NASA Environmentally Responsible Aviation Hybrid Wing Body Flow-Through Nacelle Wind Tunnel CFD

Michael J. Schuh and Joseph A. Garcia
NASA Ames Research Center

Melissa B. Carter and Karen A. Deere
NASA Langley Research Center

Daniel M. Tompkins
Boeing Research & Technology

Paul M. Stremel
Science and Technology Corporation

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Outline

- Motivation
- Geometry
- Overview of simulations
- Four CFD codes
- Simulation results for five different configurations
- Summary & Conclusions

Motivation

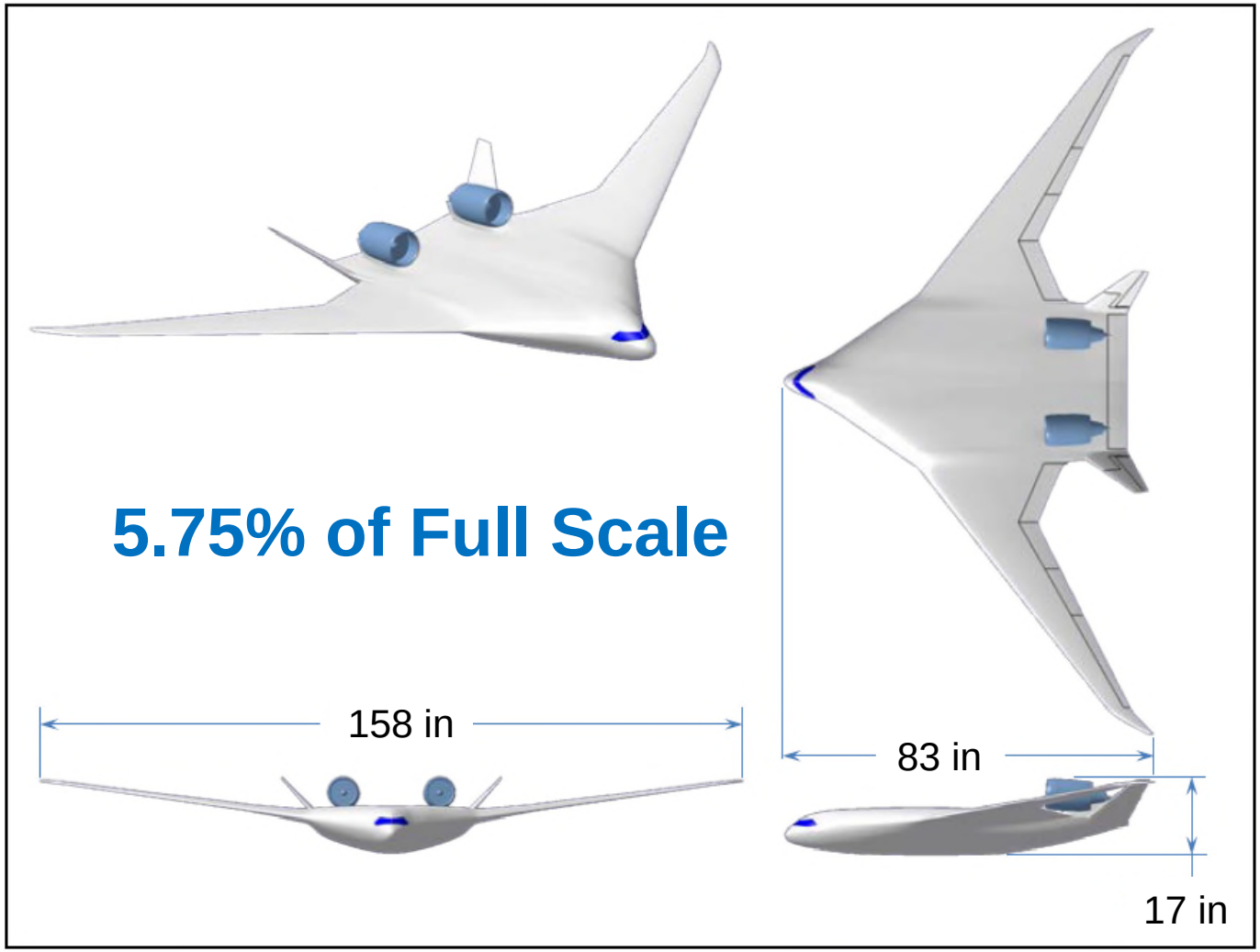
Why were we running CFD?

- Support pretest configuration changes and wind tunnel model design
- Quantify installation effects
- Guide post test data corrections
- Extrapolate from wind tunnel to free flight

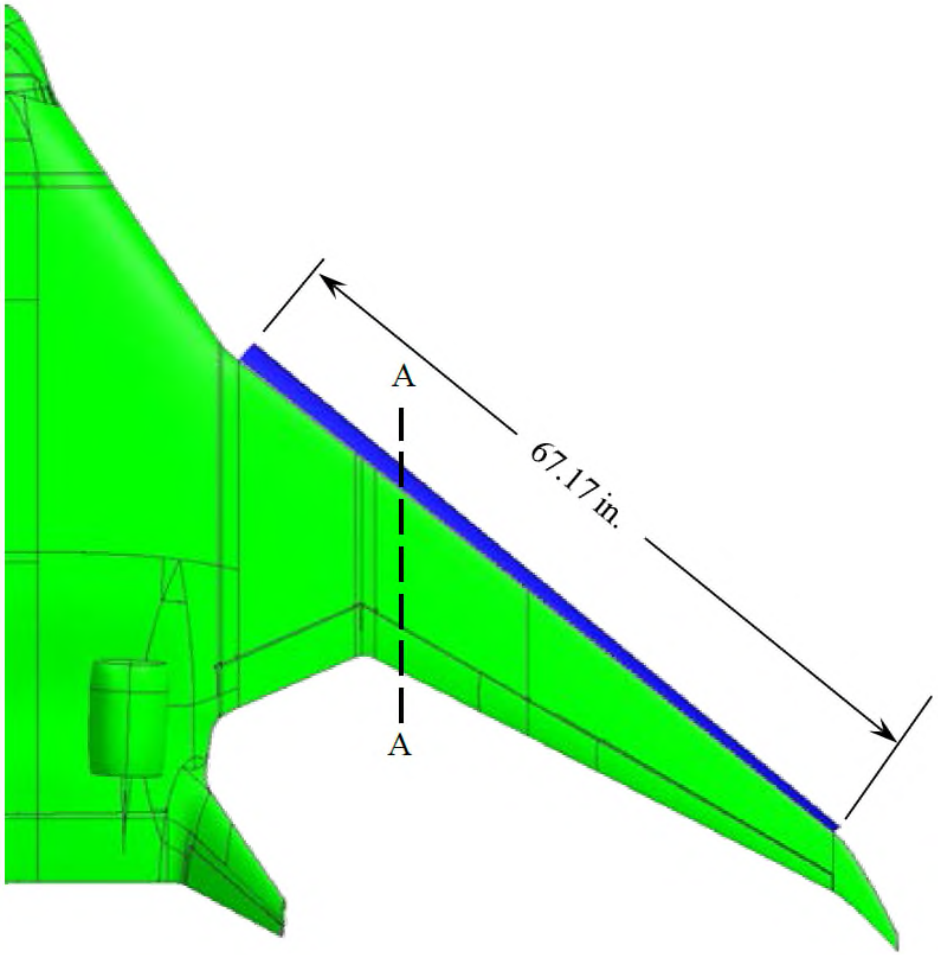
Why multiple codes?

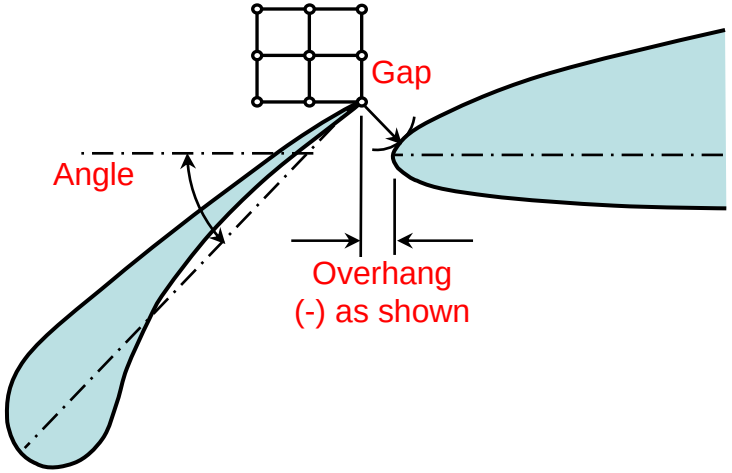
- Increased confidence in CFD predictions – especially before the availability of wind tunnel data
- Different people running different CFD codes often results in better and higher confidence results
- Opportunity for CFD modelers to learn from each other

HWB Test Model – Cruise Configuration

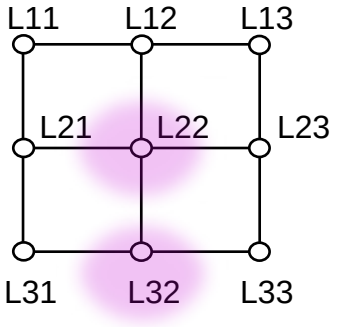


Baseline and Acoustic Krueger

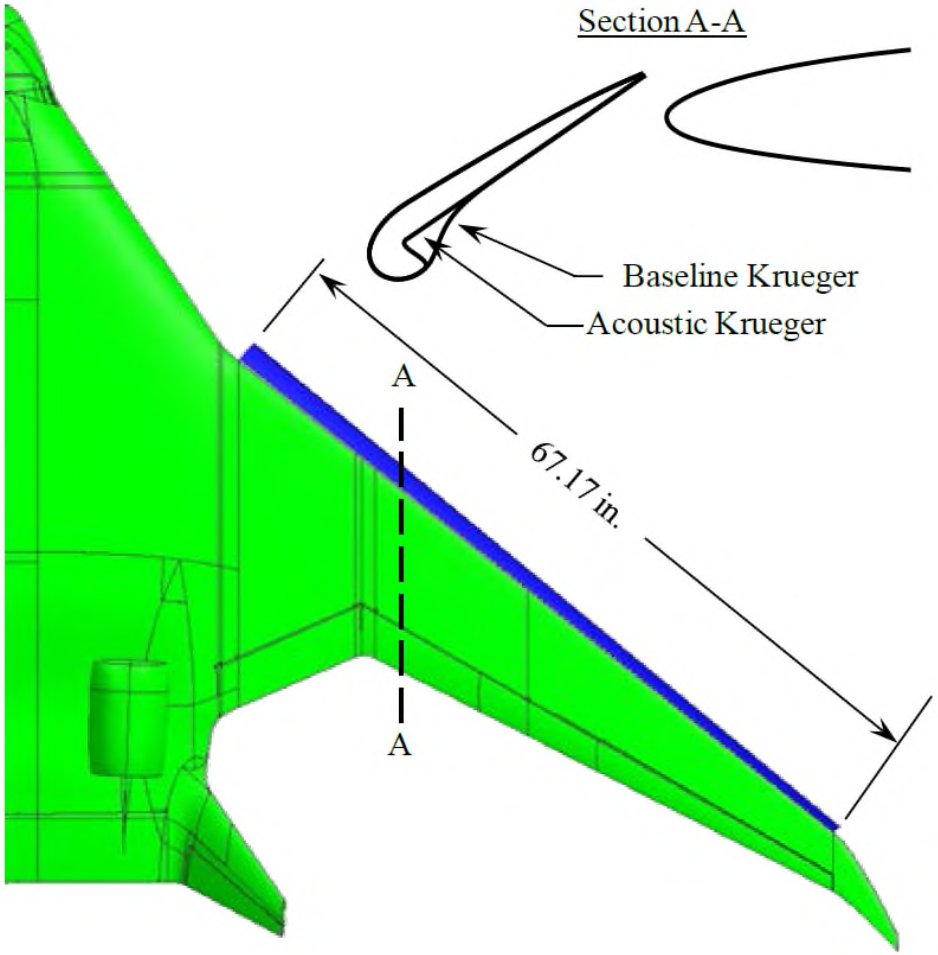


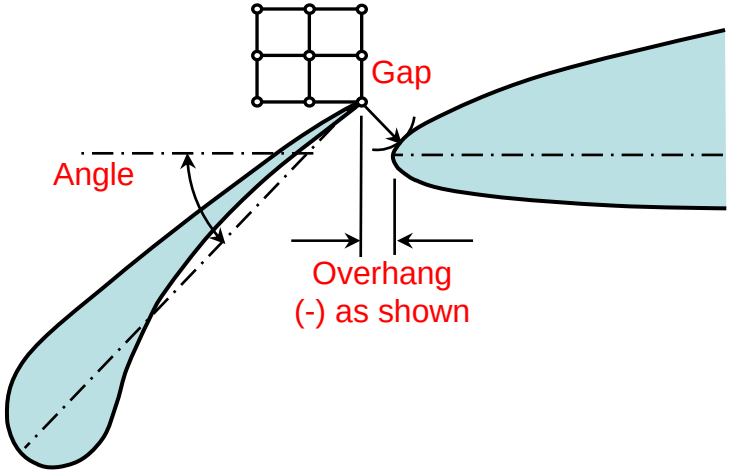


Landing Krueger grid positions are a 3x3 matrix



Baseline and Acoustic Krueger





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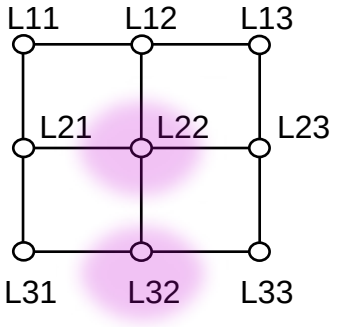
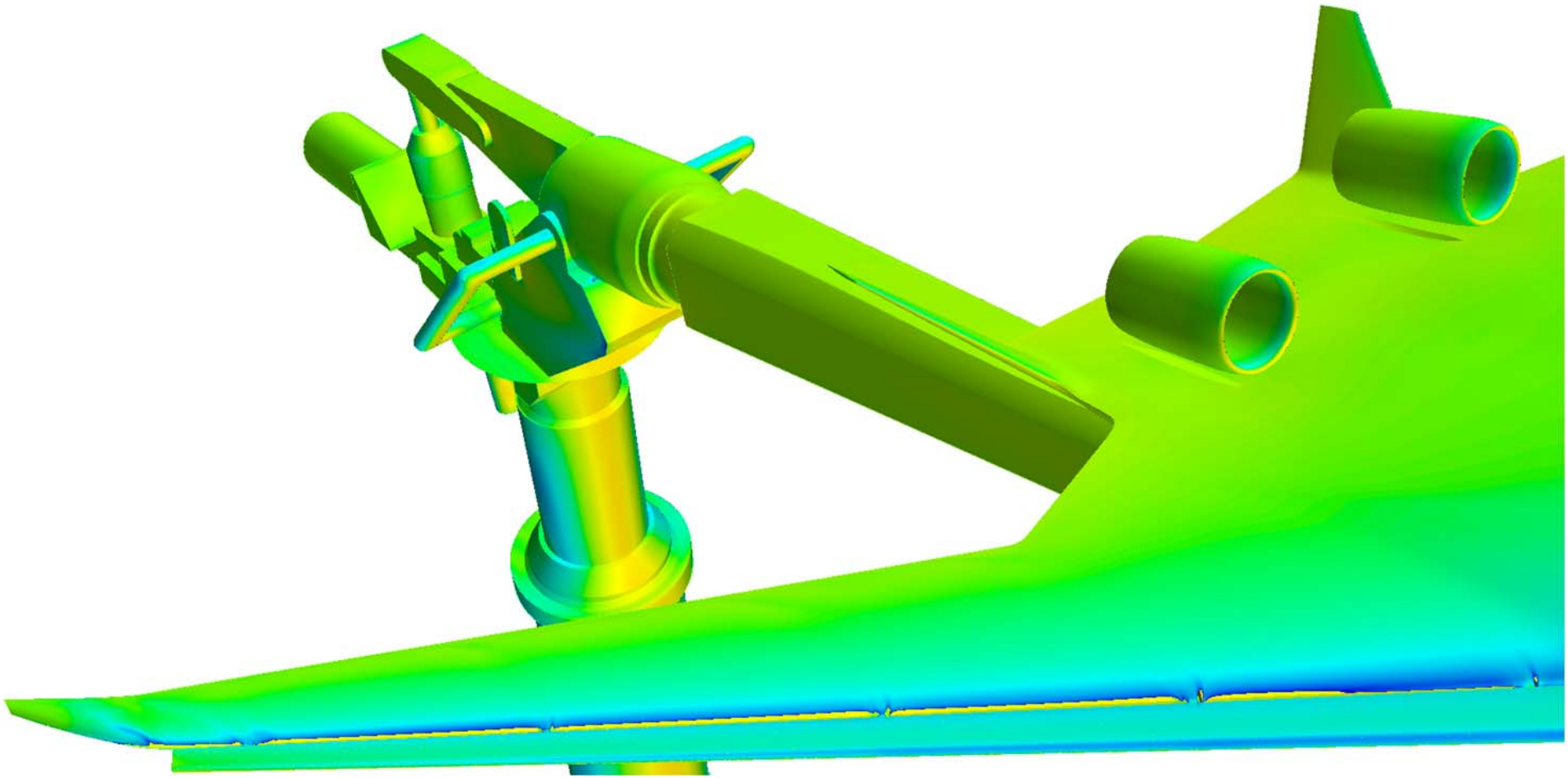
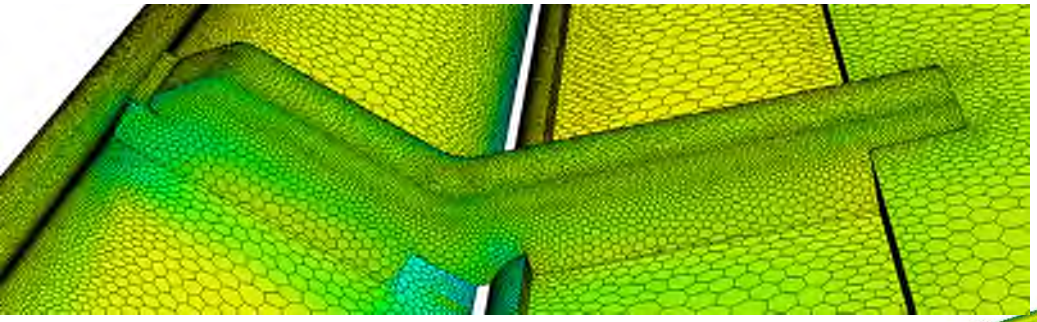


Top View of Krueger Brackets



Bottom View of Krueger Brackets



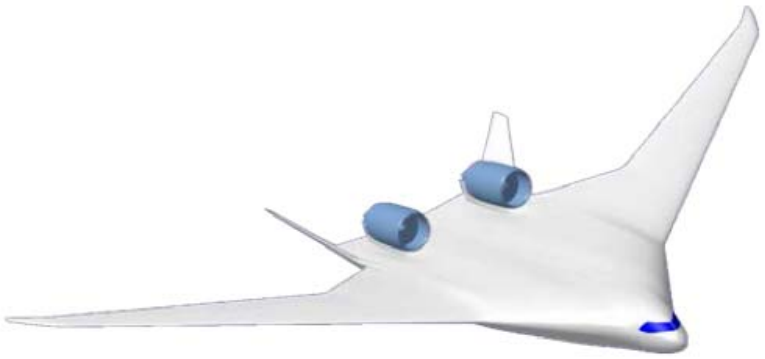
Center Bracket

Model has 5 wind tunnel Krueger brackets.
Flight vehicle would have smaller and 20+ Krueger brackets.

CFD Configurations

Cruise

- Free Air

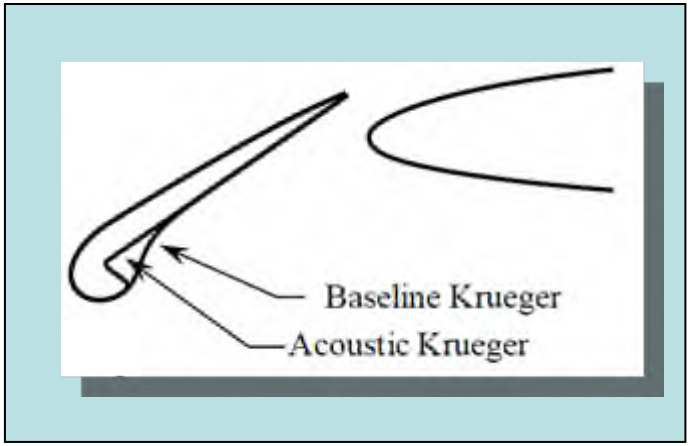


Baseline Krueger no brackets

- Free Air
- 14’x22’ Wind Tunnel

Acoustic Krueger w/brackets

- Free Air
- 40’x80’ Wind Tunnel



All results are for Freestream Mach = 0.2

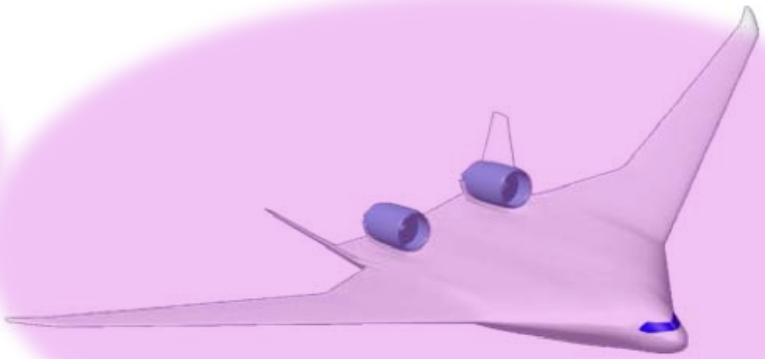
CFD Codes

- USM3D 
  - Used by NASA LaRC, NASA LaRC developed
  - Tetrahedral cell meshes
- CFD++ 
  - Used by Boeing, COTS code
  - Triangular prisms, tetrahedrals, and pyramids meshes
- STAR-CCM+ 
  - Used by NASA ARC, COTS code
  - Polyhedral volume mesh with prism layer on surface
- OVERFLOW 
  - Used by NASA ARC, NASA LaRC developed with ARC origin
  - Overset structured meshes
- All Codes ran with y+ < 1. All but STAR-CCM+ used SA turbulence model, STAR-CCM+ was run with SST turbulence model.

CFD Configurations

Cruise

- Free Air



Baseline Krueger no brackets

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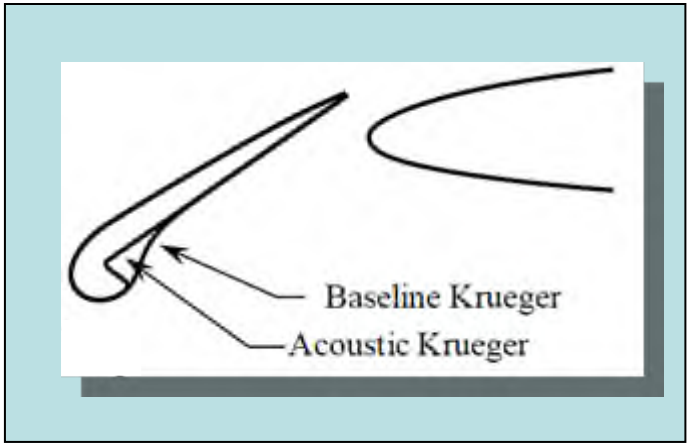
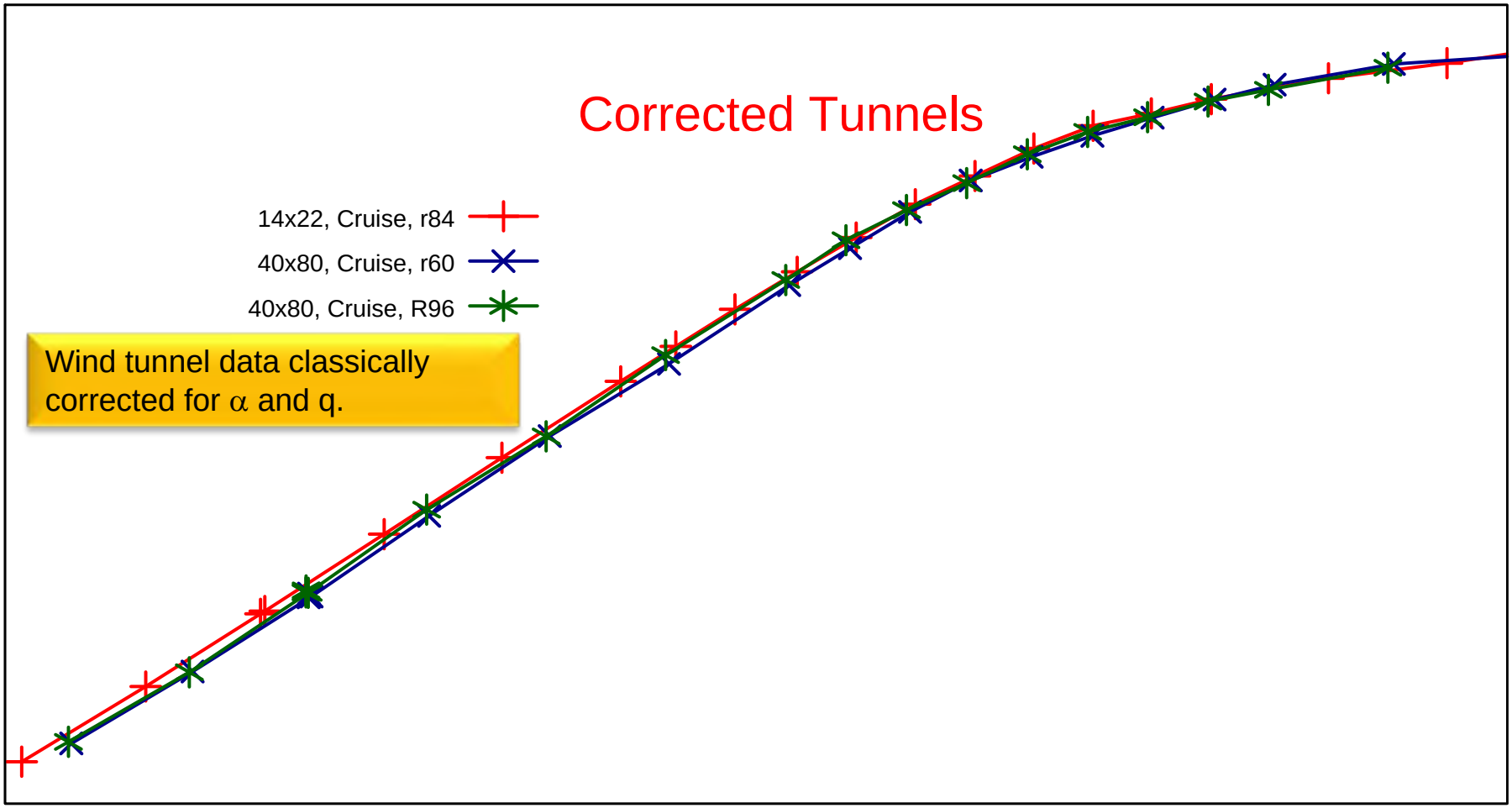
- 14’x22’ Wind Tunnel

Acoustic Krueger w/brackets

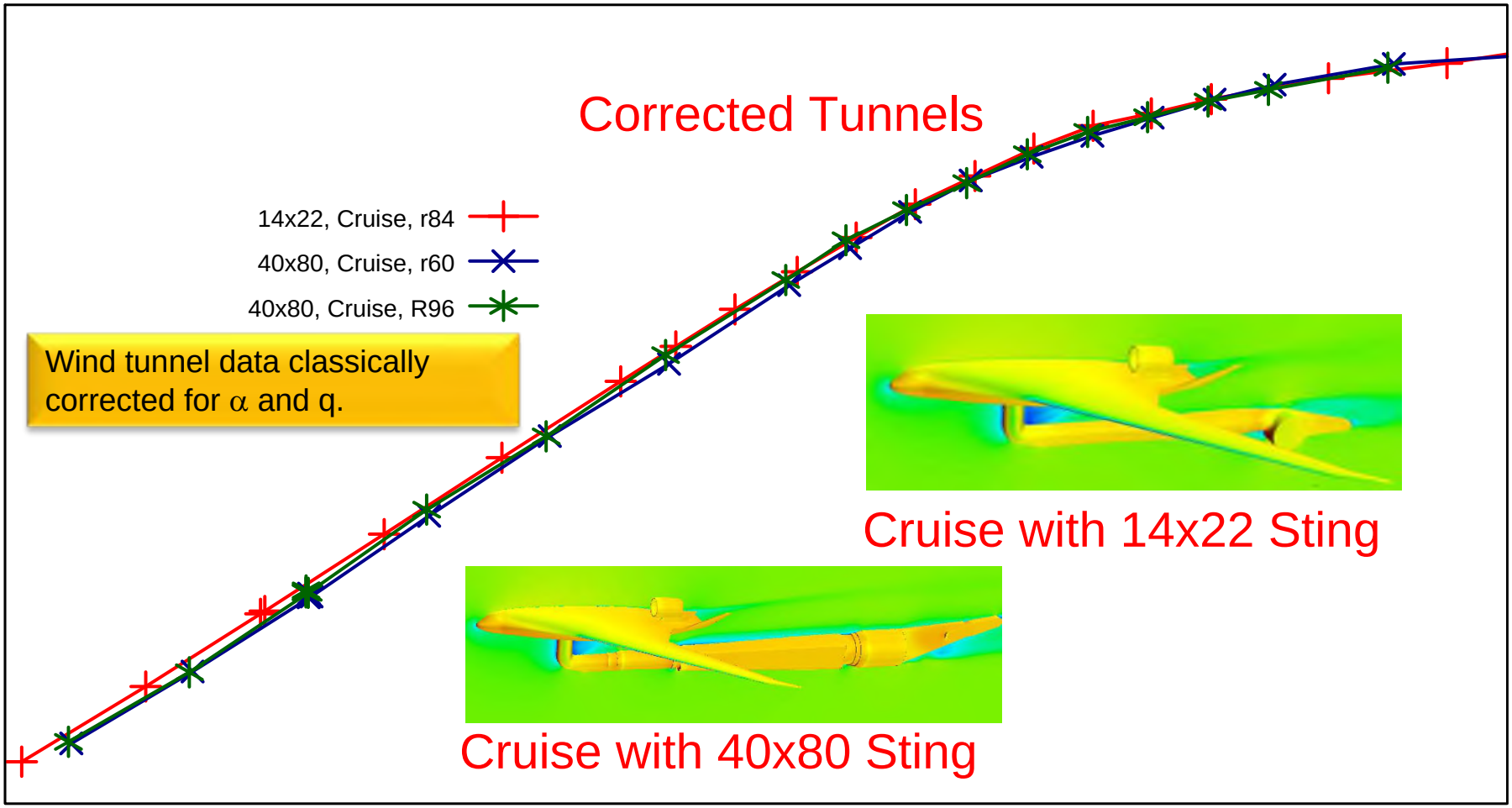
- Free Air
- 40’x80’ Wind Tunnel



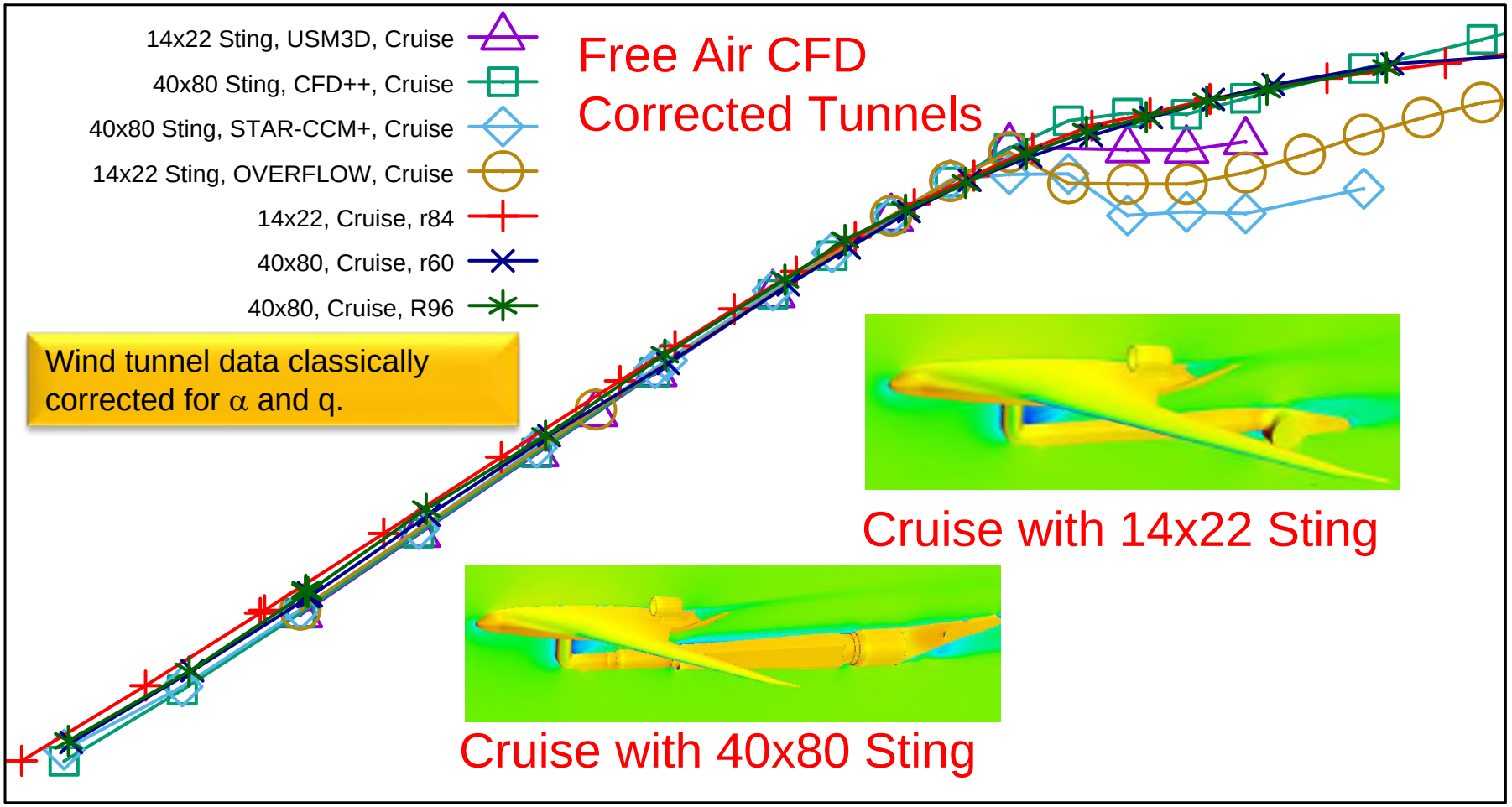
Cruise Lift


Corrected Tunnels
14x22, Cruise, r84
40x80, Cruise, r60
40x80, Cruise, R96
Wind tunnel data classically corrected for α and q.
Lift Coefficient
Angle of Attack

Cruise Lift

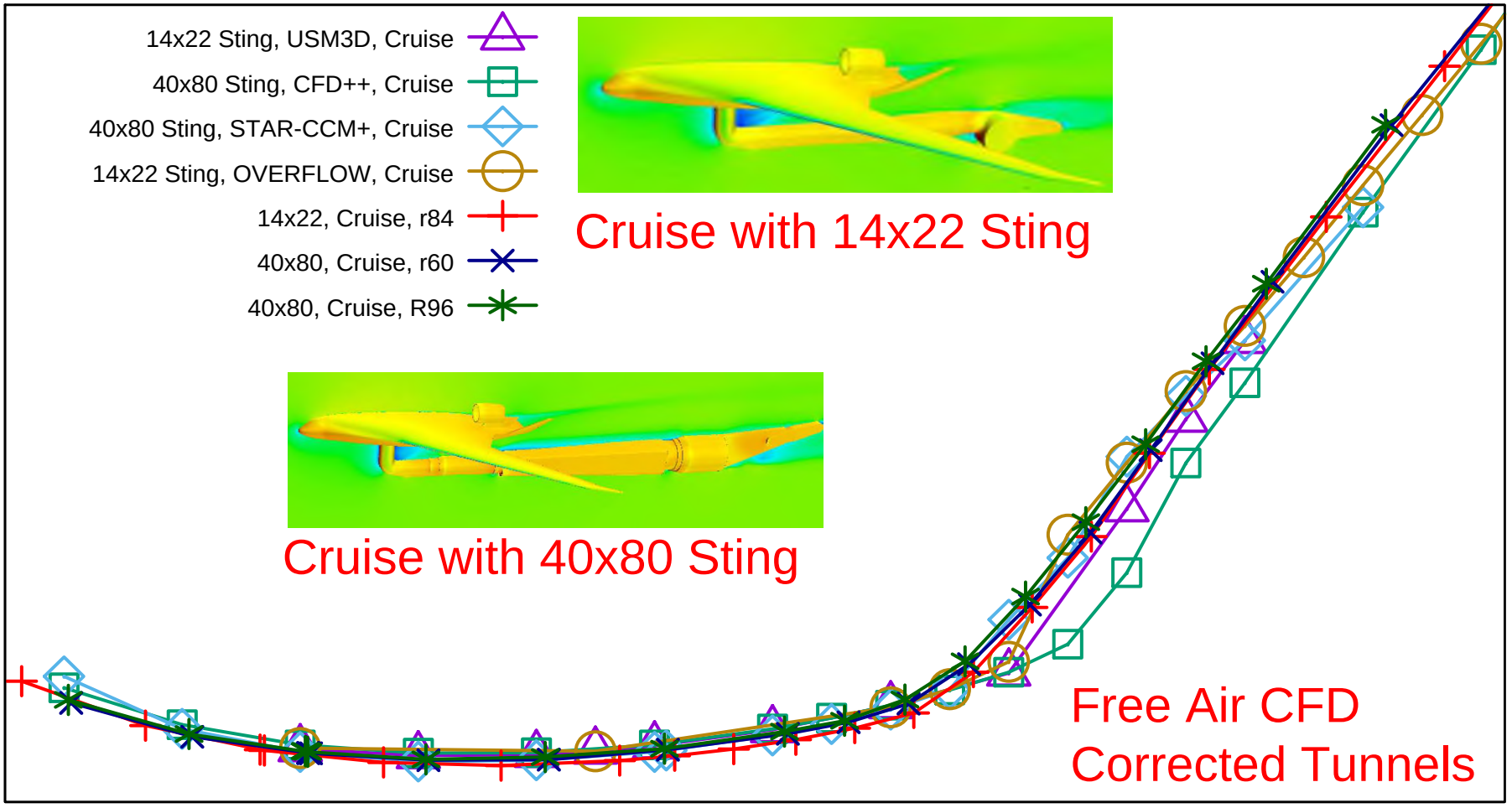

Corrected Tunnels
14x22, Cruise, r84
40x80, Cruise, r60
40x80, Cruise, R96
Wind tunnel data classically corrected for α and q.
Cruise with 14x22 Sting
Cruise with 40x80 Sting
Lift Coefficient
Angle of Attack

Cruise Lift



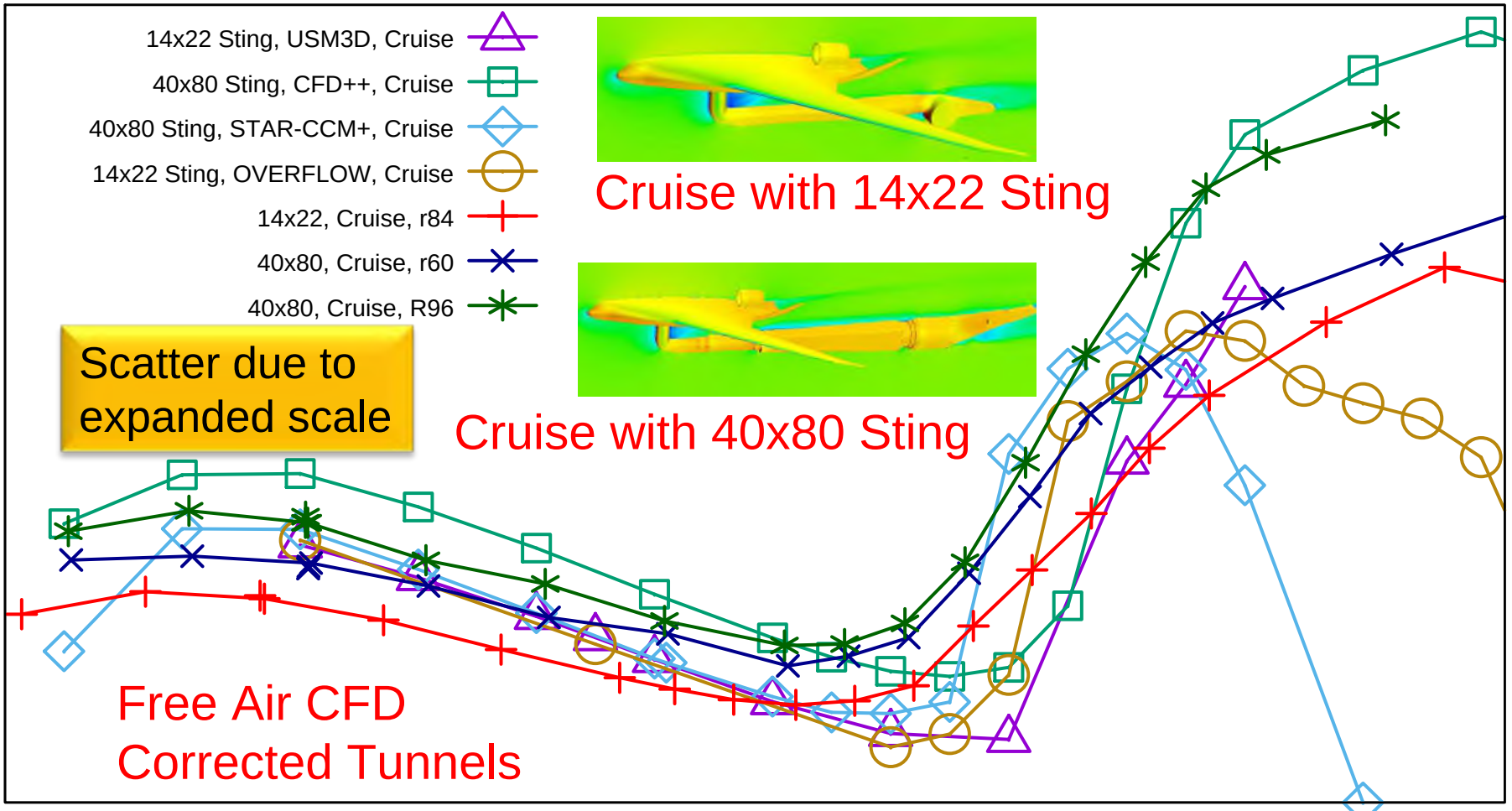
Good comparison up to stall

Cruise Drag



Good comparison up to stall

Cruise Pitching Moment

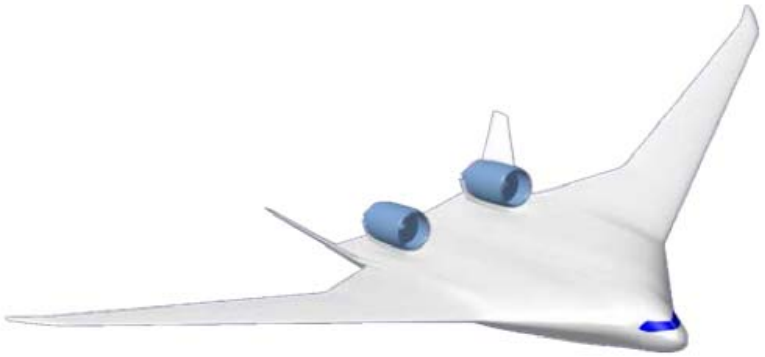


Good comparison up to stall

CFD Configurations

Cruise

- Free Air

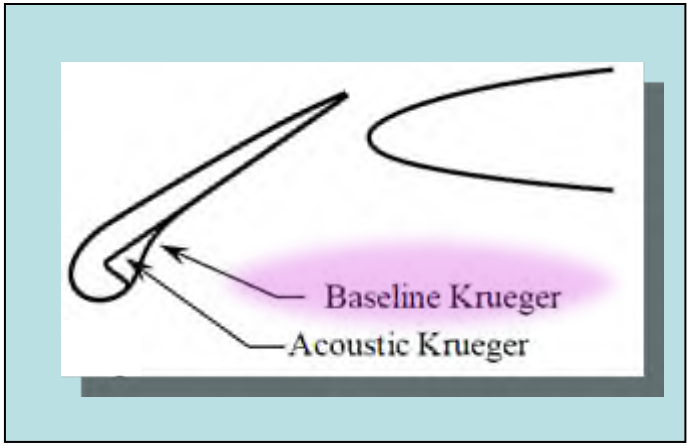


Baseline Krueger no brackets

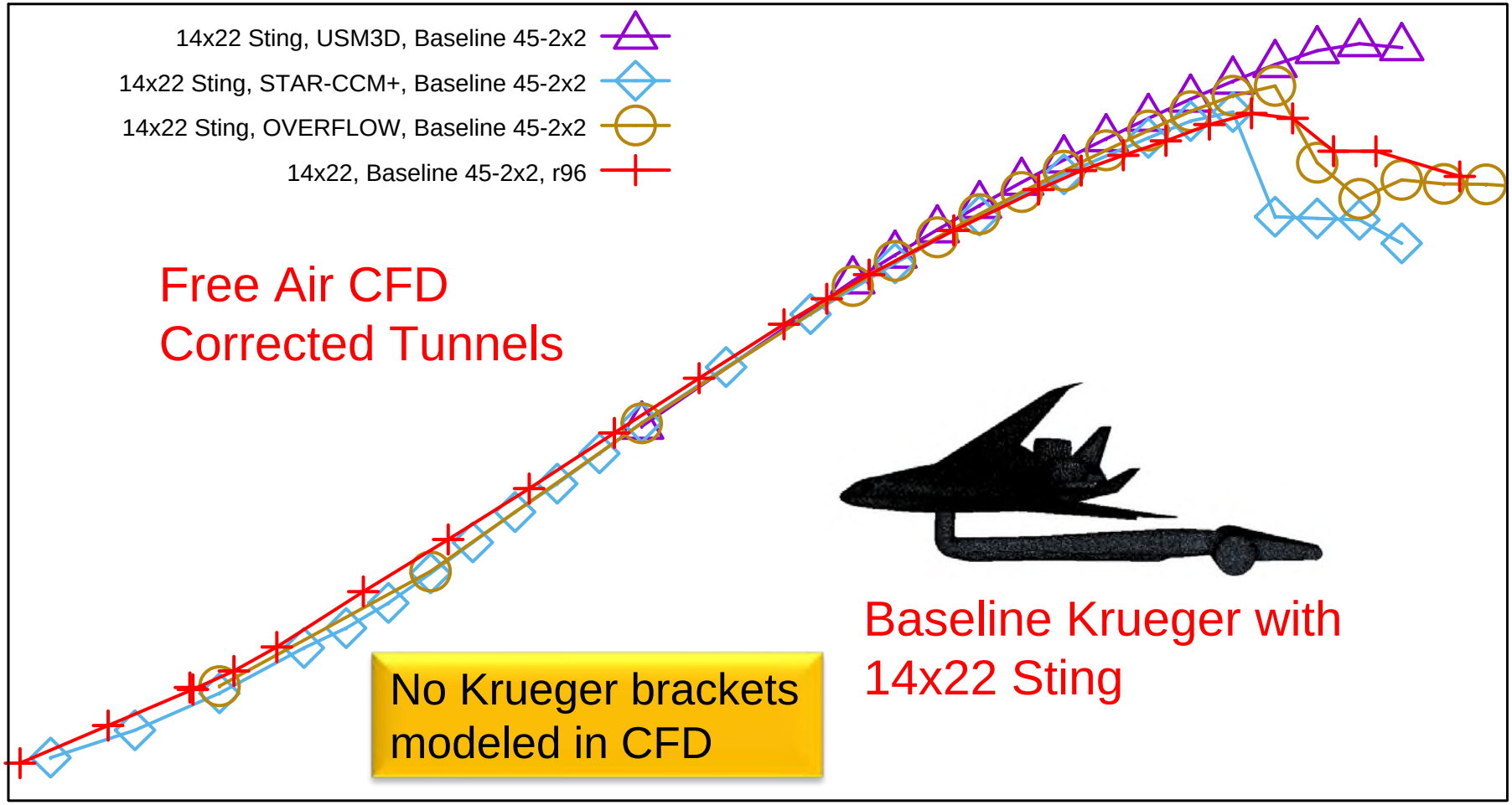
- Free Air
- 14’x22’ Wind Tunnel

Acoustic Krueger w/brackets

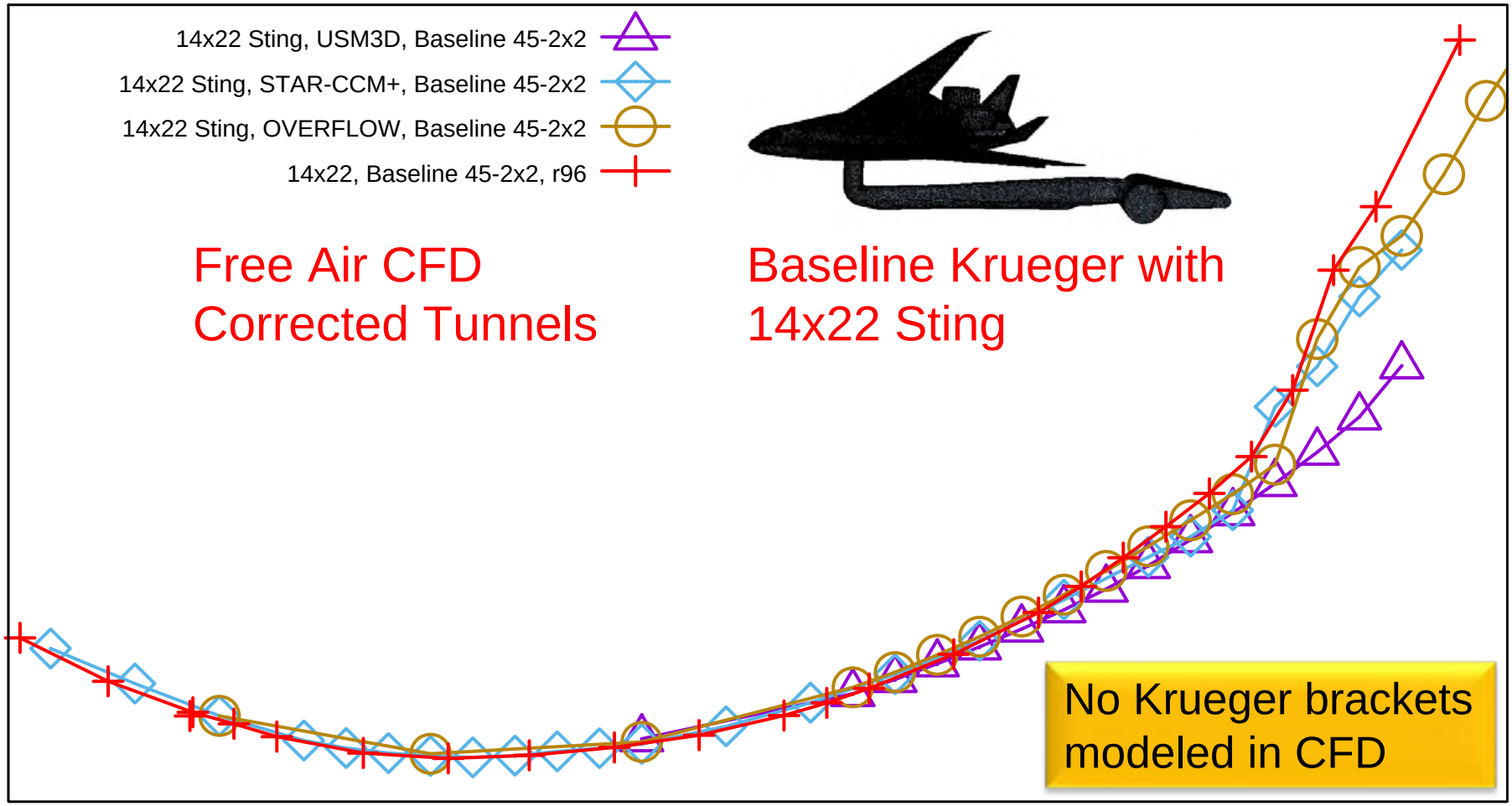
- Free Air
- 40’x80’ Wind Tunnel



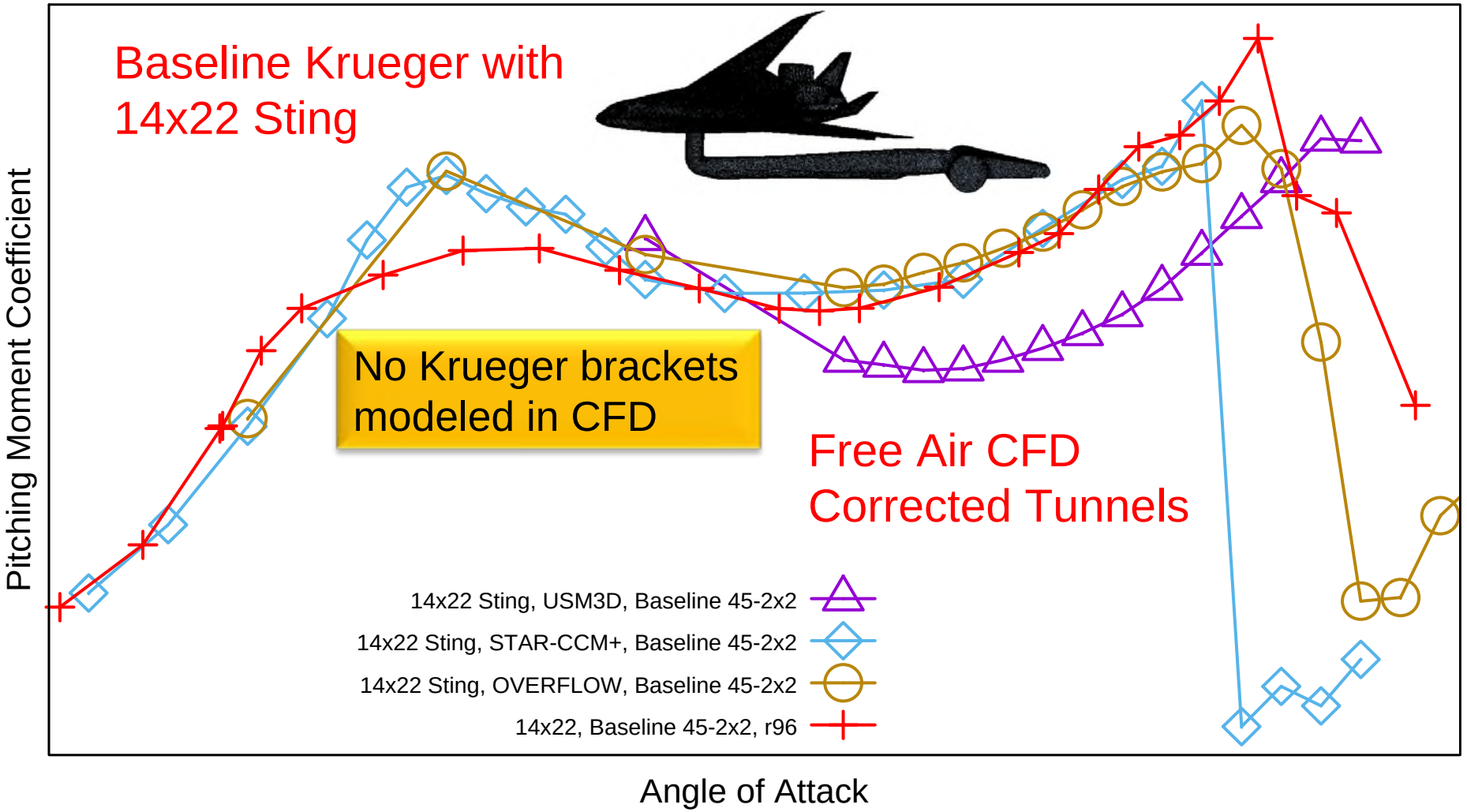
Baseline Krueger Lift



Baseline Krueger Drag



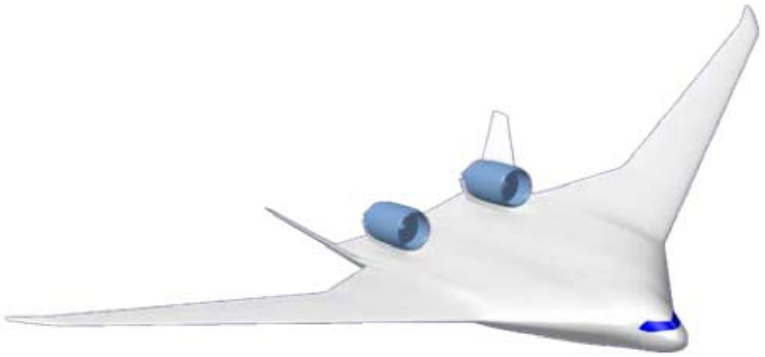
Baseline Krueger Pitching Moment



CFD Configurations

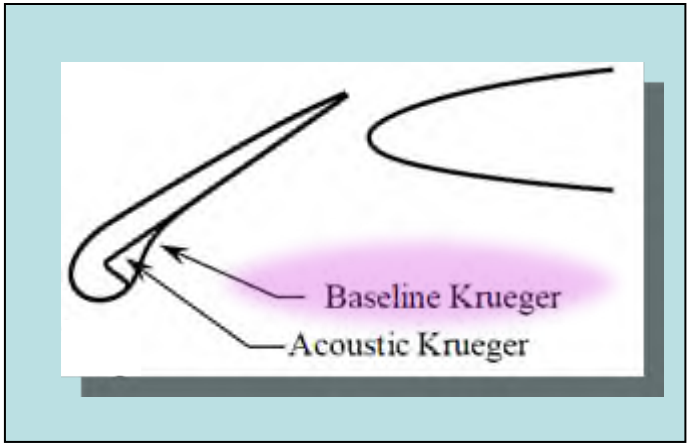
Cruise

- Free Air



Baseline Krueger no brackets

- Free Air
- 14’x22’ Wind Tunnel



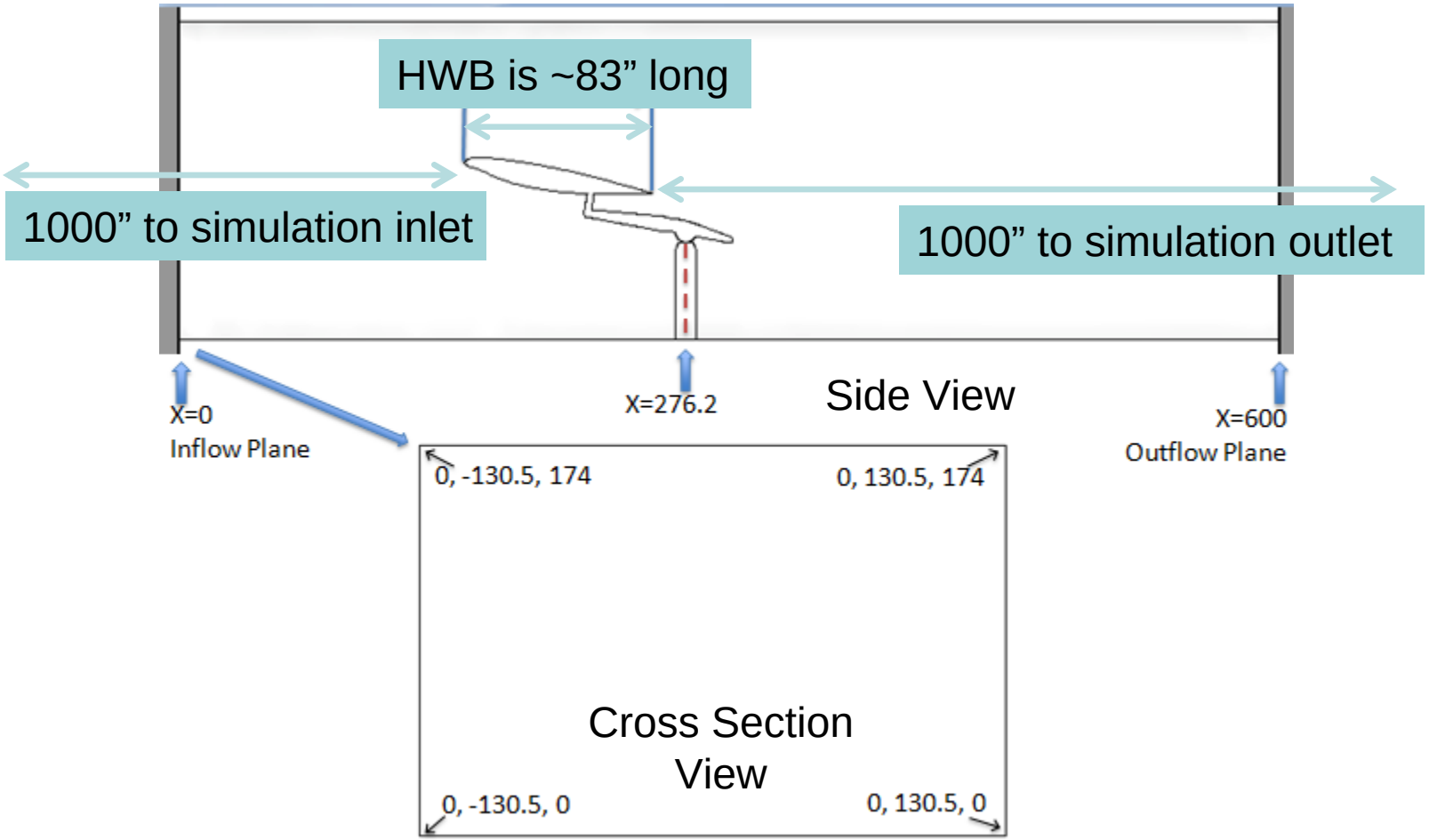
Acoustic Krueger w/brackets

- Free Air
- 40’x80’ Wind Tunnel

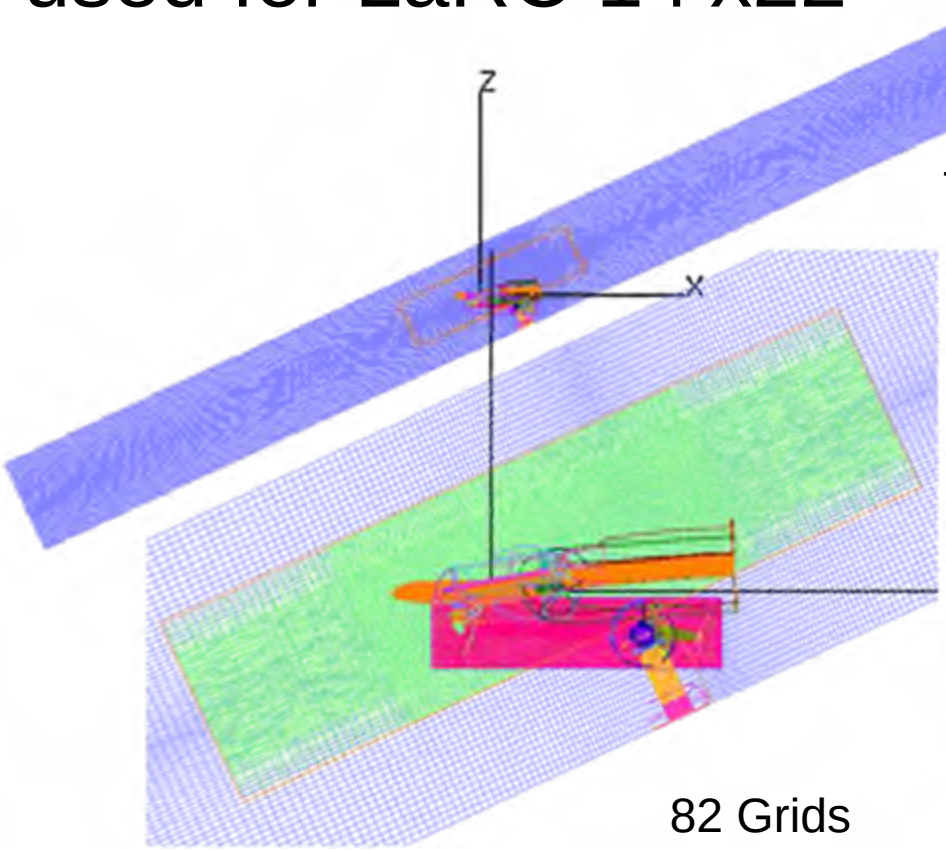
HWB in LaRC 14’x22’

Wind Tunnel Walls

CFD Configuration used for 14’x22’ in STAR-CCM+

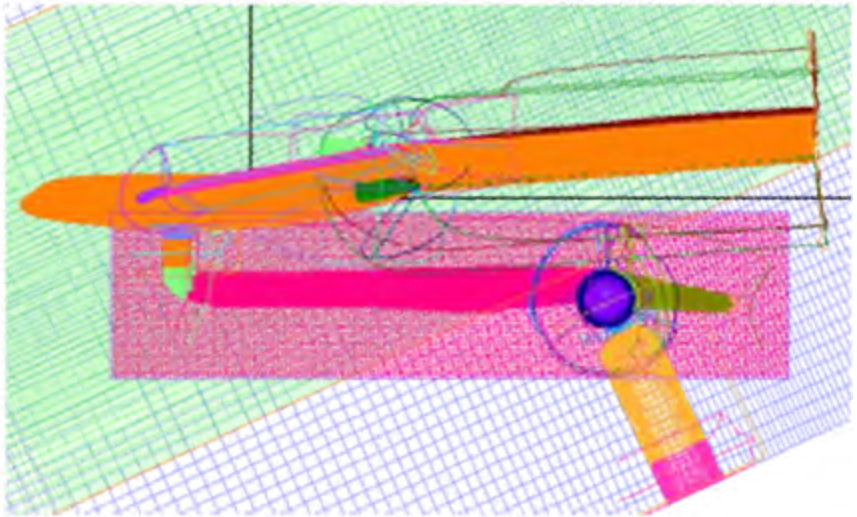


OVERFLOW meshing layout used for LaRC 14'x22'

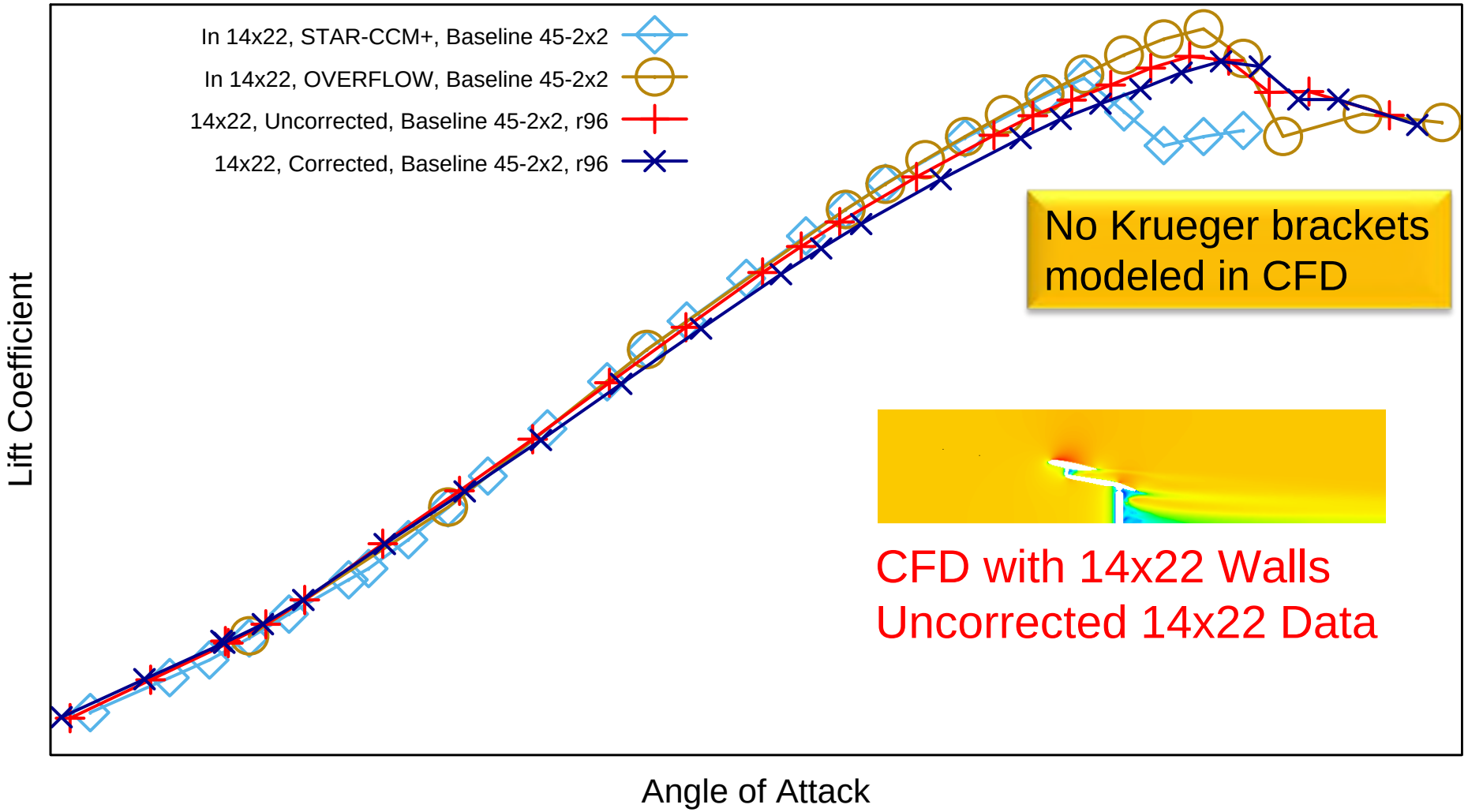


82 Grids

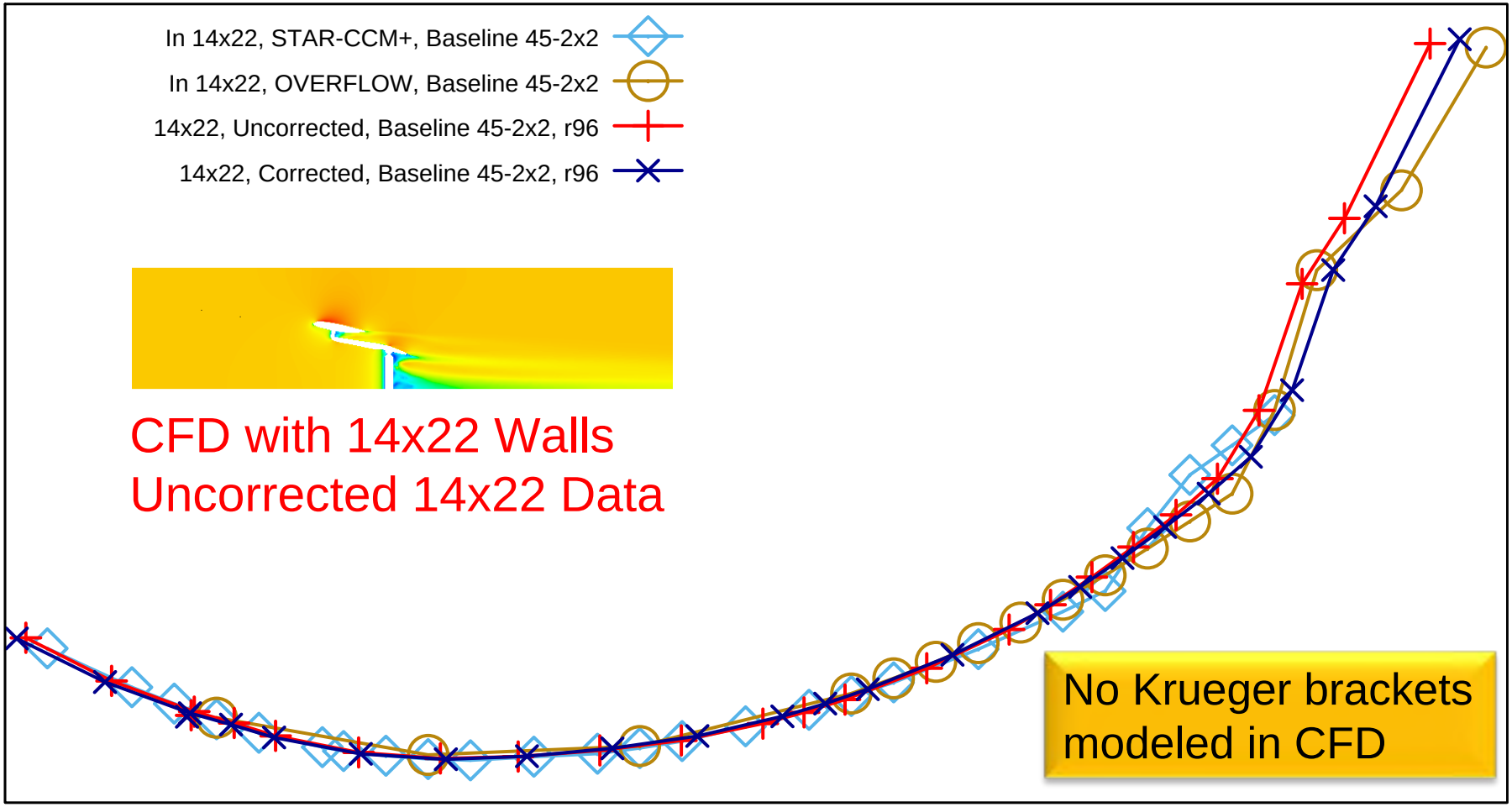
Tunnel, Wake Box, and Sting Box, α=25°



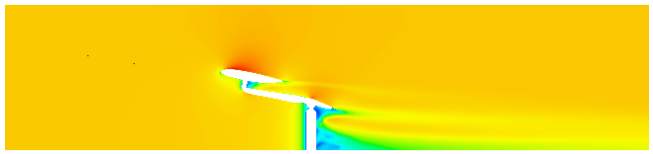
Baseline Kreuger in 14'x22' Lift



Baseline Kreuger in 14'x22' Drag



Baseline Kreuger in 14'x22' Pitching Moment



CFD with 14x22 Walls
Uncorrected 14x22 Data

No Krueger brackets modeled in CFD

Pitching Moment Coefficient

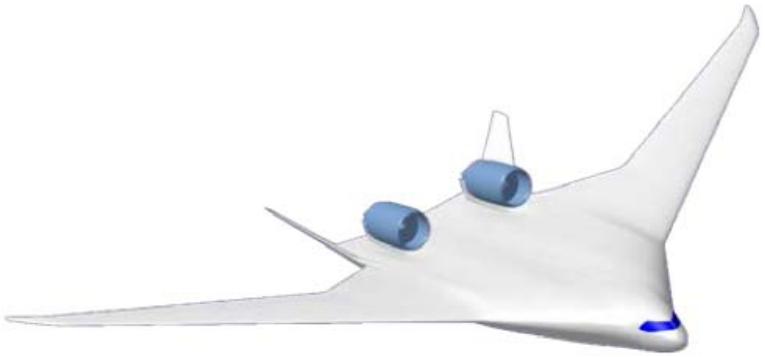
Angle of Attack

In 14x22, STAR-CCM+, Baseline 45-2x2
In 14x22, OVERFLOW, Baseline 45-2x2
14x22, Uncorrected, Baseline 45-2x2, r96
14x22, Corrected, Baseline 45-2x2, r96

CFD Configurations

Cruise

- Free Air

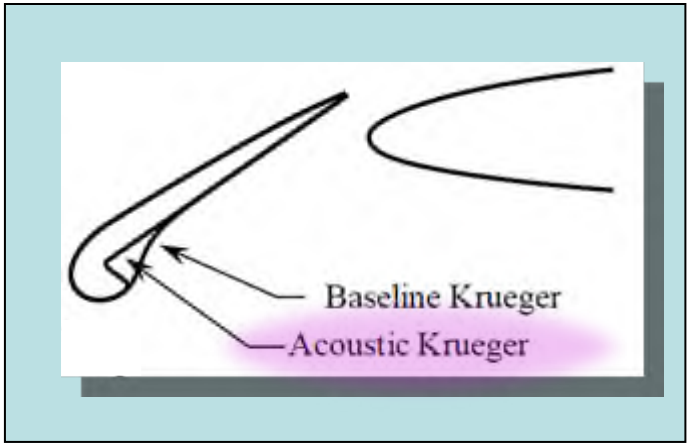


Baseline Krueger no brackets

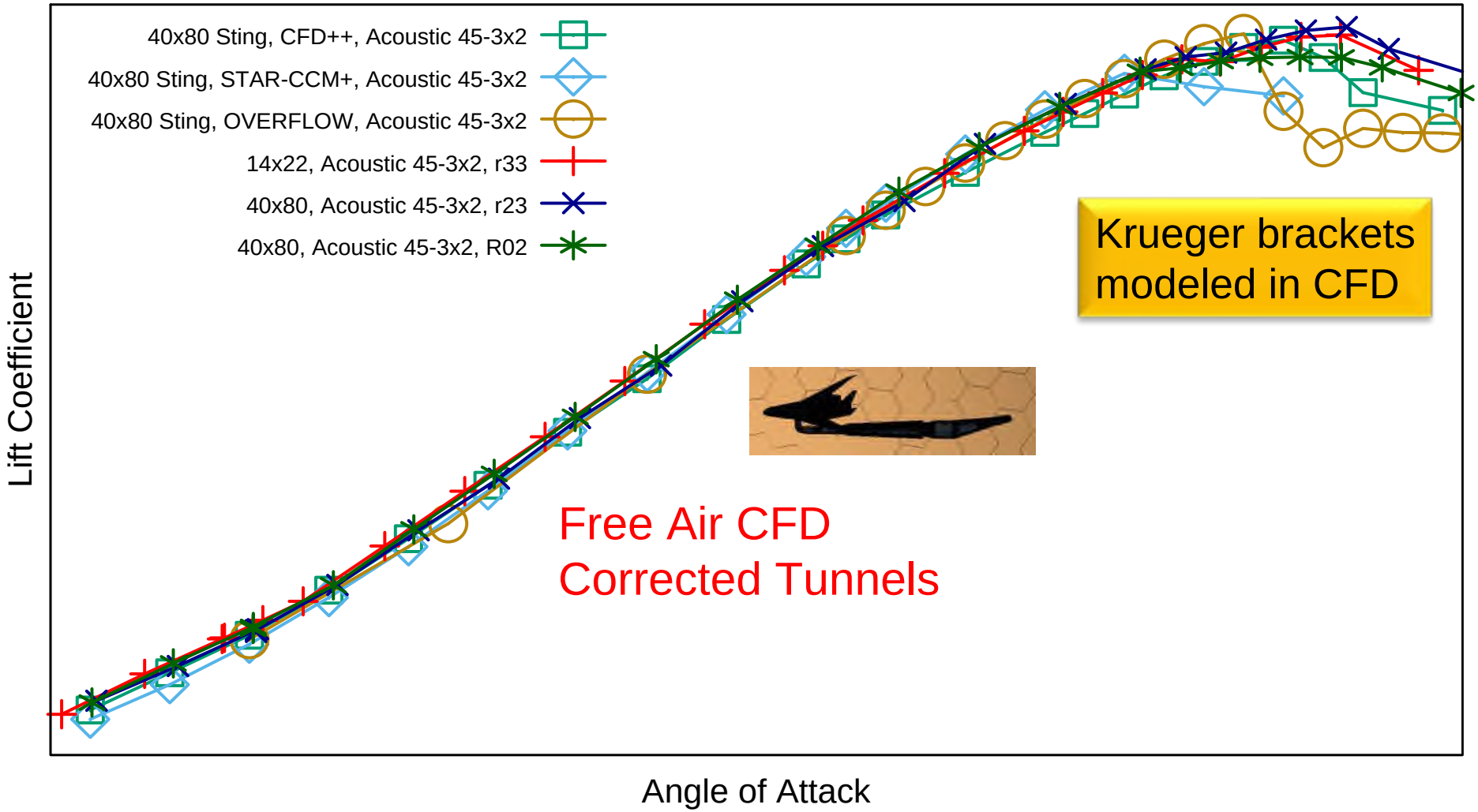
- Free Air
- 14’x22’ Wind Tunnel

Acoustic Krueger w/brackets

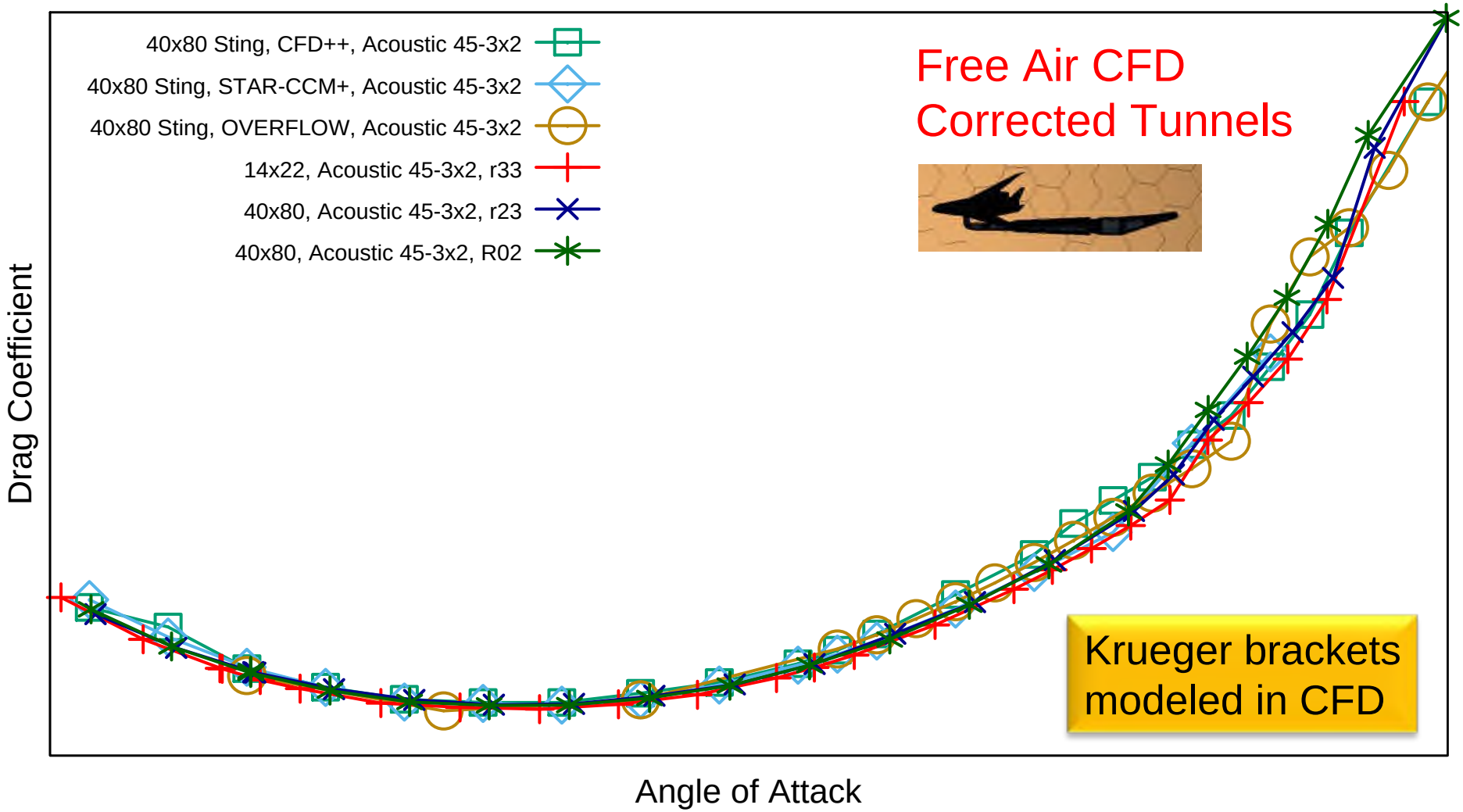
- Free Air
- 40’x80’ Wind Tunnel



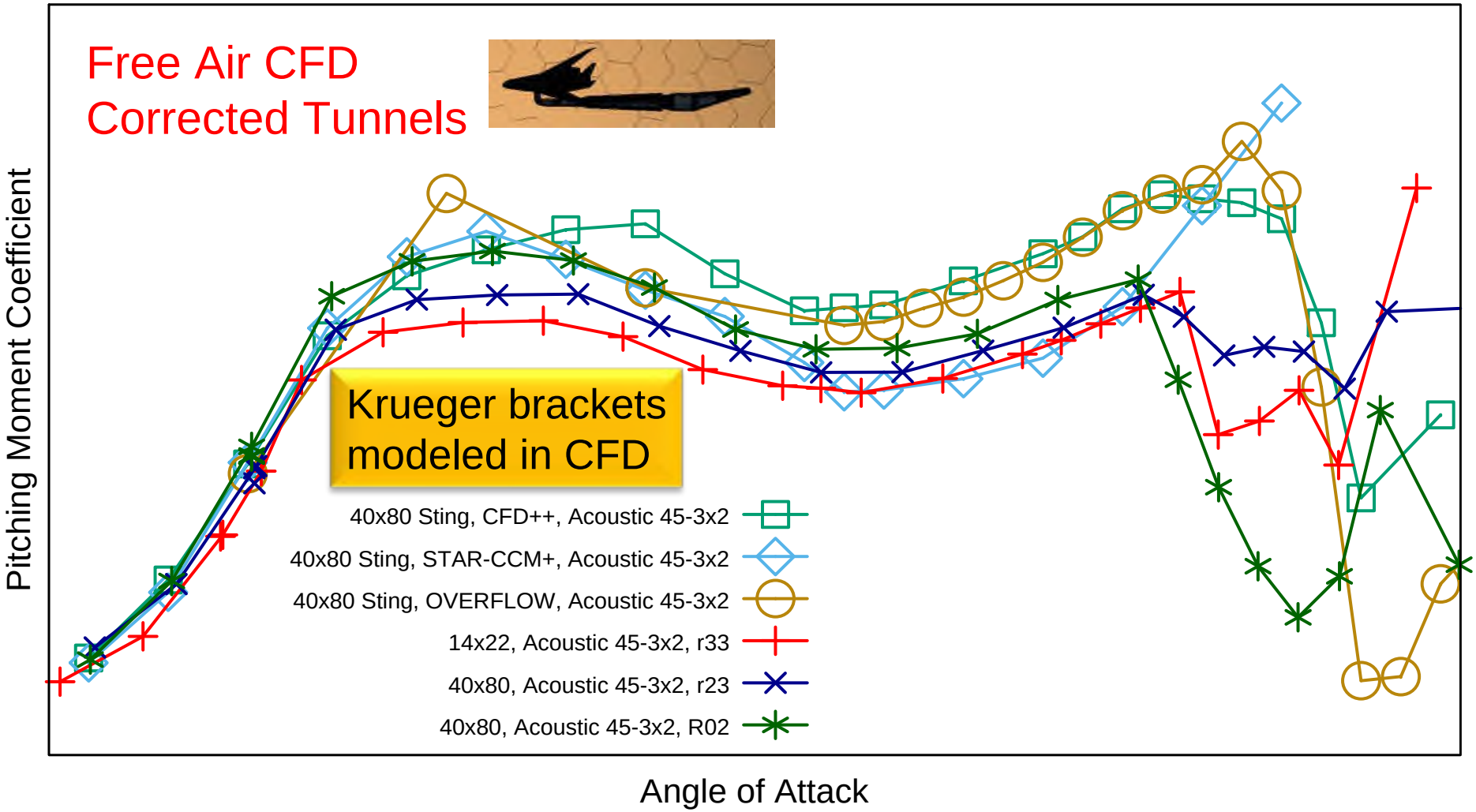
Acoustic Krueger Lift



Acoustic Krueger Drag



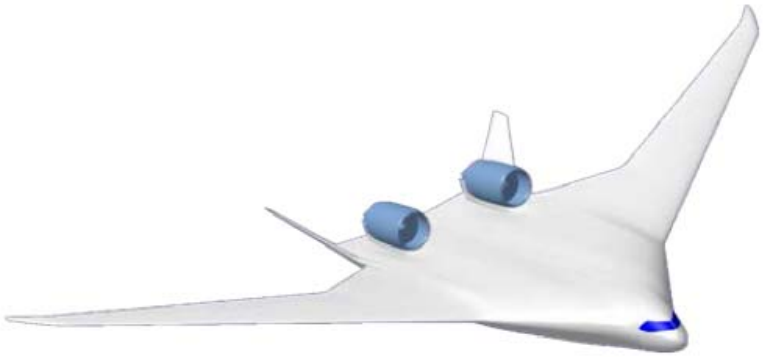
Acoustic Krueger Pitching Moment



CFD Configurations

Cruise

- Free Air

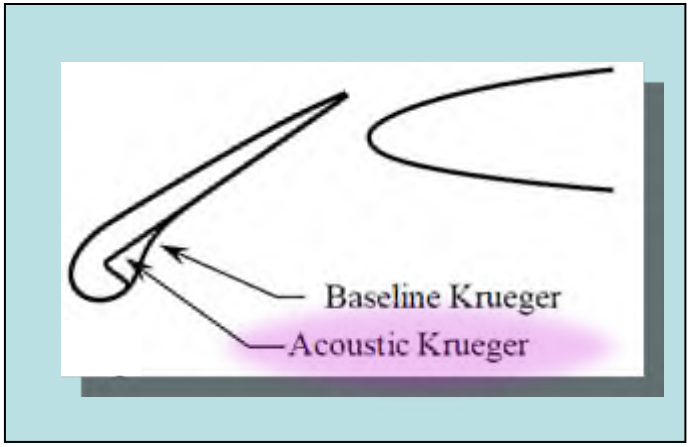


Baseline Krueger no brackets

- Free Air
- 14’x22’ Wind Tunnel

Acoustic Krueger w/brackets

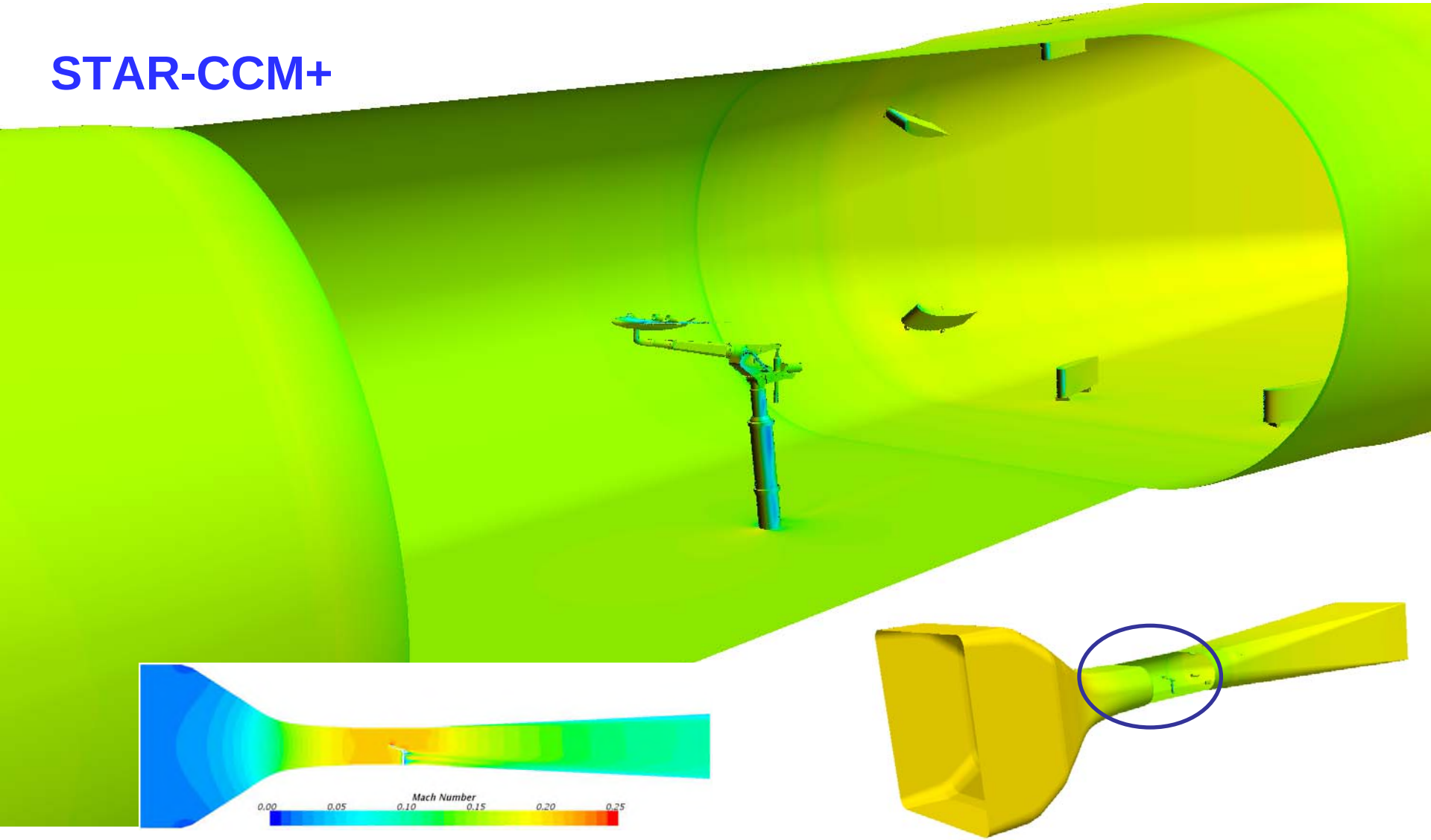
- Free Air
- 40’x80’ Wind Tunnel



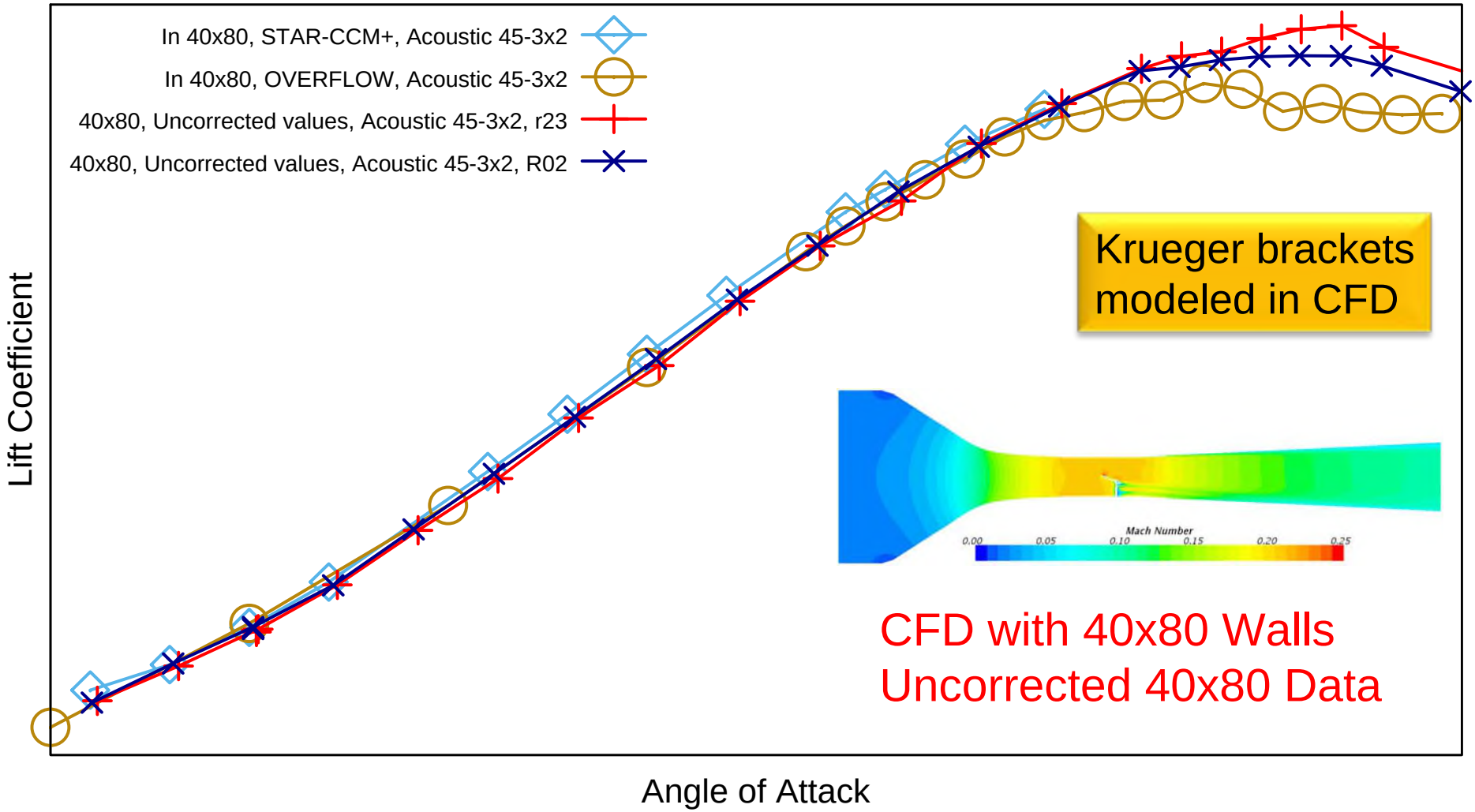
HWB in NASA Ames 40’x80’

CFD HWB in ARC 40'x80'

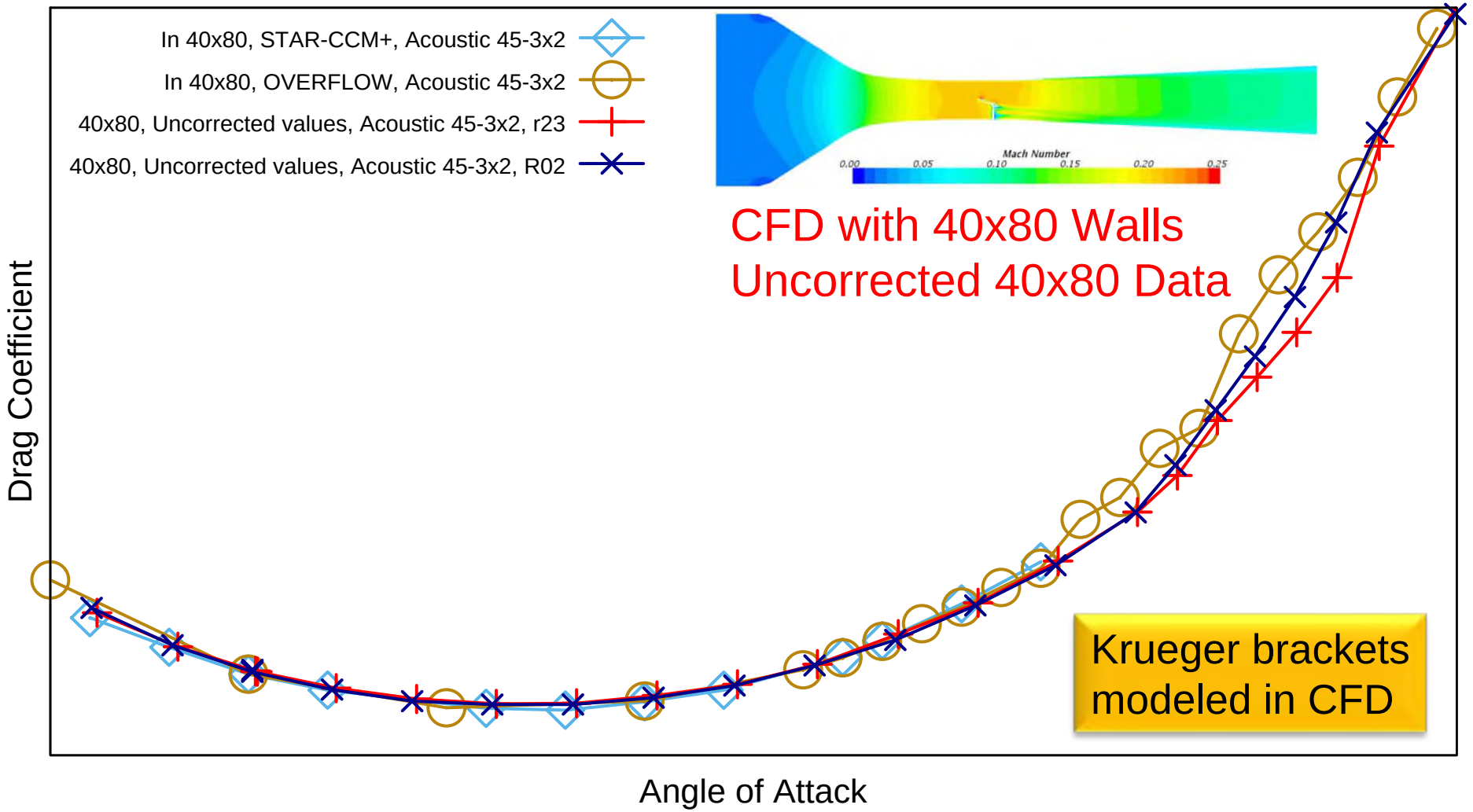
STAR-CCM+



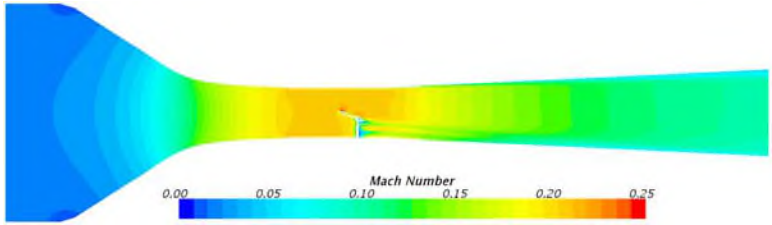
Acoustic Krueger in 40'x80' Lift



Acoustic Krueger in 40'x80' Drag



Acoustic Krueger in 40'x80' Pitching Moment



Krueger brackets modeled in CFD

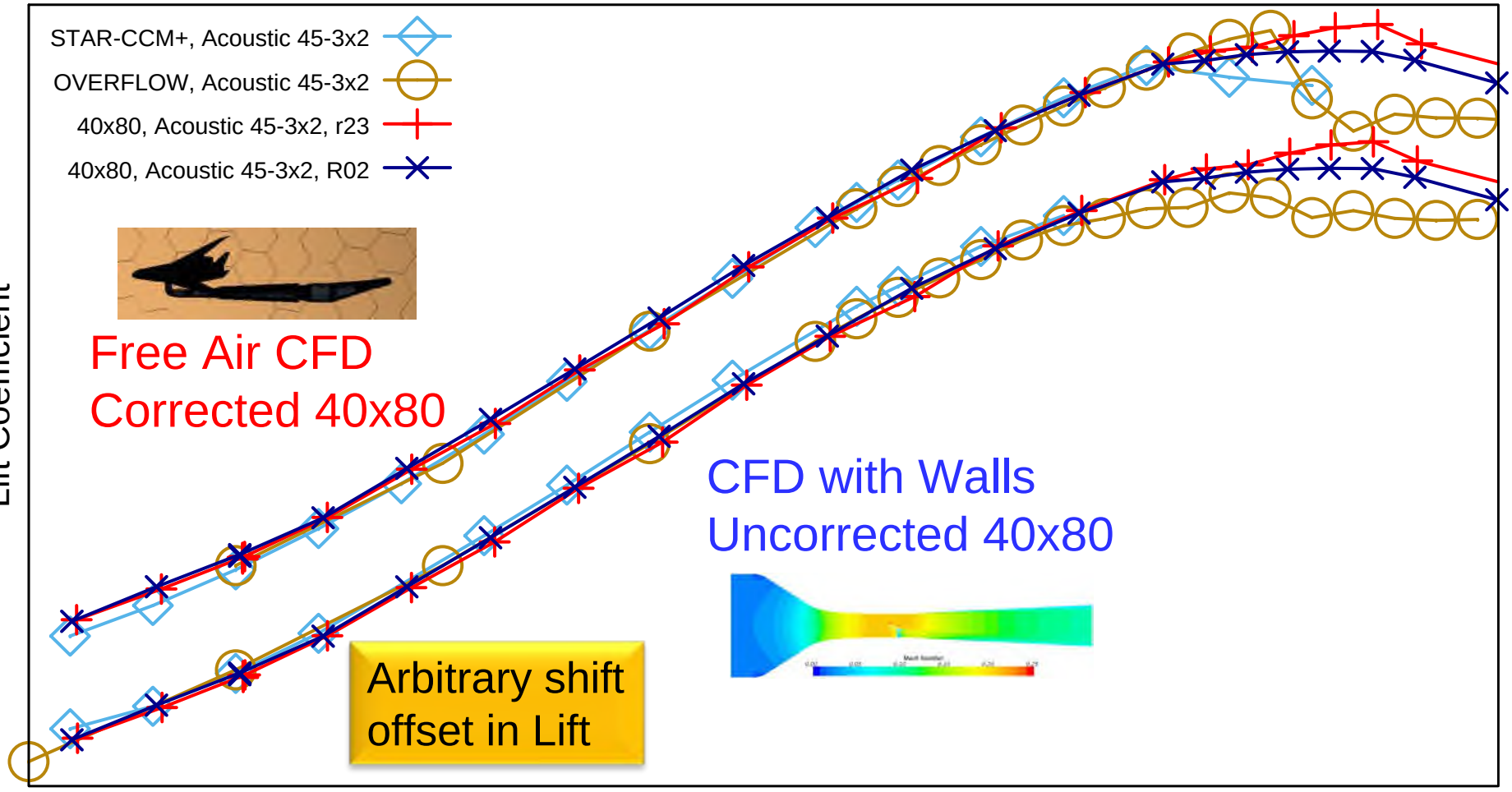
CFD with 40x80 Walls
Uncorrected 40x80 Data

In 40x80, STAR-CCM+, Acoustic 45-3x2
In 40x80, OVERFLOW, Acoustic 45-3x2
40x80, Uncorrected values, Acoustic 45-3x2, r23
40x80, Uncorrected values, Acoustic 45-3x2, R02

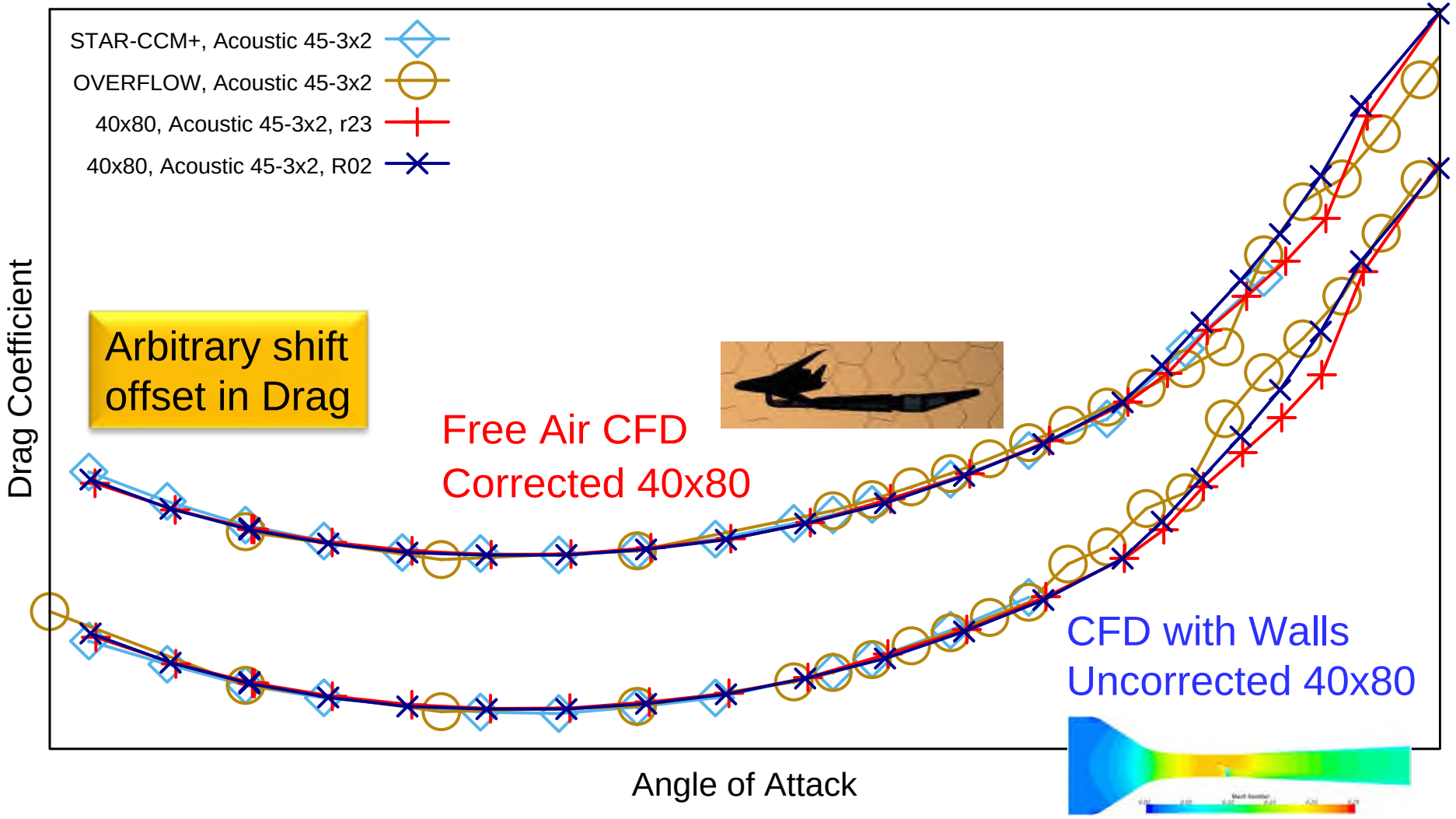
Pitching Moment Coefficient

Angle of Attack

Acoustic Krueger in 40'x80' Lift w/Free Air CFD



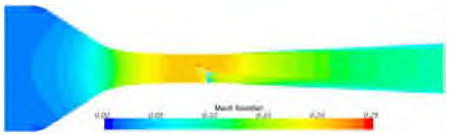
Acoustic Krueger in 40'x80' Drag w/Free Air CFD



Acoustic Krueger in 40'x80' Pitching Moment w/Free Air CFD

Free Air CFD
Corrected 40x80

CFD with Walls
Uncorrected 40x80



STAR-CCM+, Acoustic 45-3x2
OVERFLOW, Acoustic 45-3x2
40x80, Acoustic 45-3x2, r23
40x80, Acoustic 45-3x2, R02

Pitching Moment Coefficient

Angle of Attack

Arbitrary shift offset in Pitching Moment

Matrix of CFD and Tunnel Data

All data is for Freestream Mach = 0.2

	14'x22' LaRC	40'x80' ARC	USM3D LaRC	CFD++ Boeing	STAR-CCM+ ARC	OVERFLOW ARC
Cruise in Free Air			14'x22' Sting	40'x80' Sting	40'x80' Sting	14'x22' Sting
Cruise in Tunnel	x	x				
Baseline Krueger 45°-2x2 in Free Air			14'x22' Sting		14'x22' Sting	14'x22' Sting
Baseline Krueger 45°-2x2 in Tunnel	x				14'x22' Tunnel	14'x22' Tunnel
Acoustic Krueger 45-3x2 in Free Air				40'x80' Sting	40'x80' Sting	40'x80' Sting
Acoustic Krueger 45-3x2 in Tunnel	x	x			40'x80' Tunnel	40'x80' Tunnel

Summary & Conclusions

- CFD simulations were performed before and after testing
- Used 4 different CFD codes
- 5.75% HWB scale model tested in the NASA LaRC 14’x22’ and NASA ARC 40’x80’ wind tunnels
- Good agreement with the measured results up to the stall
- Less agreement after the onset of stall
- Accurately modeled the vehicle in free air and with the wind tunnel walls