for high P/T cores
  - Compact cores – stable and efficient
  - Hybrid Gas Electric Propulsion – new engine options

- Flight Demonstrations and Capabilities Project (FDC)
- New Aviation Horizons (NAH) – flight demonstrators
Potential Impacts
What does Stage 4 - 40 EPNdB sound like?

## TECHNOLOGY BENEFITS

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TECHNOLOGY BENEFITS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise (cum margin rel. to Stage 4)</td>
<td>-32 dB</td>
<td>-42 dB</td>
<td>-52 dB</td>
</tr>
<tr>
<td>LTO NOx Emissions (rel. to CAEP 6)</td>
<td>-60%</td>
<td>-75%</td>
<td>-80%</td>
</tr>
<tr>
<td>Cruise NOx Emissions (rel. to 2005 best in class)</td>
<td>-55%</td>
<td>-70%</td>
<td>-80%</td>
</tr>
<tr>
<td>Aircraft Fuel/Energy Consumption† (rel. to 2005 best in class)</td>
<td>-33%</td>
<td>-50%</td>
<td>-60%</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

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**ERA Focus**

Complete Alignment with the NASA Strategic Implementation Plan & The National Aeronautics R& D Plan

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Potential Impacts
Vehicle Level – AIAA 2016-1030 & 0863

• NPSS – Numerical Propulsion Simulation System
  – ITD and partner data utilized to help create input assumptions

• WATE++ - Weight Analysis for Turbine Engines

• FLOPS & OpenVSP – Flight Optimization System & Vehicle Sketch Pad
  – HCDStruct utilized for HWB weights analysis
  – FUN3D corrections utilized for HWB aero analysis
  – ITD and partner data utilized to help create input assumptions

• HCDStruct – Hybrid Wing Body Conceptual Design and Structural Optimization
  – New capability developed under ERA
  – Wing-tip to wing-tip HWB finite element model with NASTRAN solver
  – Validated using Boeing benchmark cases (OREIO, 9H1)

• MVL-15 – Modified Vortex Lattice for Low Speed Aerodynamic Performance Estimation
  – New semi-empirical capability developed under ERA
  – Provides low speed drag polars for tube+wing aircraft
  – Capable of analyzing multi-element high lift systems

• ANOPP2 – Aircraft Noise Prediction Program
  – ITD and partner data utilized to help create refined input assumptions and improved predictions
  – Shielding, fan noise, and noise reduction technology impact estimates supported by test data
  – New prediction capabilities developed
### Potential Impacts
Vehicle Level – AIAA 2016-1030 & 0863

Table 13. N+2 Large Twin Aisle class T+W and HWB Concepts

<table>
<thead>
<tr>
<th>Units</th>
<th>T+W301-DD</th>
<th>T+W301-GTF</th>
<th>HWB301-DD</th>
<th>HWB301-GTF</th>
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</thead>
<tbody>
<tr>
<td>TOGW lb</td>
<td>570,195</td>
<td>570,533</td>
<td>537,641</td>
<td>534,491</td>
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<tr>
<td>OEW lb</td>
<td>265,290</td>
<td>270,084</td>
<td>251,281</td>
<td>253,326</td>
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<tr>
<td>Payload lb</td>
<td>118,100</td>
<td>118,100</td>
<td>118,100</td>
<td>118,100</td>
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<tr>
<td># Pax</td>
<td>301</td>
<td>301</td>
<td>301</td>
<td>301</td>
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<tr>
<td>Range nm</td>
<td>7500</td>
<td>7500</td>
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<tr>
<td>Total Fuel lb</td>
<td>186,805</td>
<td>182,349</td>
<td>168,259</td>
<td>163,065</td>
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<tr>
<td>Block Fuel lb</td>
<td>168,687 (-39.1%)</td>
<td>164,748 (-40.6%)</td>
<td>151,597 (-45.3%)</td>
<td>147,011 (-47.0%)</td>
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<tr>
<td>Wing Area ft²</td>
<td>4664</td>
<td>4670</td>
<td>10169</td>
<td>10169</td>
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<tr>
<td>Wing Span ft</td>
<td>226.5</td>
<td>226.6</td>
<td>250</td>
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<tr>
<td>Wing Aspect Ratio</td>
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<td>6.2</td>
<td>6.1</td>
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<td>Wing Loading lb/ft²</td>
<td>122.2</td>
<td>122.2</td>
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<td>Cruise Mach</td>
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<td>0.84</td>
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<tr>
<td>Start of Cruise L/D</td>
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<td>22.0</td>
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<td>23.7</td>
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<tr>
<td>Number of Engines</td>
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<td>2</td>
<td>2</td>
<td>2</td>
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<tr>
<td>Thrust per Engine lb</td>
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<td>66,989</td>
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<td>Start of Cruise SFC</td>
<td>0.483</td>
<td>0.467</td>
<td>0.49</td>
<td>0.475</td>
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</table>

Notes – (1) Impacts also modeled all other seat classes. (2) HWB- GTF vehicles provided the best overall performance.