X-48B Blended Wing Body Flight Control Demonstrator
X-48B IS NOT JUST ANOTHER UAV

INSTEAD, IT IS:

A PILOT-IN-THE-LOOP TECHNOLOGY DEMONSTRATOR
FOR A FULL SCALE, PILOTED VEHICLE
Disclaimer

FOR A FULL SCALE, PILOTED VEHICLE
1903
Concept Genesis

1903
1947
1992

44 years
45 years

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1/3 Less Wetted Area than Conventional

**Effect of Body Type**

- Minimum Surface Area: 7,000 sq-ft
- Streamlined Options: 23,000 sq-ft (22,000 sq-ft)

**Effect of Wing/Body Integration**

- Surface Area: 35,000 sq-ft
- Surface Area: 28,000 sq-ft

**Effect of Engine Installation**

- Surface Area: 39,000 sq-ft
- Surface Area: 39,600 sq-ft

**Effect of Controls Integration**

- Surface Area: 44,000 sq-ft
- Surface Area: 29,700 sq-ft
Critical Flight Control Technology

Performance gain – reduced wing area and weight

Controllable in post-stall region

BWB post-stall \( \alpha \) limit

B-2 pre-stall \( \alpha \) limit

Increased challenge to maintain control in unstable post-stall region

Unstable

Stable

High-rate large control surfaces create large secondary power demands

Need to Prove that the BWB is as Robust as a C-17
Flying Wing Spin & Tumble Departures

**Then...**

- Flying wing dynamics dominated by minimal aerodynamic pitch and yaw damping
- Post-stall, this could lead to unrecoverable spin and tumble modes

**Now**

- Spin testing shows that the BWB potentially has unrecoverable spin and tumble modes
- Need to prove that an advanced flight control system will prevent entry into departure regions
• **Flight testing provides:**
  - Flight Control System risk reduction
  - Required to convince customers that BWB configuration is as safe as a conventional airplane

• **Investigate:**
  - Stall Characteristics
  - Departure Onset Boundaries
  - Asymmetric Thrust Control
  - Flight Control Algorithms
  - Envelope Protection Schemes
  - Dynamic Ground Effects
  - Control Surface Hinge Moments
X-48B BWB Low Speed Vehicle

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Blended Wing Body – X-48B

• Two X-48B Aircraft and Ground Control Station (GCS)
  • Research Partnership of Boeing, NASA, and AFRL
  • Design and fabrication contracted to Cranfield Aerospace

• Air Vehicle Highlights:
  • Dynamically Scaled
  • Uninhabited Air Vehicle
    – Flown by Pilot from Ground Station
  • Powered by 3 Small Turbojets
    – Ground Start only
  • Conventional takeoff and landing
    – Non-retractable Tricycle Gear
    – Slats are Fixed for either Extended or Retracted Configuration
  • Recovery System
    – Drogue, Parachute, and Air Bags
• Design Approach
  • Use low cost (COTS) equipment where possible
    – Engines - JetCat P200
    – Landing Gear - mountain bike shocks & brakes
  • Use normal industry practice for electronic equipment
  • Use aircraft spec equipment where necessary
    – Radios, IMU, Actuators, Flight Termination System (FTS) parts
  • Save weight to meet dynamic scaling requirements
X-48B 30x60 Wind Tunnel Test

• NASA / AFRL contributed test time in ODU Langley Full-Scale Tunnel
• Wind tunnel test completed April / May 2006
• 250 hours of testing with flight control hardware active
• Data used by Boeing for X-48B simulation and flight control software
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Validation Testing

Landing Gear Drop Tests

Wing Load Test

Drogue Boom Load Test
### Vehicle Characteristics

<table>
<thead>
<tr>
<th>Characteristic</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>Maximum Weight</td>
<td>523 lbs</td>
</tr>
<tr>
<td>Static Thrust</td>
<td>162 lbs</td>
</tr>
<tr>
<td>Maximum Airspeed</td>
<td>118 kts</td>
</tr>
<tr>
<td>Maximum Altitude</td>
<td>10,000 ft MSL</td>
</tr>
<tr>
<td>Load Factor Limits</td>
<td>+4.5 g’s to -3.0 g’s</td>
</tr>
<tr>
<td>Flight Duration</td>
<td>30 minutes + 5 minute reserve</td>
</tr>
</tbody>
</table>
Blended Wing Body – X-48B

8.5% Dynamically Scaled X-48B BWB

Vehicle Characteristics
- Wing Span: 20.4 ft
- Wing Area: 100.5 ft²
- Maximum Weight: 523 lbs
- Static Thrust: 162 lbs
- Maximum Airspeed: 118 kts
- Maximum Altitude: 10,000 ft MSL
- Load Factor Limits: +4.5 g's to -3.0 g's
- Flight Duration: 30 minutes + 5 minute reserve
X-48B Configuration – Top View

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Blended Wing Body – X-48B

- Triple JetCat P200 Engines
- Drogue Boom
- Clean Top Surface
- Interchangeable Slat Assemblies
- ‘Pilots View’ Camera
- Air Data Booms
X-48B Configuration – Internal View

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Blended Wing Body – X-48B

- Laser Height Sensor (Under)
- Drogue Ejector Control Panel
- Drogue ‘Chute Lines (Under Boom)
- Drogue Boom
- Drogue Ejector
- Fuel Pumps & ECUs
- Control Surface Actuators
- Fuel Tank
- Air Data Boom
- Transponder
- Antennae
- BIT Panel
- Avionics Crate
- Batteries
- IMU (Rear of Bulkhead)
- GPS Antennae
- Air Bag Inflation System
- Main ‘Chute
- Drogue ‘Chute Lines (Under Boom)
- Air Data Boom
X-48B Configuration – Underside View

- Fixed Landing Gear
- Triple Airbags for Impact Attenuation
- Split Drag Rudders
- Access Hatches for Avionics, Fuel Tank, Actuator access, etc.
- Drogue Boom
- 20 Flying Control Surfaces
Recovery System

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Blended Wing Body – X-48B

Drogue

Main

Airbags
GCS – Trailer

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GCS – Pilot Station
First Flight Video

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Blended Wing Body – X-48B

[Image of the X-48B aircraft in flight]
X-48B Flight Test Summary

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• Fifty Flights completed (as of 2 April 2009)
  • 32 Flights w/ Slats Extended
  • 18 Flights w/ Slats Retracted
    – 8 Multi Mission Operations
• Test Highlights:
  • Test Maneuvers
    – Real-Time Stability Margins – Envelope Expansion
    – Automated Parameter Identifications (PID) – Freq Sweeps/Doublets
    – Steady Heading Sideslips - Simulate Cross-winds
    – Lazy-8s and Wind-up Turns
    – Airspeed Calibrations (Triangle method)
    – Approach to Stalls
    – Stalls & Deep Stall Recoveries
    – Engine Out Maneuvering
    – Trim in Ground Effect

• Operations from Hard Surface Runway vs. Lakebed Runway
  – Edwards AFB North Base 6/24 – 3,000 Feet (Eastern End)
X-48B Initial Flight Test Results

• Extremely Maneuverable in Roll
• Aircraft Very Closely Matches GCS for Up/Away Flight (and Landing)
  • Pitch / Yaw Limiters different in Simulator than Airplane
  • Potential Air Data Calibration issue – under investigation

• Flight Control Design is Very Robust
  • Some Control Law deficiencies were masked during Slat Ext flights
    – Beta Vane Switching (Average to Single) / Takeoff Pitch Authority
• Overall, the Aircraft Flies Extremely Well
  • Despite no peripheral cues (2-D only) / no seat-of-the-pants
X-48B Lessons Learned

• COTS Design approach
  • Initial Equipment Cost Low, But Integration Cost may be High
  • Original planned Engine Design not COTS – large impact to Flight Duration
• Waypoint Nav Design / Software V&V testing
  • Test Limits - Windshear, Gusts / Weather Balloon Data
• Flight Simulator invaluable for Successful Tests
  • Very good match for flight – Excellent flight rehearsal / pilot training tool
• Braking PIO potential High
  • No Decel Feedback to Pilot / Brake Spring or Ground Models inaccuracies
• Robust Flight Control System can Mask some Control Law Deficiencies
X-48B What’s Next for the Future

- Current Funding to complete a total of ~65 Flights
  - Follow-on Testing planned to continue thru FY2010
- Next Phases – Slats Ext first, then Slats Ret
- Phase 3/4:
  - Stalls / High Alpha / Engine Out Assym
- Phase 5/6:
  - Departure Resistance - Limiter Assaults / High Beta
- Potential new Engine Design
  - More Efficient = More Duration