AIRCRAFT AND TECHNOLOGY CONCEPTS FOR AN N+3 SUBSONIC TRANSPORT

MIT, Aurora Flights Science, and Pratt & Whitney

Elena de la Rosa Blanco
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Message

- Defined documented scenario and aircraft requirements
- Created two conceptual aircraft: D (double-bubble) Series and H (Hybrid Wing Body) Series
  - D Series for domestic size meets fuel burn, LTO NOx, and balanced field length N+3 goals, provides significant step change in noise
  - H Series for international size meets LTO NOx and balanced field length N+3 goals
  - D Series aircraft configuration with current levels of technology can provide major benefits
- Developed first-principles methodology to simultaneously optimize airframe, engine, and operations
- Generated risk assessment and technology roadmaps for configurations and enabling technologies
Project Enabled by University-Industry Collaboration

• MIT
  – (GTL) Propulsion, noise, (ACDL) aircraft configurations, systems, (ICAT) air transportation, and (PARTNER) aircraft-environment interaction
  – Student engagement (education)

• Aurora Flight Sciences
  – Aircraft components and subsystem technology; Aerostructures and manufacturing; System integration

• Pratt & Whitney
  – Propulsion; System integration assessment

• Collaboration and teaming
  – Assessment of fundamental limits on aircraft and engine performance
  – Seamless teaming within organizations AND between organizations
NASA System Level Metrics

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

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<thead>
<tr>
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<tbody>
<tr>
<td>Noise</td>
<td>- 32 dB (cum below Stage 4)</td>
<td>- 42 dB (cum below Stage 4)</td>
<td>-71 dB (cum below Stage 4)</td>
</tr>
<tr>
<td>LTO NOx Emissions</td>
<td>-60%</td>
<td>-75%</td>
<td>better than -75%</td>
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<tr>
<td>(below CAEP 6)</td>
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</tr>
<tr>
<td>Performance: Aircraft Fuel</td>
<td>-33%**</td>
<td>-40%**</td>
<td>better than -70%</td>
</tr>
<tr>
<td>Burn</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance: Field Length</td>
<td>-33%</td>
<td>-50%</td>
<td>exploit metro-plex* concepts</td>
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- Energy intensity metric for comparison of fuel burn
- Add a **climate impact** metric for evaluation of the aircraft performance
  - Global temperature change as a result of the emissions
Three Major Results from N+3 Program

• Development and assessment of two aircraft configurations:
  – D Series for domestic size meets fuel burn, LTO NOx, and balanced field length N+3 goals, provides significant step change in noise
  – H Series for international size meets LTO NOx and balanced field length N+3 goals

• Comparison of D Series and H Series for different missions (domestic and international)

• Trade study identification of D Series benefits from configuration vs. advanced technologies
Two Scenario-Driven Configurations

Double-Bubble (D series):
modified tube and wing with lifting body

Baseline: B737-800
Domestic size

Hybrid Wing Body (H series)

Baseline: B777-200LR
International size

Two diagrams show the performance metrics for each configuration:
- Fuel burn (kJ/kg-km)
- Noise
- Field length
- LTO NOx

100% of N+3 goal is highlighted for each metric.
D and H Series Fuel Burn for Different Missions

- D Series has better performance than H Series for missions examined
- H Series performance improves at international size
Fuel Burn Baselines and Results

PFEI for 50 Best Existing Aircraft within Global Fleet Computed using Piano-X software

- B737-800
- B777-200LR

Productivity (Payload*Range, kg-km)

PFEI (kJ/kg-km)

70% Reduction

D8.5

H3.2

70% Reduction
D Series Configuration is a Key Innovation

% Fuel burn reduction relative to baseline
% LT NOx reduction relative to CAEP6

D8 configuration

2035 Engine Technology

Airframe materials/processes

Natural laminar flow on bottom wing

Airframe load reduction

Approach operations

LDI combustor

Balanced Field Length for all designs = 5000 feet

EPNdB Noise reduction relative to Stage 4

Fuel burn
Noise
LTO NOx
D8 Configurations: Design and Performance

D8.1 (Aluminum)

D8.5 (Composite)

Fuel Burn (kJ/kg-km)

Field Length (feet)

Noise (EPNdB below Stage 4)

LTO NOx (g/kN) (% below CAEP 6)

100% of N+3 Goal
**D8 – Double Bubble Configuration with current technologies**

- Double bubble lifting fuselage with pi-tail
- Engines flush-mounted at aft fuselage with boundary layer ingestion; engine noise shielding and extended rearward liners
- Reduced cruise Mach number with unswept wings and optimized cruise altitude
- Eliminates slats
- BFL = 5000 feet

Payload: 180 PAX
Range = 3000 nm
**D8.5 Airframe Technology Overview**

**Operations Modifications:**
- Reduced Cruise Mach: 0.72 for D8.1 and 0.74 for D8.5
- Optimized Cruise Altitude: 40,000 ft. for D8.1 and 45,000 ft. for D8.5
- Descent angle of 4º
- Approach Runway Displacement Threshold
D8.5 Engine Technology Overview

- High Bypass Ratio Engines (BPR=20) with high efficiency small cores
- LDI Advanced Combustor
- Distortion Tolerant Fan
- Tt4 Materials and advanced cooling
- Advanced Engine Materials
- Variable Area Nozzle
- Multi-segment rearward acoustic liners
Design Modification Sequence from B737-800 to D8.1 and D8.5

- Case 0: B737-800
- Case 1: Optimized B737-800
- Case 2: Fuselage replacement from tube+wing to double bubble
- Case 3: Reduced cruise Mach number from 0.8 to 0.72
- Case 4: Engines flush-mounted on top, rear fuselage
- Case 5: 2010 Engine technology
- Case 6: Slats elimination
- Case 7 (D8.1): Balanced Field Length reduced from 8000 ft. to 5000 ft.
- Case 8: Faired Undercarriage
- Case 9: 2035 Engine technology
- Case 10: Advanced Airframe materials and processes
- Case 11: Natural laminar flow on bottom wing
- Case 12: Airframe loads reduction
- Case 13: Approach operations
- Case 14 (D8.5): LDI combustor
Fuel burn evolution from B737-800 to D8.1 and D8.5

- B737-800 M=0.8
- B737-800 optimized
- Double-bubble fuselage
- Slow to M=0.72
- Eng rear
- 2010 Eng. tech.
- Slats remove
- BFL=5000 ft
- Faired undercarriage
- 2035 engine tech.
- Airframe materials/processes
- NLF on bottom wing
- Load reduction

- 100%
- 96%
- 77%
- 71%
- 55%
- 51%
- 50%
- 51%
- 39%
- 33%
- 30%
- 29%
LTO NOx evolution from B737-800 to D8.1 and D8.5

- B737-800 M=0.8
- B737-800 optimized
- Double-bubble fuselage
- Slow to M=0.72
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- 2010 Engine Tech.
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- 2035 engine tech.
- Airframe materials/processes
- NLF on bottom wing
- Load reduction
- LDI com.

%LTO NOx relative to CAEP 6

TSFC (lb/lbf-hr)
Noise evolution from B737-800 to D8.1 and D8.5
B737 ➔ D8 Study—Main Observations

- Improvement arises from integration and exploitation of indirect benefits – there is no one “magic bullet”
- Design methodology allows exploration of interactions
- D8 fuselage alone is slightly draggier than B737's, but enables…
  - lighter wing
  - smaller lighter tails
  - enables fuselage BLI
  - smaller, lighter engines
  - shorter, lighter landing gear
  - … etc
**D8 BLI Approach**

- Entire upper fuselage BL ingested
- Exploits natural aft fuselage static pressure field
  - Fuselage's potential flow has local $M = 0.6$ at fan face
  - No additional required diffusion into fan
  - No generation of streamwise vorticity
  - Distortion is a smoothly stratified total pressure
**Improved Load/Unload Time and Airport Capacity**

- **Climate change impact.** D8 results on over 80% climate improvement from B737-800

- **Improved Load/Unload Time.** D8.5 provides reduction in block time during load and unload and approach operations

![Diagram showing B737-800 load configuration vs D8.5 load configuration]

<table>
<thead>
<tr>
<th>Flight time (hr)</th>
<th>Trip time (hr)</th>
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<tbody>
<tr>
<td><strong>NYC-LAX</strong></td>
<td></td>
</tr>
<tr>
<td>B737 4.81</td>
<td>5.98</td>
</tr>
<tr>
<td>D8.5 5.29</td>
<td>5.96</td>
</tr>
<tr>
<td>(D8.5 is 1 minute faster than B737)</td>
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</tbody>
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| **NYC-ORD**      |                |
| B737 1.55        | 2.71           |
| D8.5 1.73        | 2.40           |
| (D8.5 is 19 minutes faster than B737) |

| **BOS-DCA**      |                |
| B737 0.93        | 2.09           |
| D8.5 1.06        | 1.73           |
| (D8.5 is 22 minutes faster than B737) |

- **Airport capacity.** D8 could allow for increased airport capacity due to wake vortex strength reduction
First principle innovative aircraft design optimization tool (M. Drela)

TASOPT (Transport Aircraft System OPTimization)

- Modelled on a first-principles basis, NOT from correlations
- Simultaneously optimizes airframe, engine, and operations parameters for given mission
- Developed in modules so easily integrated with other tools
- Generate required output files for detailed aeroelastic and aerodynamic analysis
- Allows aircraft optimization with constraints on noise, balanced field length, and other environmental parameters
Summary

• Established documented scenario and aircraft requirements
• Created two conceptual aircraft: D (double-bubble) Series and H (Hybrid Wing Body) Series
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Elena de la Rosa Blanco (edlrosab@mit.edu)
Link to presentation: http://www.nasa.gov/topics/aeronautics/features/future_airplanes.html