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

- Wing Span: 20.4 ft
- Wing Area: 100.5 ft²
- Max Weight: 523 lbs
- Static Thrust: 162 lbs
- Max Airspeed: 118 kts
- Max Altitude: 10,000 ft MSL
- Load Limits: +4.5 g’s to -3.0 g’s
- Duration: 30 min + 5 min reserve
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>1999</td>
<td>1% Free spin &amp; tumble test (20' Spin Tunnel)</td>
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<tr>
<td>2000</td>
<td>3% Low-speed static test (14x22)</td>
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<tr>
<td>2001</td>
<td>3% Large angle test (14x22)</td>
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<tr>
<td>2002</td>
<td>7% X-48A Canceled</td>
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<tr>
<td>2003</td>
<td>3% Forced oscillation test (14x22)</td>
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<td>2004</td>
<td>2nd Spin Tunnel study (NTF)</td>
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<tr>
<td>2005</td>
<td>5% Static Test (LFST)</td>
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<tr>
<td>2006</td>
<td>2% Transonic S&amp;C Buffet (NTF)</td>
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<tr>
<td>2007</td>
<td>5% Free Flight Test (LFST)</td>
</tr>
<tr>
<td>2008</td>
<td>2% Transonic Test (LFST)</td>
</tr>
<tr>
<td>2009</td>
<td>X-48C Static Test Phase I 1.5 Test (DFRC)</td>
</tr>
<tr>
<td>2010</td>
<td>X-48B Flight Test (LFST)</td>
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- **Streamlined XBW**
  - 2009: X-48C Flight Test (LFST)
  - 2010: X-48B Flight Test (LFST)
- **AEDC 16T**
  - 2009: Transonic S&C Buffet (NTF)
  - 2010: 5% Free Flight Test (LFST)
- **Spin Tunnel**
  - 2004: 2nd Spin Tunnel study (NTF)
  - 2005: 5% Static Test (LFST)
- **Static Test**
  - 2009: X-48C Static Test Phase I 1.5 Test (DFRC)
  - 2010: X-48B Flight Test (LFST)
Suite of Ground Tests

- Free-flight Test
- Rotary Test
- Forced Oscillation Test
- Static Aero Test
- Large Angle Test
- X-48B Flight Test
- X-48 Test in 30x60
- Free Spin/Tumble Test
- AEDC 16T Test
- NTF Test

Vehicle Scale vs Chord Reynolds Number, millions

Region of Interest
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**

- **Departure Limiter Assaults / Turning Stalls**

- **Increasing Risk**

- **Completed**
X-48B Flight Rate

Flight control computer software upgrade

IMU dropout

Runway resurface

GPS/IMU rebuild

Major maintenance check

Scrub

Block 1

Block 2

Block 3

Block 4

Block 5

Block 6

SSPID

SSPID
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

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
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

**Slats Retracted**

1g, Static Conditions
0.95 < Nz < 1.05
-1.0 < β < +1.0
-2.0 < p, q, r < +2.0

**Flight Fwd CG, ~34.2%**

**Flight Aft CG, ~39.0%**

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**Slats Extended**

**Free-flight 36.4% mac**

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**Equivalent Airspeed**

- 1°
- 5 kts

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**Equivalent Airspeed**

- 1°
- 5 kts
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

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<th>2010</th>
<th>2011</th>
<th>2012</th>
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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**
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?