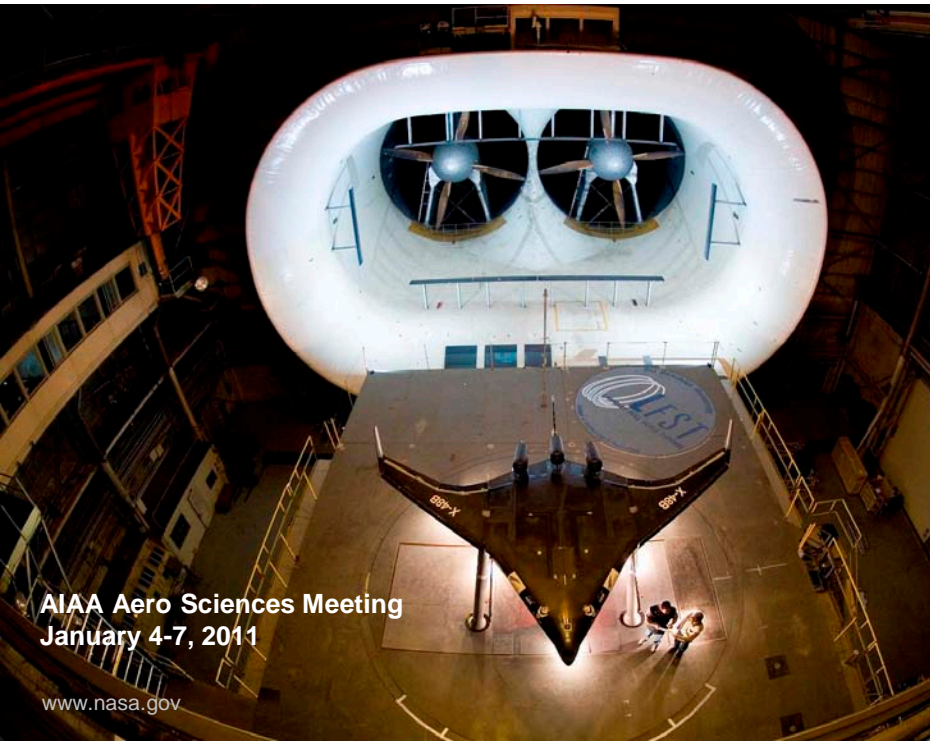




# X-48B Blended Wing Body Ground to Flight Correlation Update

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[www.nasa.gov](http://www.nasa.gov)





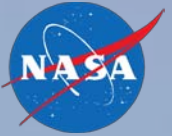
# Contributors

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- 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

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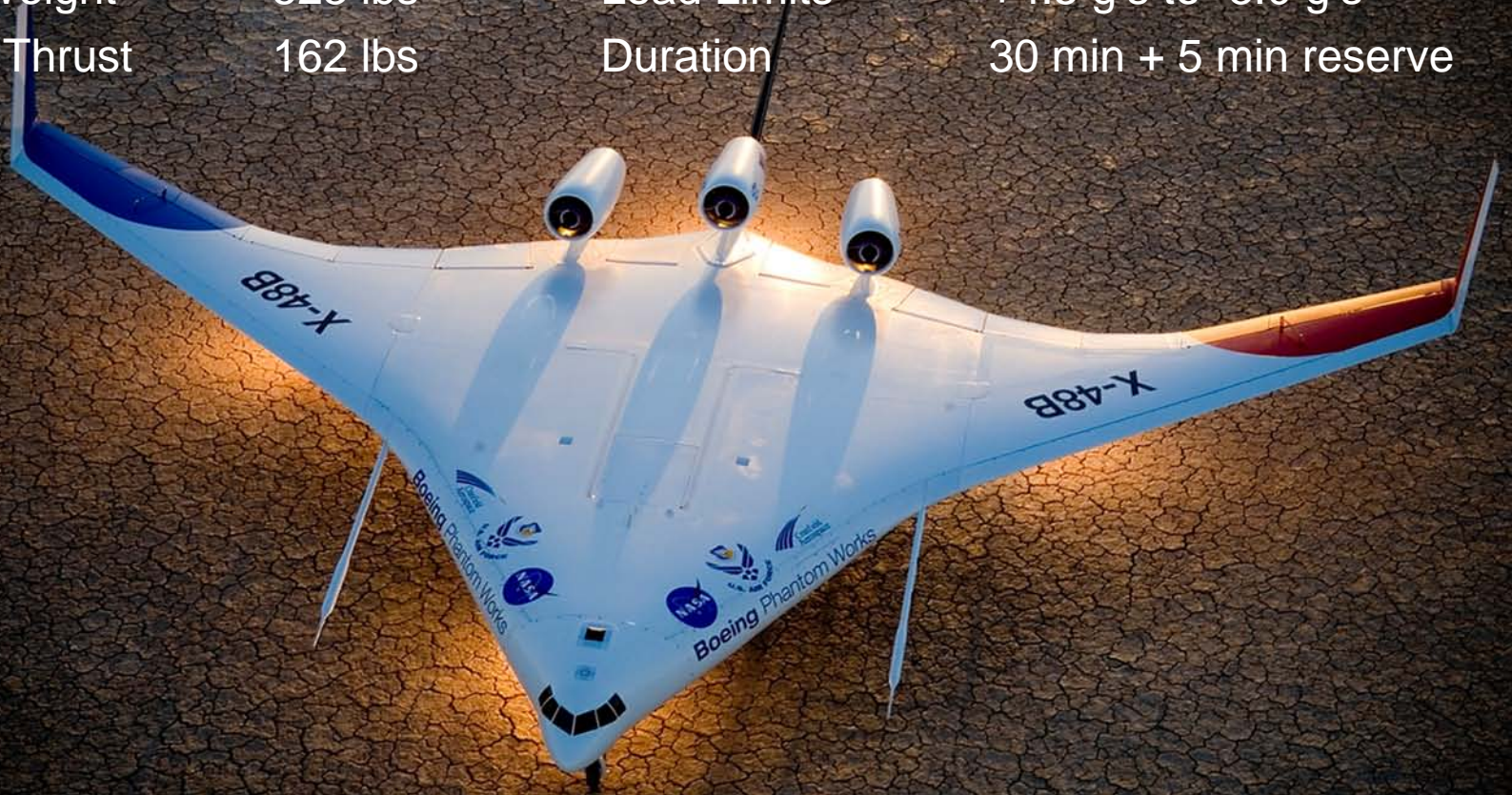
- X-48B – What is it and why
- BWB ground tests
- X-48B flight tests
- Some ground to flight comparisons
  - Pitching moment
  - 1-g stall limits
- What's next
- Summary
- Questions



# X-48B - 8.5% Dynamically Scaled BWB



•Wing Span	20.4 ft	Max Airspeed	118 kts
•Wing Area	100.5 ft <sup>2</sup>	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

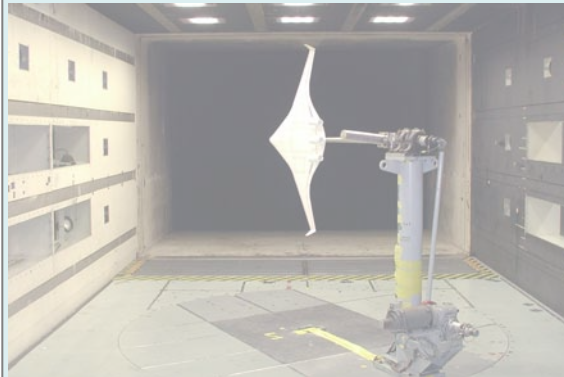
- **Assess stability & control characteristics of a BWB class vehicle in free-flight conditions:**
  - Assess dynamic interaction of control surfaces
  - Assess control requirements to accommodate asymmetric thrust
  - Assess stability and controllability about each axis at a range of flight conditions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



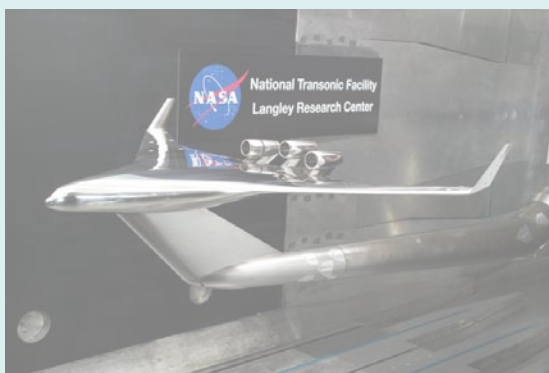
Langley 14' x 22' Tunnel

- 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

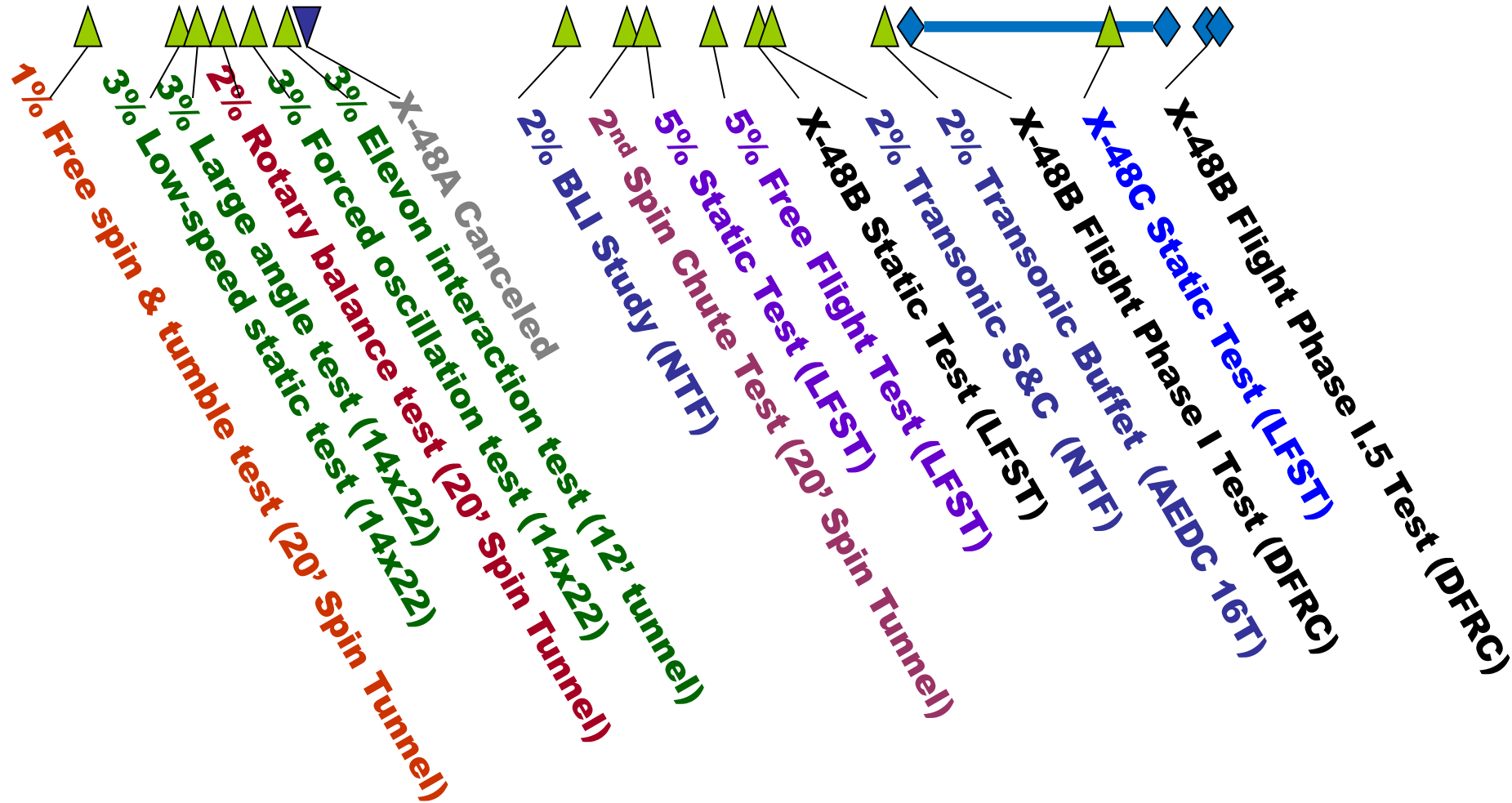


X-48B Flight Test DFRCC

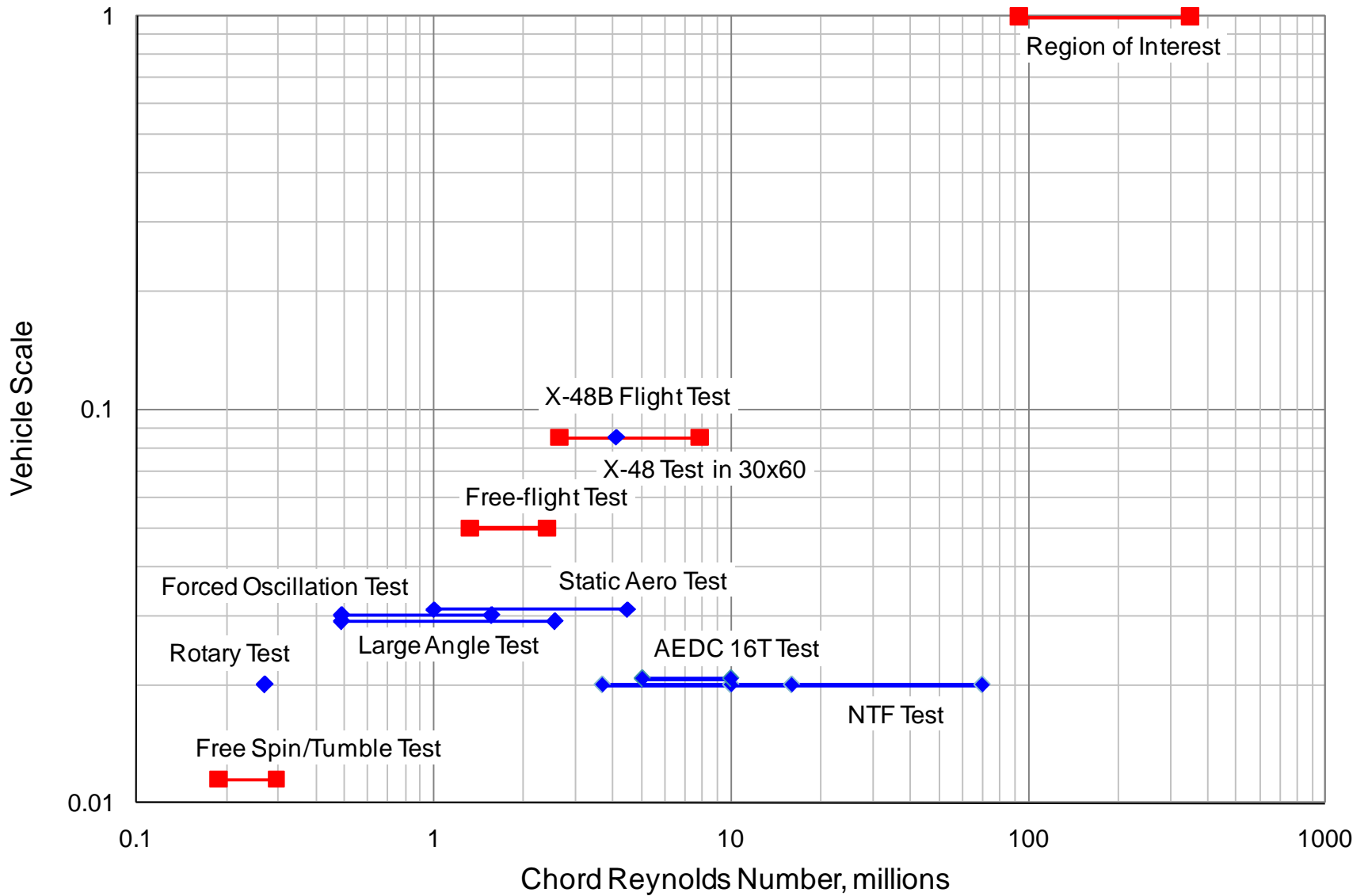
# BWB Flight Dynamics Research Timeline



99	00	01	02	03	04	05	06	07	08	09	10
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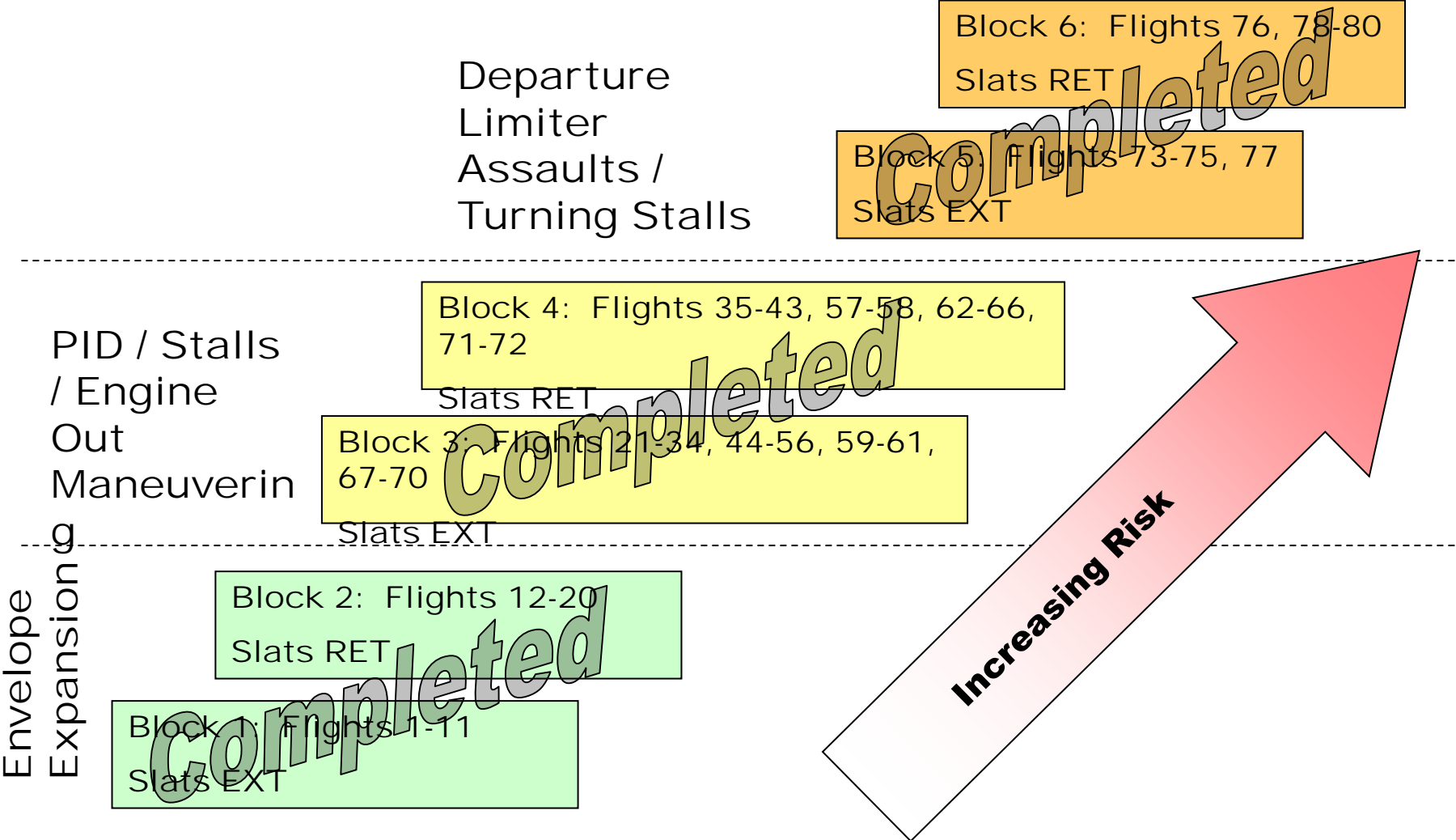
# Suite of Ground Tests



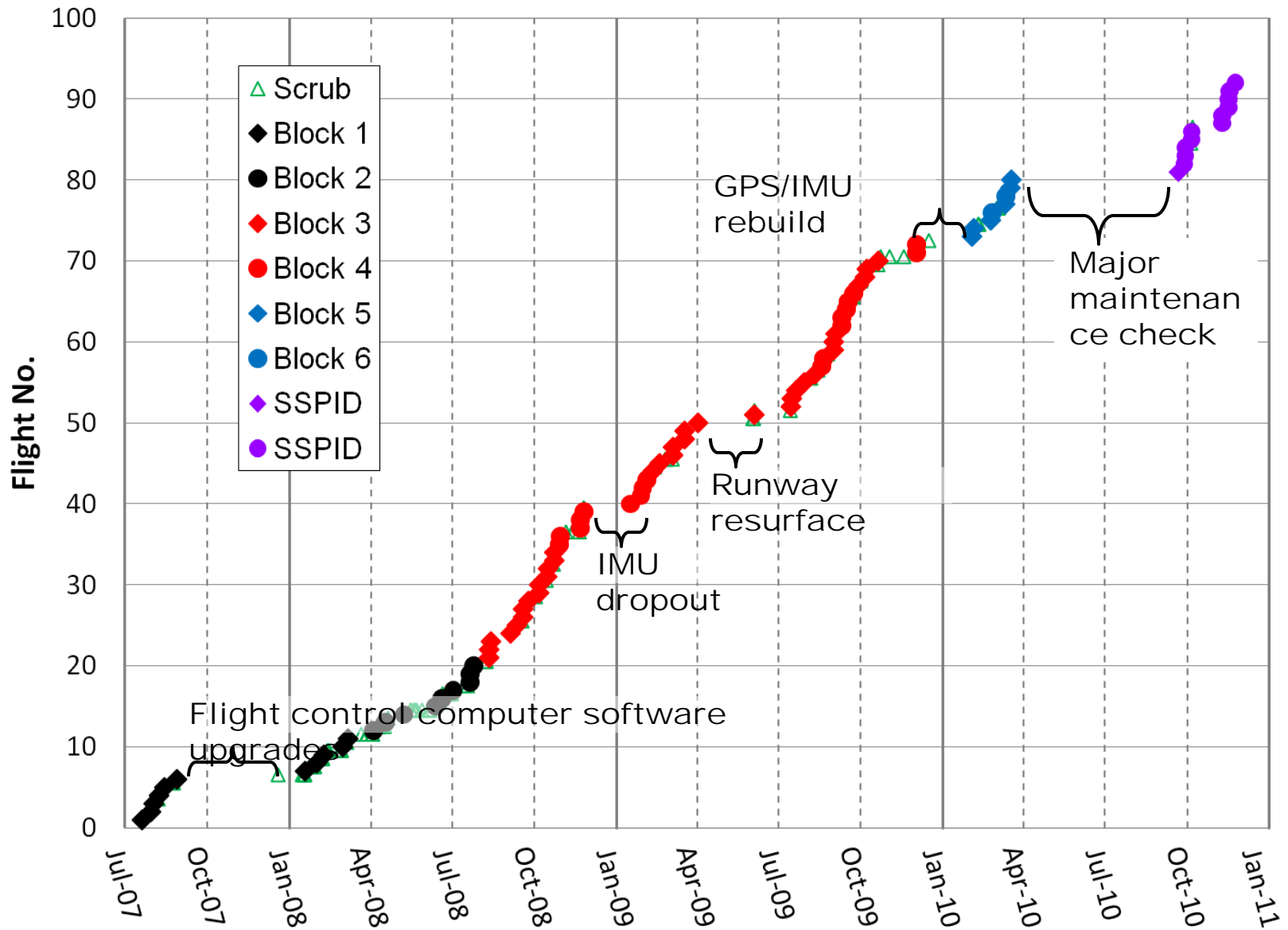




# Phase I Flight Test Blocks



# X-48B Flight Rate



# Flight Test Video

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# 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  $CL_{max}$
- Slat RET stalls successful to 14 deg alpha
- Departure limiter assaults highly successful!
- Overall, the aircraft flies extremely well





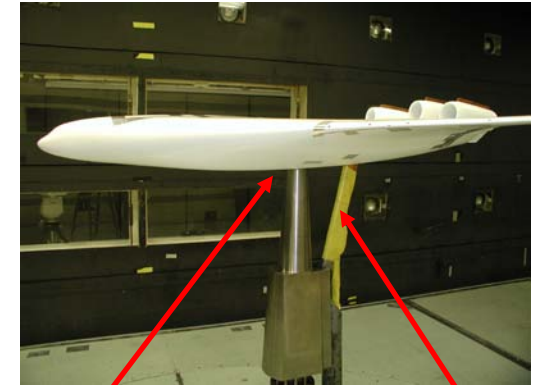
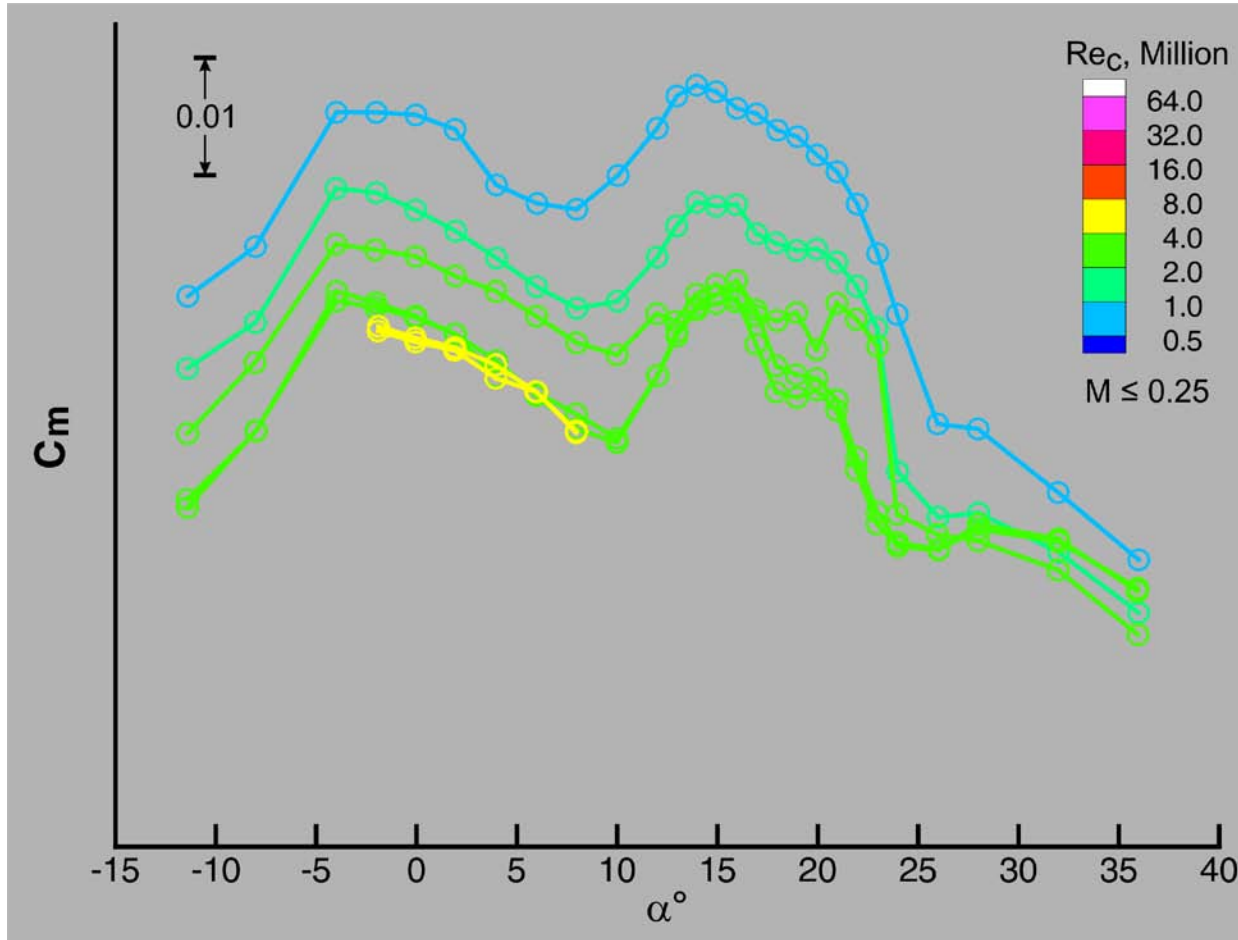
# Where are the poor comparisons?

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- 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

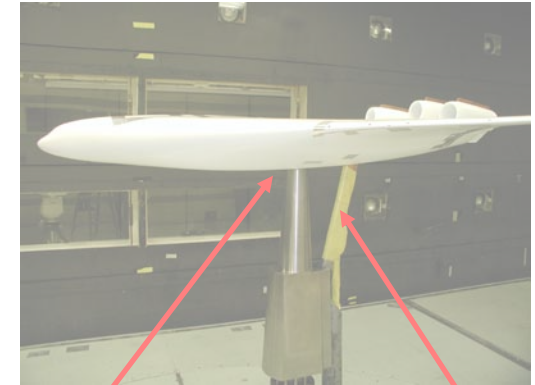
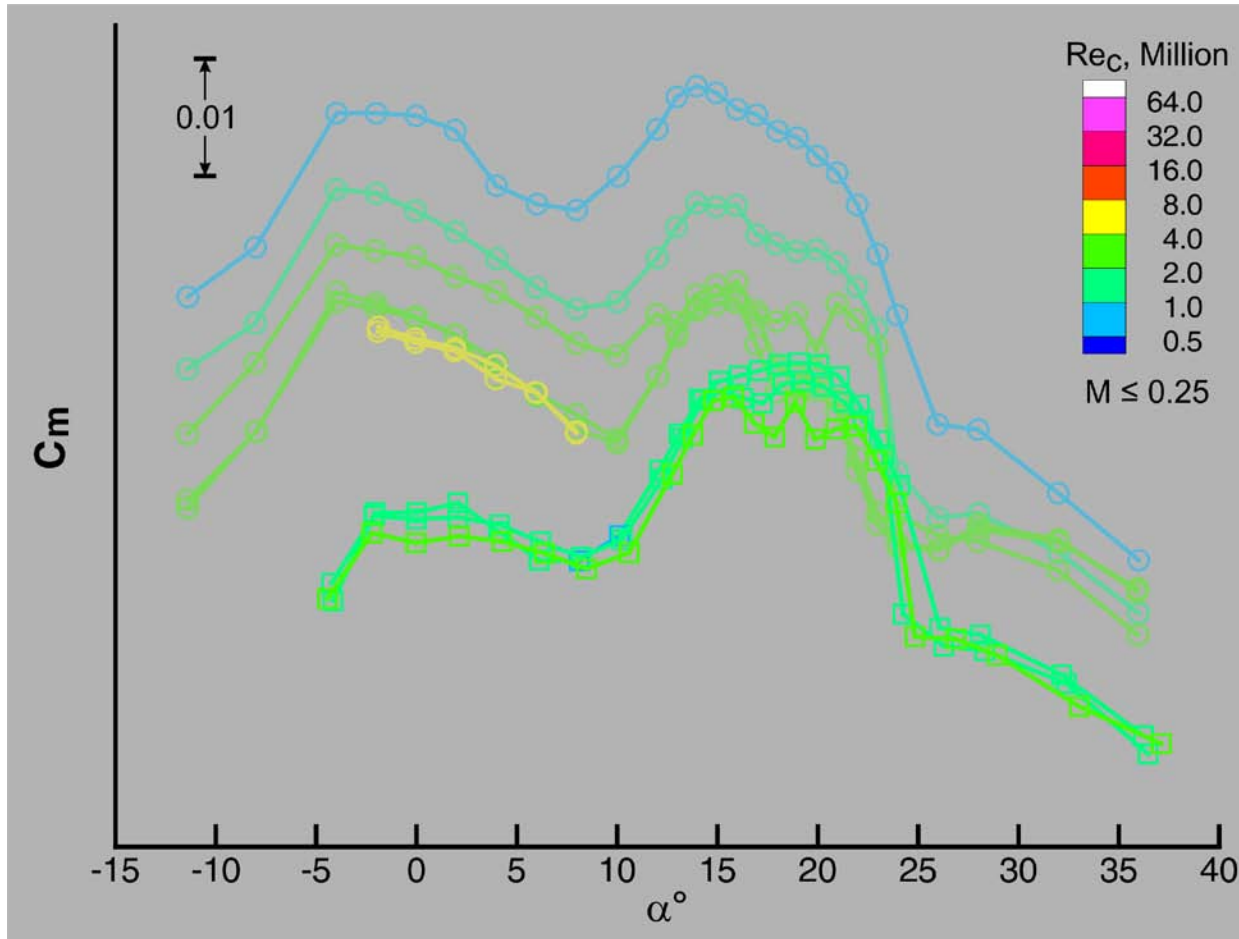
- Magnitude of support interference effect on pitching moment much greater than anticipated



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



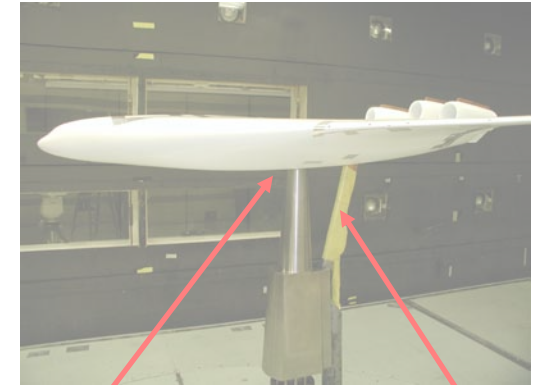
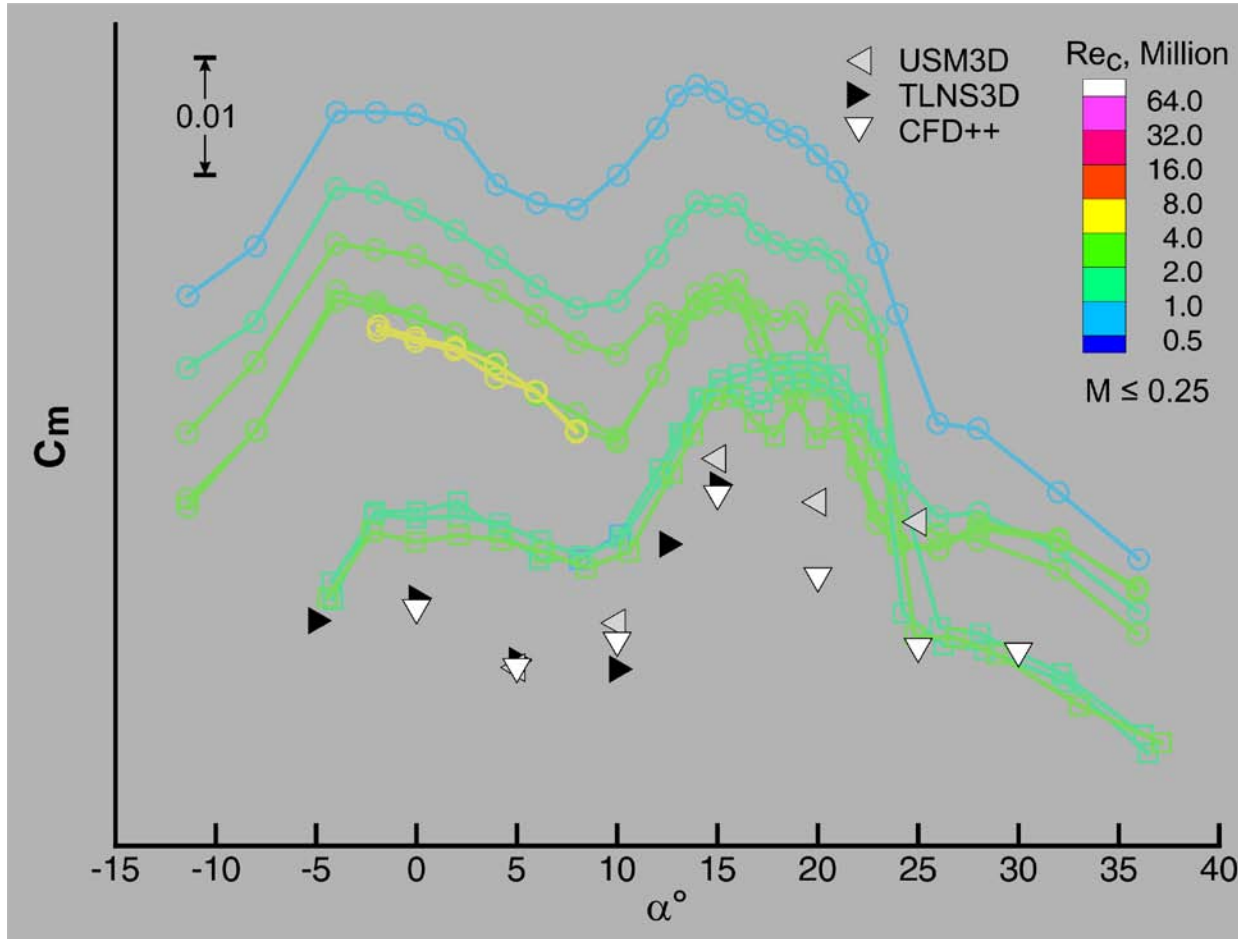
3" dia. large post + pitch link



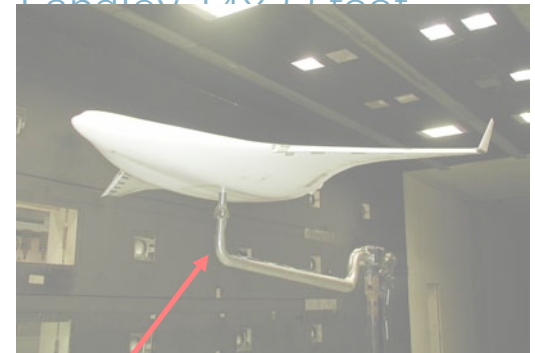
1.2" dia. bent sting  
Langley 14x22 foot  
Tunnel

# 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

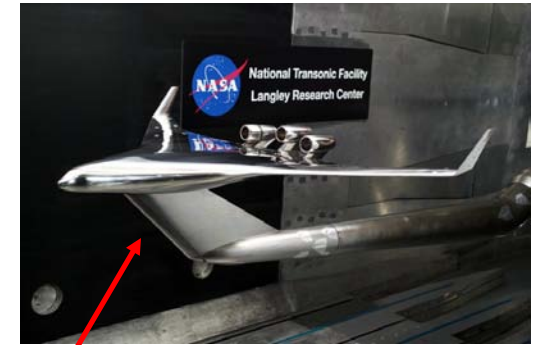
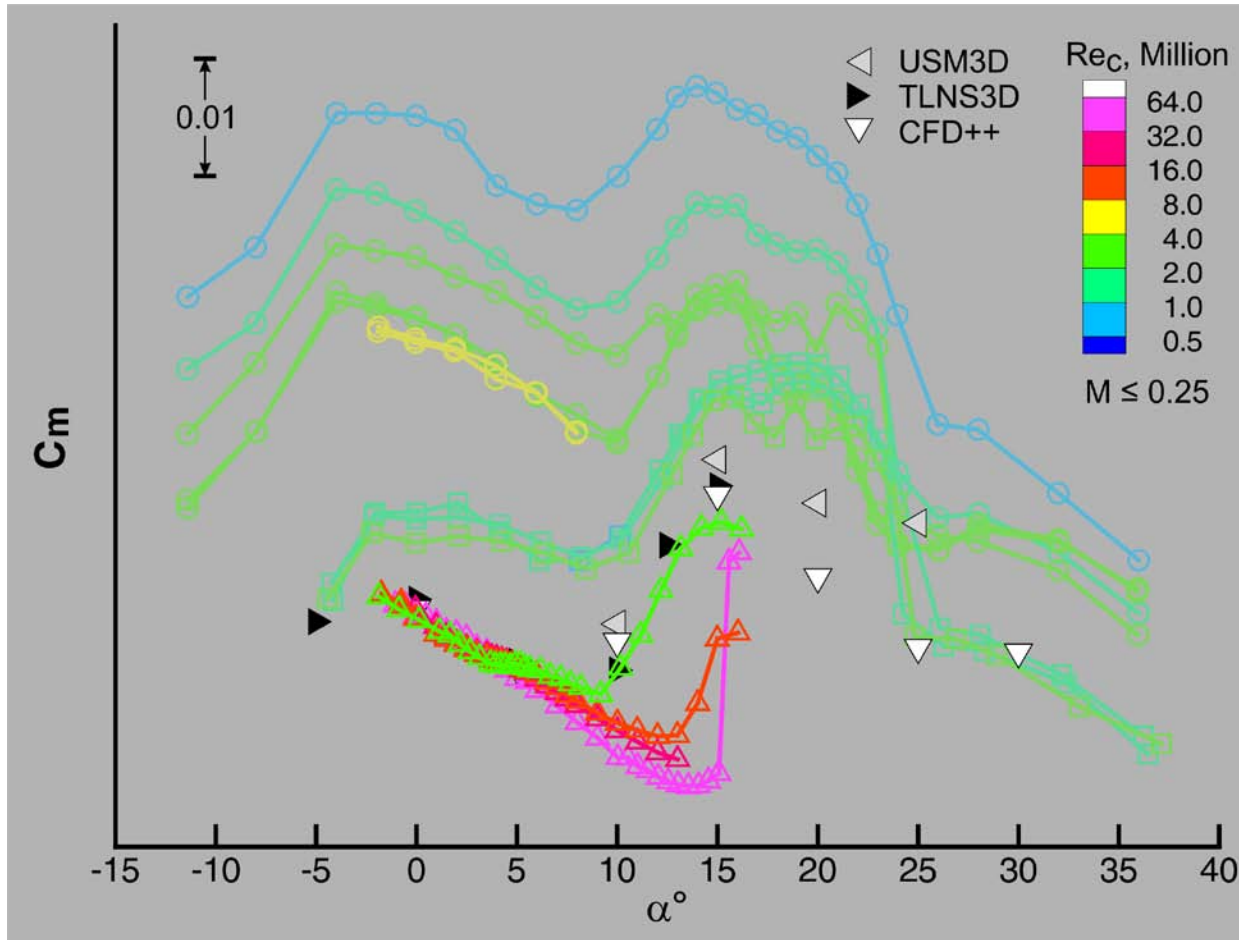


1.2" dia. bent sting  
Langley 14x22 foot  
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# Cm vs $\alpha$ from various ground tests

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

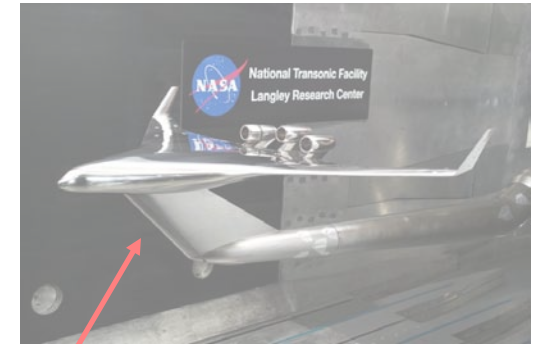
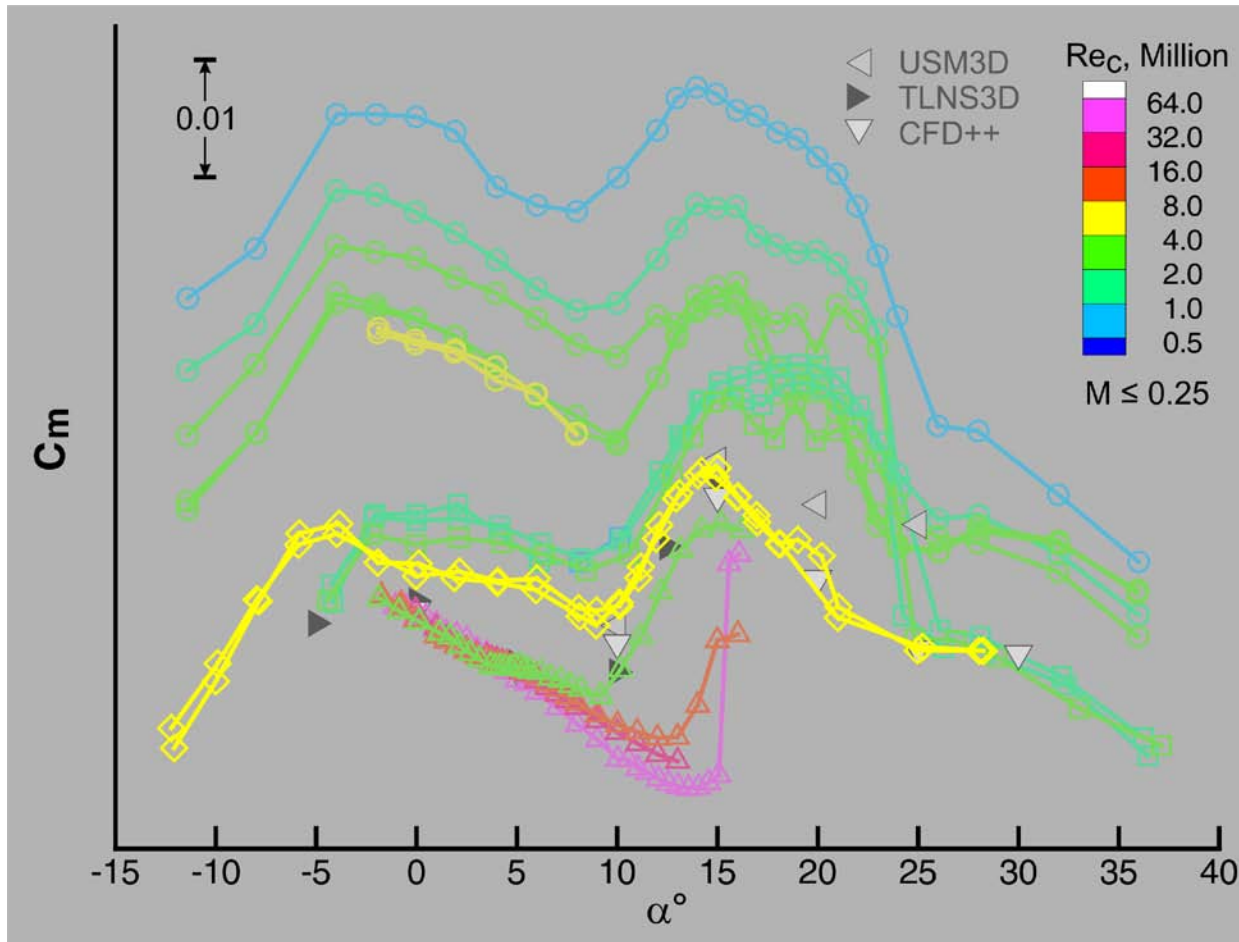


Swept strut designed for minimum interference in NTF

# Cm vs $\alpha$ from various ground tests



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



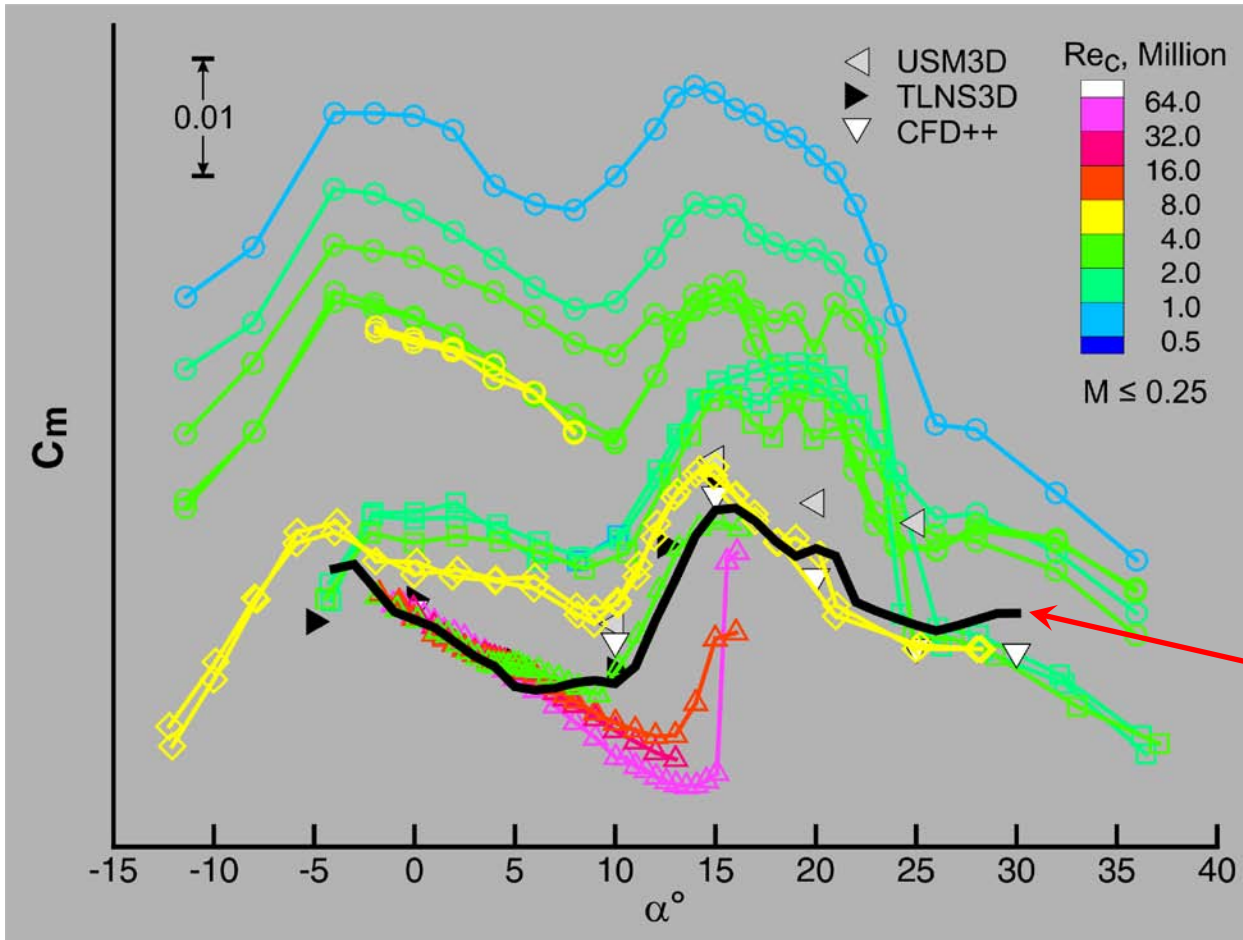
Swept strut designed for minimum interference in



X-48B strut mounted in Langley Full Scale Tunnel

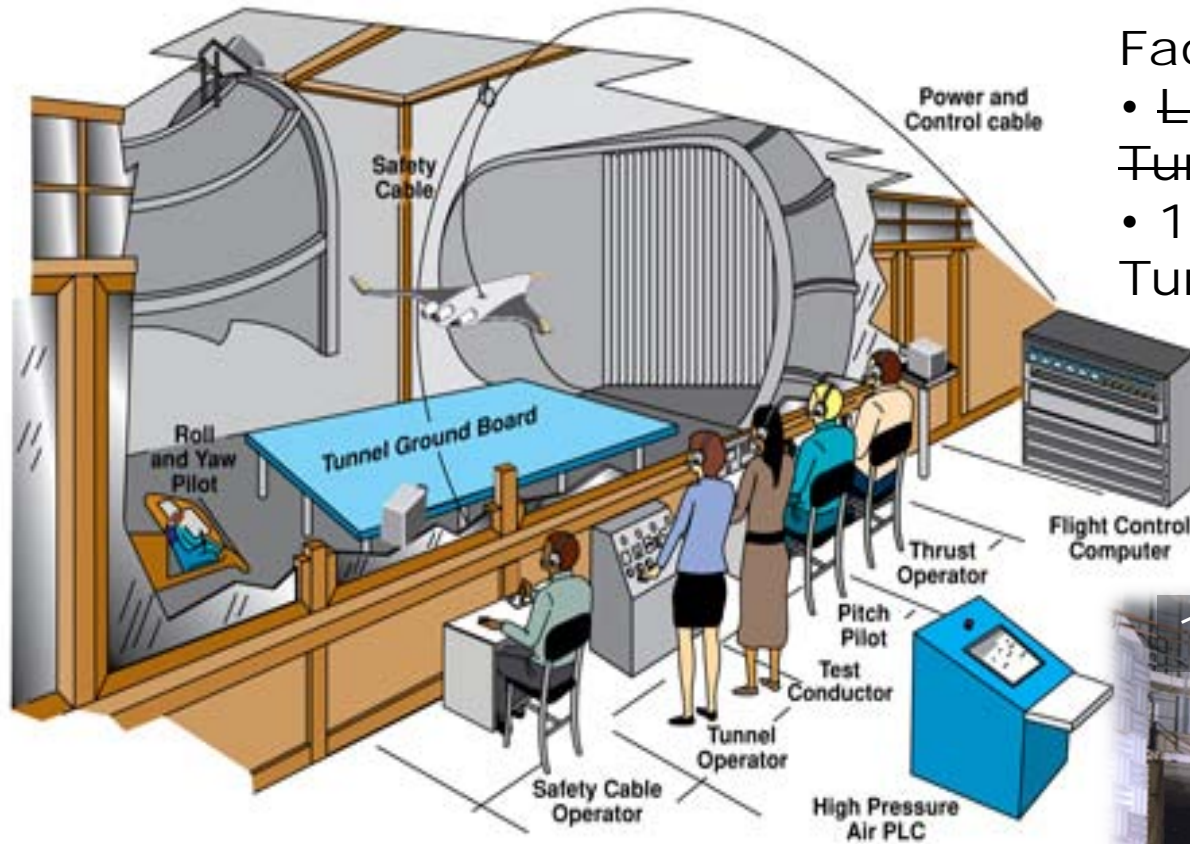
# Cm vs $\alpha$ from various ground tests

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



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:

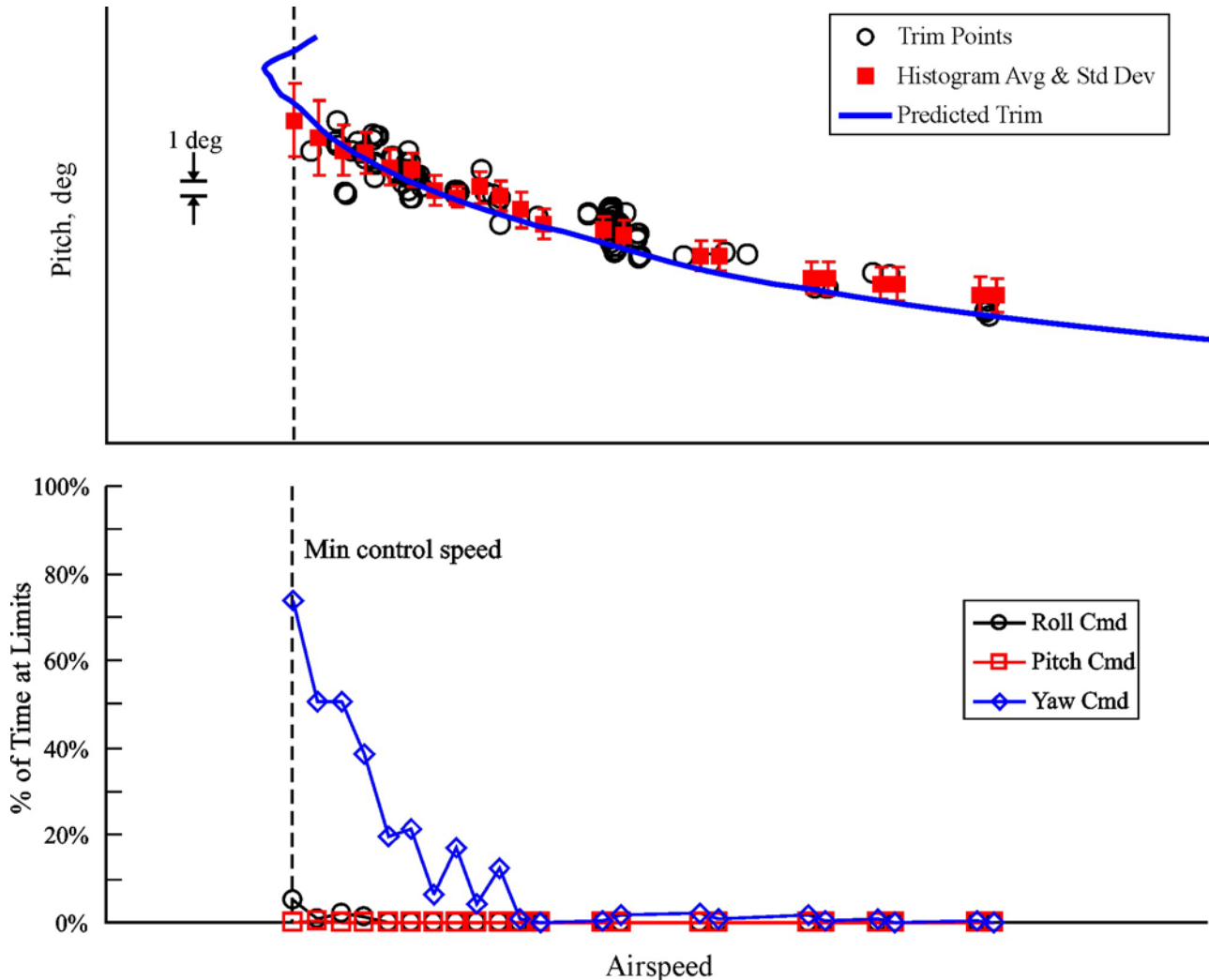
- 1g departure onset control
- Asymmetric thrust control limits
- Center engine thrust vectoring control



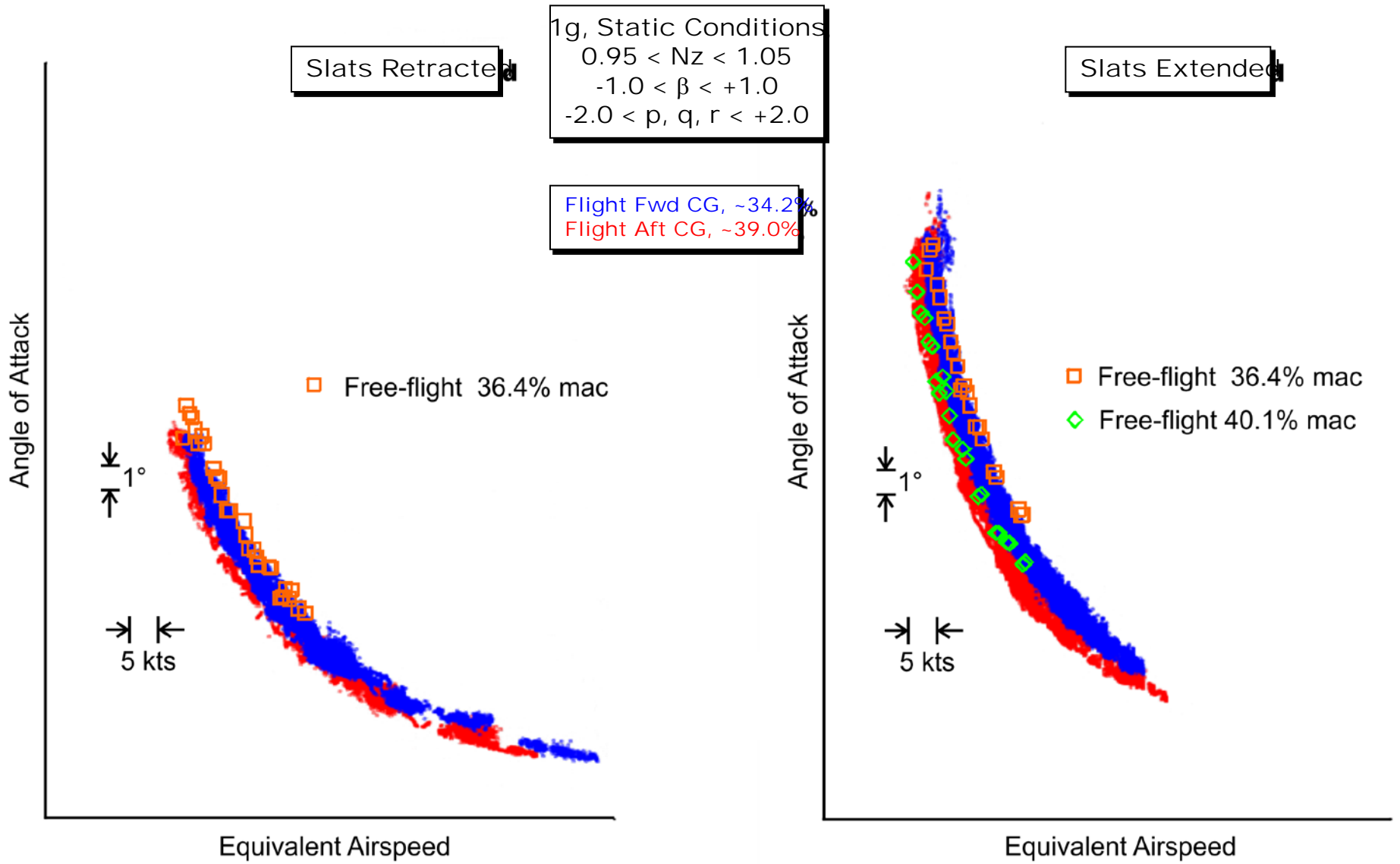
# Free-flight Data Example



- Slats extended
- Aft cg



# Free-flight and Flight Test Comparison





# Some lessons learned

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- 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

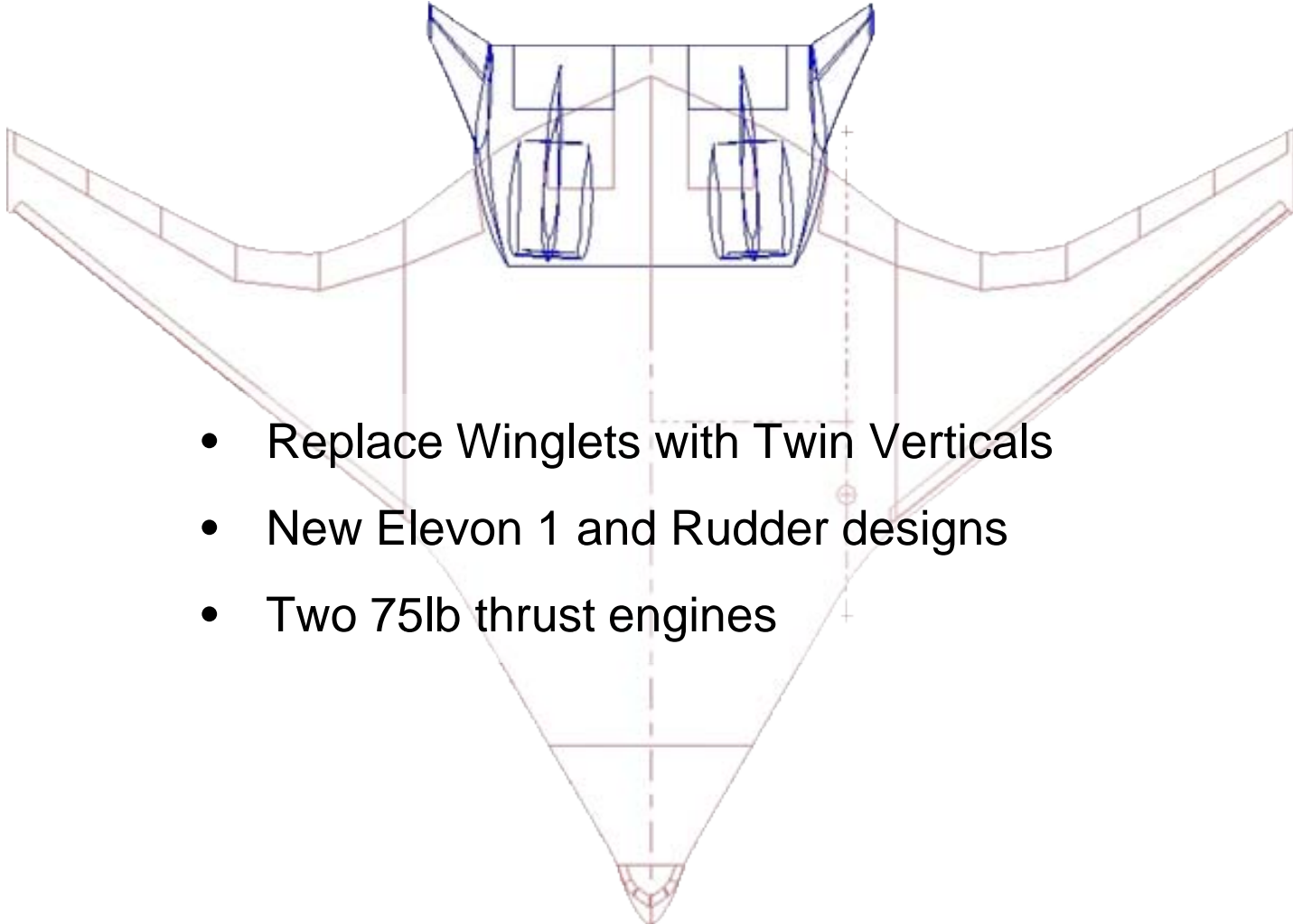
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- Transonic
  - NTF and AEDC 16T data
- Post departure modes (falling leaf , spin, tumble)
  - Large angle static, rotary and free spin/tumble data

# So what's next?



## X-48C Configuration



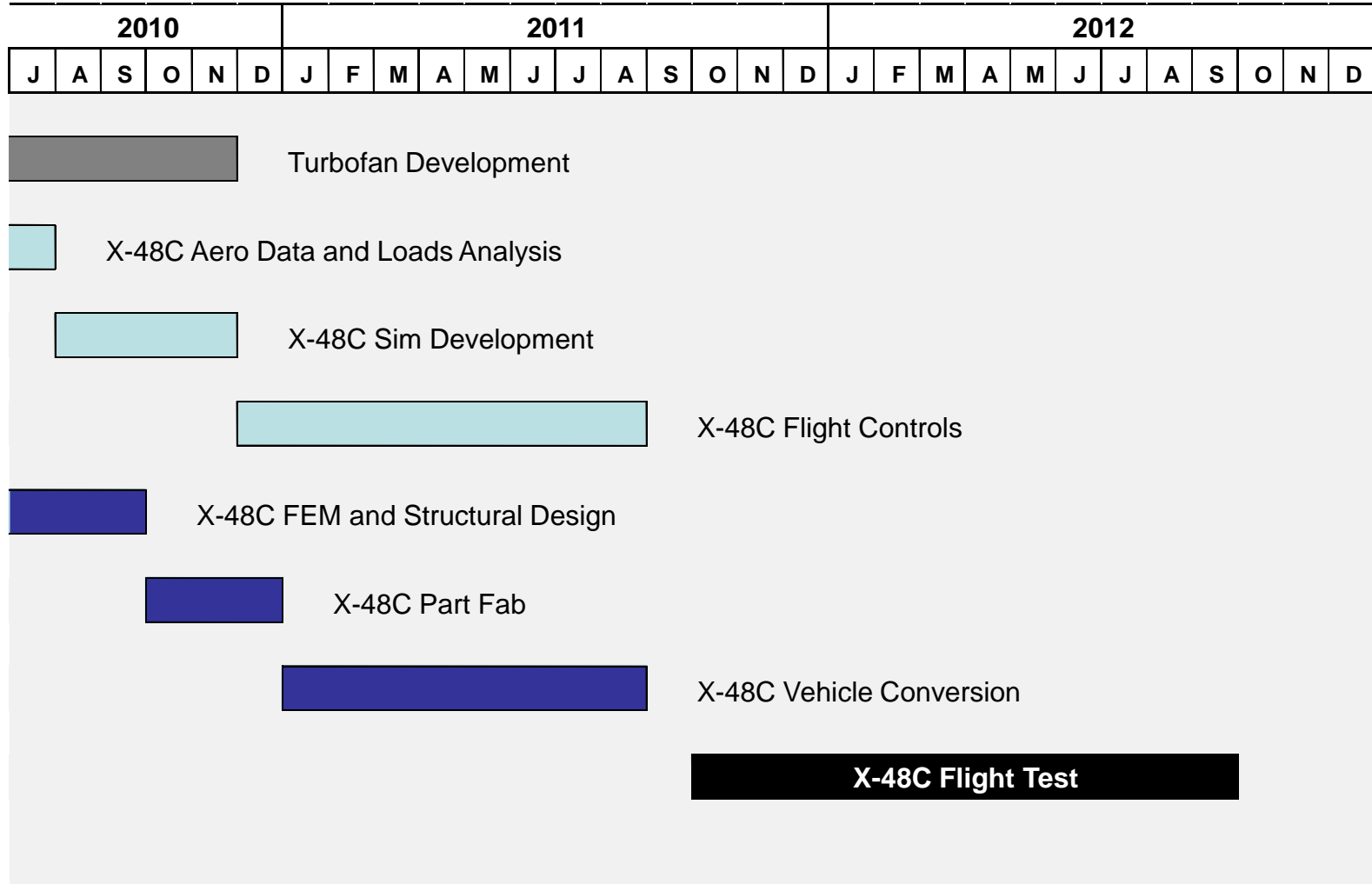
- Replace Winglets with Twin Verticals
- New Elevon 1 and Rudder designs
- Two 75lb thrust engines

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



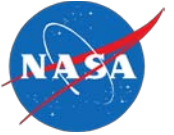


# X-48C Test Plan



# Summary

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- 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?

