X-48B Flight Research Progress Overview

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Fundamental Aeronautics Program
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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
SFW System Level Metrics

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<tbody>
<tr>
<td>Noise</td>
<td>-32 dB (cum below Stage 4)</td>
<td>-42 dB (cum below Stage 4)</td>
<td>55 LDN (dB) at average airport boundary</td>
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<tr>
<td>LTO NOx Emissions (below CAEP 6)</td>
<td>-60%</td>
<td>-75%</td>
<td>better than -75%</td>
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<tr>
<td>Performance: Aircraft Fuel Burn</td>
<td>-33%**</td>
<td>-40%**</td>
<td>better than -70%</td>
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<tr>
<td>Performance: Field Length</td>
<td>-33%</td>
<td>-50%</td>
<td>exploit metro-plex* concepts</td>
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** An additional reduction of 10 percent may be possible through improved operational capability

* Concepts that enable optimal use of runways at multiple airports within the metropolitan areas

EIS = Entry Into Service; IOC = Initial Operating Capability

** N+1 Conventional

![N+1 Conventional Aircraft](image1)

** N+2 Hybrid Wing/Body

![N+2 Hybrid Wing/Body Aircraft](image2)

** N+3 Generation

![N+3 Advanced Aircraft](image3)
X-48B Flight Research Program

• Flight research provides:
  – Flight Control System risk reduction
  – Required to ensure HWB 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
Fundamental Aeronautics Program Subsonic Fixed Wing Project

Major Program Accomplishments

- 30 successful flights including 2 flights in 1 day four times
- Completion of envelope expansion phases in both slats extended and slats retracted configurations
- Aircraft capable of operating from hard surface and lakebed runways at Dryden
- Both Boeing and NASA pilots trained to fly aircraft and first NASA pilot mission flown on 8/13/08
- High quality data for various maneuvers recorded and archived for future use
- Preliminary data analysis ongoing with quick look data report for first 20 flights available before end of year
- Five high AOA flights performed and stable AOA limit found
- Multiple versions of software upgrades performed resulting in stable test platform
- Significant positive press coverage of flight test including articles in Aviation Week and Space Technology, Popular Science, Outside, Aviation/Yahoo, AeroTech News
Definition of Test Flight Blocks

Block 1: Flights 1-11
Slats EXT – S/W V2.1.4.2

Block 2: Flights 12-20
Slats RET – S/W V3.2.4.0

Block 3: Flights 21-25
Slats EXT – S/W V3.X

Block 4: Flights 26-30
Slats RET – S/W V3.X

Block 5: Flights 31-35
Slats EXT – S/W VX.X

Block 6: Flights 36-40
Slats RET – S/W VX.X

Envelop Expansion

PID / Stalls / Engine Out Maneuvering

Departure Limiter Assaults

March 1, 2008

July 25, 2008

November 30, 2008

Current Phase
Increasing Risk

Fundamental Aeronautics Program
Subsonic Fixed Wing Project

July 25, 2008

March 1, 2008

November 30, 2008
Flight Test Progress
Fundamental Aeronautics Program
Subsonic Fixed Wing Project

X-48B BWB Low Speed Vehicle

• 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
X-48B Vehicle

• 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

JetCat P200 Engines
Nose & Main Landing Gear
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
8.5% Dynamically Scaled X-48B

- 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 – Internal View

- Laser Height Sensor (Under)
- Main ‘Chute
- Drogue Ejector
- Control Panel
- Drogue Boom
- Drogue Boom
- Drogue ‘Chute Lines (Under Boom)
- Drogue Ejector
- Air Data Boom
- Antennae
- IMU (Rear of Bulkhead)
- Batteries
- Air Data Interface
- Air Bag Inflation System
- Drogue Boom Lines (Under Boom)
- Control Surface Actuators
- Transponder
- BIT Panel
- Avionics Crate
- GPS Antennae
- Fuel Tank
- Fuel Pumps & ECUs
Fixed Landing Gear

Triple Airbags for Impact Attenuation

Access Hatches for Avionics, Fuel Tank, Actuator access, etc.

Split Drag Rudders

20 Flying Control Surfaces

Drogue Boom
Recovery System

Drogue

Main

Airbags
Spin Chute Testing
Ground Control Station – Trailer
GCS – Pilot Station
First Flight Video

X-48B Skyray
1st Flight Highlights
• Twenty Flights completed in Blocks 1 & 2
  – 11 Flights w/ Slats Extended
    • Slats result in lower speeds and higher lift
  – 9 Flights w/ Slats Retracted
    • New Flight Control Laws / “1st Flight”
    • Envelope Expansion to Max Speed

• 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
• Ten Flights completed in Block 3 (all slats extended)
• Highlights:
  – Test Maneuvers
    • Real-Time Stability Margins
    • Automated Parameter Identifications (PID) – Freq Sweeps/Doublets
    • Steady Heading Sideslips - Simulate Cross-winds
    • Lazy-8s and Wind-up Turns
    • AOA Maneuvers above $C_L_{\text{max}}$
High Angle of Attack Maneuver
Real Time Stability Margin (RTSM)

• In-Flight Stability has a long history at NASA Dryden Flight Research Center
  – Application to a wide variety of flight programs
    X-29, X-36, X-43, X-45, NF-15B 837
  – Method is motivated by inability to break loops on unstable aircraft

• Proprietary dynamic inversion based flight control
  – Numerous options for on-board excitations

• Excitation parameters and command sent via telecommand from GCS
  – Selectable injection points
  – Selectable waveforms
  – Selectable magnitudes
RTSM Results

X-48B In-Flight Stability Analysis - Roll Axis
Flight - GM: 16.6 dB (23.0 rad/sec) - PM: Inf deg (NaN rad/sec)
Simulation - GM: 21.9 dB (23.5 rad/sec) - PM: Inf deg (NaN rad/sec)

• Extremely Maneuverable in Roll
• Aircraft Very Closely Matches GCS for Up/Away Flight (and Landing)
• Stall AOA matches wind tunnel measurements within 1 degree
• Control system modeling generally matches actual flight behavior in the regions examined

• Flight Control Design is Very Robust
• Overall, the Aircraft Flies Extremely Well
  – Despite no peripheral cues (2-D only) / no seat-of-the-pants
X-48B What’s Next for the Future

- Current plan to finish 40+ flights in early CY2009
  - Follow-on Testing planned to continue thru FY2010
- Continue Phase 3/4:
  - Stalls / High Alpha / Engine Out Assessment
- Phase 5/6:
  - Departure Resistance - Limiter Assaults / High Beta
- Potential new Engine Design
  - More Efficient = More Duration
- Low Noise Modifications
- Intelligent Flight Controls
Questions?