# X-48B Flight Research Progress Overview

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# Program Objectives

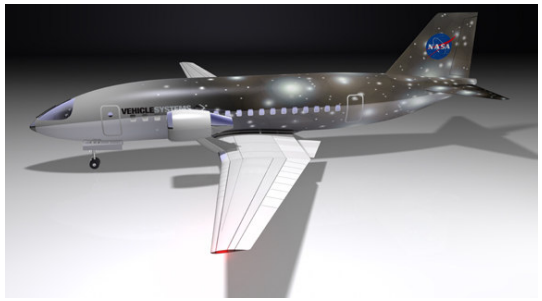
- Assess stability & control characteristics of a BWB class vehicle in free-flight conditions:
  - Assess dynamic interaction of control surfaces
  - Assess control requirements to accommodate asymmetric thrust
  - Assess stability and controllability about each axis at a range of flight conditions
- 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

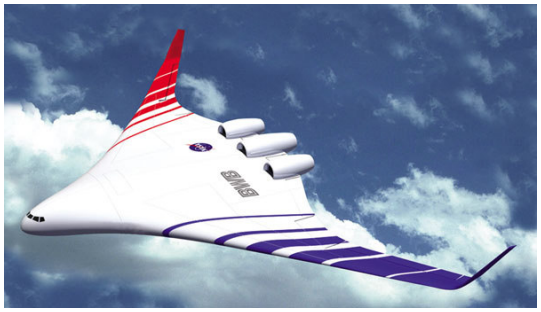
| CORNERS OF THE TRADE SPACE | N+1 (2015 EIS) Generation Conventional Tube and Wing (relative to B737/CFM56) | N+2 (2020 IOC) Generation Unconventional Hybrid Wing Body (relative to B777/GE90) | N+3 (2030-2035 EIS) Generation Advanced Aircraft Concepts (relative to user defined reference) |
|---|---|---|---|
| Noise | - 32 dB (cum below Stage 4) | - 42 dB (cum below Stage 4) | 55 LDN (dB) at average airport boundary |
| LTO NOx Emissions (below CAEP 6) | -60% | -75% | better than -75% |
| Performance: Aircraft Fuel Burn | -33%** | -40%** | better than -70% |
| Performance: Field Length | -33% | -50% | exploit metro-plex* concepts |

** An additional reduction of 10 percent may be possible through improved operational capability
* Concepts that enable optimal use of runways at mutiple airports within the metropolitan areas
EIS = Entry Into Service; IOC = Initial Operating Capability

## N+1 Conventional



## N+2 Hybrid Wing/Body



## N+3 Generation

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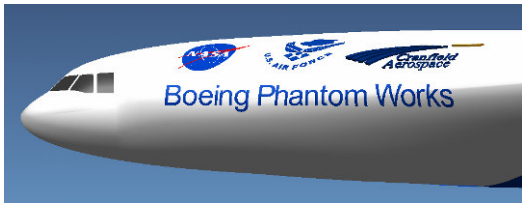
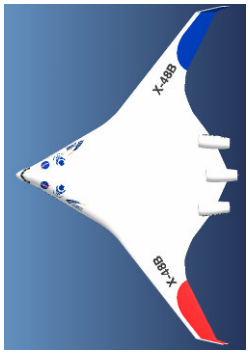
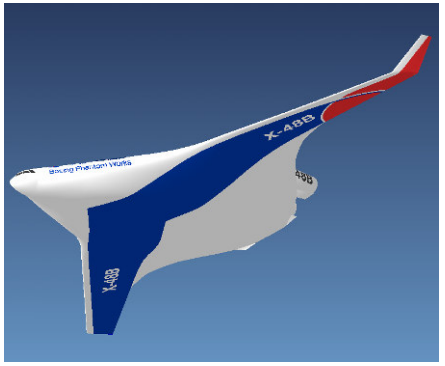
# X-48B Flight Research Program

- 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



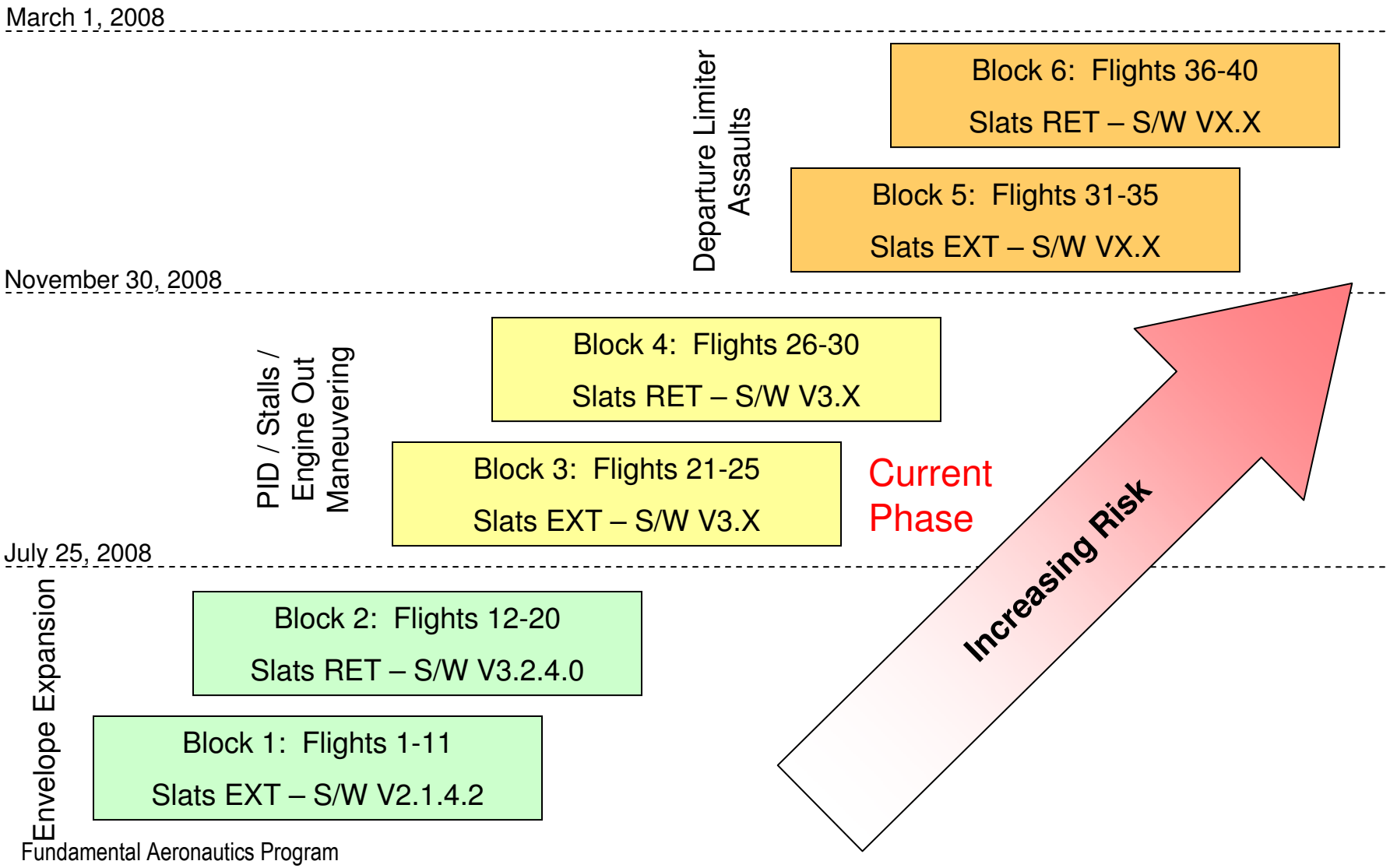



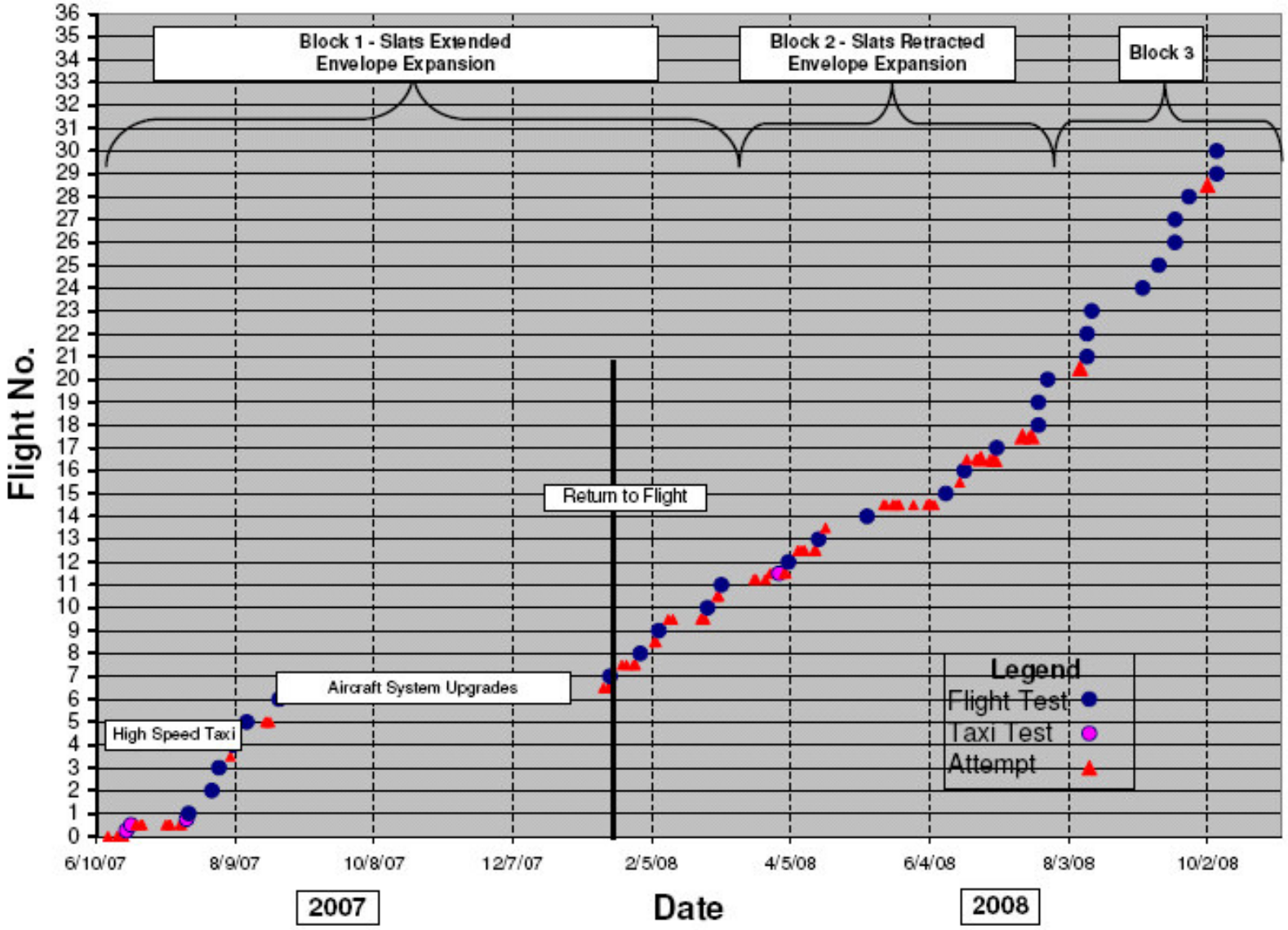
# Major Program Accomplishments

- 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

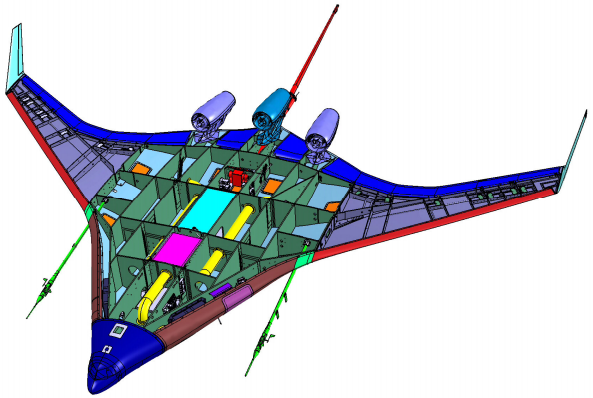


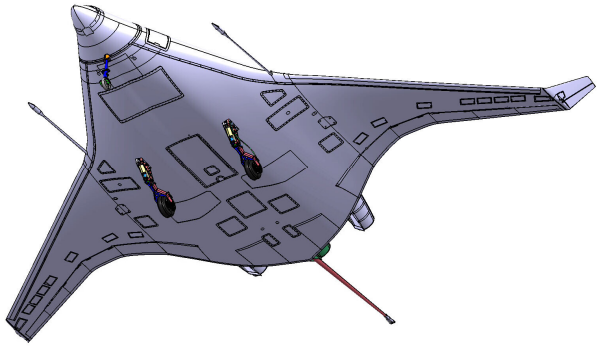
# Flight Test Progress



# 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 Retra
  - Recovery System
    - Drogue, Parachute, and Air Bags

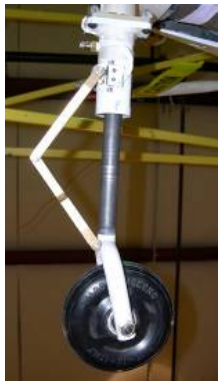




# X-48B Vehicle

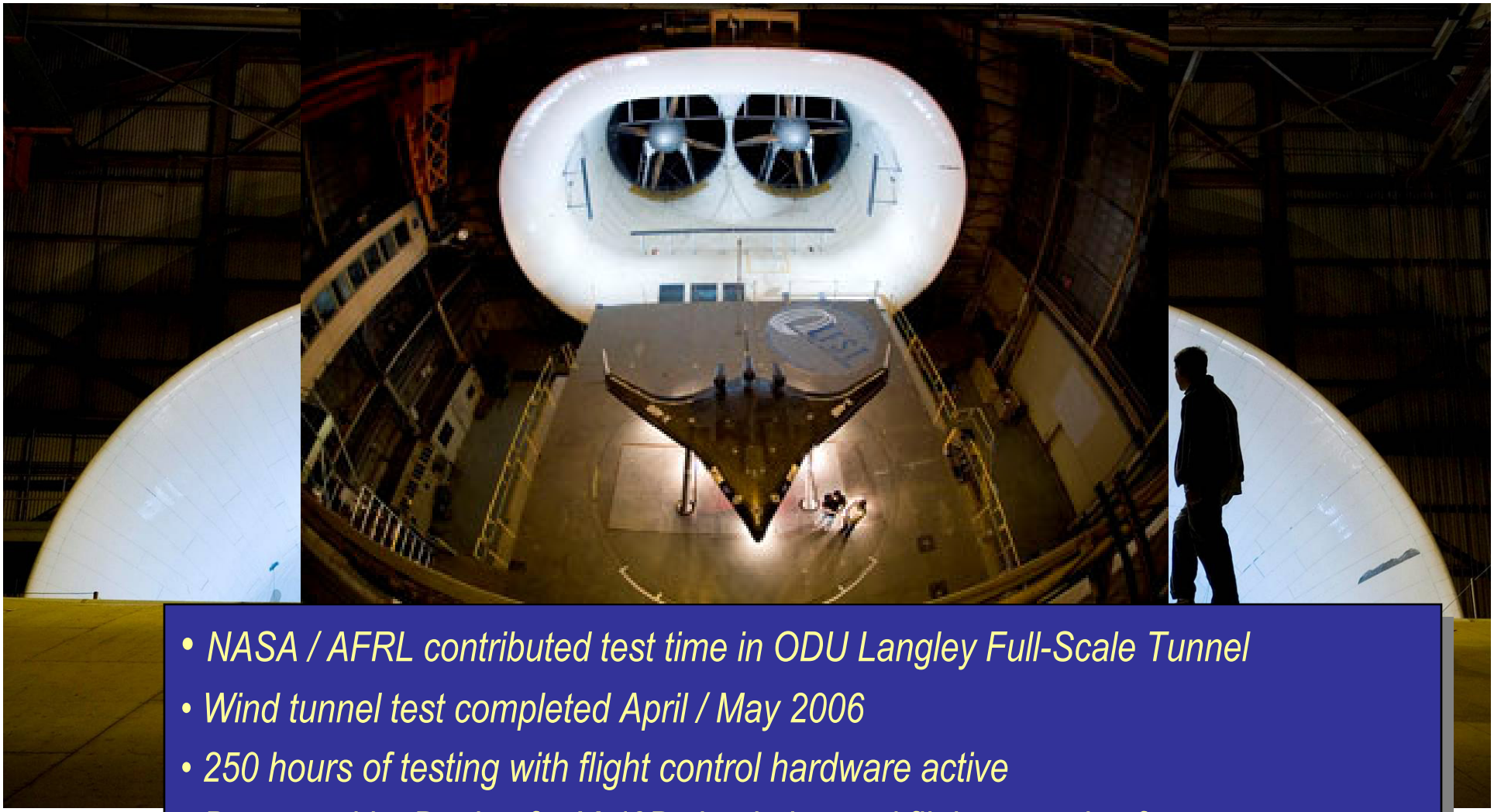
- Design Approach
  - Use low cost (COTS) equipment where possible
    - Engines - JetCat P200
    - Landing Gear - mountain bike shocks & brakes
  - Use normal industry practice for electronic equipment
  - Use aircraft spec equipment where necessary
    - Radios, IMU, Actuators, Flight Termination 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

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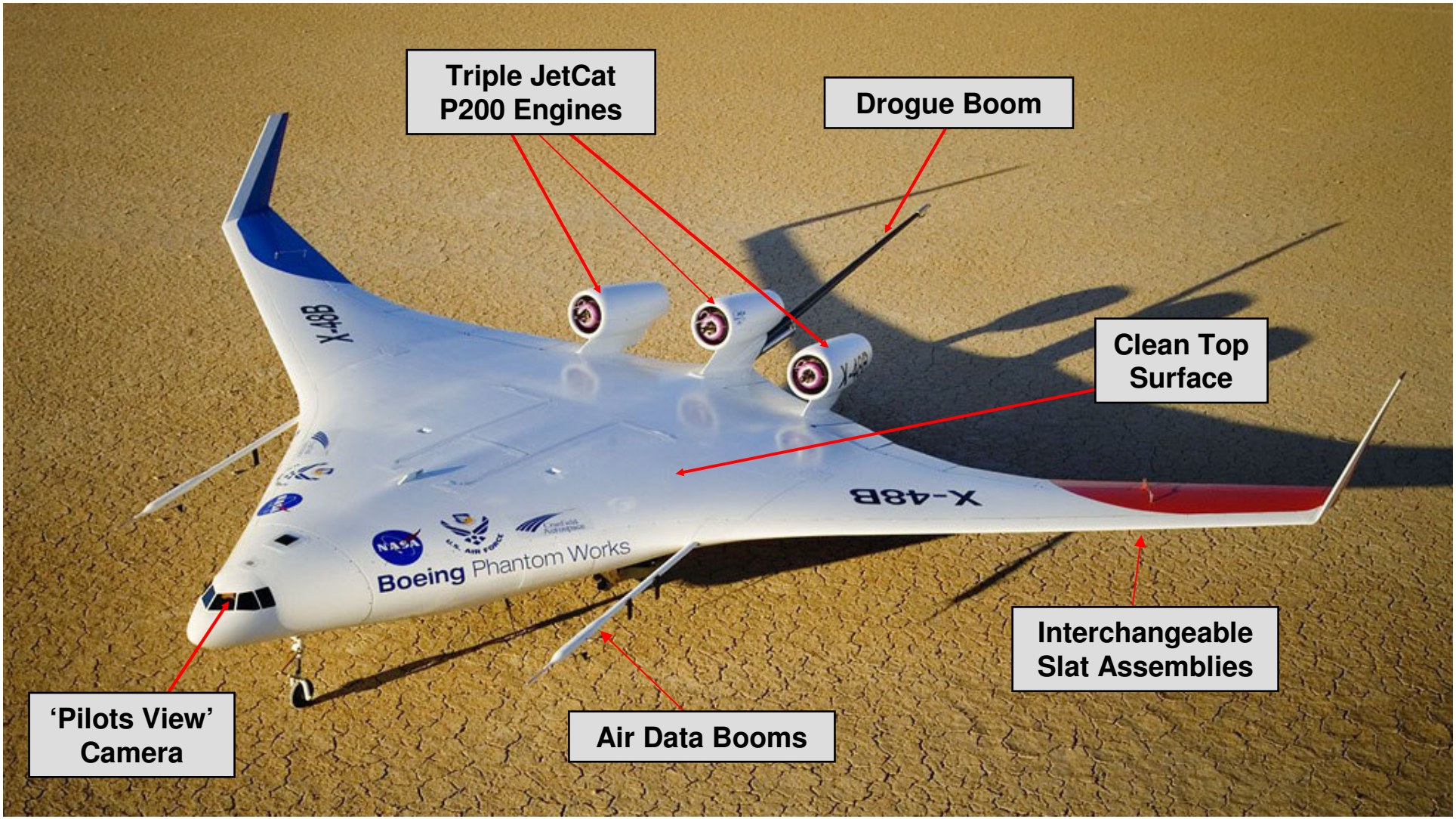
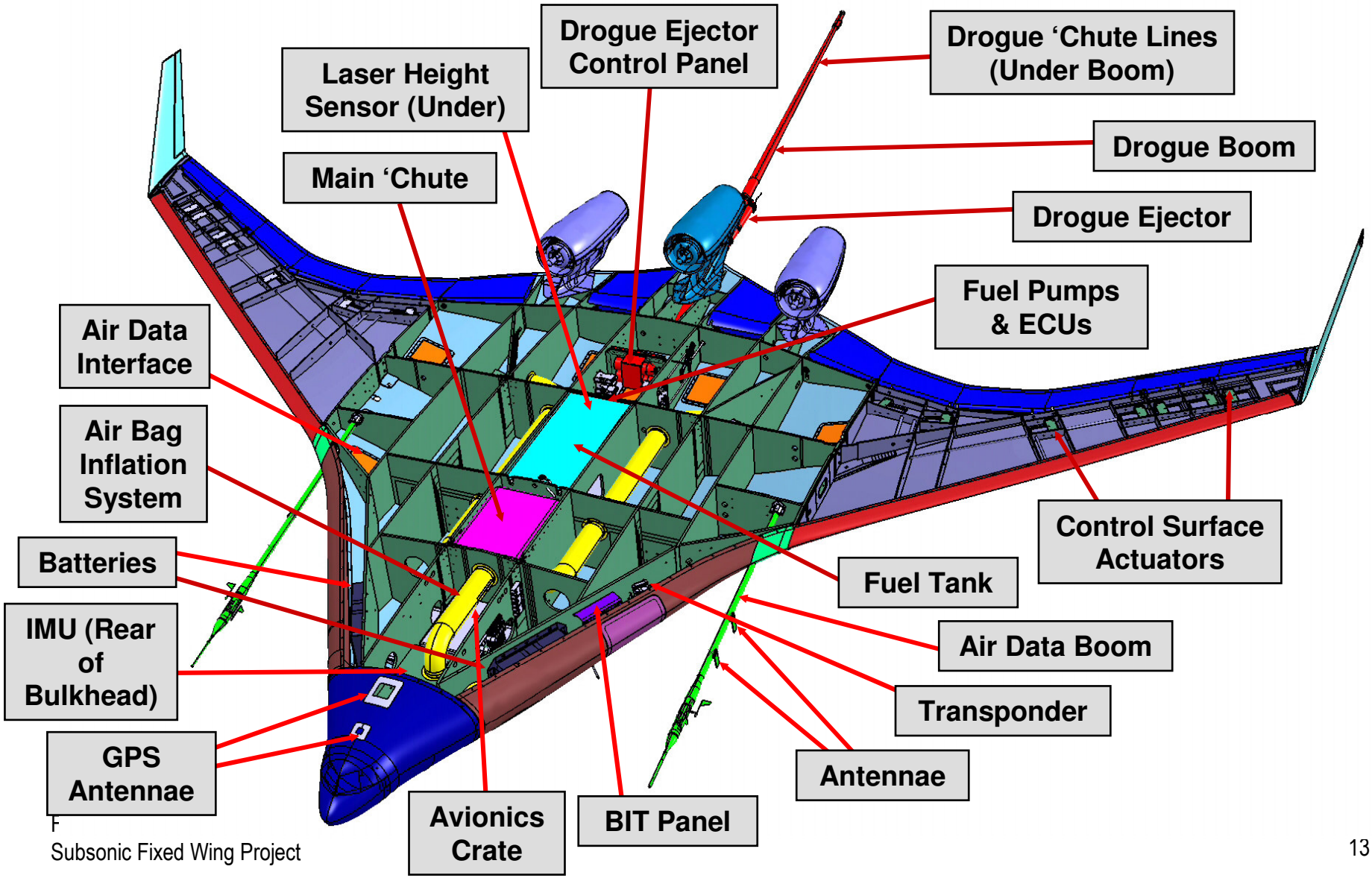
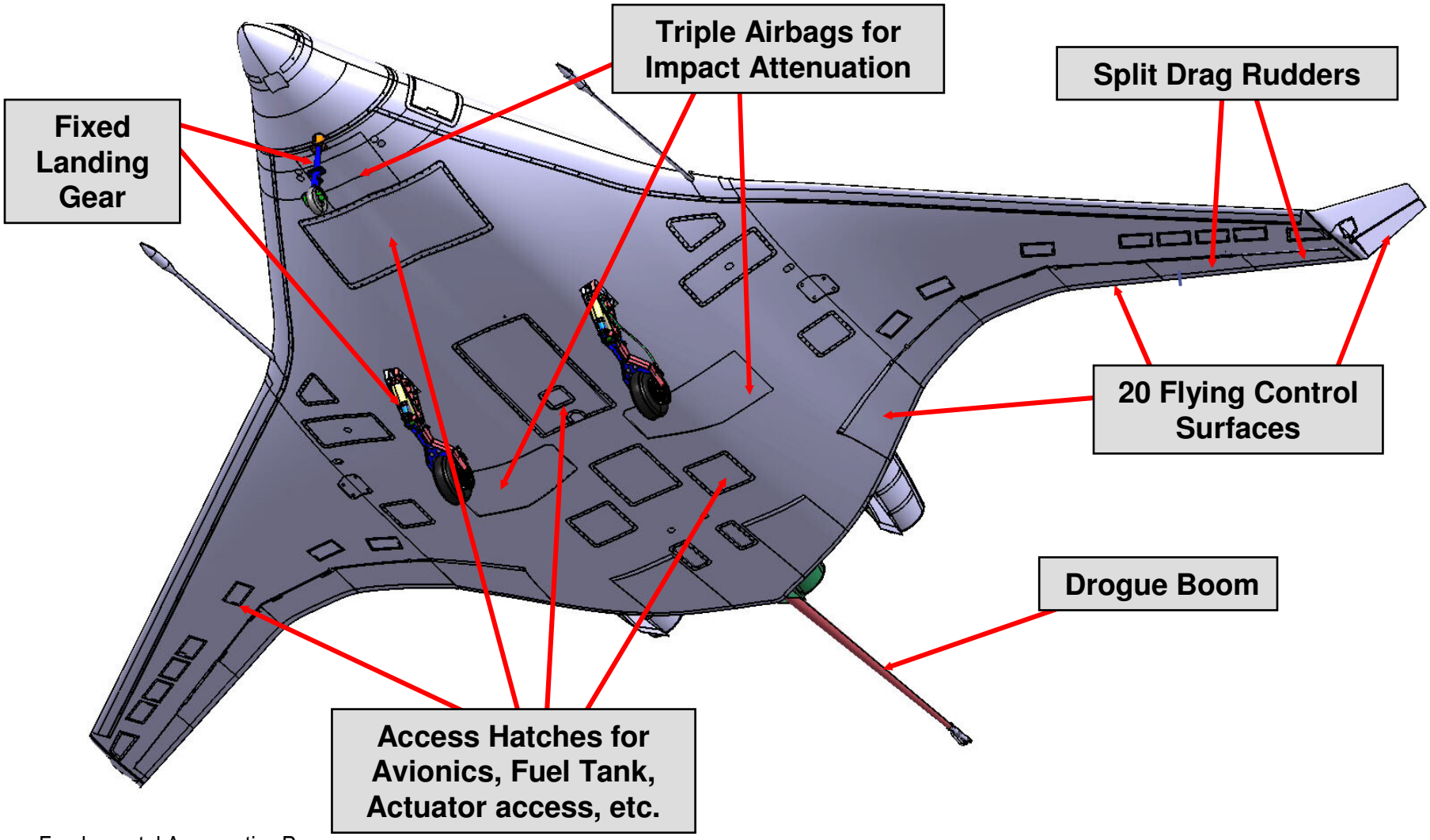
# X-48B Configuration – Top View



# X-48B Configuration – Internal View



# X-48B Configuration – Underside View

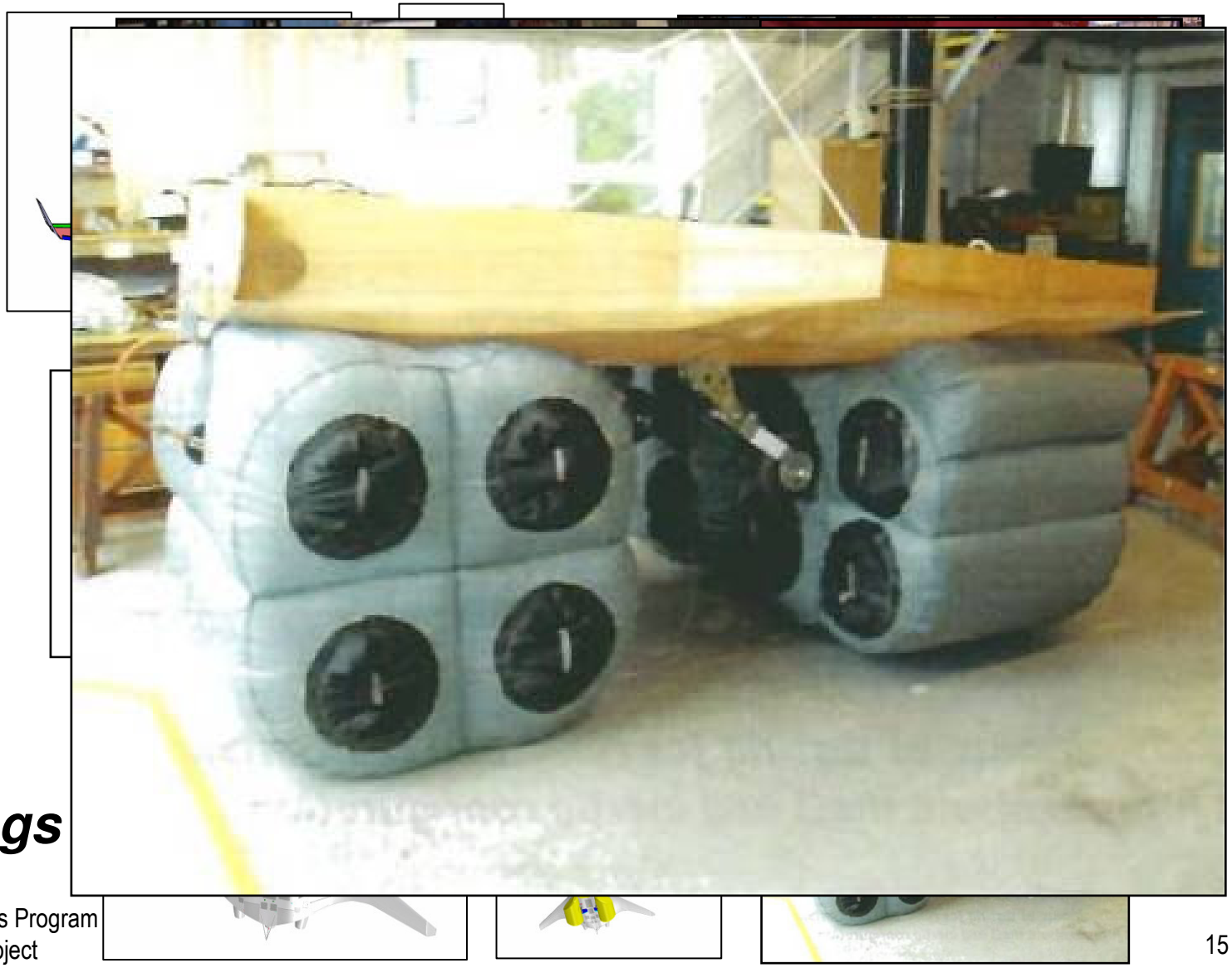


# Recovery System

***Drogue***

***Main***

***Airbags***



# Spin Chute Testing

# Ground Control Station – Trailer

# GCS – Pilot Station

# Lakebed Operations

# First Flight Video

# X-48B Flight Research Summary - I

- 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

# X-48B Flight Research Summary - II

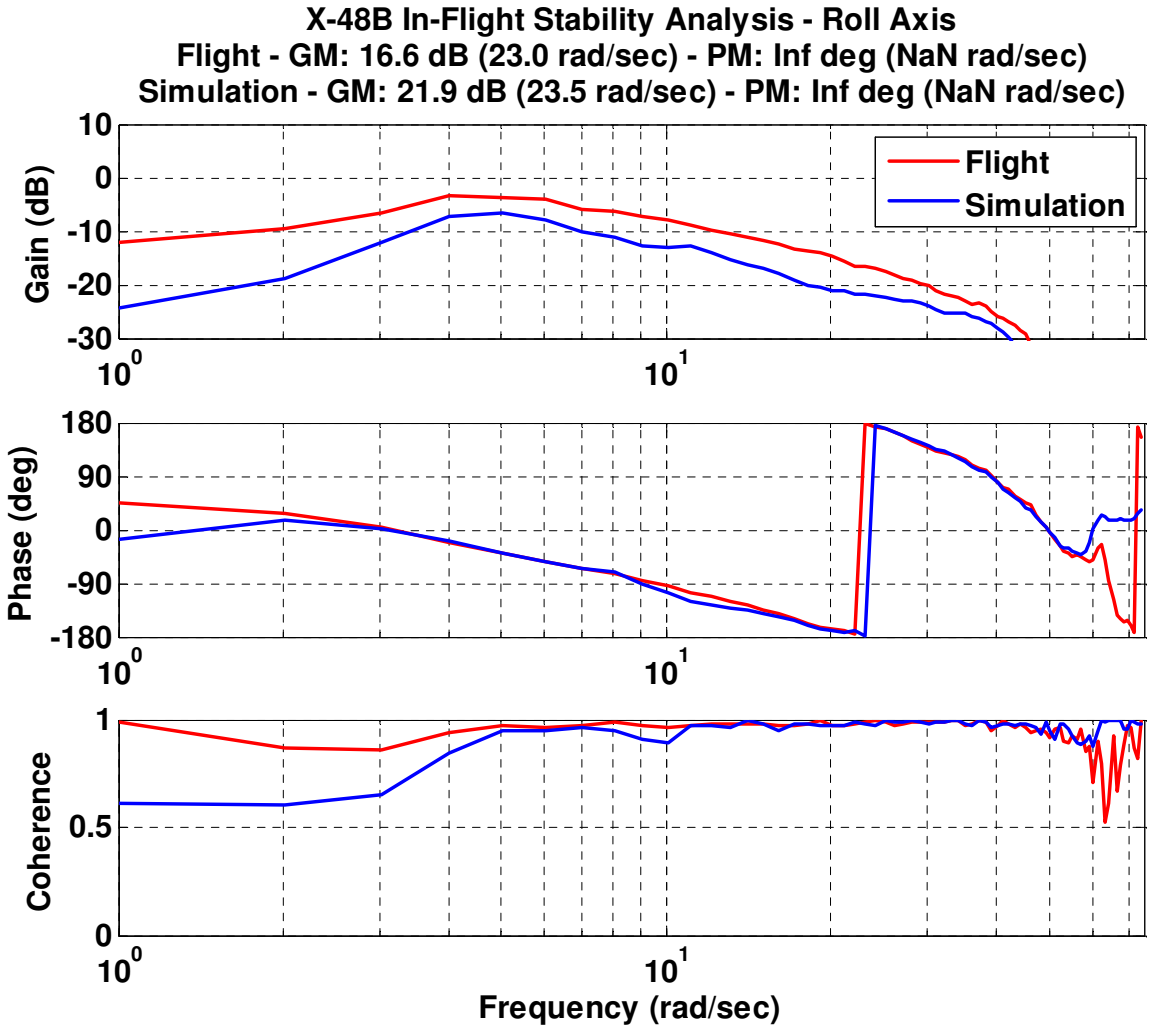
- Ten Flights completed in Block 3 (all slats extended)
- Highlights:
  - Test Maneuvers
    - Real-Time Stability Margins
    - Automated Parameter Identifications (PID) – Freq Sweeps/Doublets
    - Steady Heading Sideslips - Simulate Cross-winds
    - Lazy-8s and Wind-up Turns
    - AOA Maneuvers above $C_L$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

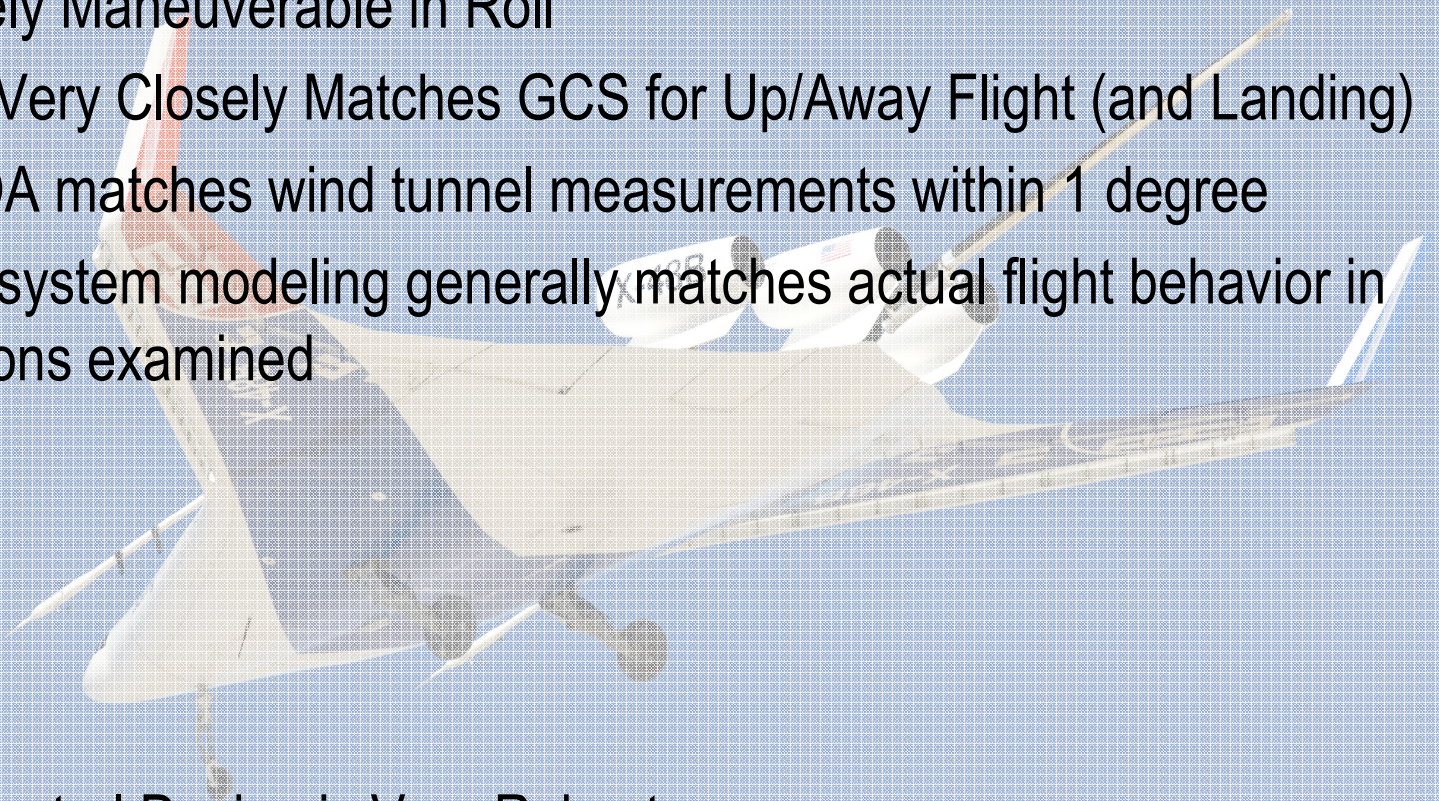
# RTSM Results




From: Regan, Christopher, "In-Flight Stability Analysis of the X-48B Aircraft," AIAA Paper AIAA-2008-6571,AIAA Atmospheric Flight Mechanics Conference and Exhibit, Honolulu, Hawaii, Aug. 18-21, 2008.

# X-48B Initial Flight Research Results

- 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?