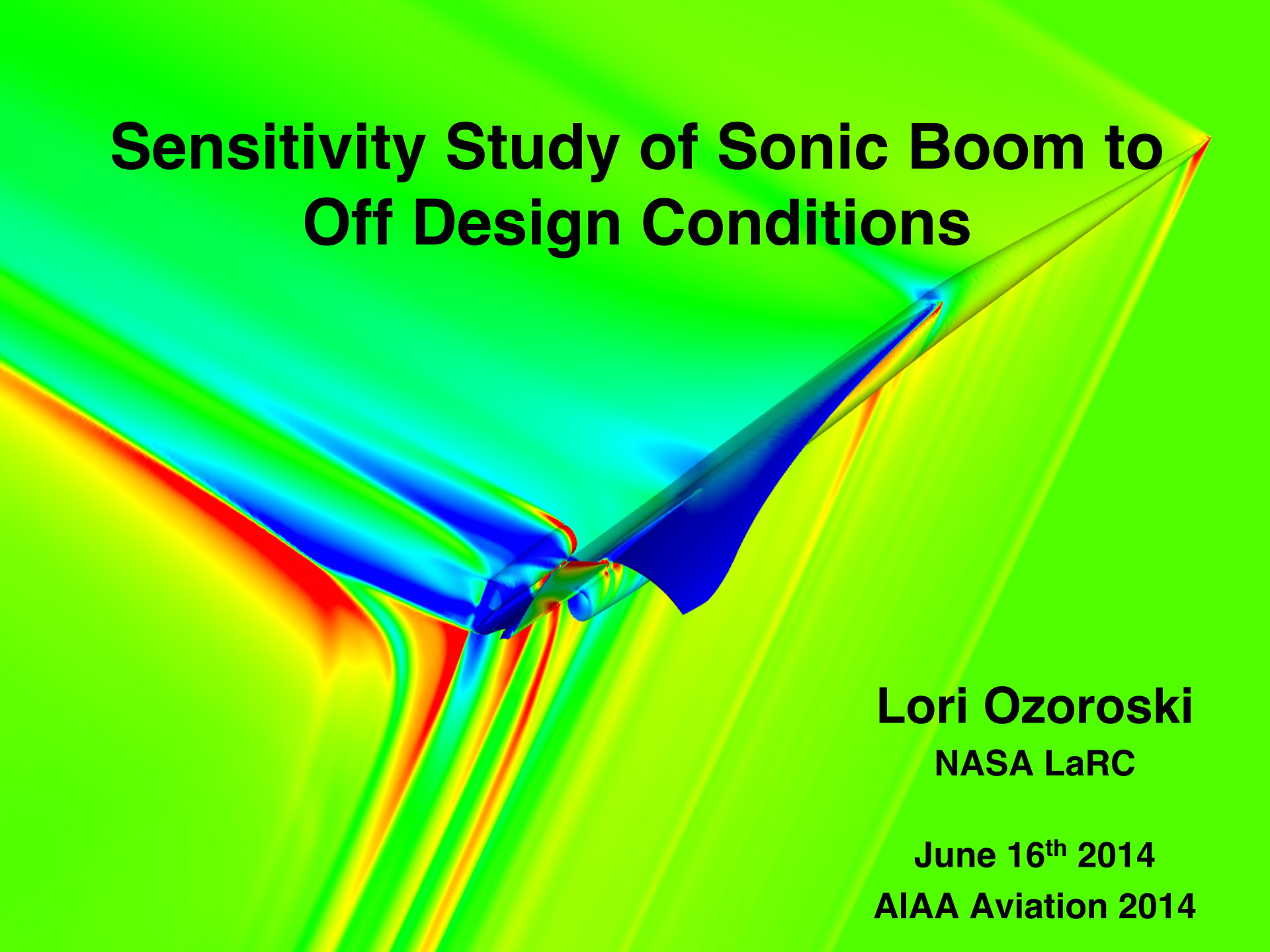
Sensitivity Study of Sonic Boom to Off Design Conditions



Lori Ozoroski
NASA LaRC

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AIAA Aviation 2014

Acknowledgements

Modeling and analysis performed by members of the System Level Tools & Concepts Discipline team of the NASA High Speed Research Project

Irian Ordaz

Karl Geiselhart

Mathias Wintzer

Jim Fenbert

Outline

- Objective
- LM1043 concept
  - Analysis background
  - Sonic boom sensitivity
    - Cruise
    - Climb
    - Control surface deflections
    - Structural deflections
- NASA demonstrator concept
  - Sonic boom sensitivity
    - Cruise
    - Climb
- Summary

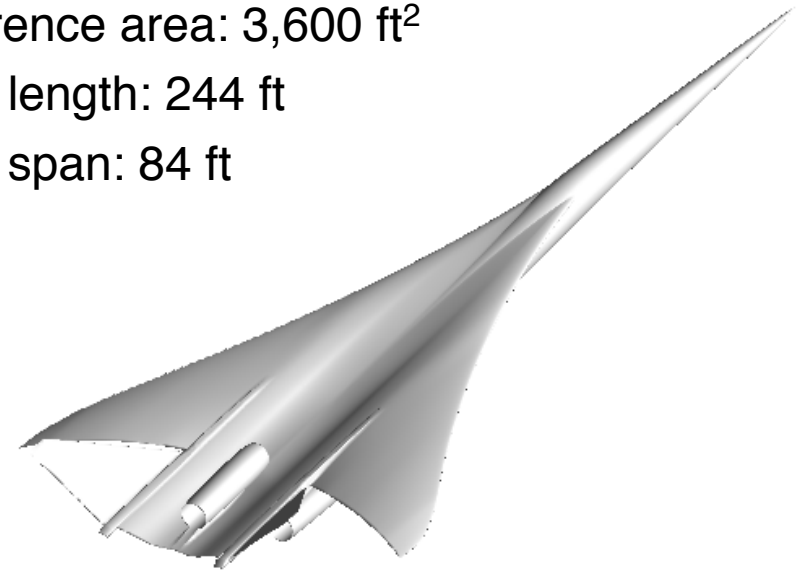
Objective

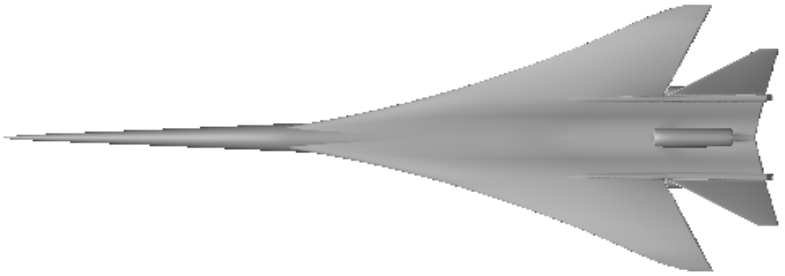
Aide program managers and discipline experts at NASA in understanding the sensitivity of a low-boom vehicle's perceived sonic boom loudness to small perturbations throughout the entire flight profile.

- Concept Designers
- Controls
- Aeroelastics
- Propulsion
- Noise

Configuration LM1043

- Received directly from Lockheed May, 2012
- Derivative of the LM1021 test case used in the 1st Sonic Boom Prediction Workshop
- Flow-through nacelles
- Reference area: 3,600 ft^2
- Body length: 244 ft
- Wing span: 84 ft

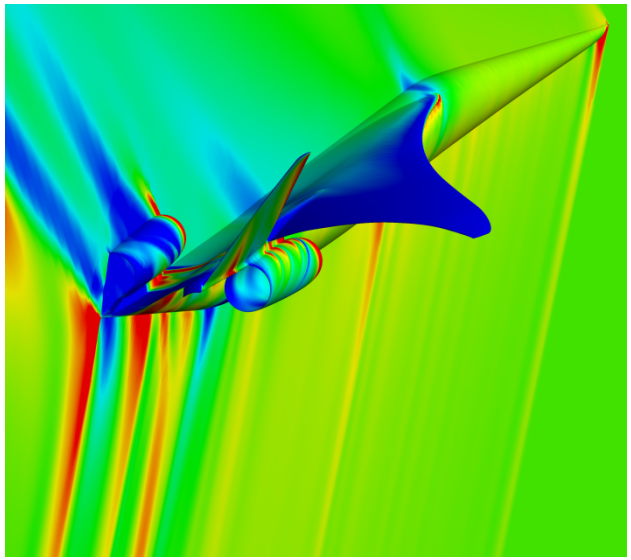


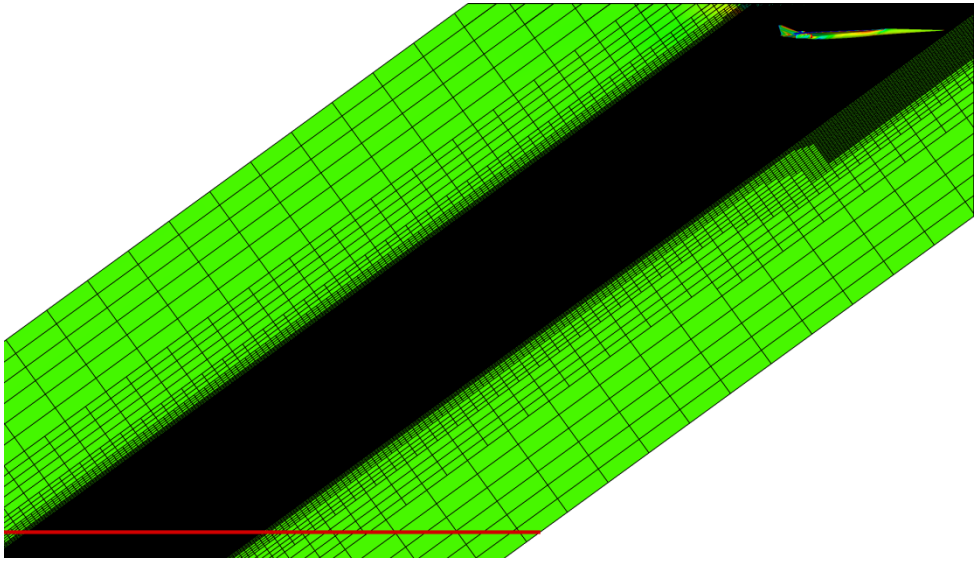


Description of CFD Analysis

Conducted with Cart3D

- Stretched and rotated volume grid for Mach alignment
- Y/X and Z/X cell stretching is 3:1
- Van Leer limiter
- Pressure distribution calculated at 3 body lengths below aircraft
- Pressure distribution consists of 450 points or more
- 800 solver iterations (2 orders of drop in magnitude of residual)
- Verified with adjoint mesh refinement





Description of Sonic Boom Analysis

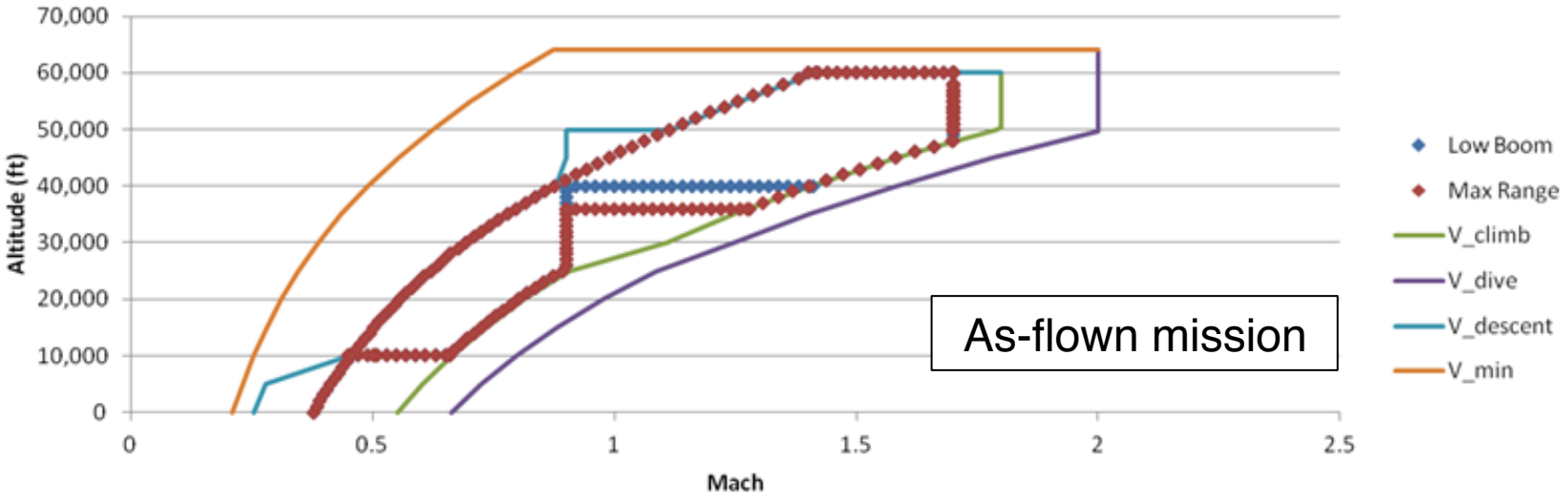
Conducted with sBOOM

- Based on Augmented Burgers equation
- Accounts for nonlinearity, thermoviscous absorption, and molecular relaxation effects
- Standard atmospheric temperature and humidity
- Reflection factor of 1.9
- Double event loudness calculation (does not subtract 3 PLdB)
- Climb angle and acceleration
  - Not accounted for in LM1043 analysis
  - *Accounted for in NASA demonstrator concept analysis*

Mission Analysis

As-drawn cruise segment obtained from Lockheed

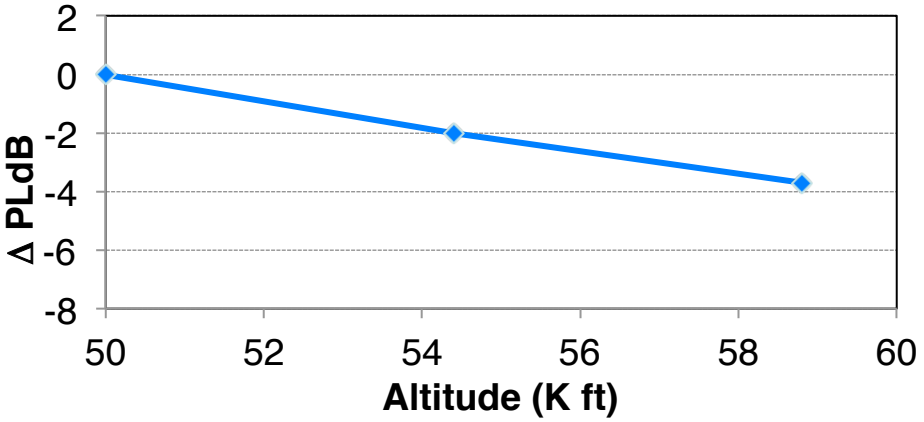
Case	Mach	Altitude (ft)	AoA (deg)	Weight (lbs)
Start of Climb	1.41	40,000	1.75	265,494
Middle of Climb	1.55	45,500	2.06	263,591
Start of Cruise	1.70	50,000	2.10	261,102
Middle of Cruise	1.70	54,400	2.10	211,332
End of Cruise	1.70	58,800	2.10	170,965

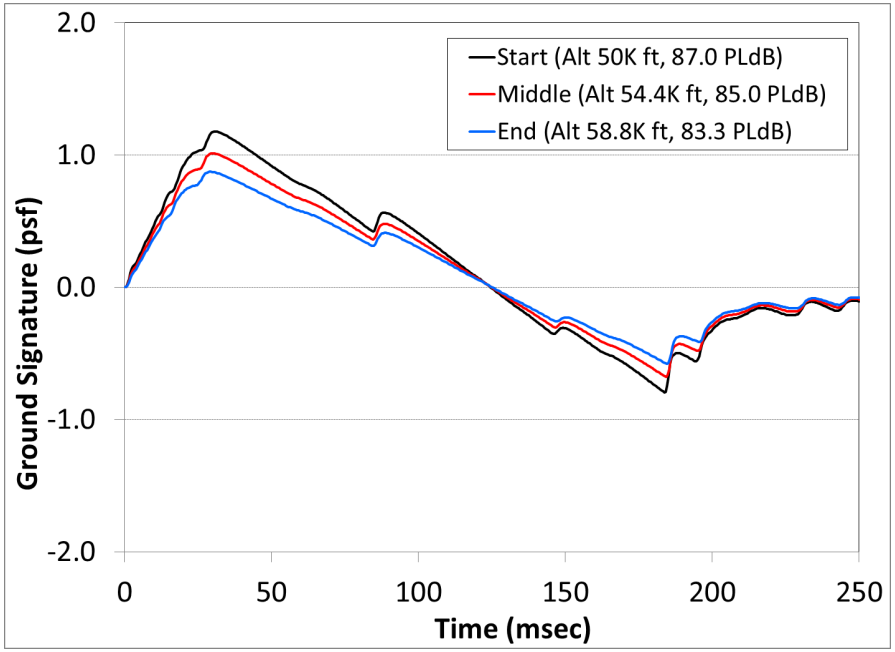


Source: LM N+2 Supersonic Validations & Verifications Phase II Final Review

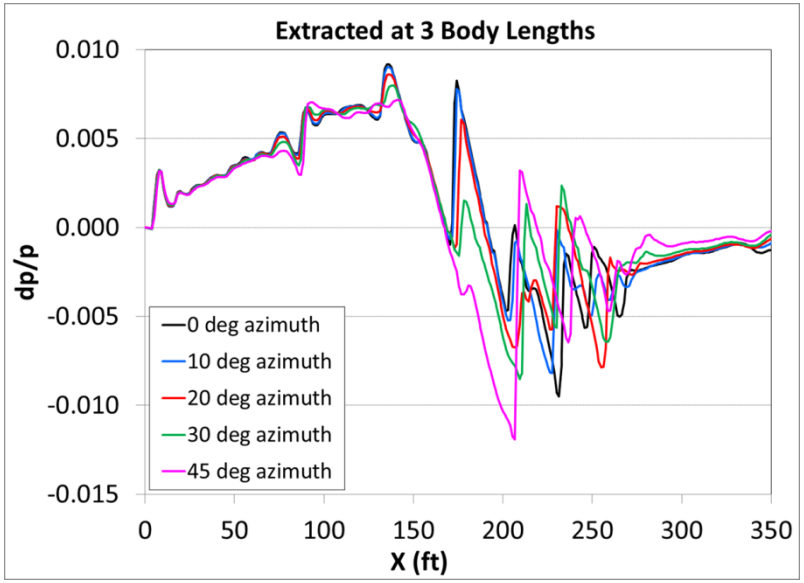
Sonic Boom Analysis of Cruise Segment

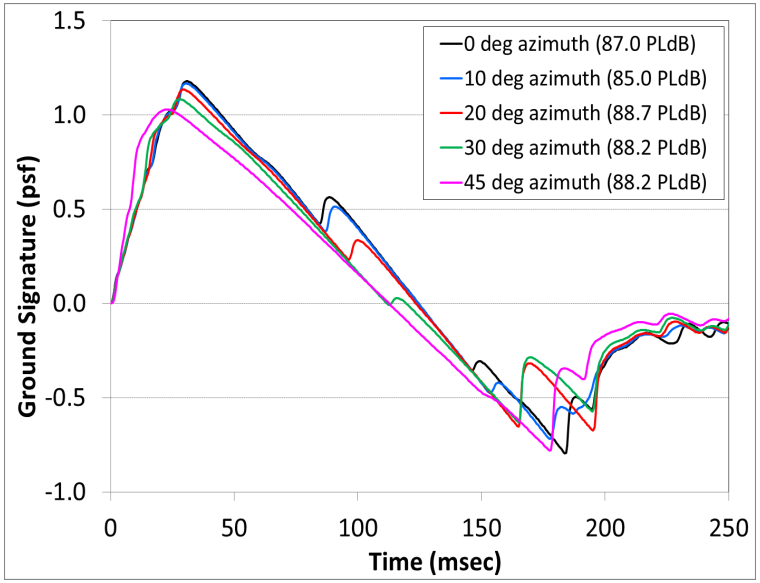
- Basic effect on sonic boom for a climbing cruise is propagation distance
- 4000 nmi range; 9k ft altitude change with a 90K lb reduction in cruise weight
- Moderate reduction during long climbing cruise
- Similar sensitivity for constant altitude cruise segments where C_L is changing?

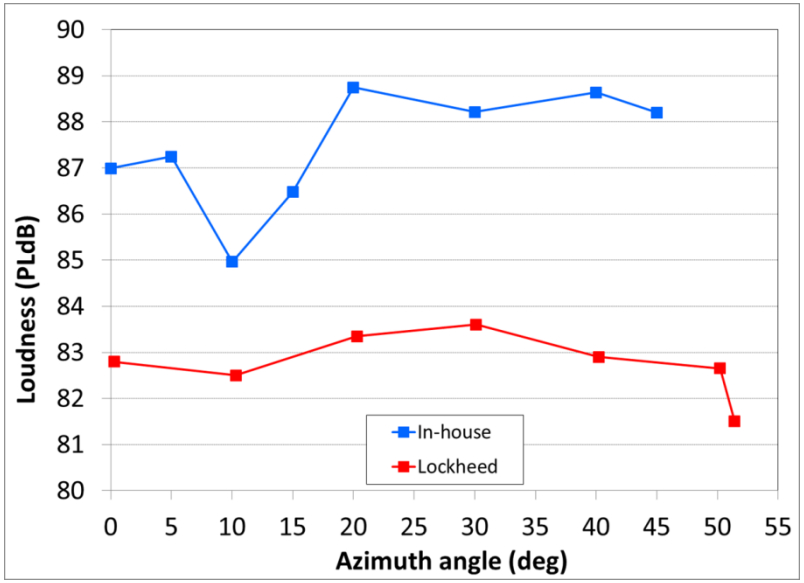


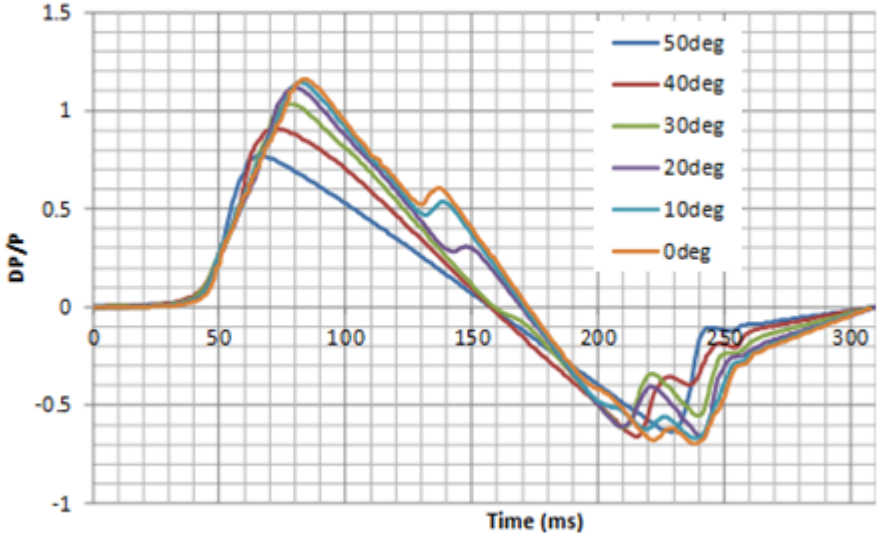


Sonic Boom Analysis at Start of Cruise



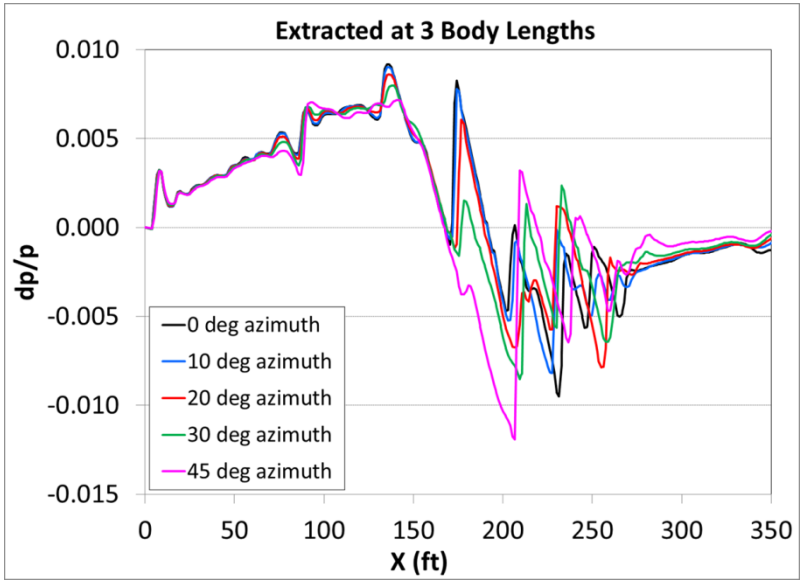


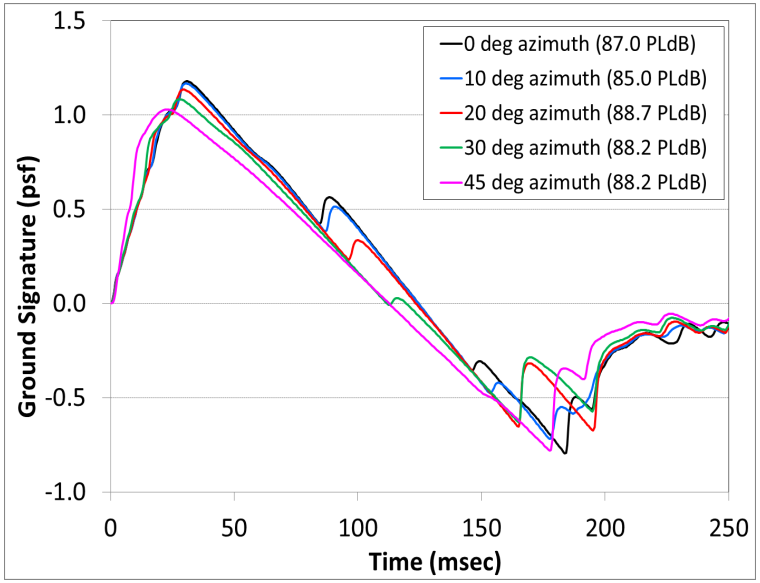


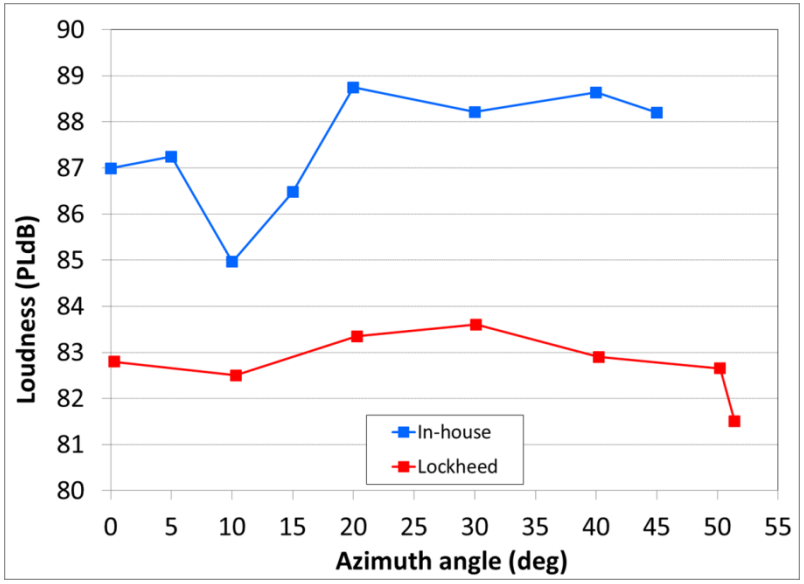


Source: LM N+2 Supersonic Validations & Verifications Phase II Final Review

Sonic Boom Analysis at Start of Cruise



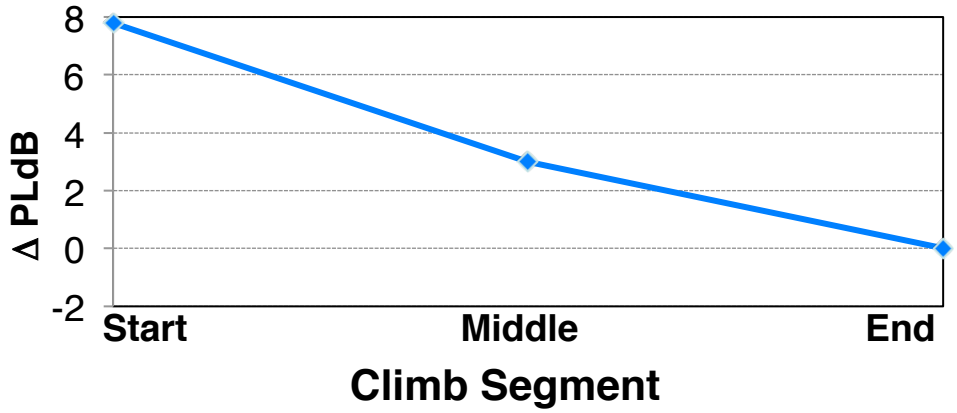


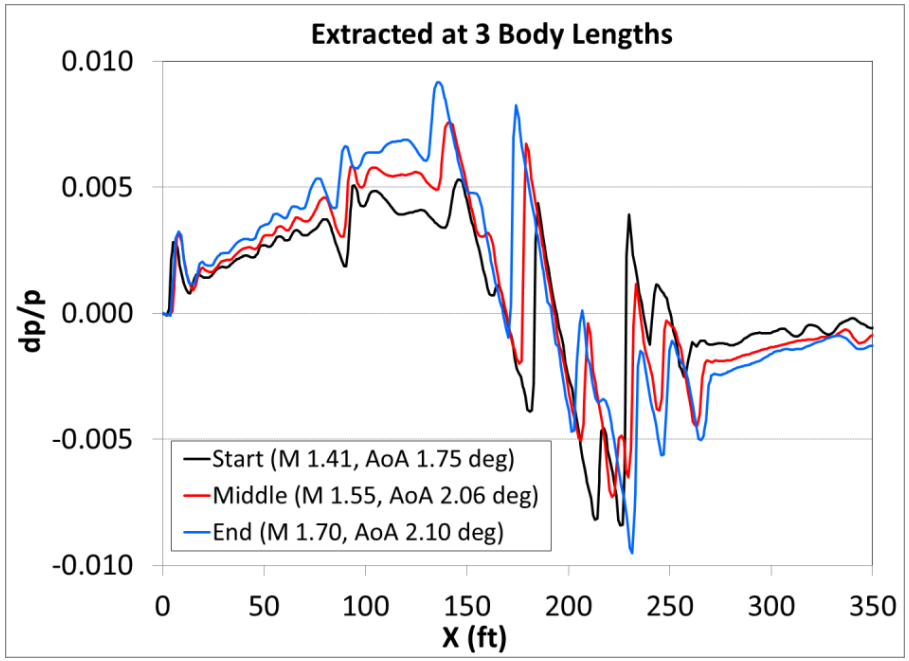


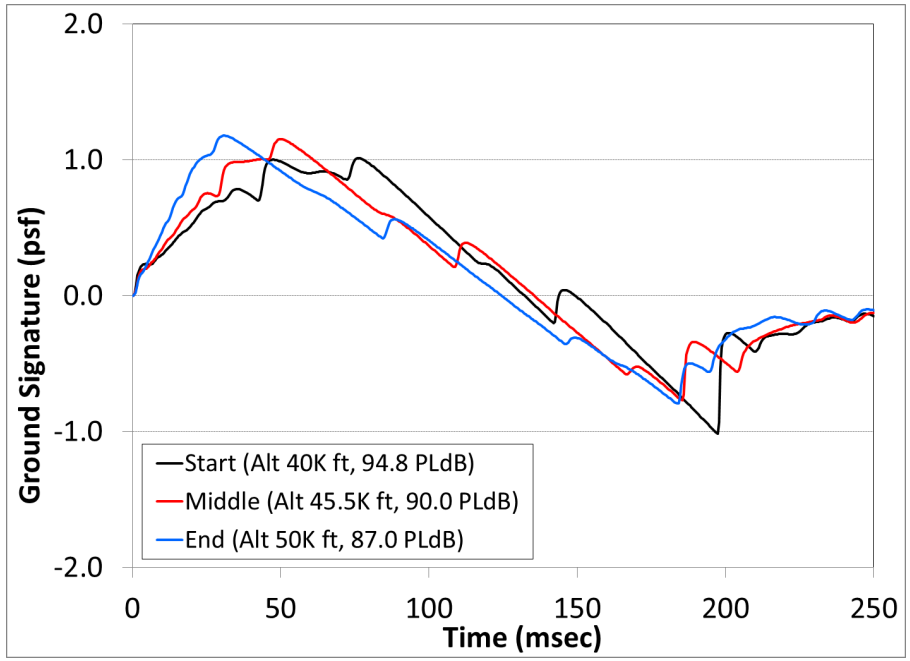
- Sensitivity to sonic boom levels off-track are very configuration specific

Sonic Boom Analysis of Climb Segment

- Significant impact on sonic boom levels during climb
- Climb angle not included
- Acceleration not included
  - ➢ Both can have an even greater impact on sonic boom level and boom focusing

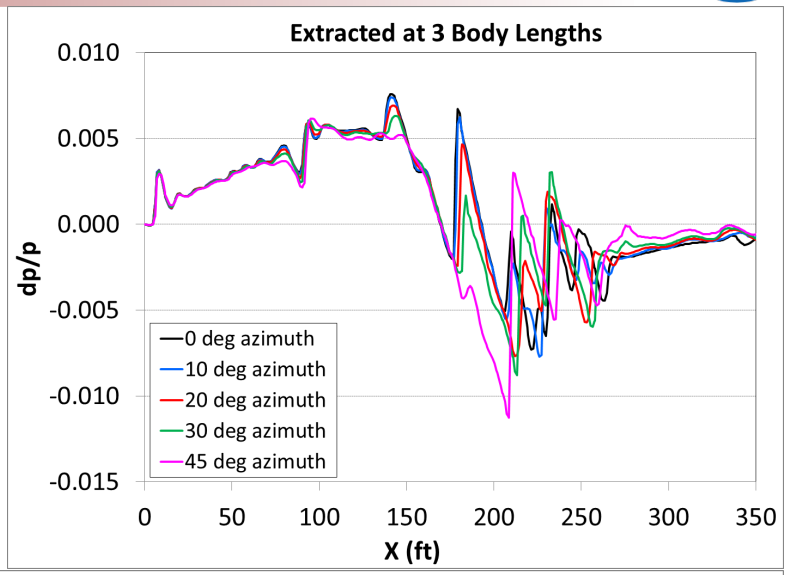


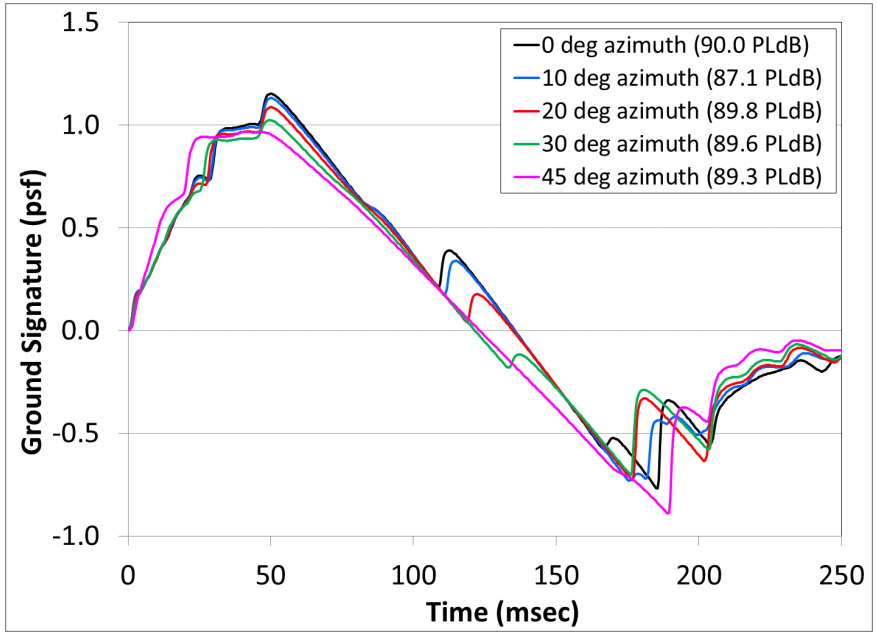


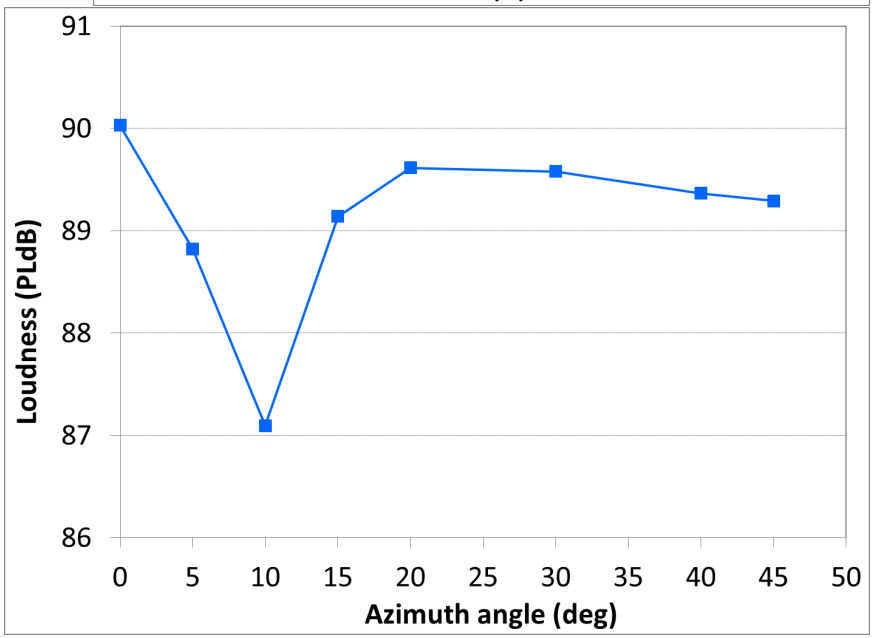


Sonic Boom Analysis at Mid-Climb

- Mid-climb conditions:
  - Mach 1.55
  - Angle of attack 2.06 deg
  - Altitude 45.5K ft
- Sonic boom levels typically drop off as you move off track
- Again off-track sensitivity is very configuration specific



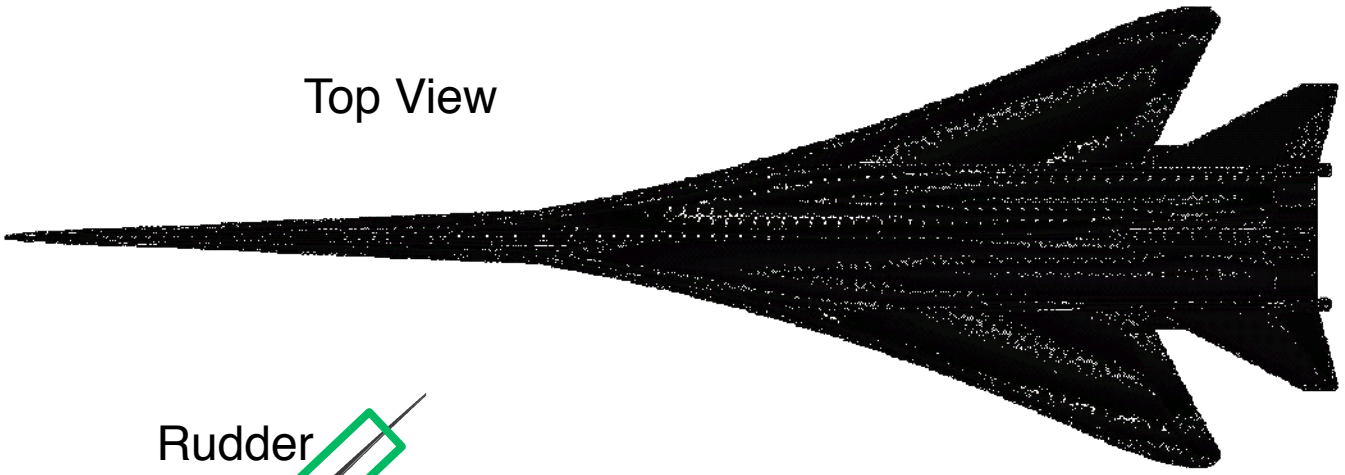


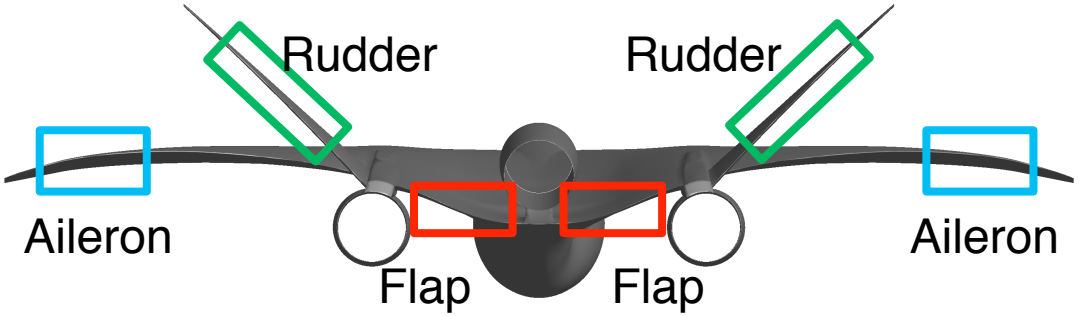


Control Surface Definition

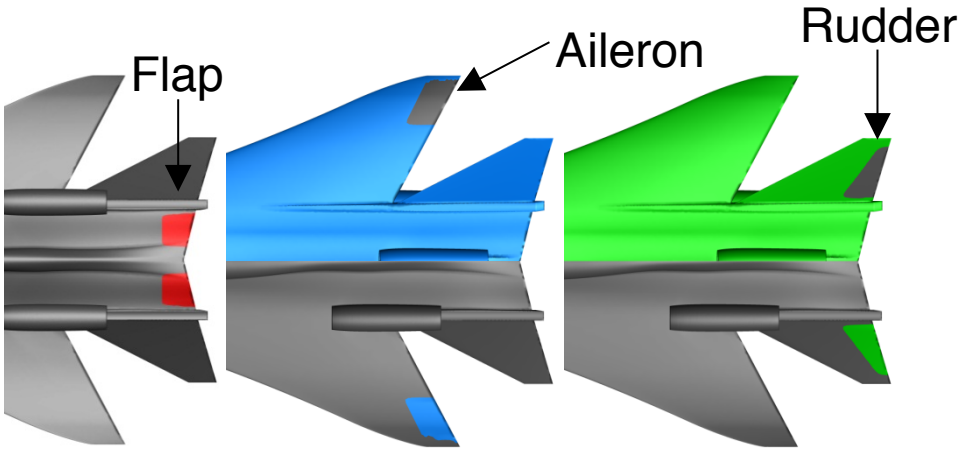
Base geometry
Pitch geometry
Roll geometry
Yaw geometry

Top View



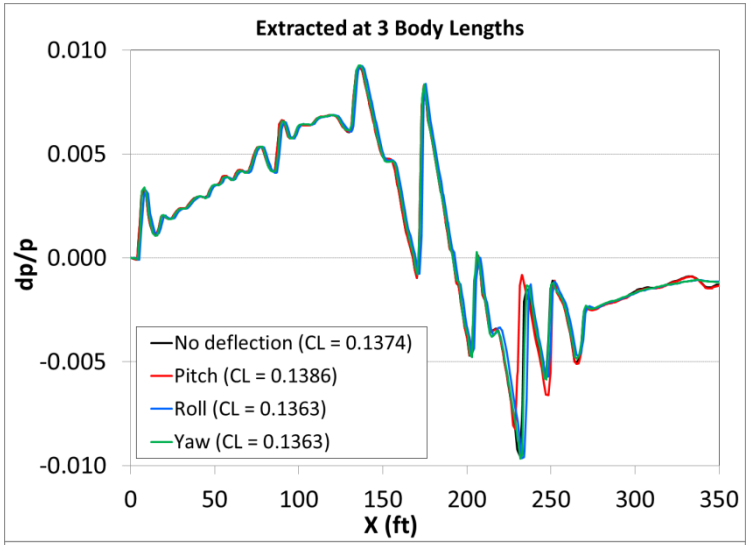


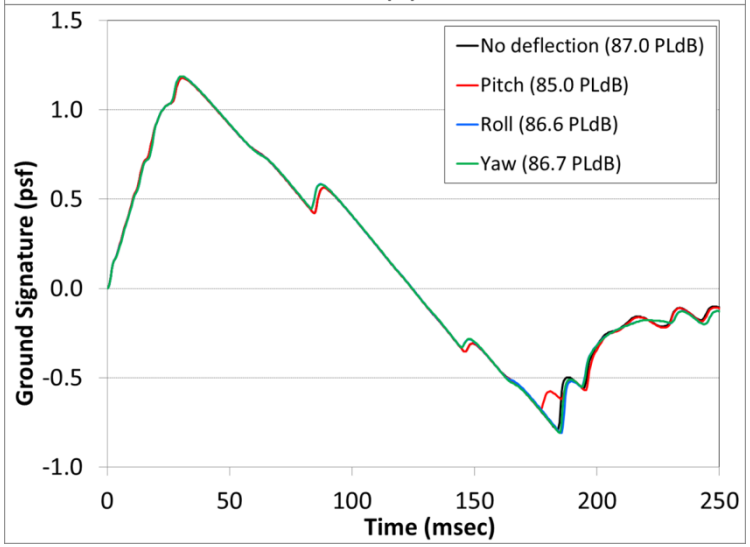
Rear View



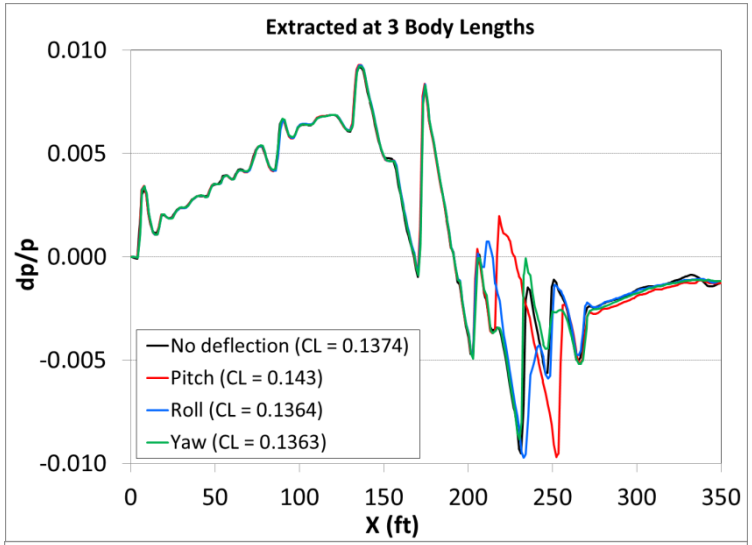
Sensitivity to Control Surface Deflections

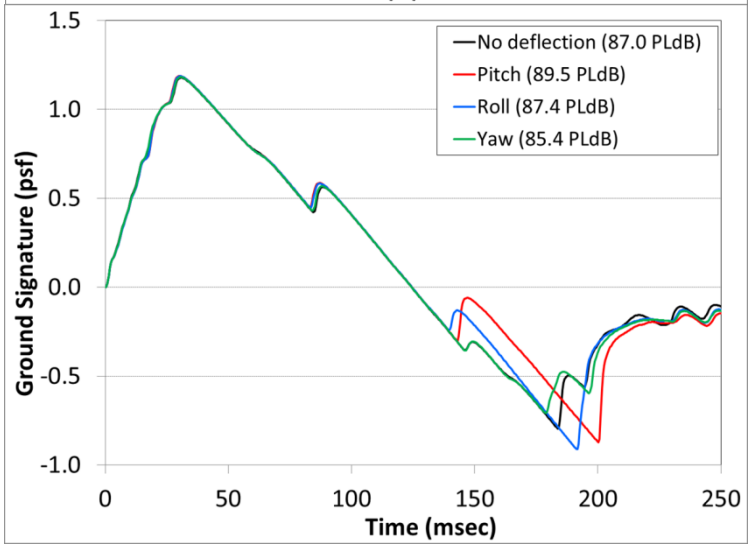
+1 deg deflection of control surface





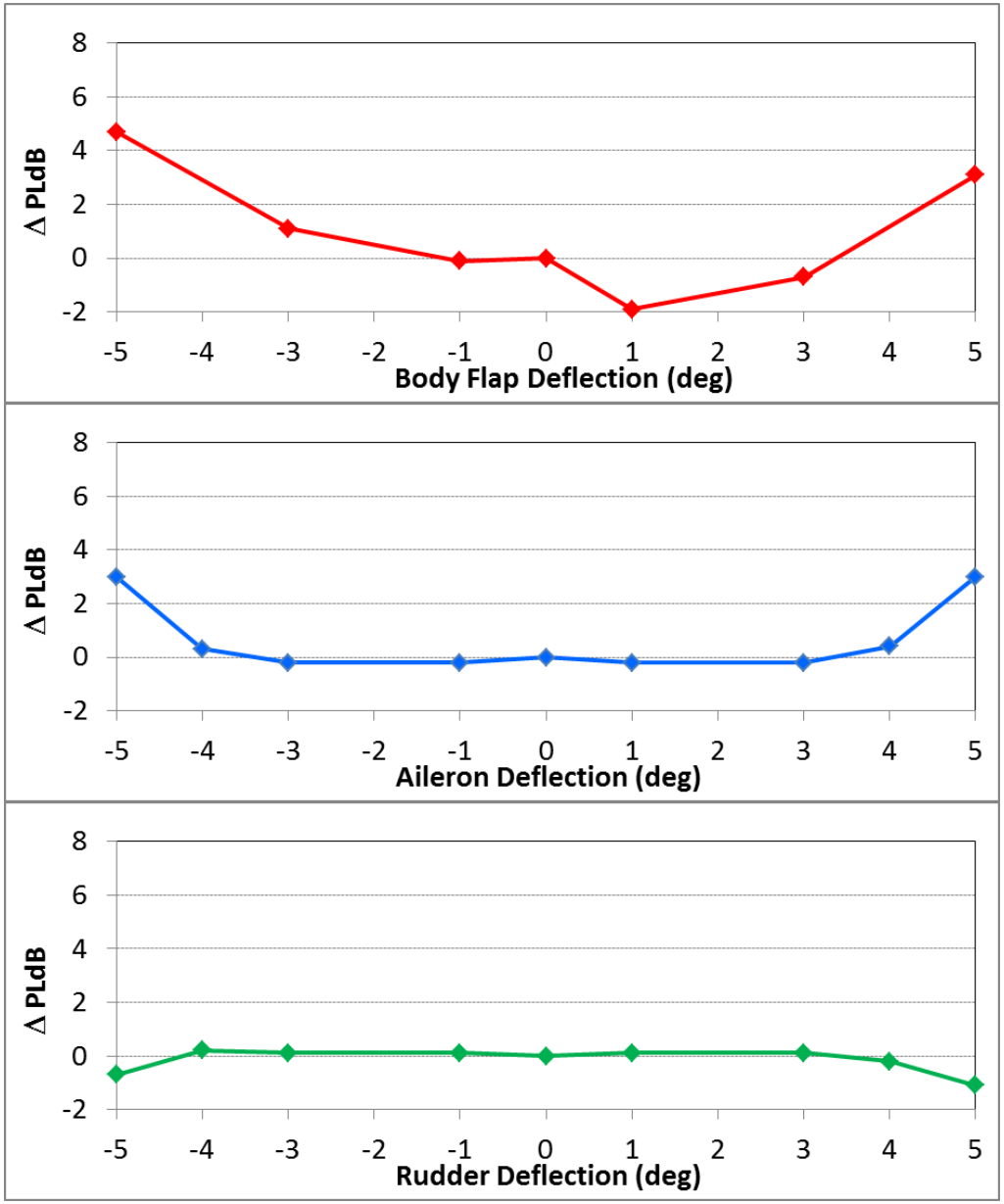
+5 deg deflection of control surface





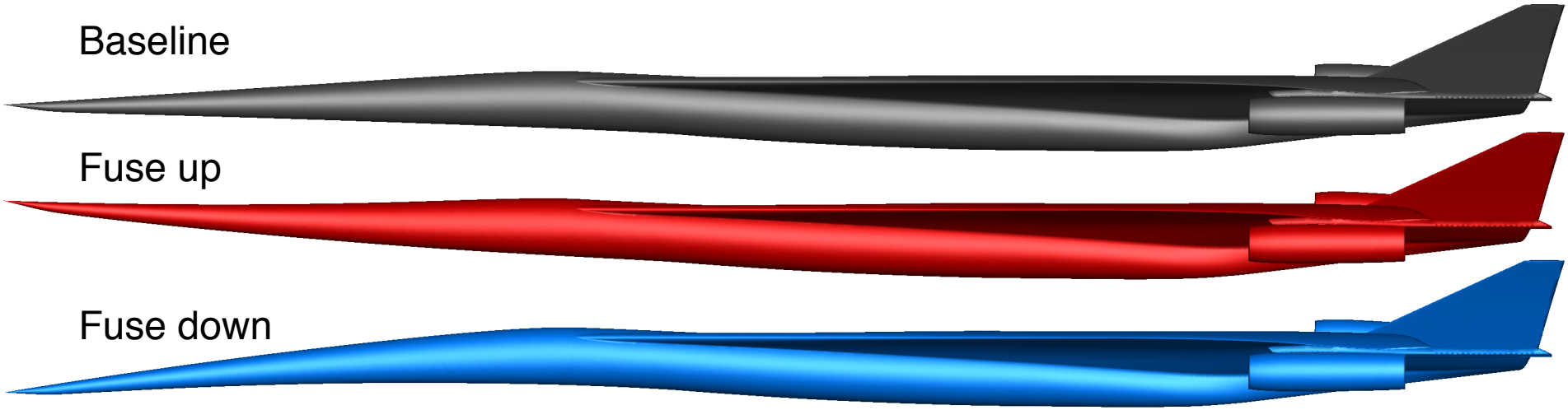
Sensitivity to Control Surface Deflections

- Start of cruise conditions
  - Mach = 1.70
  - AoA = 2.10 deg
  - Altitude = 50,000 ft
- Highest sensitivity due to pitch control
- Encouragingly low sensitivity to small aileron and rudder deflections
- Results are for under-track and the effect of aileron and rudder deflection may be more severe off-track



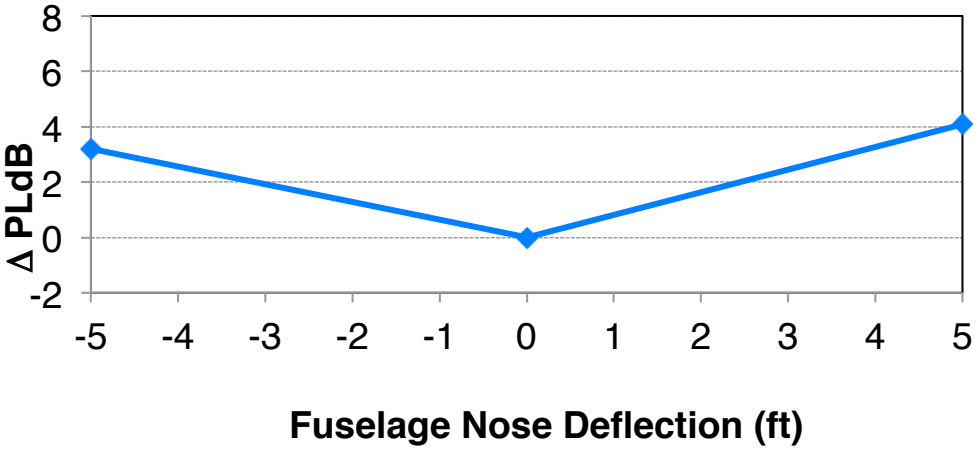
Fuselage Deflection

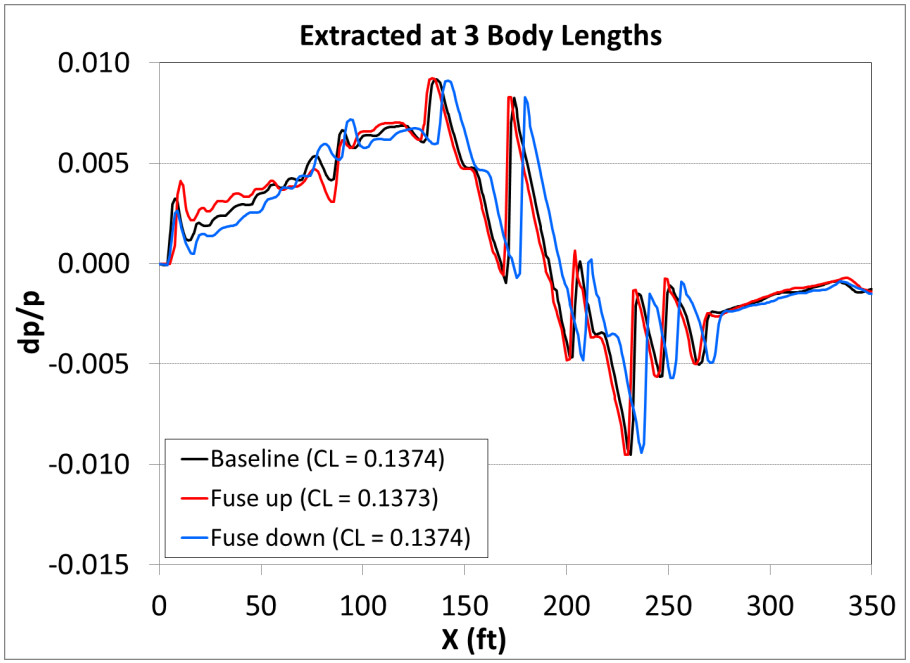
- Parabolic and shearing deformation
- Deformation starts fore of wing
- Magnitude of deformation is 5 ft at the nose (244 ft overall length)
- Deformation is **arbitrary** and not based on structural analysis

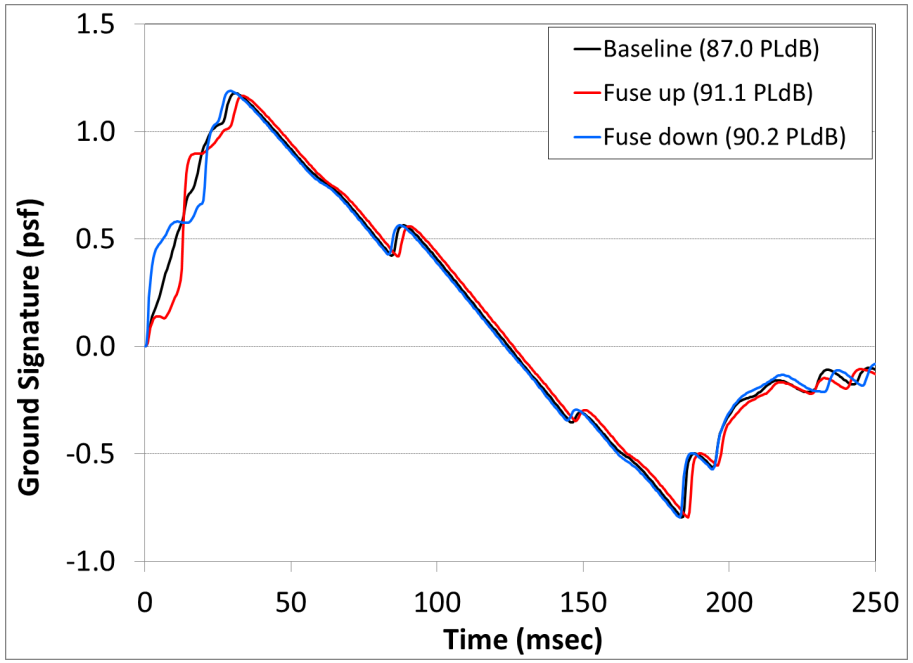


Sensitivity to Fuselage Deflection

- Start of cruise conditions
- Primary impact on fore shocks
- Change seen in volume dominated portion of signature
- Little to no impact seen on lift dominant portion of signature
- Results are for under-track but should be similar for off-track

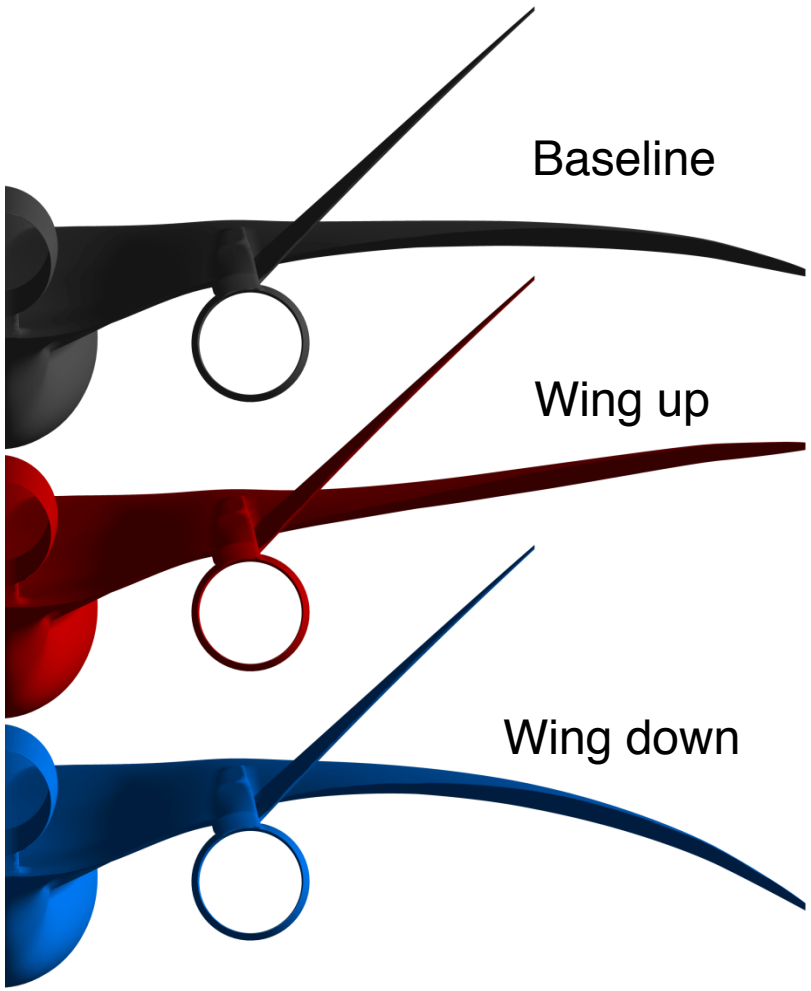






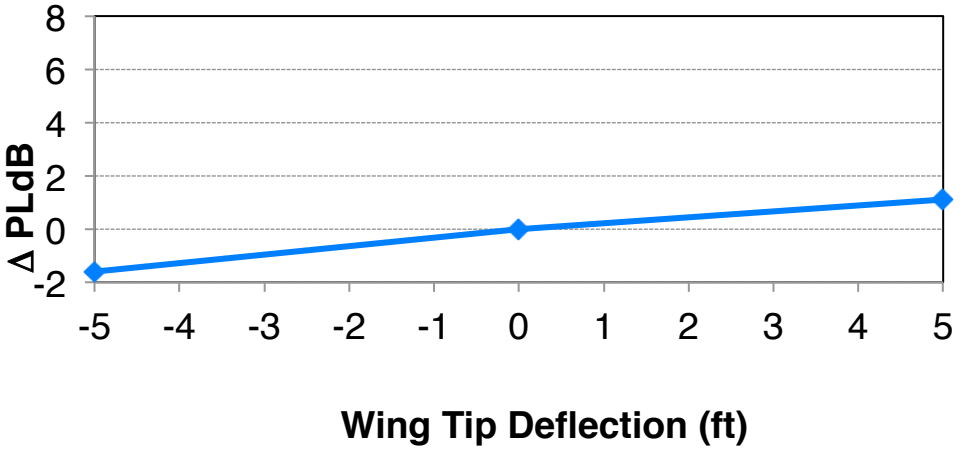
Wing Deflection

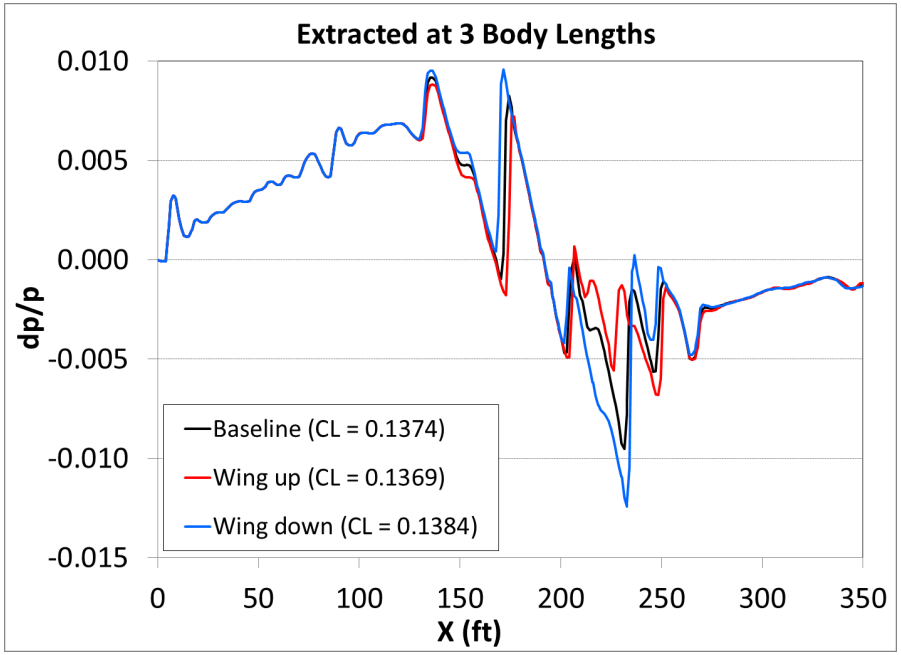
- Parabolic and shearing deformation
- Deformation starts just outboard of engine pylon
- Magnitude of deformation is -5 ft and +5 ft at the wing tip
- Deformation is **arbitrary** and not based on structural analysis
- Results computed for “disrupted” state (vehicle has not returned to steady state C_L or angle of attack)

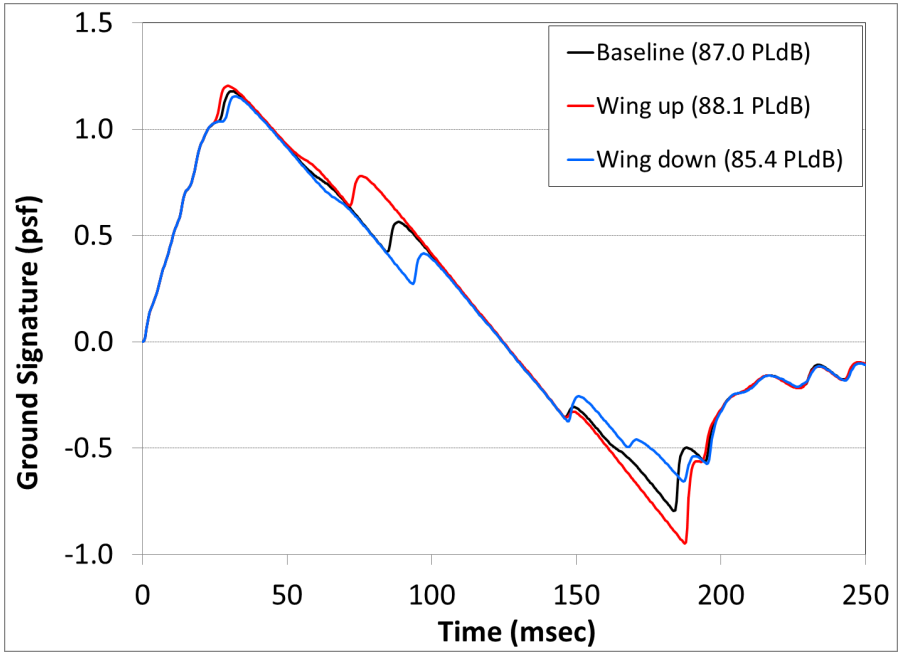


Sensitivity to Wing Deflection

- Start of cruise conditions
- Resulting “gulling” of wing due to wing tip deflecting down seems to have a beneficial impact
- Results are for under-track and the effect of wing deflection may be more severe off-track

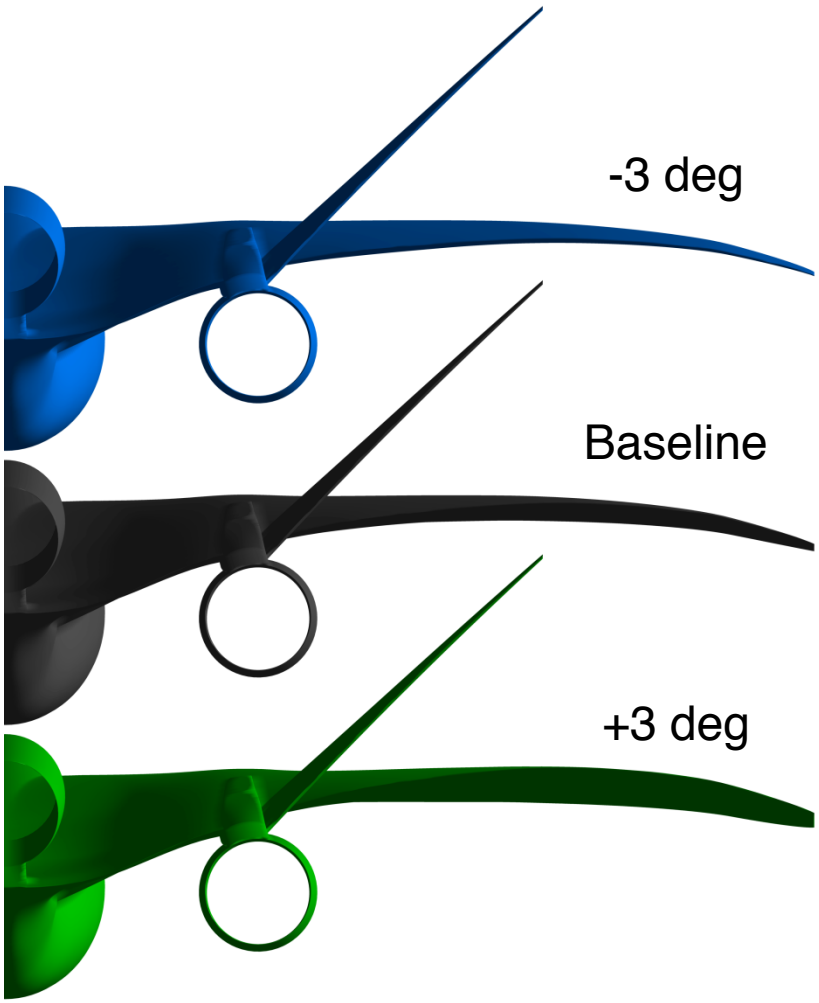






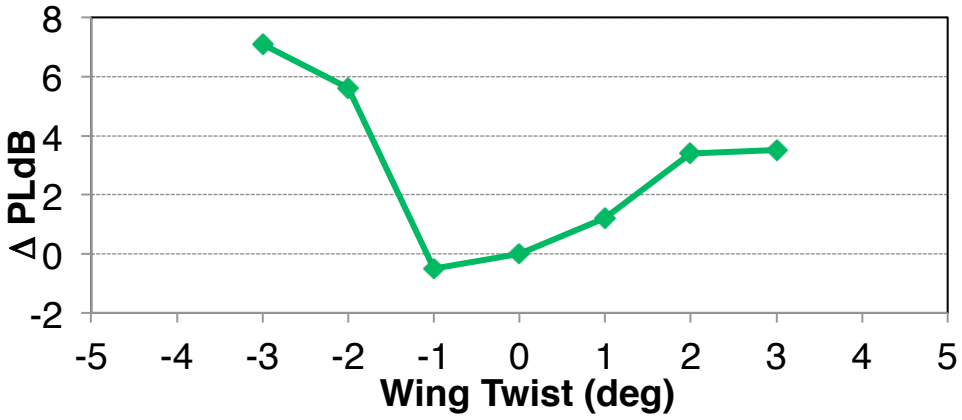
Wing Twist

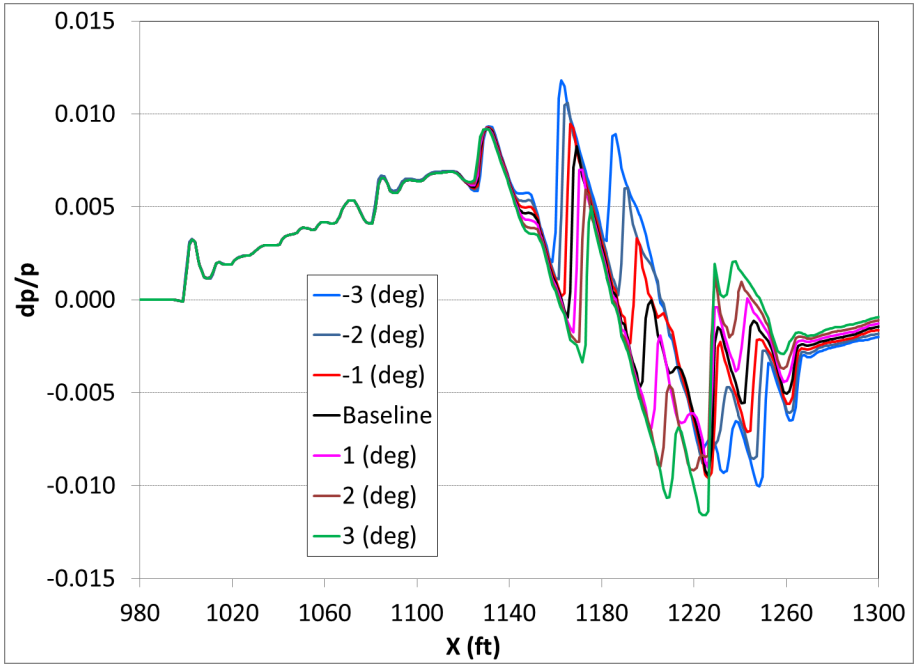
- Deformation starts just outboard of engine pylon
- Linear twist distribution
- Magnitude of deformation is -3 deg to +3 deg at the wing tip
- Deformation is **arbitrary** and not based on structural analysis
- Results computed for “disrupted” state (vehicle has not returned to steady state C_L or angle of attack)

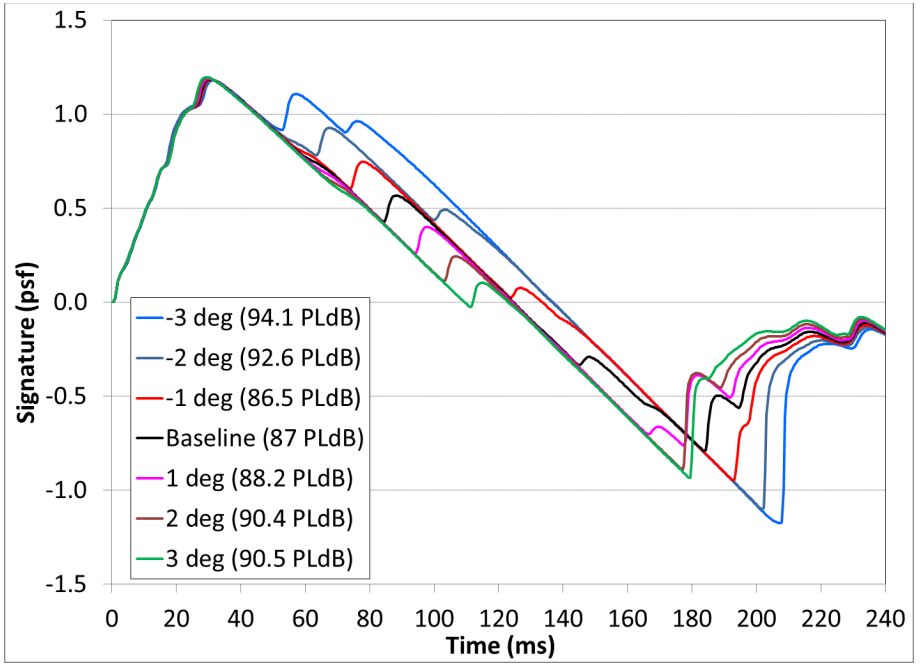


Sensitivity to Wing Twist

- Results show strong sensitivity to wing twist changes
- Greater sensitivity to negative changes in twist

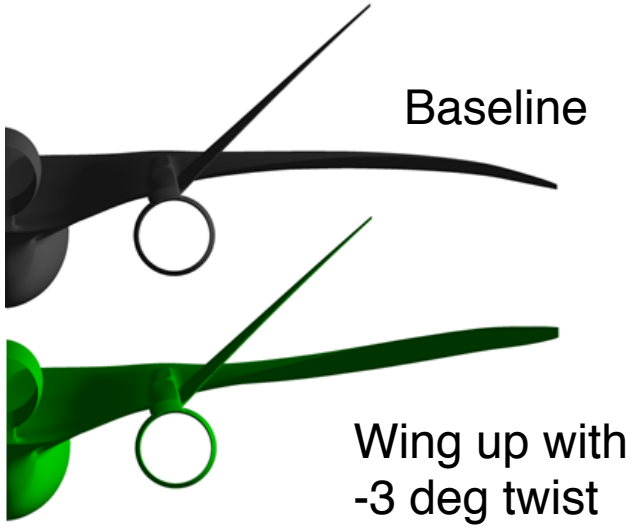


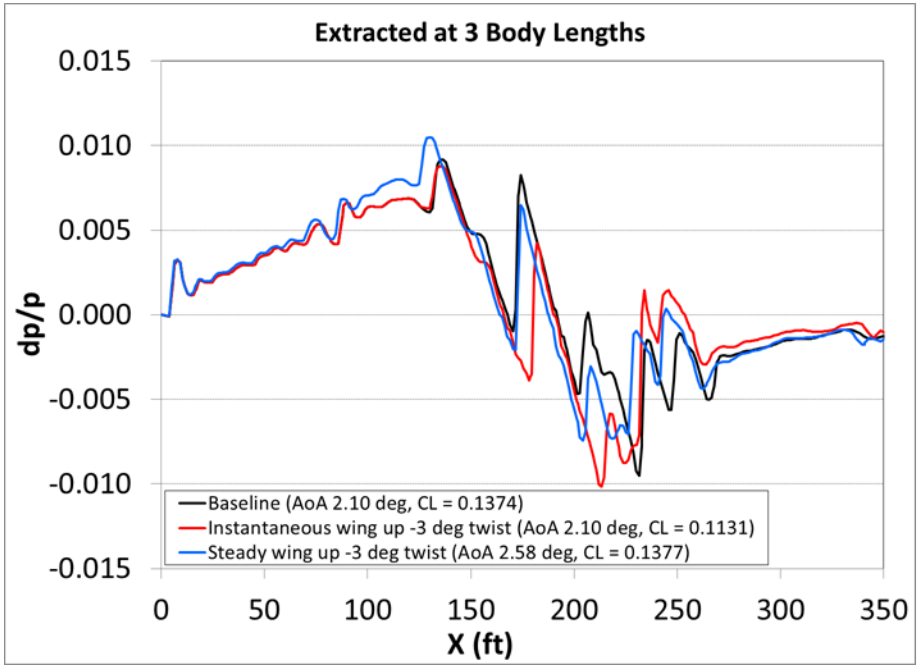


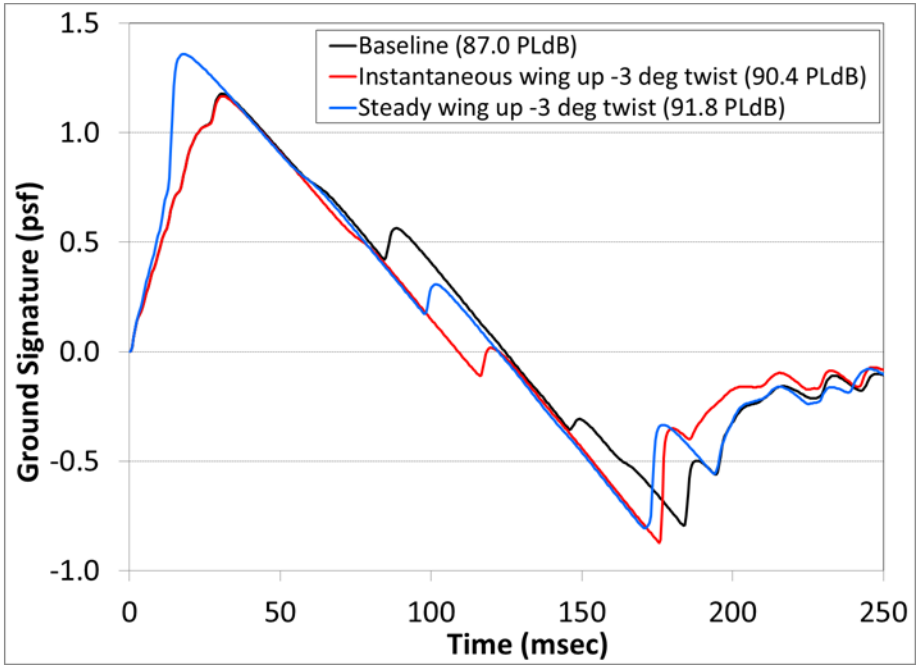


Steady Effects of Arbitrary Structural Deflections

- Combined deformation of deflection and twist
  - 5ft up; -3 deg twist
- Deformation is **arbitrary** and not based on structural analysis
- Steady means that the C_L is matched to pre-deflection condition by varying AoA



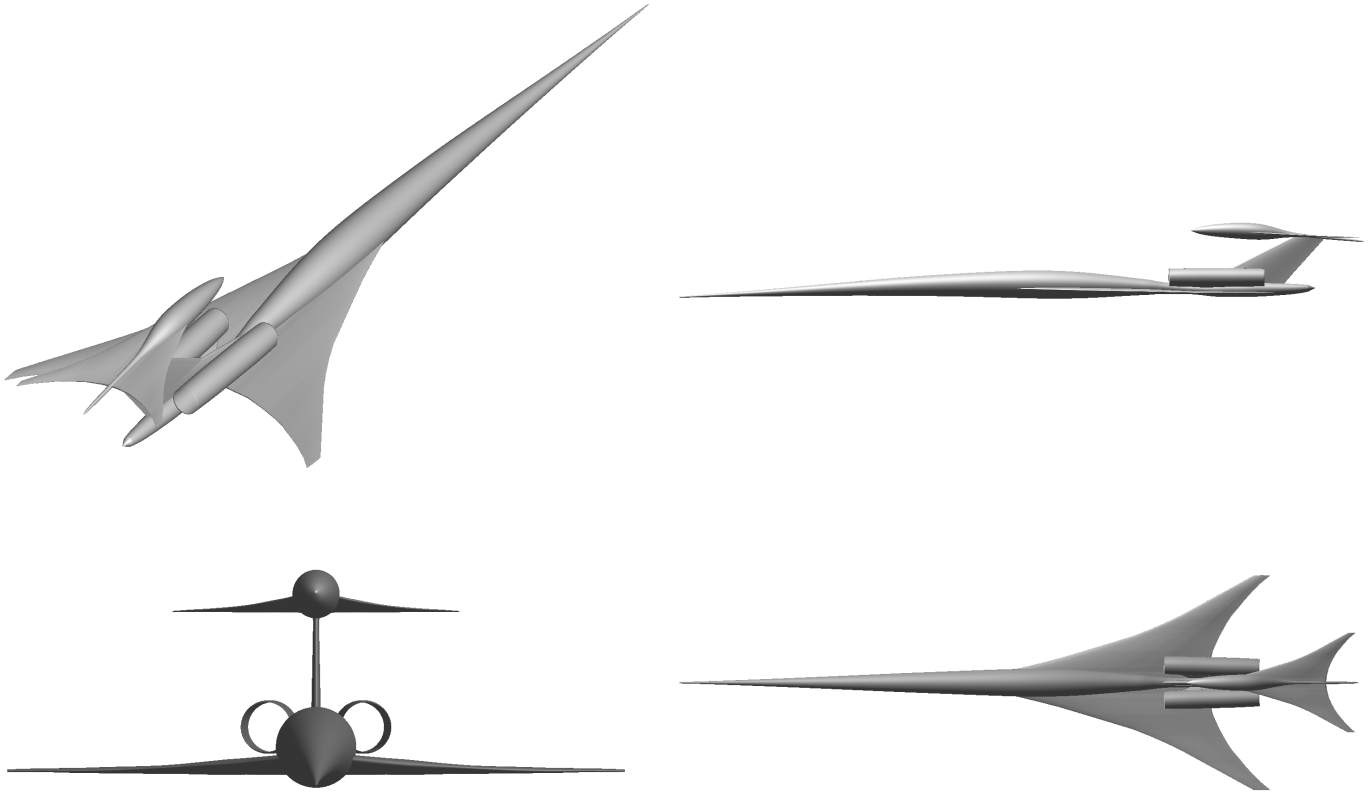




Analysis of a NASA Low-Boom Demonstrator Concept

NASA Low-Boom Demonstrator

- Published for the 29th AIAA Applied Aerodynamics Conference by Wu Li and Sriram Rallabhandi (AIAA 2011-3498)
- Flow-through nacelles
- Reference area: 688 ft2
- Body length: 127 ft
- Wing span: 39 ft



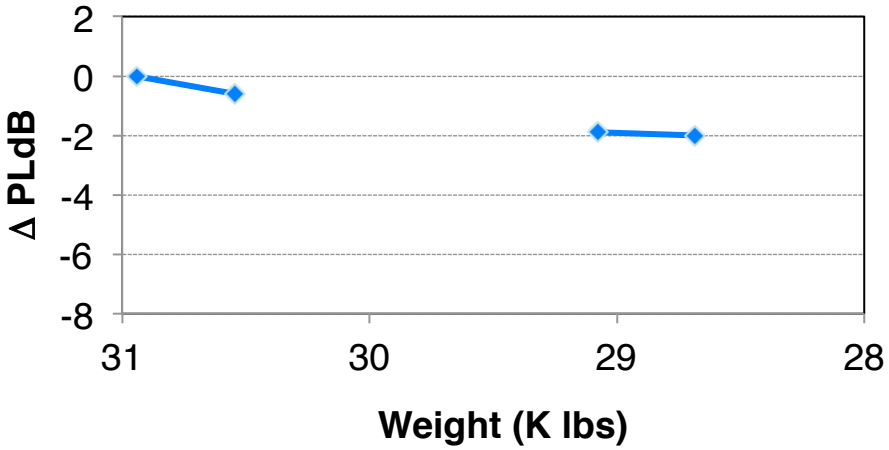
Mission Analysis

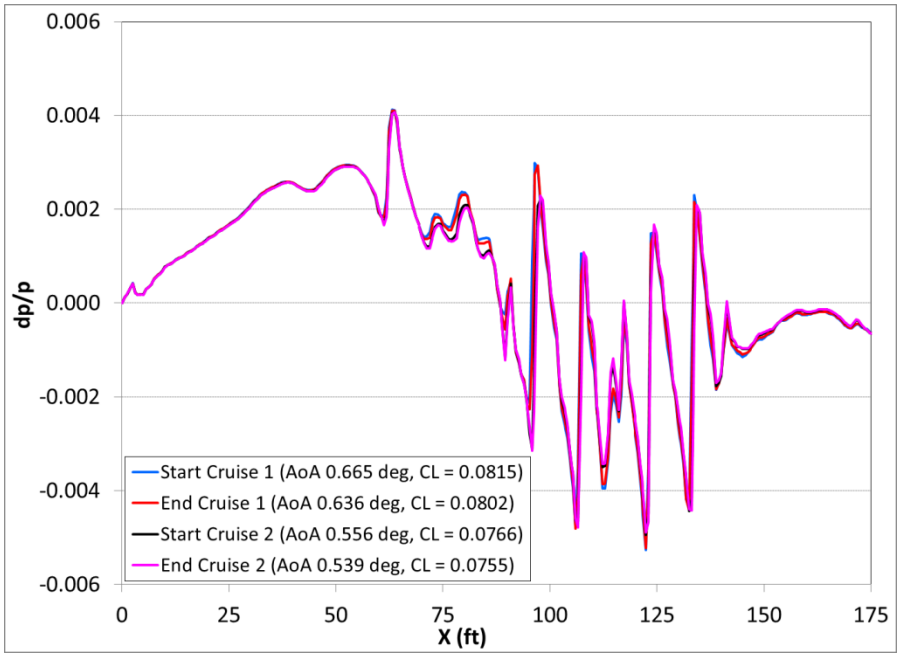
- Demonstrator-type mission

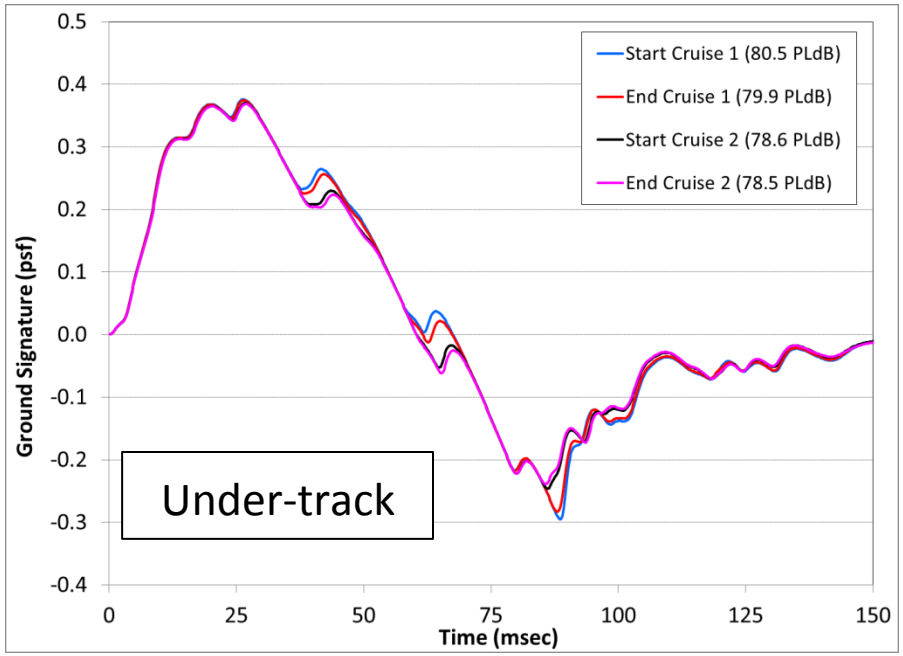
Case	Mach	Altitude (ft)	AoA (deg)	Weight (lbs)	Climb Angle (deg)	Climb Angle Rate (deg/sec)	dMach / dt (1/ sec)
Start of Climb	1.33	39,370	0.661	31,226	0.0725	1.7389	0.0143
“End” of Climb	1.55	43,759	0.656	30,996	7.7322	-0.1481	0.0065
Start of 1st Dash	1.60	45,000	0.665	30,940	0	0	0
End of 1st Dash	1.60	45,000	0.636	30,545	0	0	0
Start of 2nd Dash	1.60	45,000	0.556	29,076	0	0	0
End of 2nd Dash	1.60	45,000	0.539	28,686	0	0	0

Sonic Boom Analysis of Cruise Segment

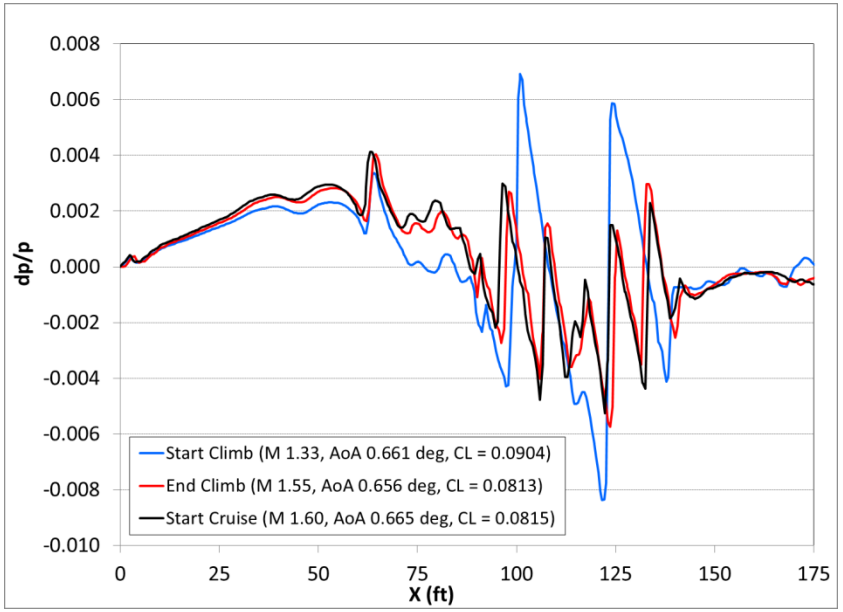
- Mach 1.60
- Altitude 45K ft
- Constant altitude cruise for demonstrator mission
  - ➢ C_L changing
- Small sonic boom level change over a short demonstrator dash mission (but important to consider for public response planning & testing)

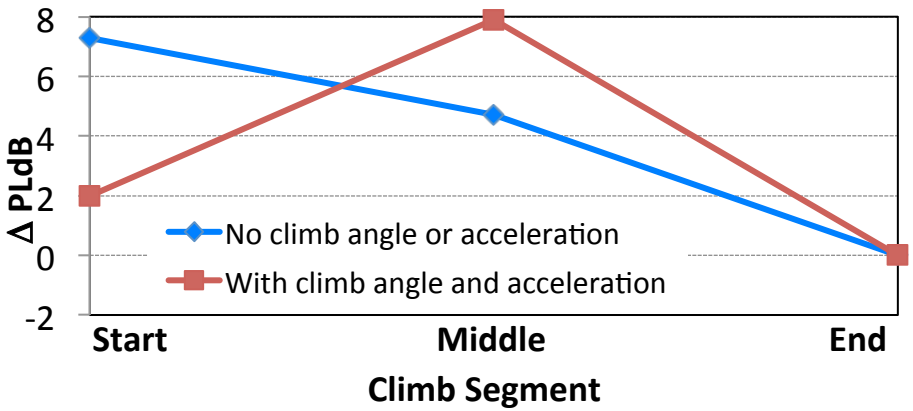


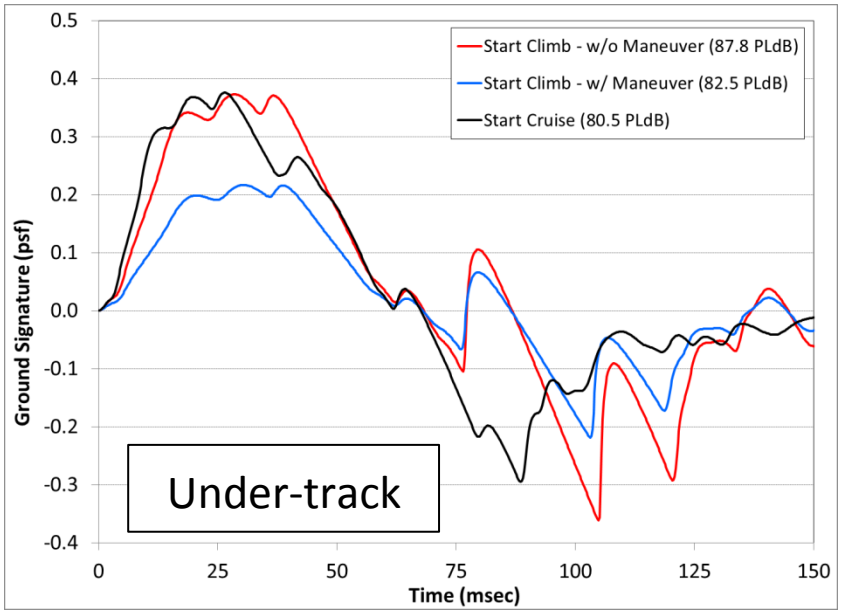


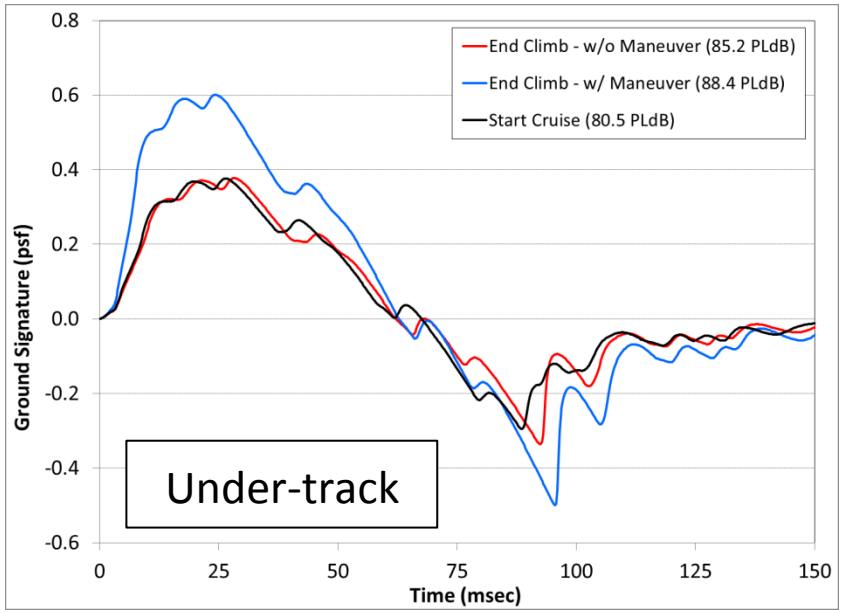


Sonic Boom Analysis Climb Segment









Summary

- Sonic boom much more sensitive to pitch control deflections than yaw and roll control deflections
- Sonic boom can be significantly impacted by transient changes to steady state cruise
- Structural/Aeroelastic deflections can have a moderate impact on sonic boom
  - Important to fully characterize fuselage and wing shape in cruise flight
  - Important to fully understand dynamic impacts on boom
- Acceleration and climb angle can have significant effects on signature
  - Further studies are required to better understand climb requirements (post focus) for sonic boom