X-48B Blended Wing Body
Ground to Flight Correlation Update

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• Joe Boland – X-48B Parameter Identification, Boeing

• And many others
Outline

• X-48B – What is it and why
• BWB ground tests
• X-48B flight tests
• Some ground to flight comparisons
  – Pitching moment
  – 1-g stall limits
• What’s next
• Summary
• Questions
<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing Span</td>
<td>20.4 ft</td>
</tr>
<tr>
<td>Wing Area</td>
<td>100.5 ft²</td>
</tr>
<tr>
<td>Max Airspeed</td>
<td>118 kts</td>
</tr>
<tr>
<td>Max Altitude</td>
<td>10,000 ft MSL</td>
</tr>
<tr>
<td>Max Weight</td>
<td>523 lbs</td>
</tr>
<tr>
<td>Load Limits</td>
<td>+4.5 g’s to -3.0 g’s</td>
</tr>
<tr>
<td>Static Thrust</td>
<td>162 lbs</td>
</tr>
<tr>
<td>Duration</td>
<td>30 min + 5 min reserve</td>
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</table>
Program Objectives

• **Assess stability & control characteristics of a BWB class vehicle in free-flight conditions:**
  – Assess dynamic interaction of control surfaces
  – Assess control requirements to accommodate asymmetric thrust
  – Assess stability and controllability about each axis at a range of flight conditions

• **Assess flight control algorithms designed to provide desired flight characteristics:**
  – Assess control surface allocation and blending
  – Assess edge of envelope protection schemes
  – Assess takeoff and landing characteristics
  – Test experimental control laws and control design methods

• **Evaluate prediction and test methods for BWB class vehicles:**
  – Correlate flight measurements with ground-based predictions and measurements
BWB Flight Dynamics Research

**Langley 20’ Spin Tunnel**
- 1% Spin/Tumble
- 2% Rotary Balance

**Langley 14’ x 22’ Tunnel**
- 3% Static Aero
- 3% Large Angle
- 3% Forced Oscillation

**Langley Full-Scale Tunnel**
- 5% Free-flight
- X-48B & C (8.5%) Static Test

**Langley NTF Tunnel**
- 2% BLI Study
- 2% Transonic S&C

**AEDC 16T Tunnel**
- 2% Transonic S&C

**X-48B Flight Test DFRC**
## BWB Flight Dynamics Research Timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>99</td>
<td>1% Free spin &amp; tumble test (20' Spin Tunnel)</td>
</tr>
<tr>
<td>00</td>
<td>3% Low-speed static test (14x22)</td>
</tr>
<tr>
<td>01</td>
<td>3% Large angle balance test (14x22)</td>
</tr>
<tr>
<td>02</td>
<td>X-48A Canceled</td>
</tr>
<tr>
<td>03</td>
<td>7% Rotary forced oscillation test (14x22)</td>
</tr>
<tr>
<td>04</td>
<td>3% Low-speed static test (14x22)</td>
</tr>
<tr>
<td>05</td>
<td>5% Static Chute Test (NTF)</td>
</tr>
<tr>
<td>06</td>
<td>2% 2nd BLI Study (NTF)</td>
</tr>
<tr>
<td>07</td>
<td>X-48B Static Flight Test (LFST)</td>
</tr>
<tr>
<td>08</td>
<td>2% Transonic Static Test (LFST)</td>
</tr>
<tr>
<td>09</td>
<td>X-48C Static Test Phase 1 Test (LFST)</td>
</tr>
<tr>
<td>10</td>
<td>X-48B Flight Phase 1 Test (LFST)</td>
</tr>
</tbody>
</table>

Note: The timeline includes various flight dynamics research events from 1999 to 2010, highlighting key milestones in the development and testing of BWB flight dynamics research.
Suite of Ground Tests

Chord Reynolds Number, millions

Vehicle Scale

Region of Interest

Free Spin/Tumble Test

Forced Oscillation Test

Rotary Test

Large Angle Test

AEDC 16T Test

NTF Test

X-48 Test in 30x60

X-48B Flight Test

Free-flight Test
Phase I Flight Test Blocks

Block 1: Flights 1-11
Slats EXT

Block 2: Flights 12-20
Slats RET

Block 3: Flights 21-34, 44-56, 59-61, 67-70
Slats EXT

Block 4: Flights 35-43, 57-58, 62-66, 71-72
Slats RET

Block 5: Flights 73-75, 77
Slats EXT

Block 6: Flights 76, 78-80
Slats RET

PID / Stalls
/ Engine
Out
Maneuvering

Envelope Expansion

Increasing Risk

Completed

Completed

Completed
Flight Test Video
X-48B Preliminary Flight Test Results

- Extremely maneuverable in roll
- Aircraft very closely matches sim for up/away flight (and landing)
- Flight control design is very robust
  - Some control law deficiencies were masked during initial slat extended flights
  - Corrected with update
- Slat EXT stalls successful to 24 deg alpha
  - Controllable to 3 degrees beyond CLmax
- Slat RET stalls successful to 14 deg alpha
- Departure limiter assaults highly successful!
- Overall, the aircraft flies extremely well
Where are the poor comparisons?

- Ground tests showed significant differences in pitching moment.
  - More on this to follow.
- Early analysis (Flights 1-11) indicated need for improved engine model.
  - Engine model updated prior to flight 73
- More analysis yet to be done.
Cm vs $\alpha$ from various ground tests

- Magnitude of support interference effect on pitching moment much greater than anticipated

3” dia. large post + pitch link
Langley 14x22 foot Tunnel
Cm vs $\alpha$ from various ground tests

- Magnitude of support interference effect on pitching moment much greater than anticipated
Cm vs $\alpha$ from various ground tests

- Magnitude of support interference effect on pitching moment much greater than anticipated

3” dia. large post + pitch link
Langley 14x22 foot Tunnel

1.2” dia. bent sting
Langley 14x22 foot Tunnel

Re$_c$, Million

- 64.0
- 32.0
- 16.0
- 8.0
- 4.0
- 2.0
- 1.0
- 0.5

M \leq 0.25
Cm vs $\alpha$ from various ground tests

- Magnitude of support interference effect on pitching moment much greater than anticipated

Swept strut designed for minimum interference in NTF
Cm vs $\alpha$ from various ground tests

- Magnitude of support interference effect on pitching moment much greater than anticipated

Swept strut designed for minimum interference in NTF

X-48B strut mounted in Langley Full Scale Tunnel
Cm vs $\alpha$ from various ground tests

- Magnitude of support interference effect on pitching moment much greater than anticipated

Flight data fit of flights 1-50
Free-flight Test Technique

Facilities:
- Langley Full-Scale Tunnel
- 14’ X 22’ Subsonic Tunnel
5% BWB Free-flight Test
Langley Full-Scale Tunnel Sept 2005

Test Objectives:
Assess:
• 1g departure onset control
• Asymmetric thrust control limits
• Center engine thrust vectoring control
Free-flight Data Example

- Slats extended
- Aft cg
Free-flight and Flight Test Comparison

1g, Static Conditions
0.95 < Nz < 1.05
-1.0 < \( \beta \) < +1.0
-2.0 < \( p, q, r \) < +2.0

Slats Retracted

Flight Fwd CG, \( \sim 34.2\% \)
Flight Aft CG, \( \sim 39.0\% \)

Slats Extended

\( \nabla \)

\( 1^\circ \)

\( \rightarrow 5 \text{ kts} \)

\( \nabla \)

\( 1^\circ \)

\( \rightarrow 5 \text{ kts} \)

\( \nabla \)

\( \rightarrow \)

\( \nabla \)

\( \rightarrow \)

○ Free-flight 36.4% mac

○ Free-flight 36.4% mac

○ Free-flight 40.1% mac
Some lessons learned

• While support interference is a usual and expected occurrence, the magnitude of the impact on pitching moment for BWB is much larger than anticipated

• Free-flight test method provided good correlation with observed 1-g flight test limits

• Ground to flight correlation is difficult without a central repository of wind tunnel, flight, CFD and simulation data
Areas without flight comparison

- Transonic
  - NTF and AEDC 16T data
- Post departure modes (falling leaf, spin, tumble)
  - Large angle static, rotary and free spin/tumble data
So what’s next?

X-48C Configuration

- Replace Winglets with Twin Verticals
- New Elevon 1 and Rudder designs
- Two 75lb thrust engines
## X-48C Test Plan

<table>
<thead>
<tr>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
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</table>

- **Turbofan Development**
- **X-48C Aero Data and Loads Analysis**
- **X-48C Sim Development**
- **X-48C Flight Controls**
- **X-48C FEM and Structural Design**
- **X-48C Part Fab**
- **X-48C Vehicle Conversion**

**X-48C Flight Test**
Summary

• 92 successful flights on a single-string flight control system
  – A wealth of low-speed data
  – Aircraft very closely matches sim for up/away flight (and landing)
  – Overall, the aircraft flies extremely well

• Full envelope aero database from ground tests of BWB configuration

• Large pitch sensitivity to support interference

• Much more analysis yet to be done

• No show stoppers
Questions?