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

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- 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
### X-48B - 8.5% Dynamically Scaled BWB

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
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<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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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>
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<tbody>
<tr>
<td>99</td>
<td>3% Large angle balance test (14x22)</td>
</tr>
<tr>
<td>00</td>
<td>3% Low-speed static test (20’ Spin Tunnel)</td>
</tr>
<tr>
<td>01</td>
<td>7% Forced oscillation test (20’ Spin Tunnel)</td>
</tr>
<tr>
<td>02</td>
<td>X-48A Canceled</td>
</tr>
<tr>
<td>03</td>
<td>2% BLI Study (NTF)</td>
</tr>
<tr>
<td>04</td>
<td>5% Static Test (LFST)</td>
</tr>
<tr>
<td>05</td>
<td>5% Free Flight Test (LFST)</td>
</tr>
<tr>
<td>06</td>
<td>2% Transonic Buffet (NTF)</td>
</tr>
<tr>
<td>07</td>
<td>X-48B Flight Phase I Test (LFST)</td>
</tr>
<tr>
<td>08</td>
<td>X-48C Static Test Phase I Test (DFRC)</td>
</tr>
<tr>
<td>09</td>
<td>X-48B Flight Phase I Test (LFST)</td>
</tr>
<tr>
<td>10</td>
<td>X-48C Static Test Phase I Test (DFRC)</td>
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</tbody>
</table>
Suite of Ground Tests

Vehicle Scale

Chord Reynolds Number, millions

Region of Interest

X-48 Test in 30x60

Free-flight Test

Forced Oscillation Test

Rotary Test

Free Spin/Tumble Test

Large Angle Test

Static Aero Test

AEDC 16T Test

NTF 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
X-48B Flight Rate

- Flight control computer software upgrade
- GPS/IMU rebuild
- IMU dropout
- Runway resurface
- Major maintenance check

Flight No. vs. Time (Jul'07 to Jan'11)
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

![Diagram showing Cm vs $\alpha$ with various ReC values and corresponding legend.]

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

1.2” dia. bent sting
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

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
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

- **Flight Fwd CG, ~34.2%**
- **Flight Aft CG, ~39.0%**

**1g, Static Conditions**
- $0.95 < N_z < 1.05$
- $-1.0 < \beta < +1.0$
- $-2.0 < p, q, r < +2.0$

**Slats Retracted**
- Free-flight 36.4% mac

**Slats Extended**
- 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>
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<tbody>
<tr>
<td>J</td>
<td>A</td>
<td>S</td>
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- **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**

## Yearly Activities

- **2010**: Turbofan Development
- **2011**: X-48C Aero Data and Loads Analysis, X-48C Sim Development
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?