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
Suite of Ground Tests

Vehicle Scale

Chord Reynolds Number, millions

Region of Interest

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

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**Envelope Expansion**

**PID / Stalls**

**/ Engine Out**

**Maneuvering**

**Departure Limiter Assaults / Turning Stalls**

Increasing Risk
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

![Graph showing Cm vs alpha](image)

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

1.2” dia. bent sting
Langley 14x22 foot Tunnel
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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
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 < \( \beta \) < +1.0
-2.0 < p, q, r < +2.0

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

Slats Extended

\( 1^\circ \)
5 kts

\( \square \) Free-flight 36.4% mac

\( \downarrow \)
5 kts

\( \square \) Free-flight 36.4% mac

\( \downarrow \)
5 kts

\( \square \) 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

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- **2010**: Turbofan Development

**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