National Aeronautics and Space Administration

X-48B Blended Wing Body Ground to Flight Correlation Update

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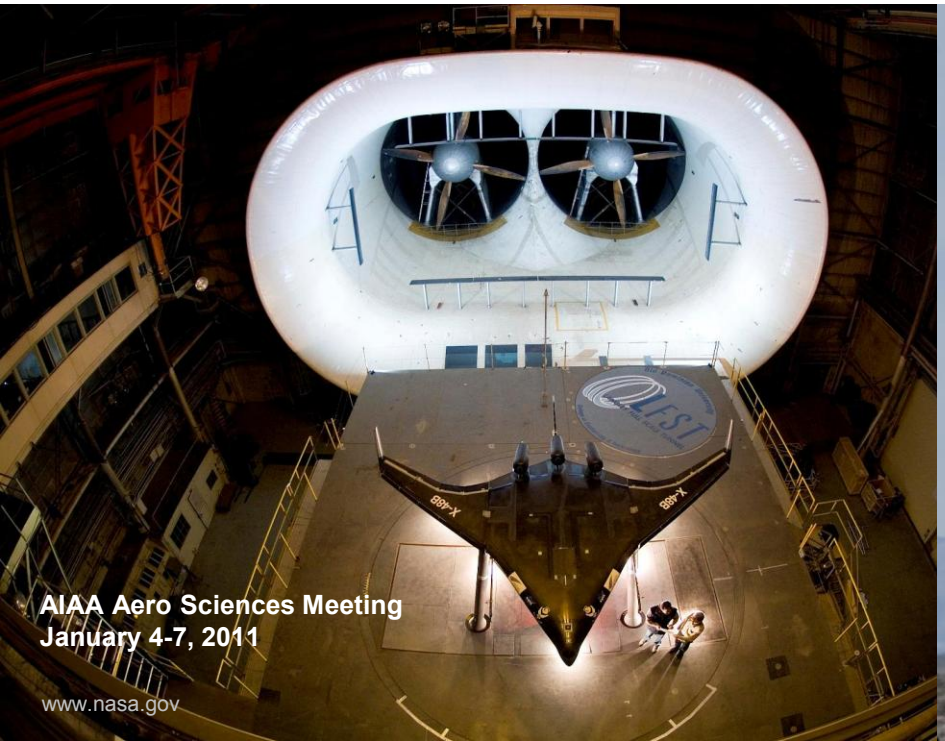
Integrated Systems Research Program



AIAA Aero Sciences Meeting
January 4-7, 2011

Contributors

- Tim Risch – X-48B Project Manager, NASA
- Mike Kisska – X-48B Project Manager, Boeing
- Norm Princen – X-48 Chief Engineer, Boeing
- Dhar Patel – X-48C Project Manager, Boeing
- Joe Boland – X-48B Parameter Identification, Boeing

- 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	Max Airspeed	118 kts
•Wing Area	100.5 ft^2	Max Altitude	10,000 ft MSL
•Max Weight	523 lbs	Load Limits	+4.5 g's to -3.0 g's
•Static Thrust	162 lbs	Duration	30 min + 5 min reserve

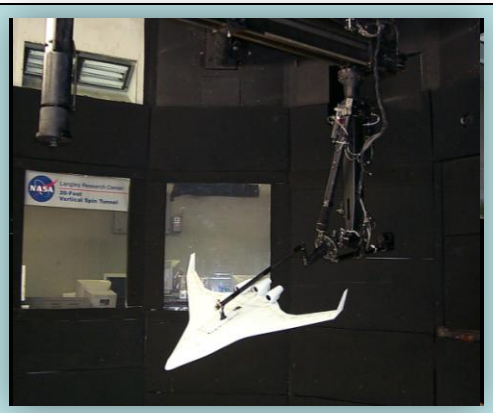
Program Objectives

- **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

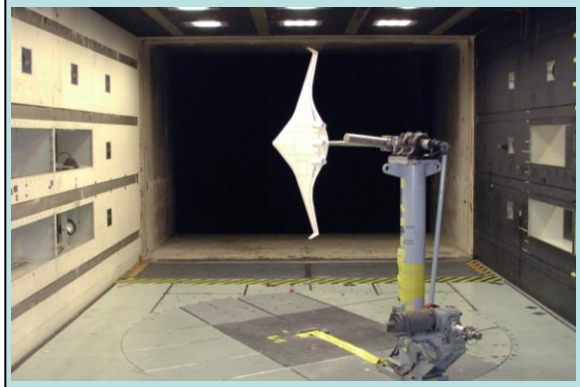
- **Assess flight control algorithms designed to provide desired flight characteristics:**
  - Assess control surface allocation and blending
  - Assess edge of envelope protection schemes
  - Assess takeoff and landing characteristics
  - Test experimental control laws and control design methods

- **Evaluate prediction and test methods for BWB class vehicles:**
  - Correlate flight measurements with ground-based predictions and measurements

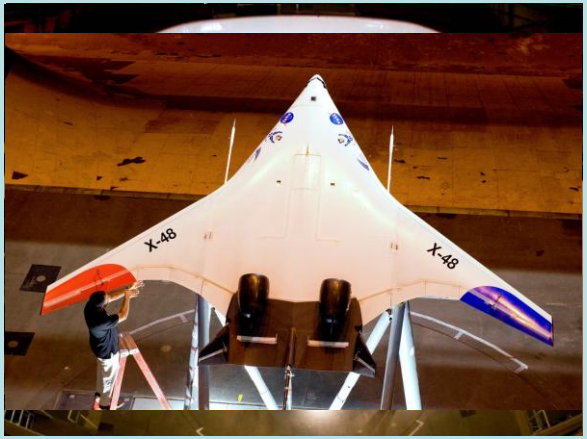
BWB Flight Dynamics Research



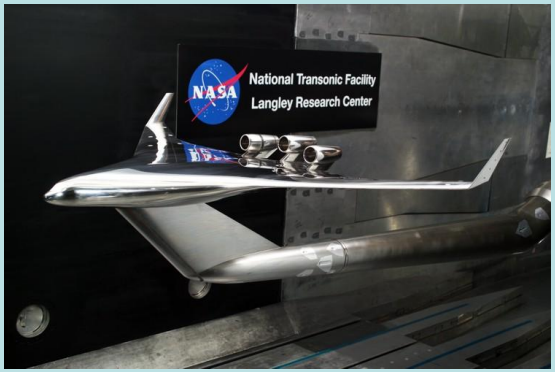
Langley 20' Spin Tunnel
- 1% Spin/Tumble
- 2% Rotary Balance



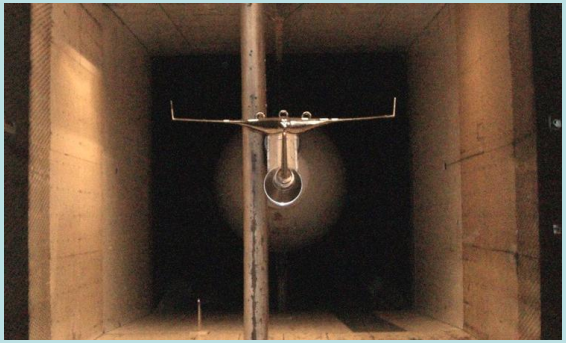
Langley 14' x 22' Tunnel
- 3% Static Aero
- 3% Large Angle
- 3% Forced Oscillation



Langley Full-Scale Tunnel
- 5% Free-flight
- X-48B & C (8.5%) Static Test



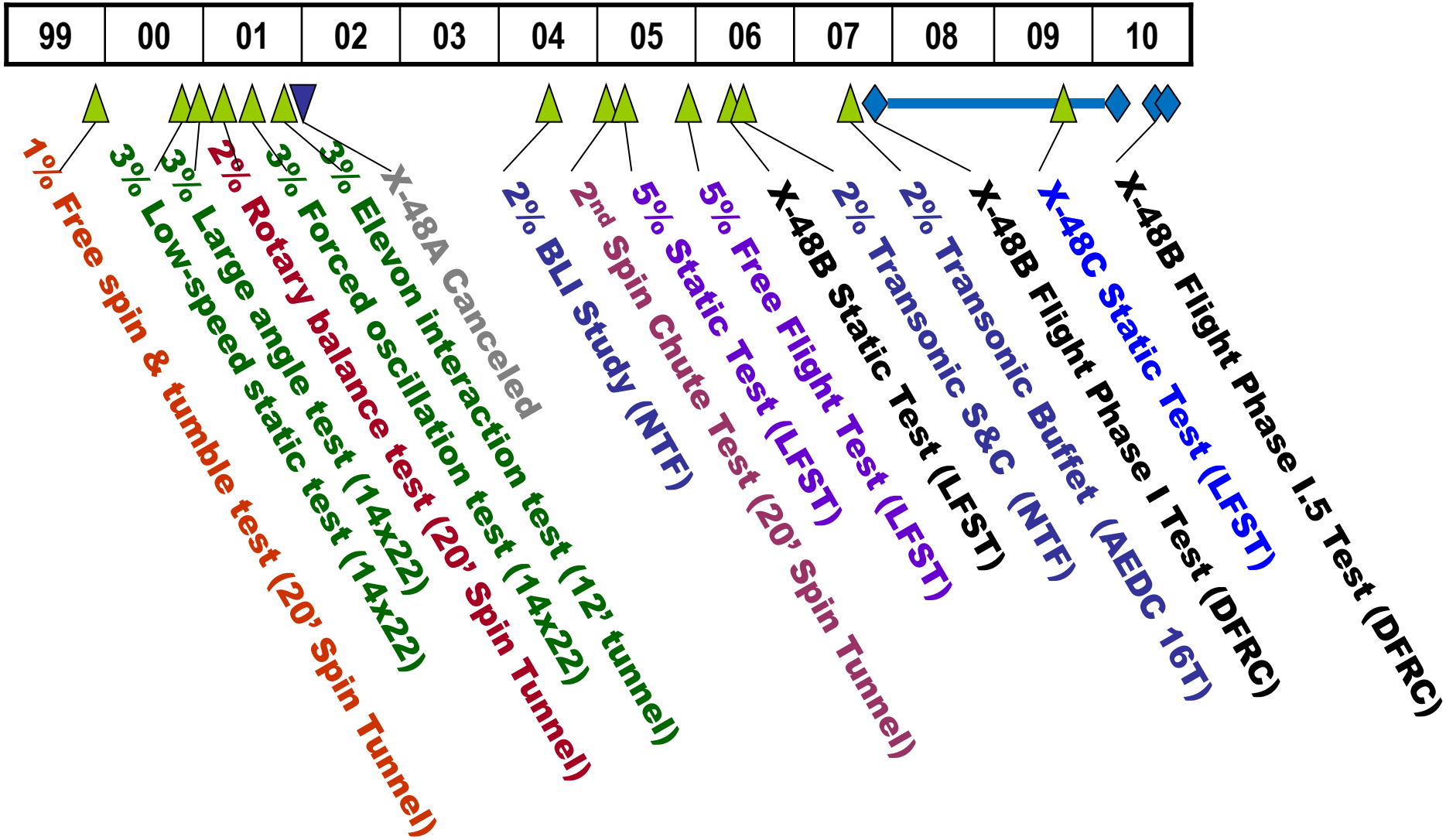
Langley NTF Tunnel
- 2% BLI Study
- 2% Transonic S&C



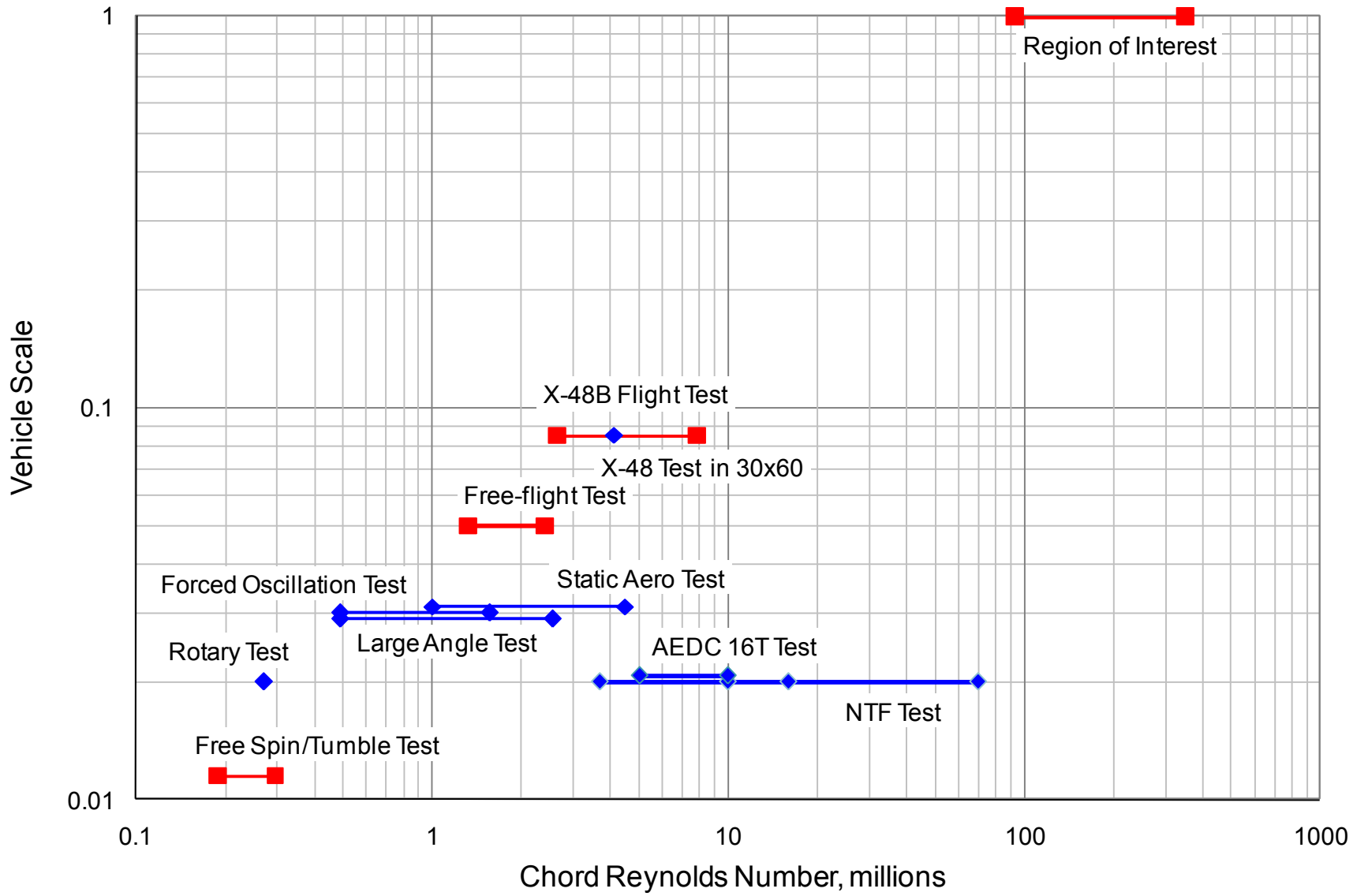
AEDC 16T Tunnel
- 2% Transonic S&C

X-48B Flight Test DFRC

BWB Flight Dynamics Research Timeline



Suite of Ground Tests



Phase I Flight Test Blocks

Departure Limiter Assaults / Turning Stalls

Block 6: Flights 76, 78-80
Slats RET
Completed

Block 5: Flights 73-75, 77
Slats EXT
Completed

PID / Stalls / Engine Out Maneuvering

Block 4: Flights 35-43, 57-58, 62-66, 71-72
Slats RET
Completed

Block 3: Flights 21-34, 44-56, 59-61, 67-70
Slats EXT
Completed

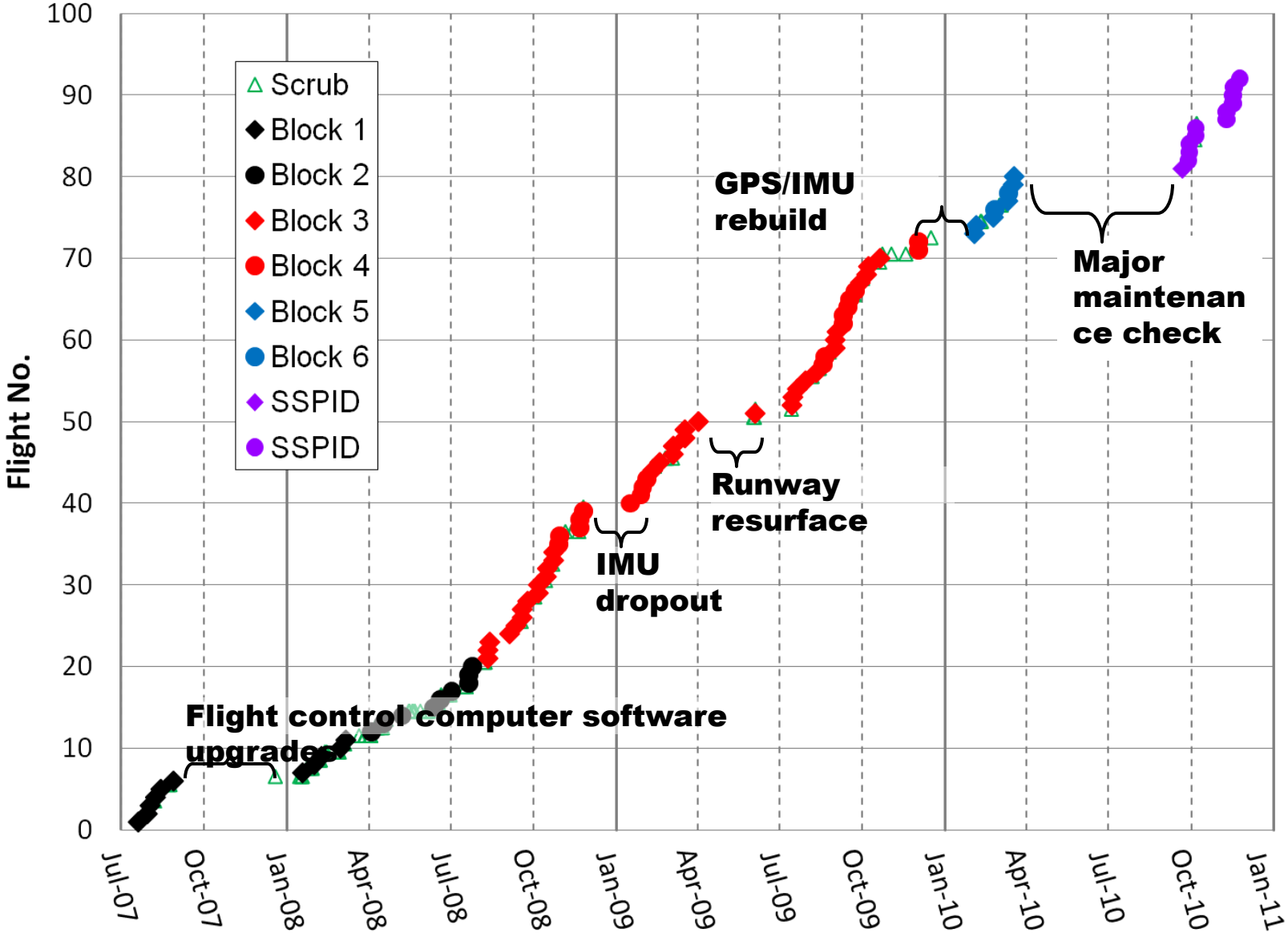
Envelope Expansion

Block 2: Flights 12-20
Slats RET
Completed

Block 1: Flights 1-11
Slats EXT
Completed

Increasing Risk

X-48B Flight Rate



Flight Test Video

X-48B Preliminary Flight Test Results

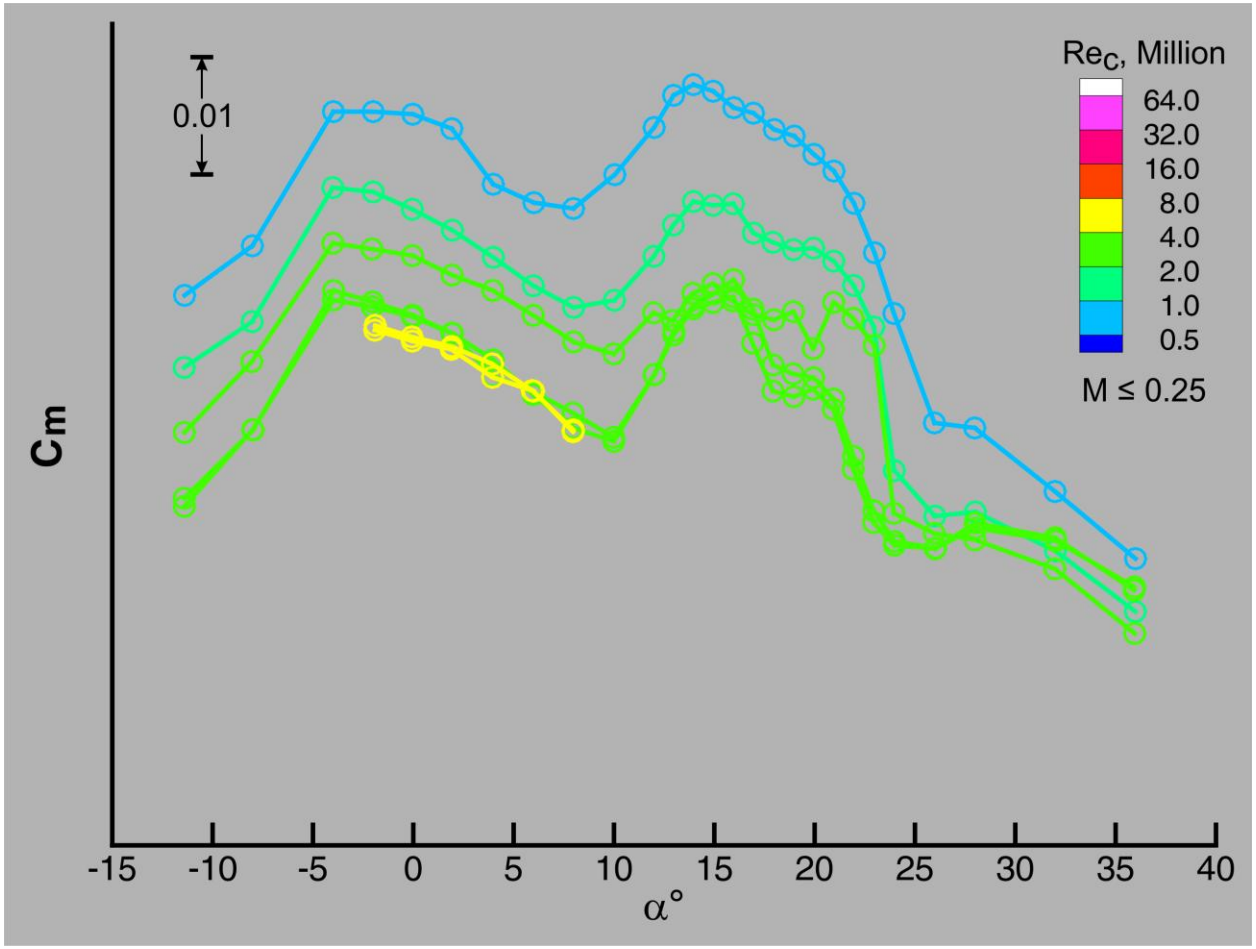
- Extremely maneuverable in roll
- Aircraft very closely matches sim for up/away flight (and landing)
- Flight control design is very robust
  - Some control law deficiencies were masked during initial slat extended flights
  - Corrected with update
- Slat EXT stalls successful to 24 deg alpha
  - Controllable to 3 degrees beyond CLmax
- Slat RET stalls successful to 14 deg alpha
- Departure limiter assaults highly successful!
- Overall, the aircraft flies extremely well

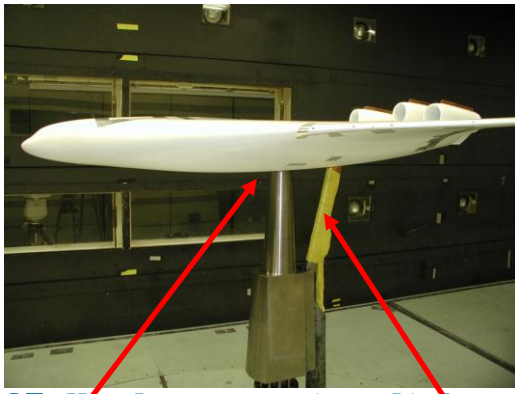
Where are the poor comparisons?

- 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 α 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

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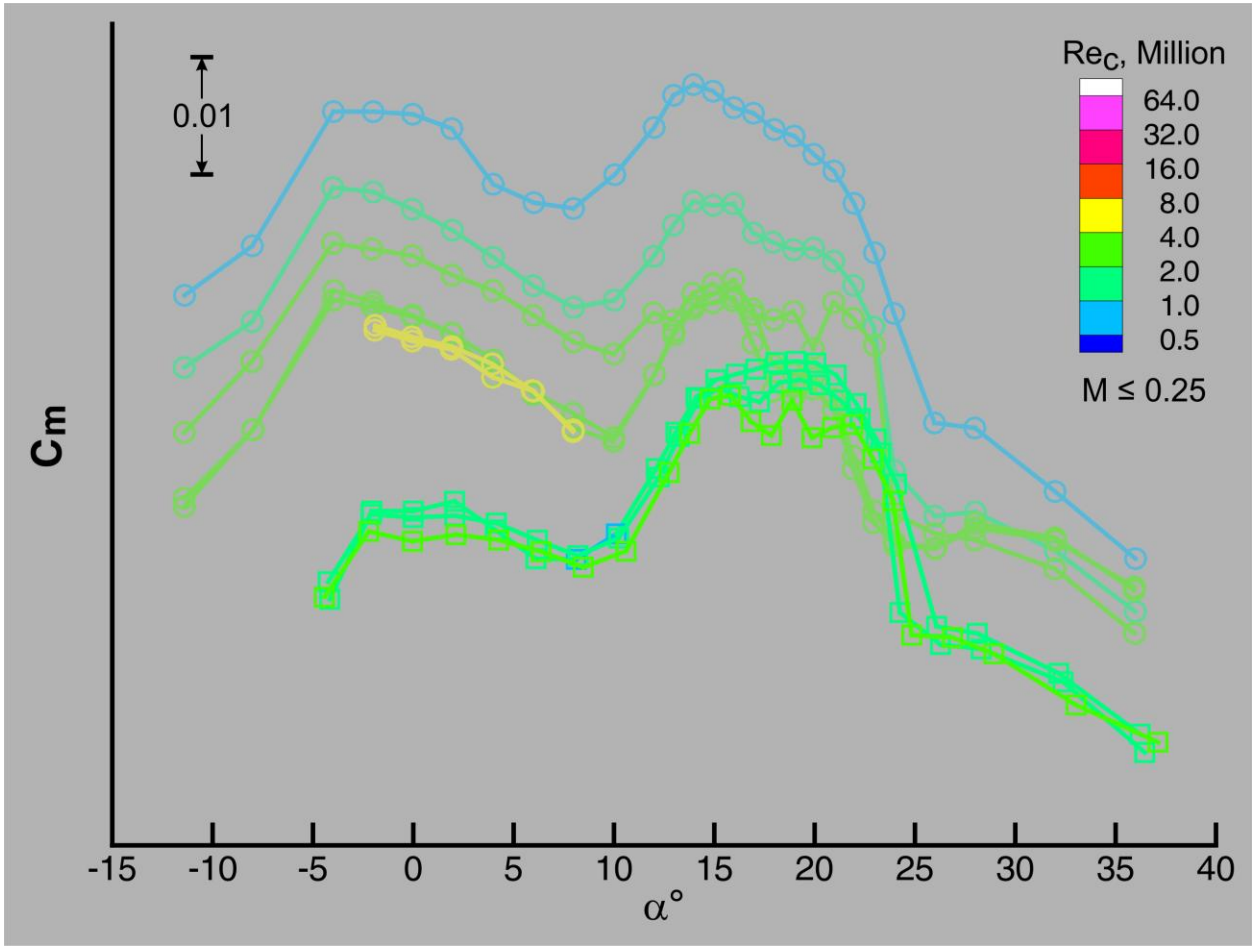

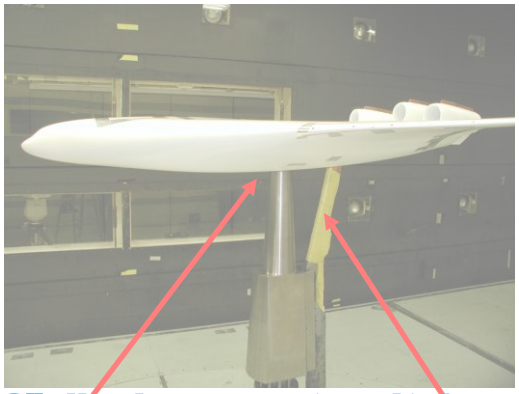

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1.2” dia. bent sting
Langley 14x22 foot Tunnel

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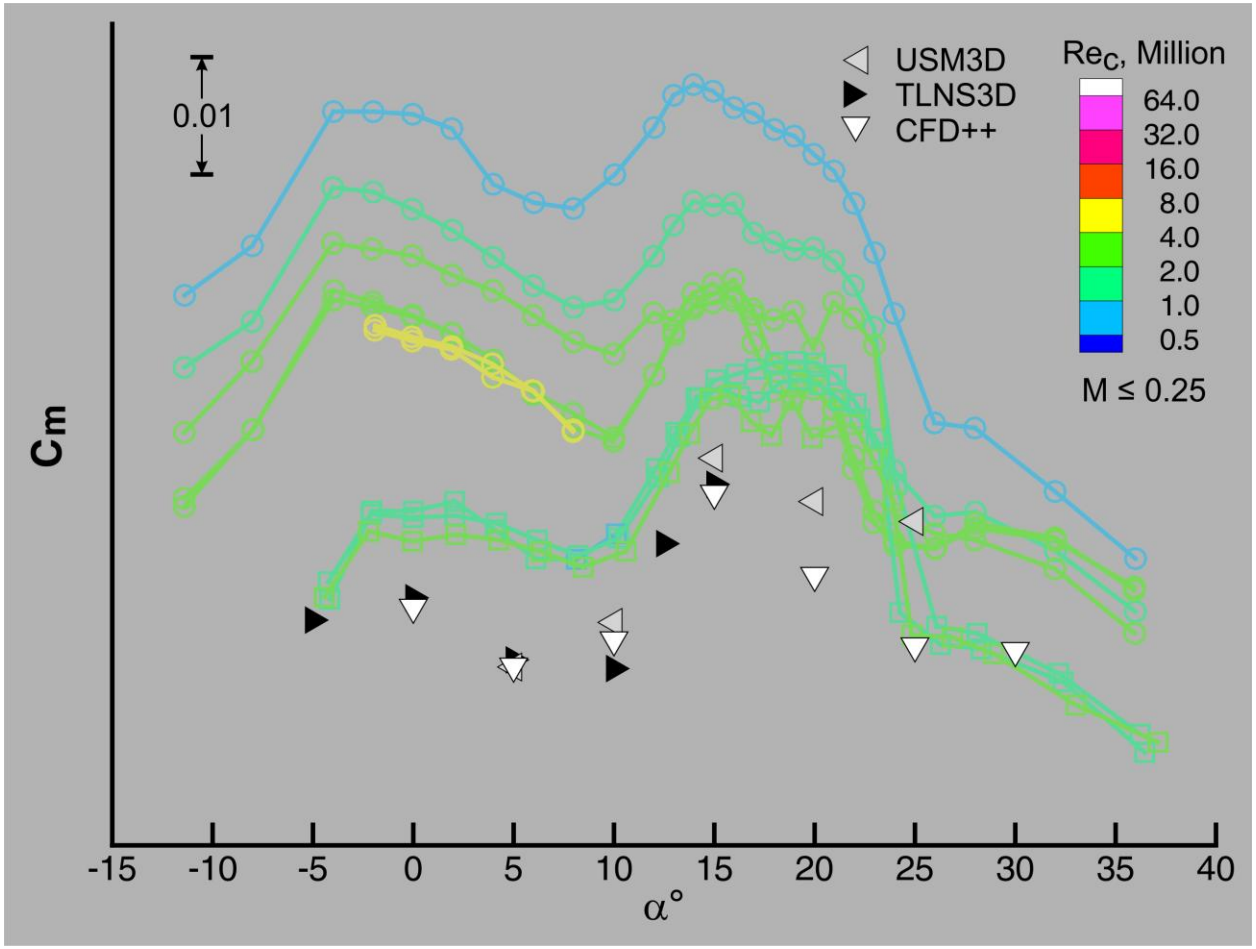

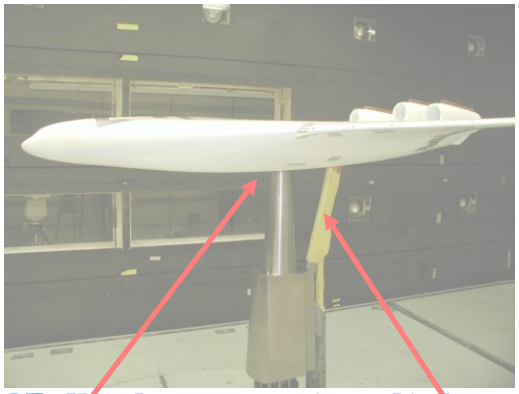

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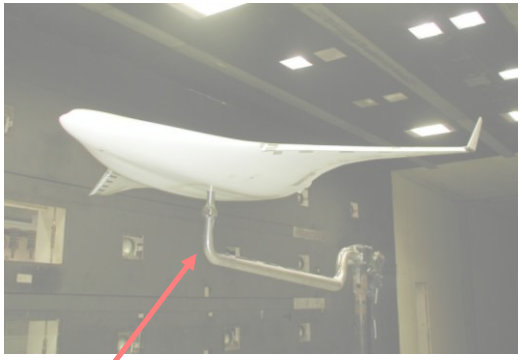

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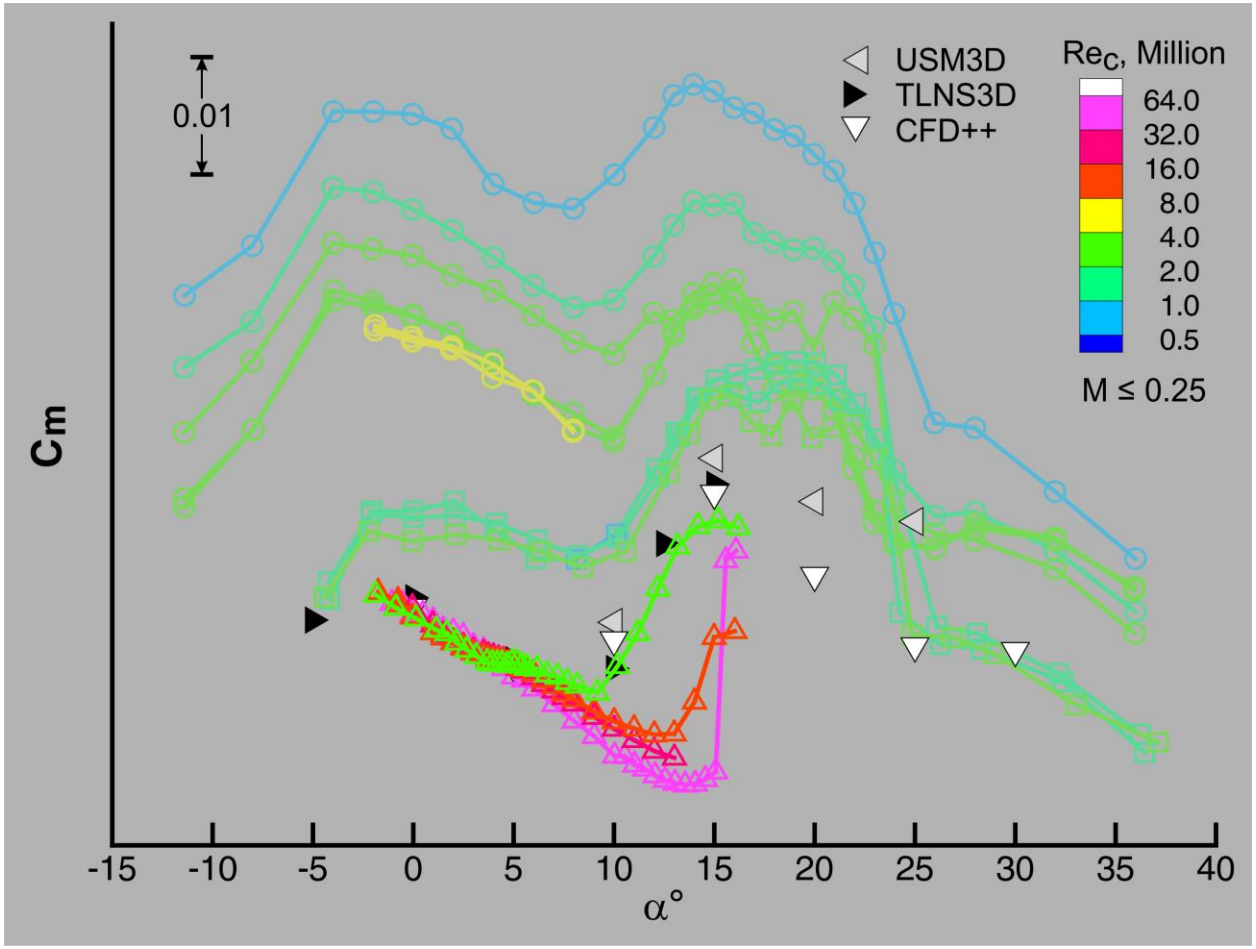
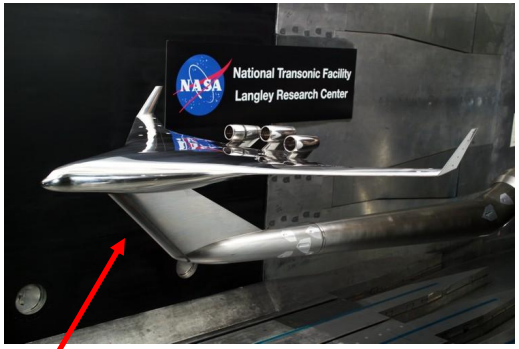
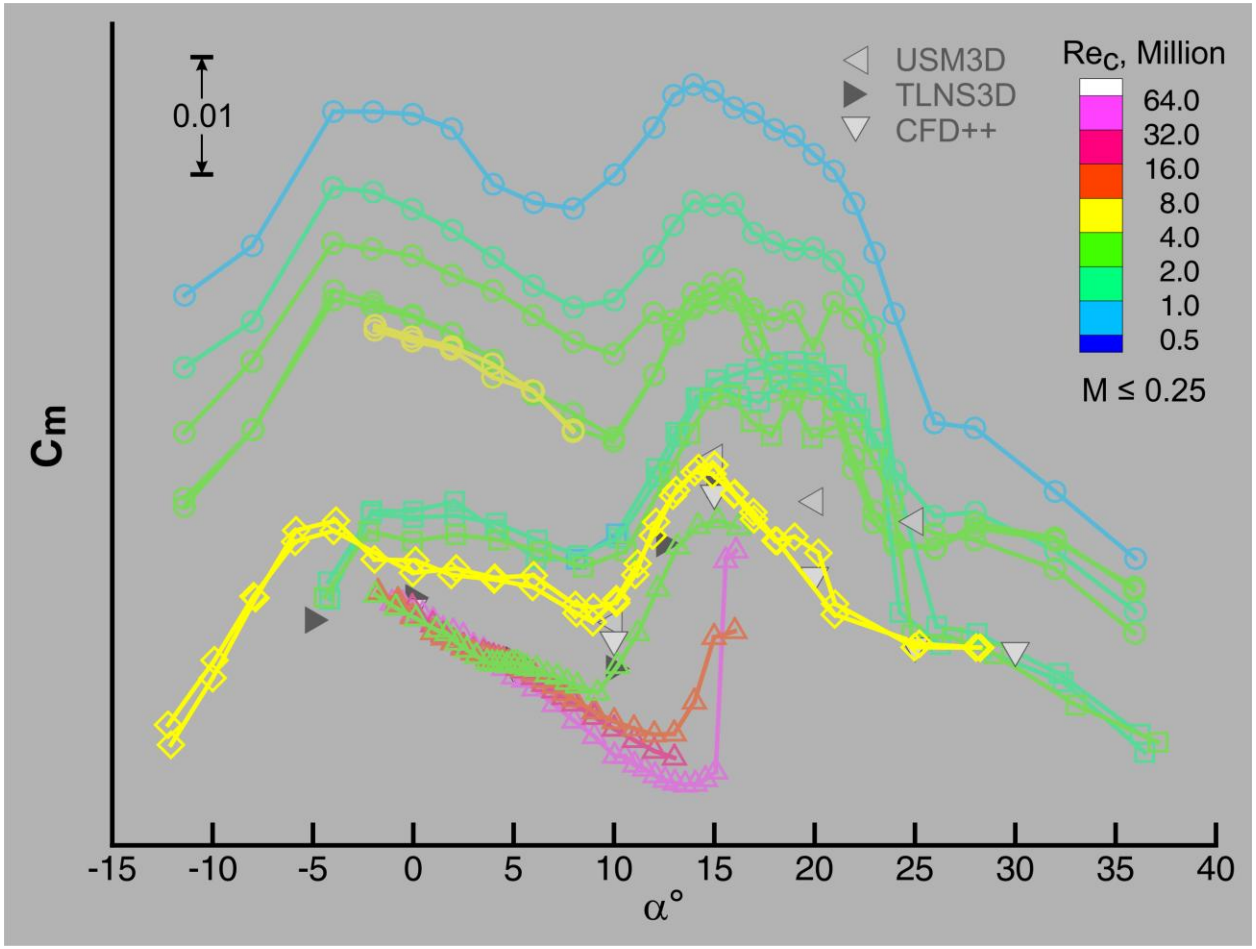


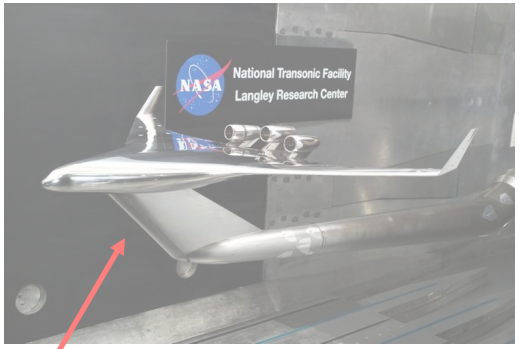


Swept strut designed for minimum interference in NTF

Cm vs α from various ground tests

- Magnitude of support interference effect on pitching moment much greater than anticipated



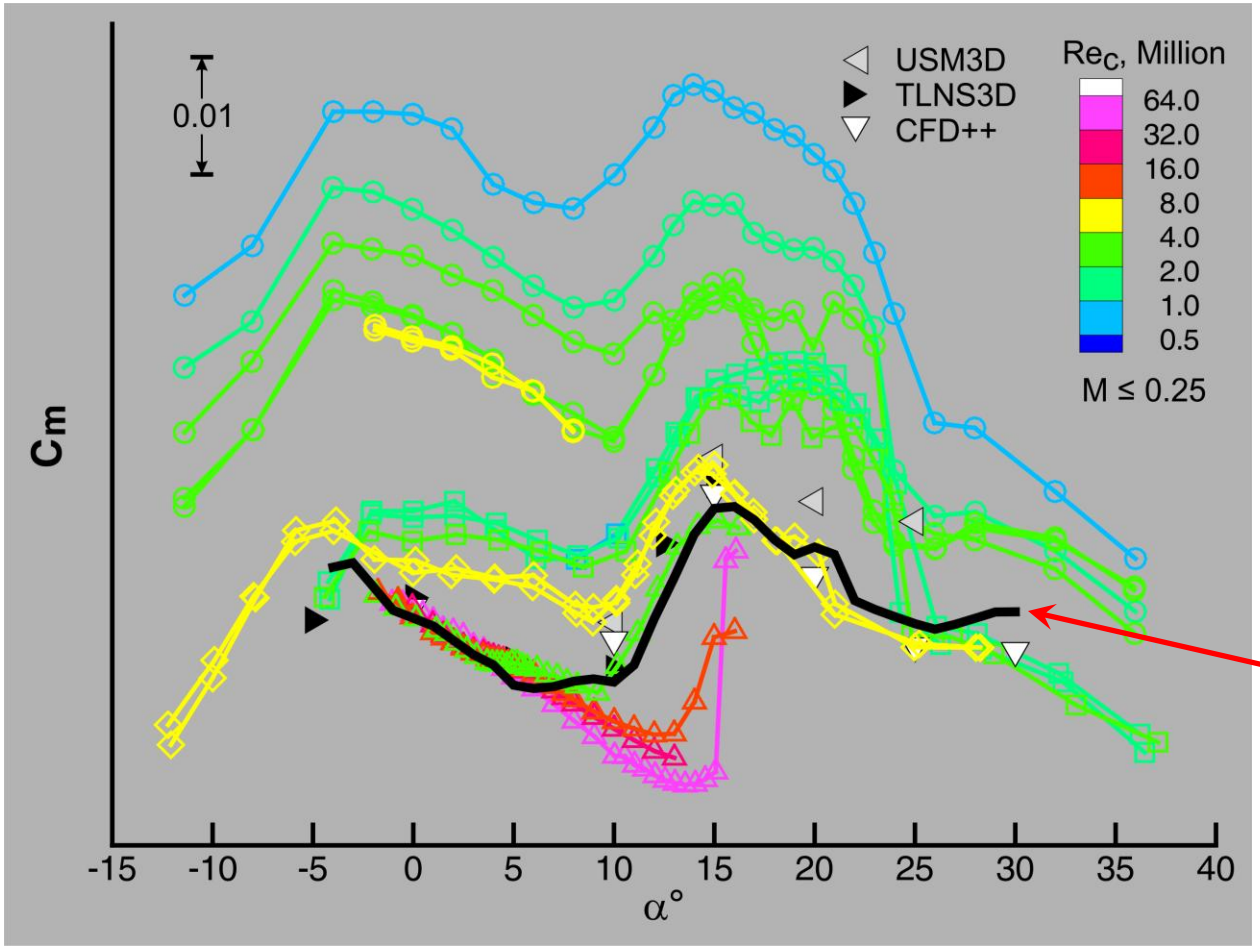


Swept strut designed for minimum interference in NTF

X-48B strut mounted in Langley Full Scale Tunnel

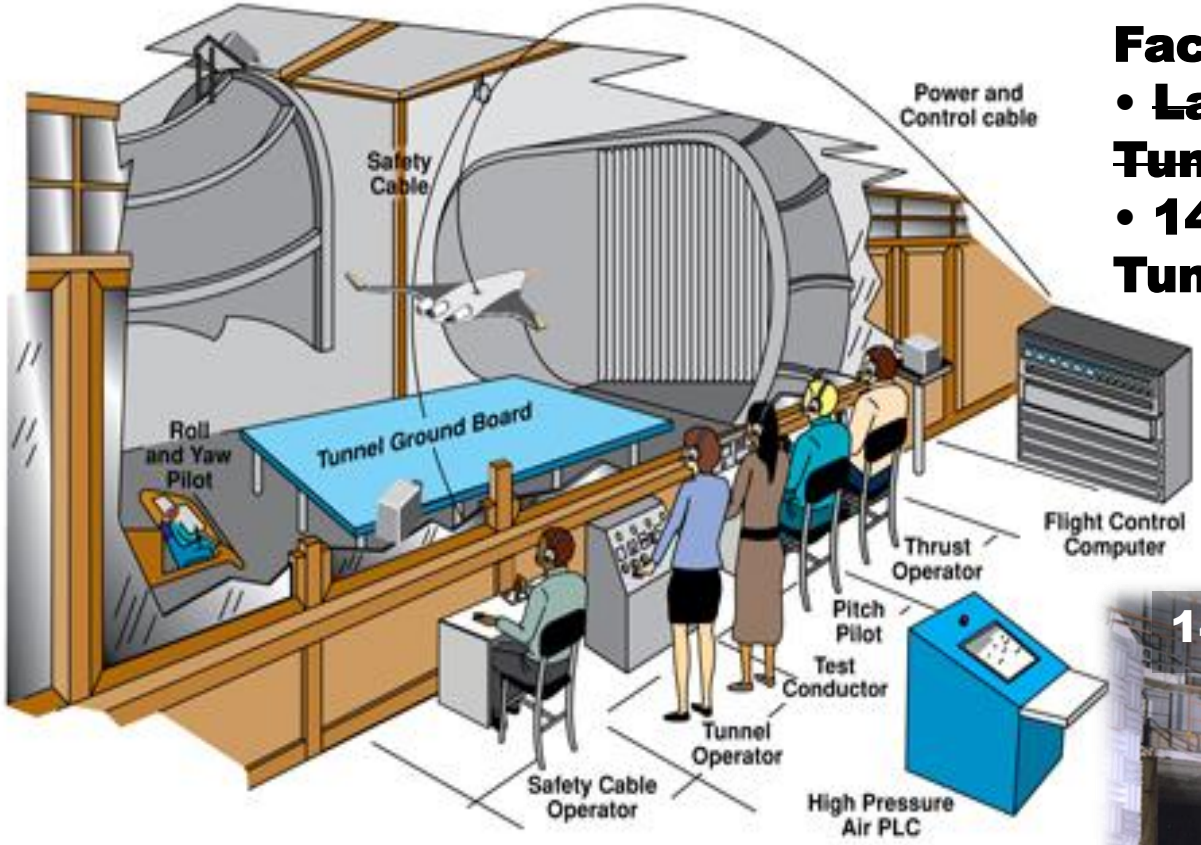
Cm vs α from various ground tests

- Magnitude of support interference effect on pitching moment much greater than anticipated



Flight data fit of flights 1-50

Free-flight Test Technique



Facilities:

- ~~**Langley Full-Scale Tunnel**~~
- **14’ X 22’ Subsonic Tunnel**

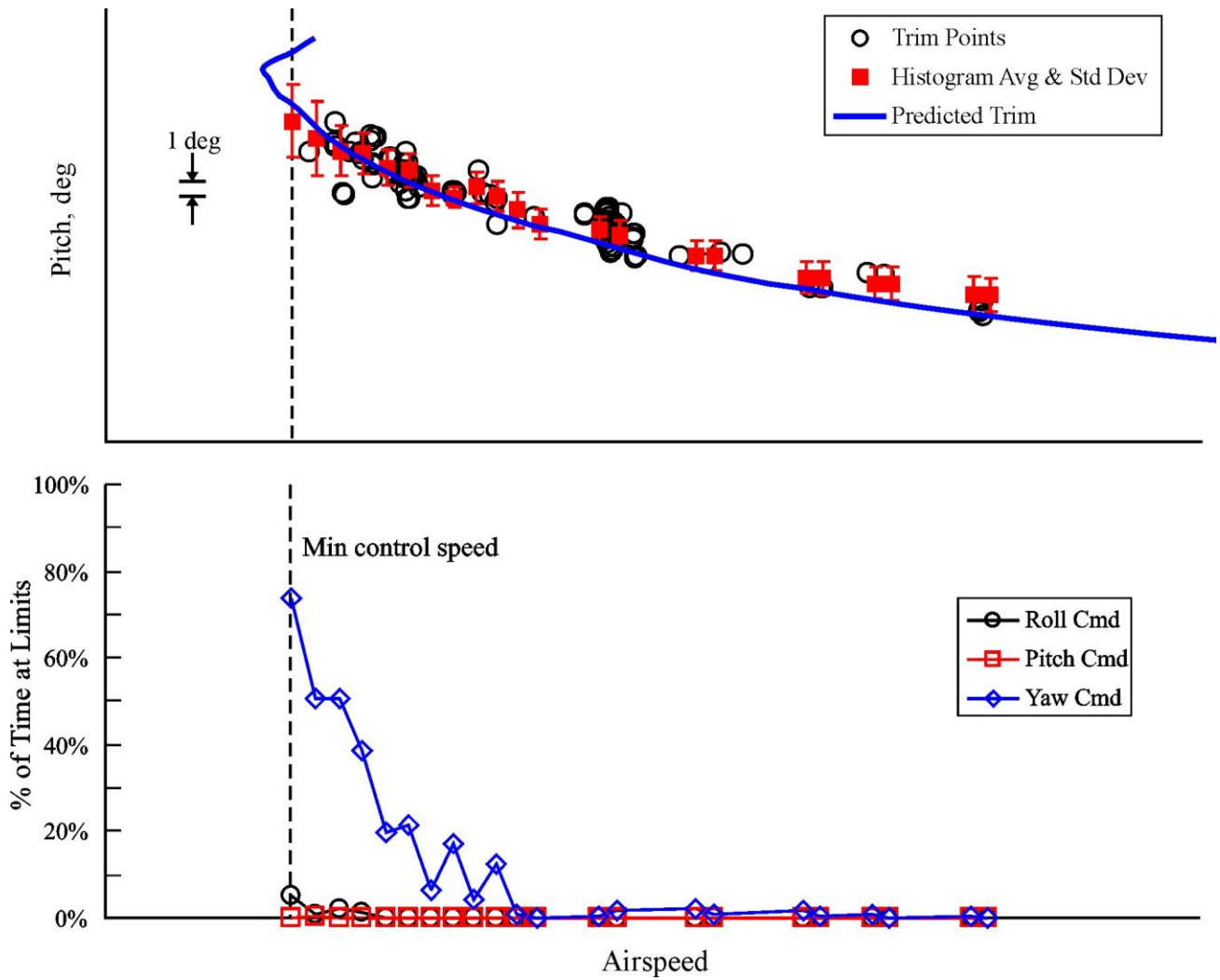
5% BWB Free-flight Test
Langley Full-Scale Tunnel Sept 2005

Test Objectives:

Assess:

- 1g departure onset control
- Asymmetric thrust control limits
- Center engine thrust vectoring control

Free-flight Data Example

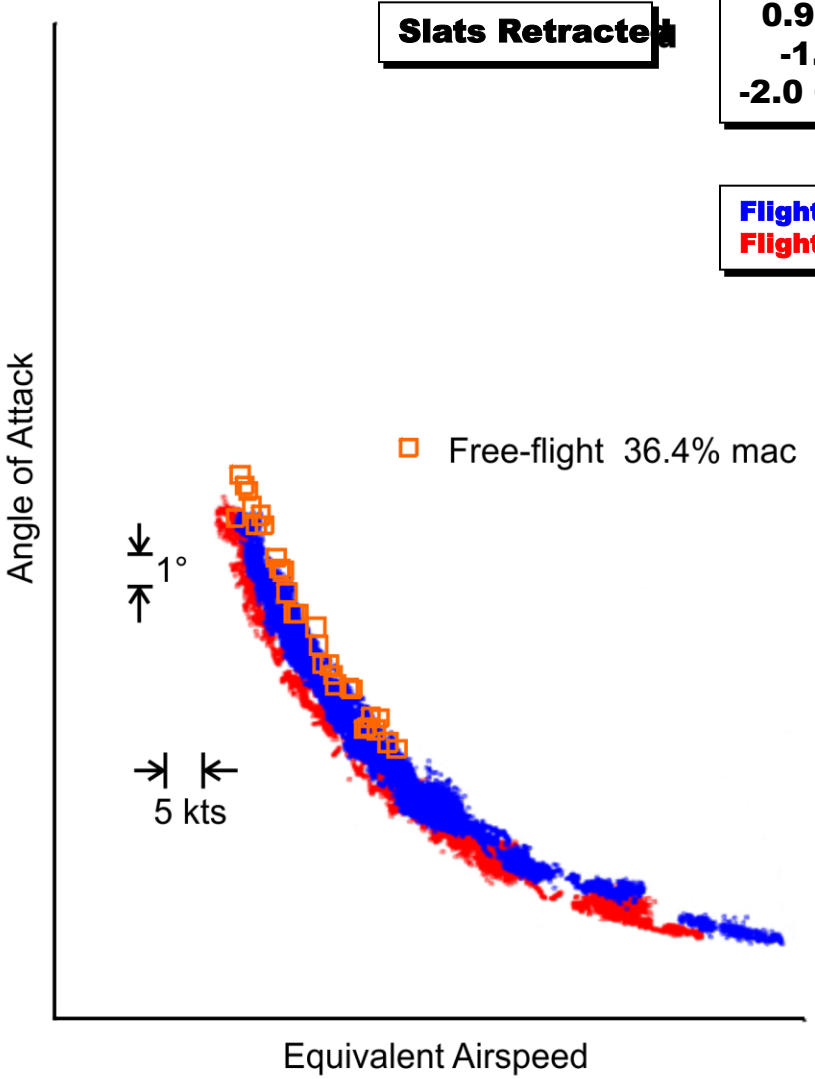


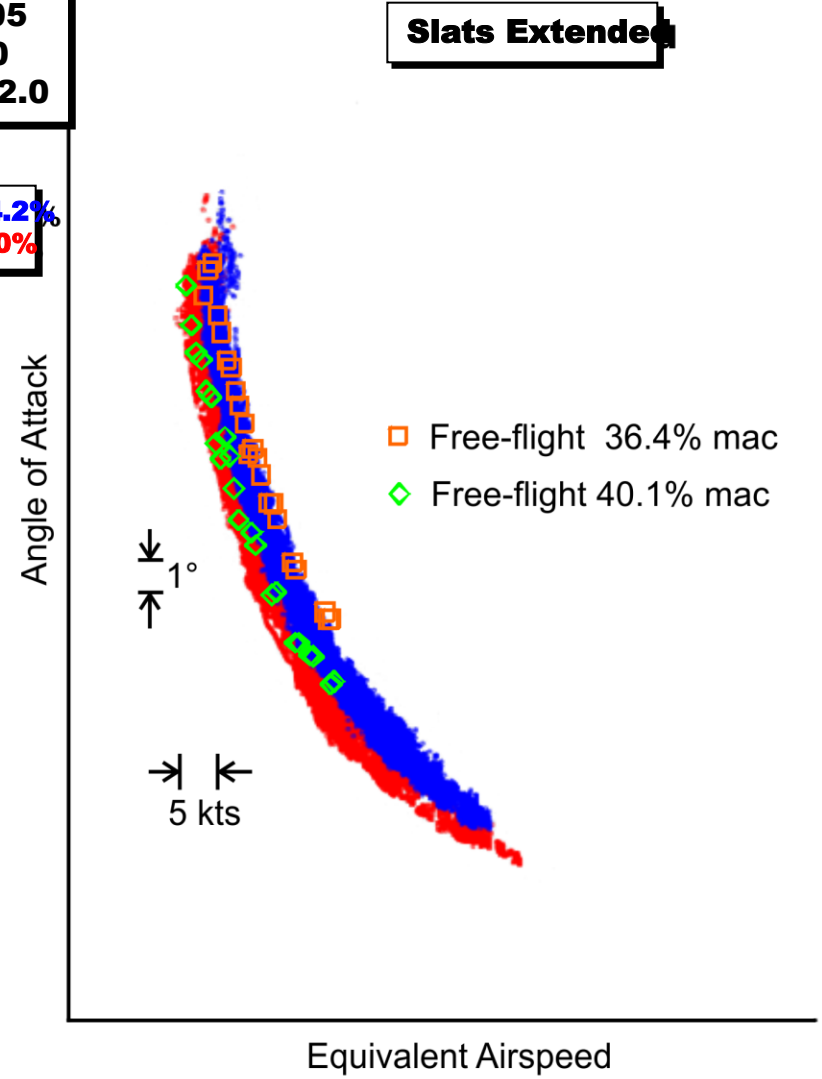
- **Slats extended**
- **Aft cg**

Free-flight and Flight Test Comparison

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%





Some lessons learned

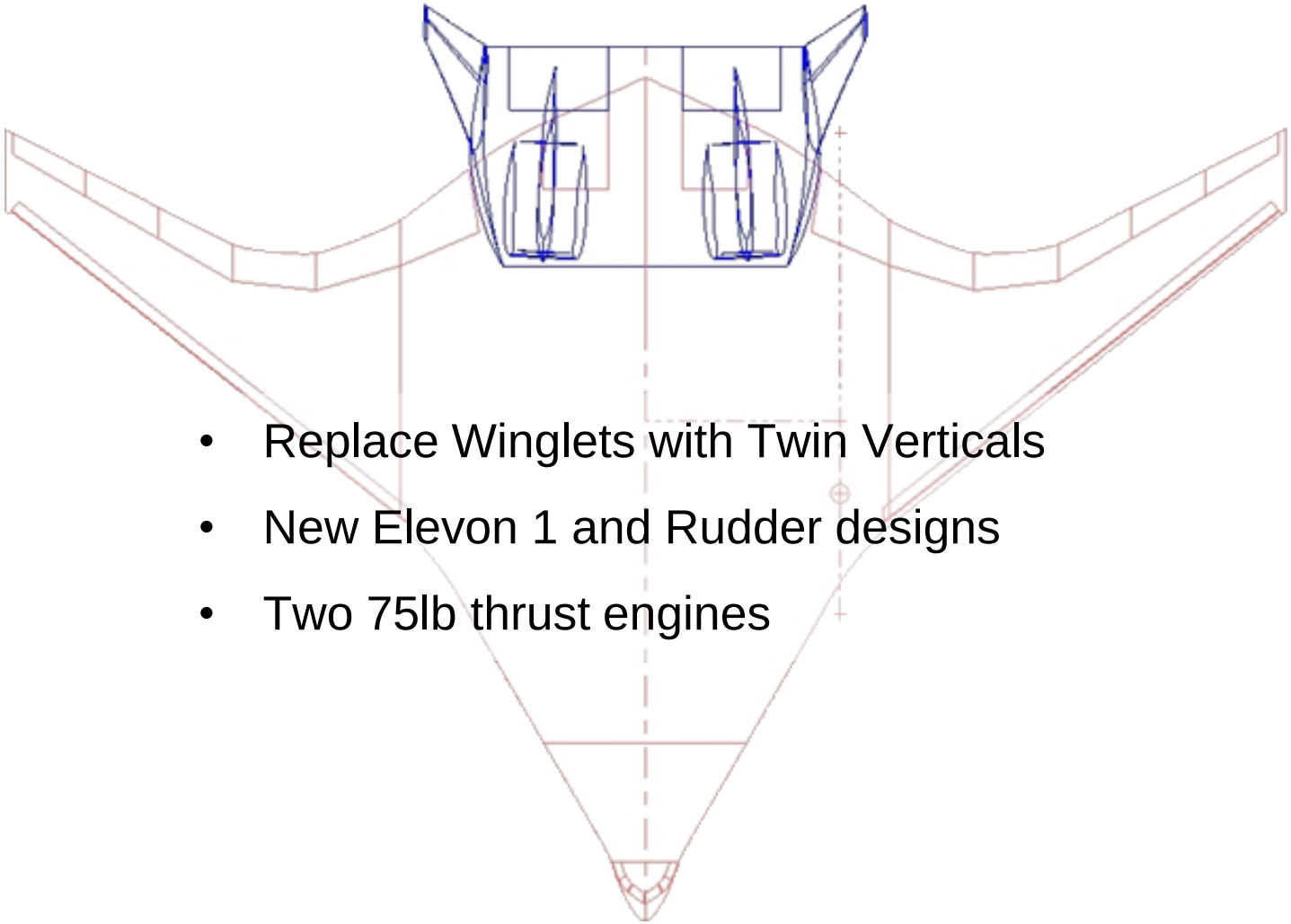
- While support interference is a usual and expected occurrence, the magnitude of the impact on pitching moment for BWB is much larger than anticipated
- Free-flight test method provided good correlation with observed1-g flight test limits
- Ground to flight correlation is difficult without a central 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?

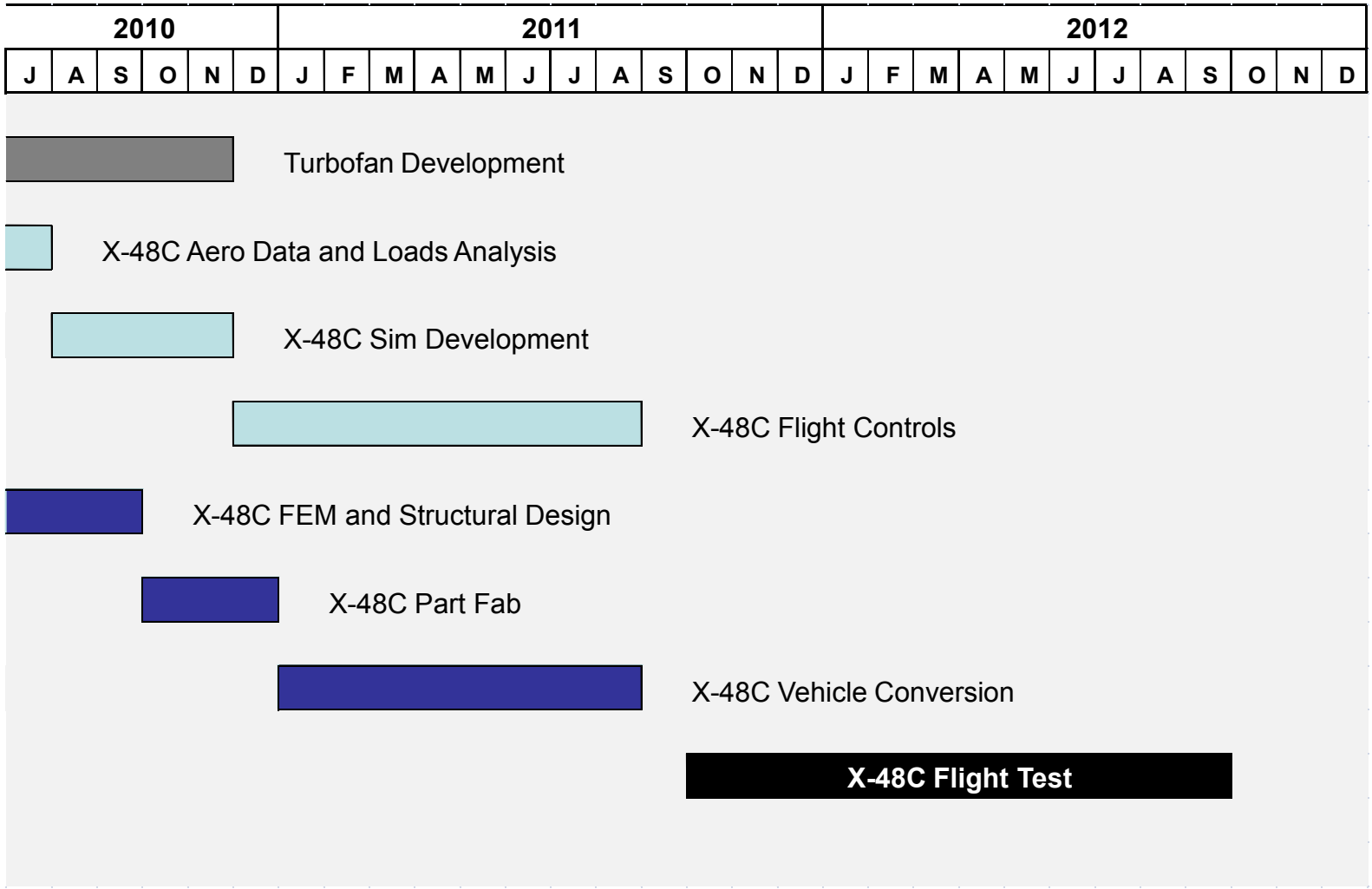
X-48C Configuration



- Replace Winglets with Twin Verticals
- New Elevon 1 and Rudder designs
- Two 75lb thrust engines

X-48C in Langley Full Scale Tunnel – Aug. ‘09

X-48C Test Plan



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?