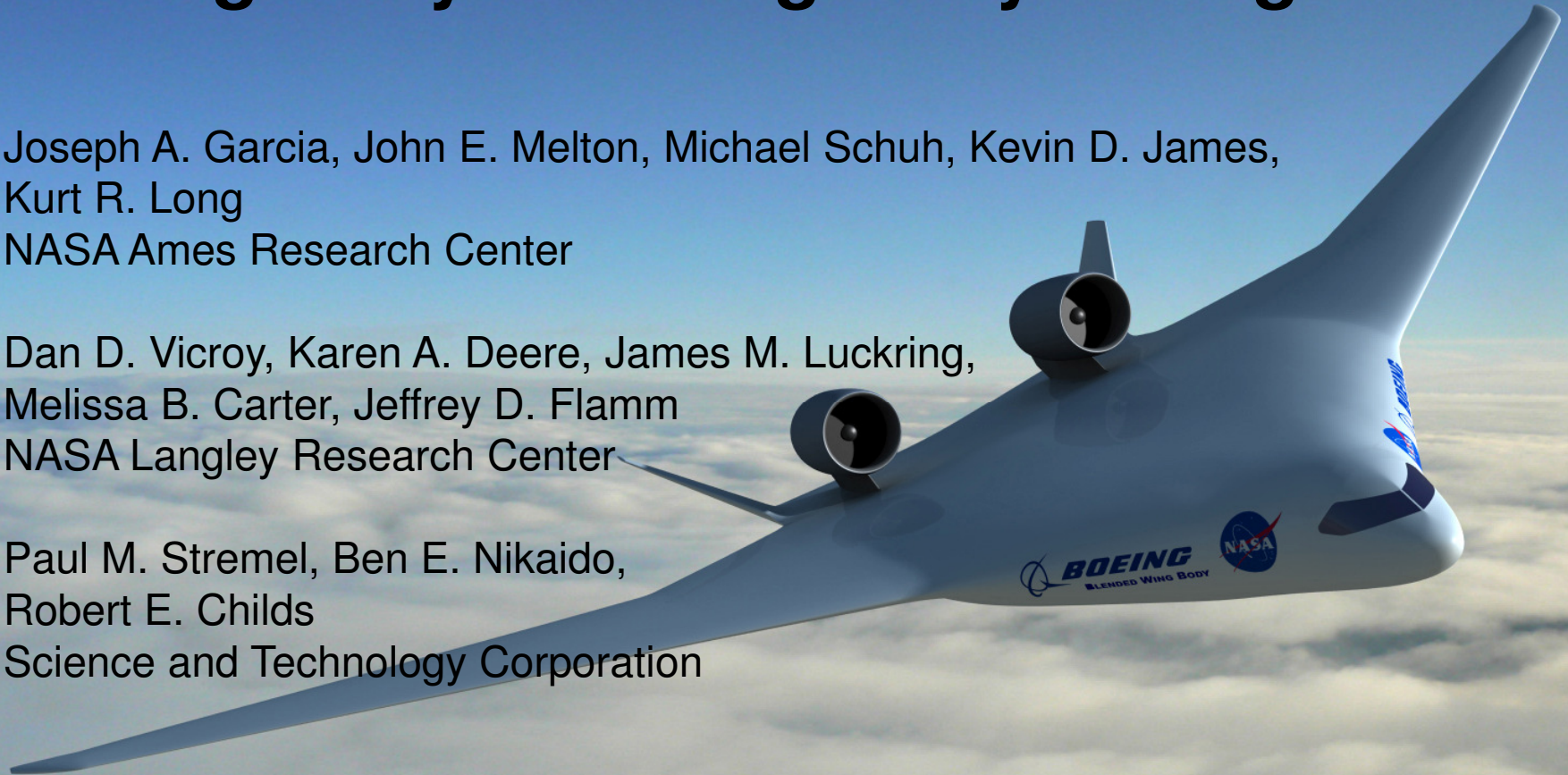


# NASA ERA Integrated CFD for Wind Tunnel Testing of Hybrid Wing-Body Configuration

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NASA Langley Research Center

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Robert E. Childs  
Science and Technology Corporation



# Outline

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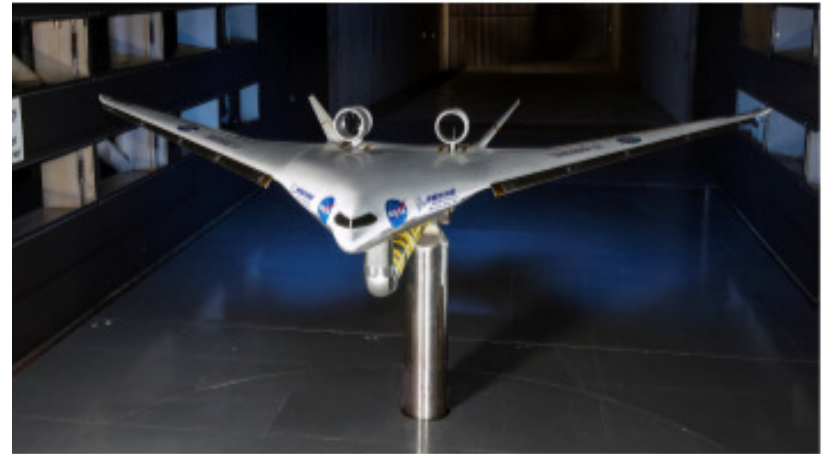
- Overview
- Efficient Use of Multiple CFD tools
- CFD Quality Assessment
- CFD Wind Tunnel Support
- Lessons Learned and Simulation Guidelines
- Conclusions

# Overview

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- ERA Project explored various enabling technologies to reduce environmental impact of aviation.
- Wind tunnel tests performed to evaluate propulsion-airframe interference effects.
- Extensive CFD was used to assist these tests in producing high quality data with minimal hardware interference and extrapolation to flight.
- High-level summary of how NASA utilized multiple CFD simulations tools in support of the wind tunnel test.
- CFD simulation guidelines based on post-test aerodynamic data.



# CFD Solvers and Methods



## Efficient use of Multiple CFD Tools

- 3 NASA's CFD Solvers utilized:
  - OVERFLOW
    - Overset grids via the Chimera Grid Tools
    - SA and SST turbulence model
  - USM3D
    - Unstructured tetrahedral meshes via TetrUSS GridTool
    - SA turbulence model
  - FUN3D
    - Unstructured prismatic/tetrahedral meshes via AFLR3
    - SA turbulence model
- 1 Commercial CFD Solver utilized:
  - STAR-CCM+
    - Unstructured prismatic/polyhedral meshes
    - SST turbulence model

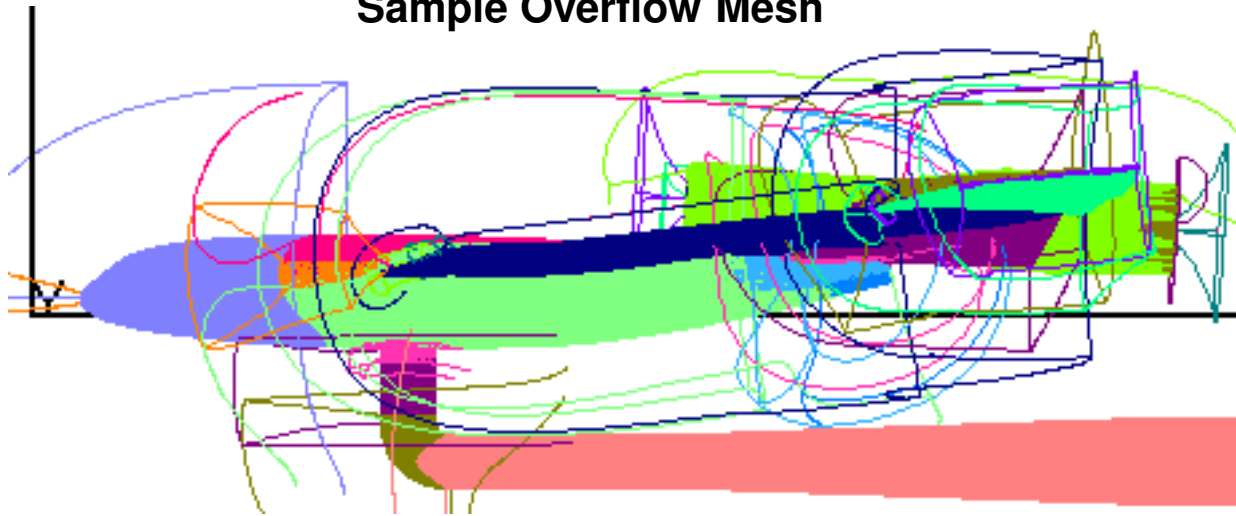


# Geometry and Mesh Generation

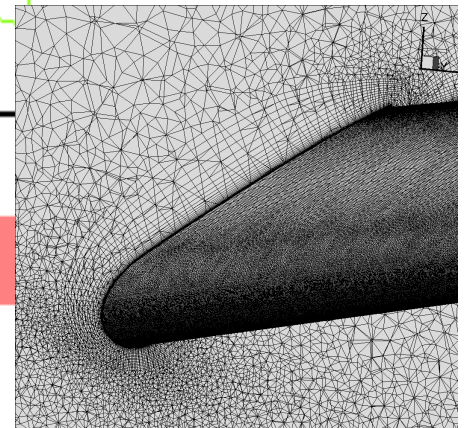


Efficient use of Multiple CFD Tools

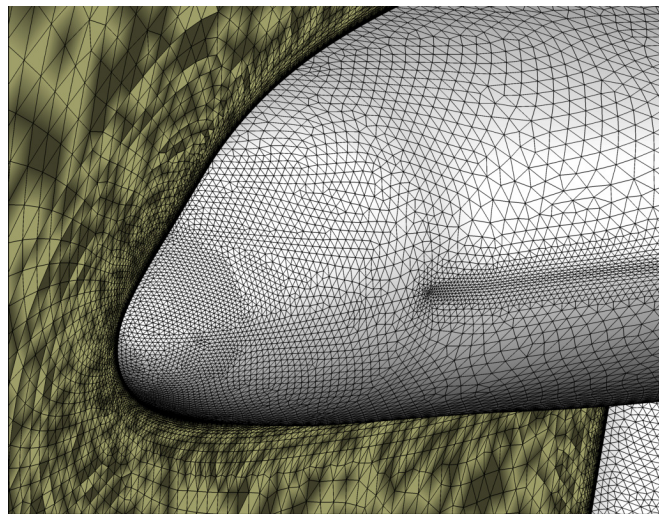
Sample Overflow Mesh



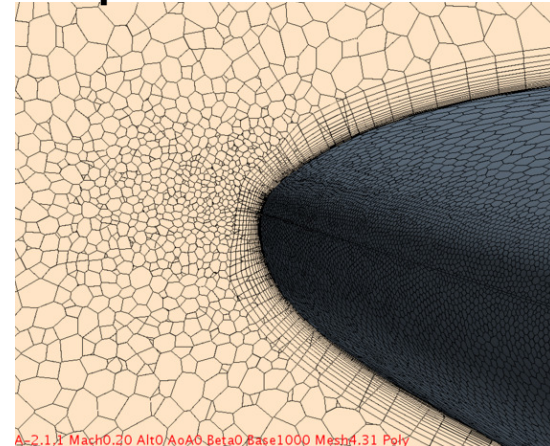
Sample FUN3D Mesh



Sample USM3D Mesh



Sample STAR-CCM+ Mesh

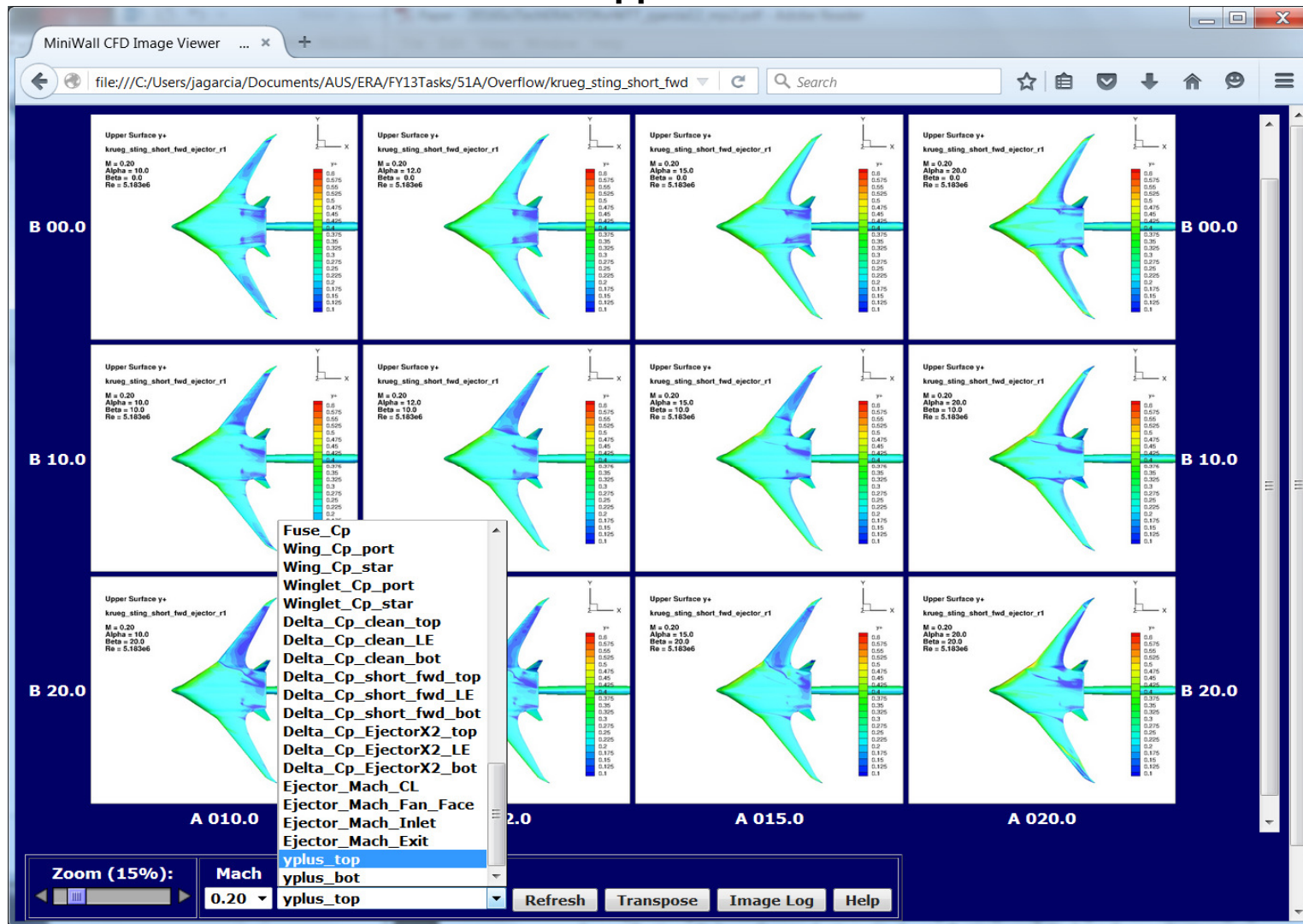


# CFD Quality Assessment



## 'Miniwall' Application

CFD Quality Assessment



# CFD Wind Tunnel Support



## CFD Wind Tunnel Support

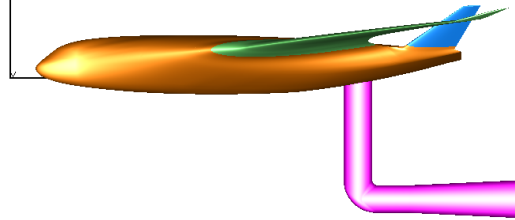
CFD was used to provide highest quality experimental testing

- Sting selection
- Ejector selection
- Acoustic array selection
- 40'x80' sting installation

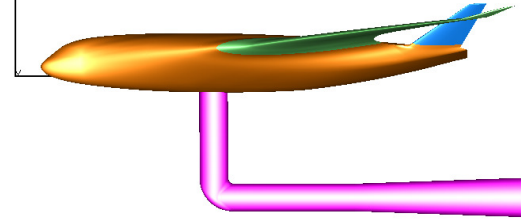
# Sting Selection



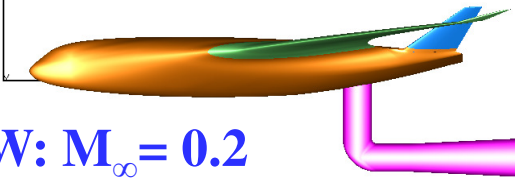
Long Aft Sting



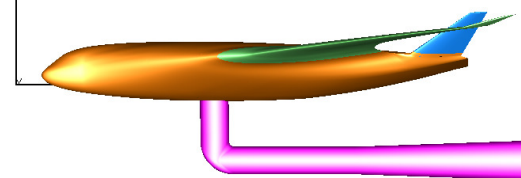
Long Forward Sting



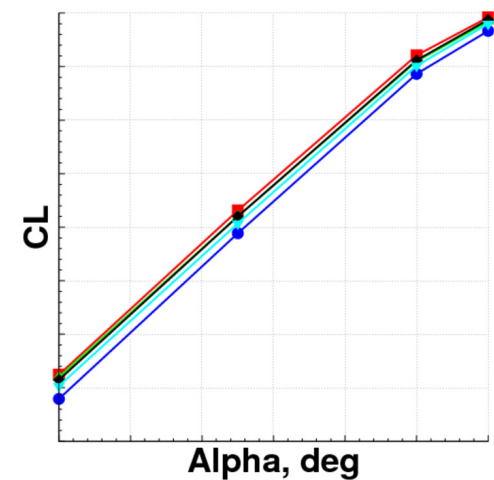
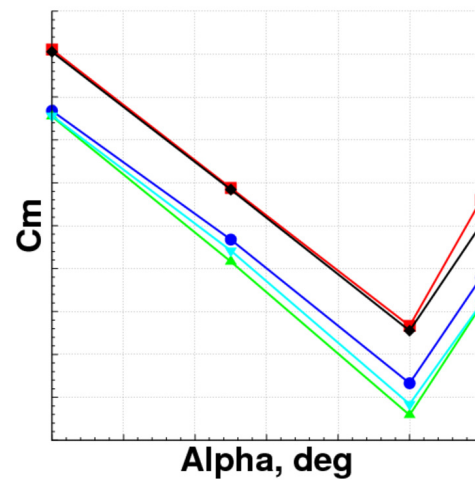
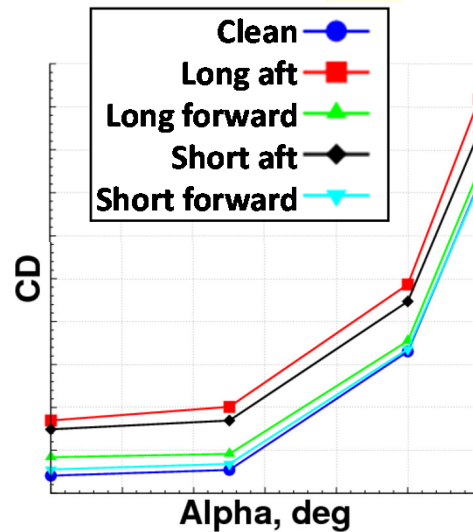
Short Aft Sting



Short Forward Sting



OVERFLOW:  $M_{\infty} = 0.2$



\*Simulations run in free air

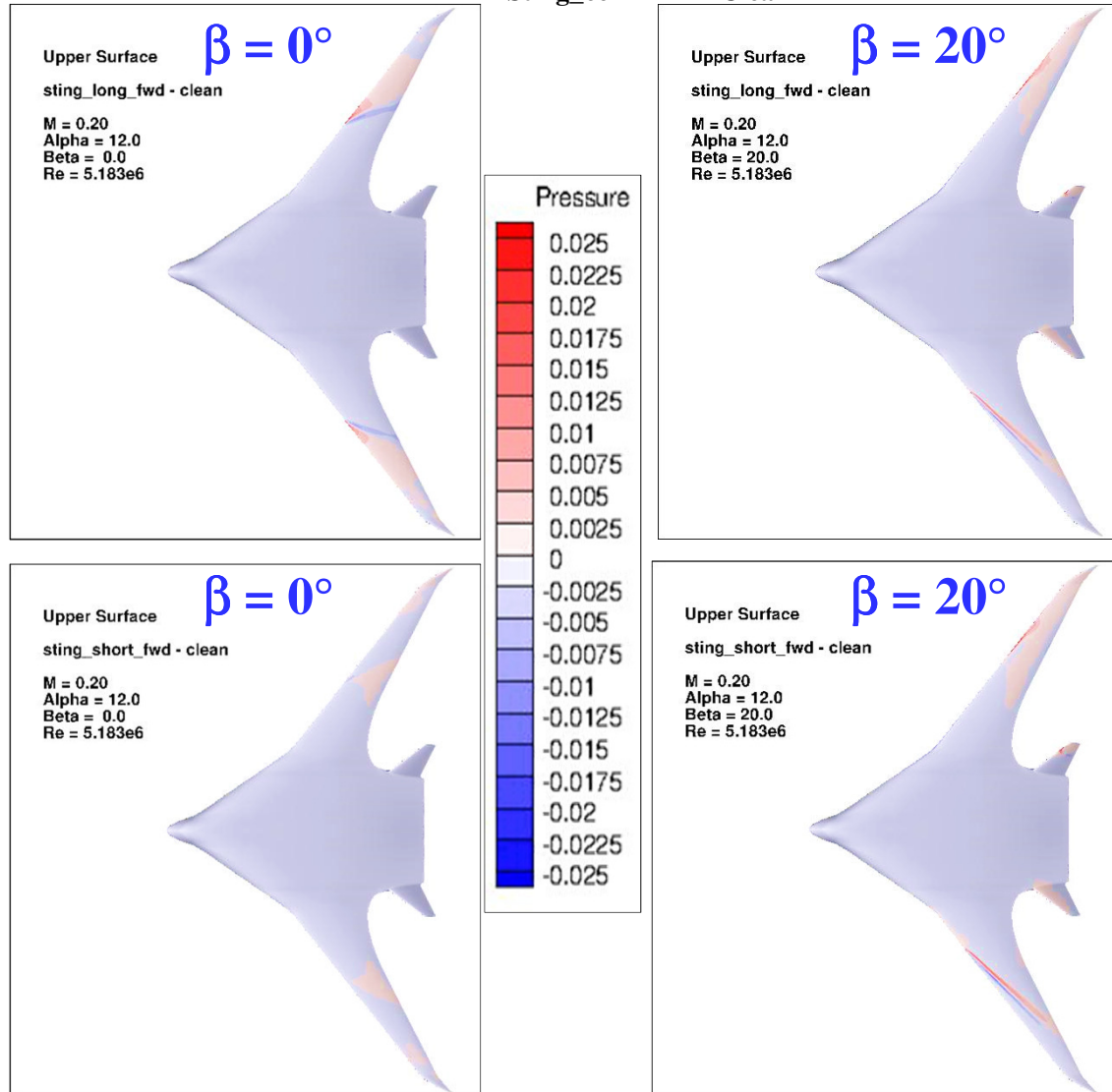


# Sting Selection



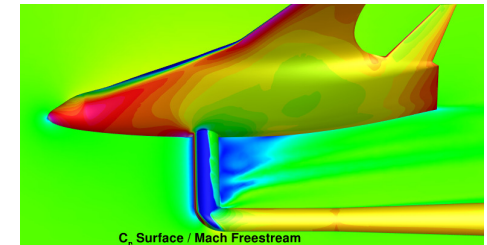
**OVERFLOW:  $M_\infty = 0.2$   $\alpha = 12^\circ$**

$$\Delta C_p = (C_{p_{\text{Sting\_conf}}} - C_{p_{\text{Clean}}})$$

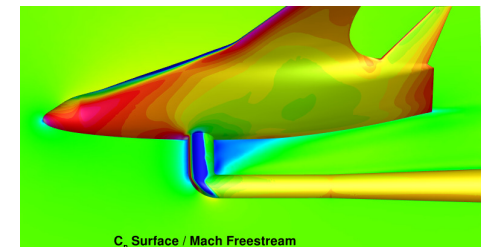


**USM3D:  $M_\infty = 0.2$   $\alpha = 20^\circ$**

**Long Forward Sting**



**Short Forward Sting**



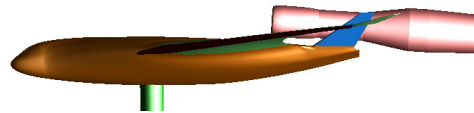
\*Simulations run in free air

# Ejector selection

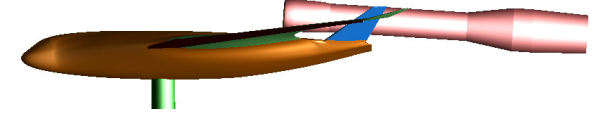


Overflow:  $M_\infty = 0.2$   $\alpha = 20^\circ$

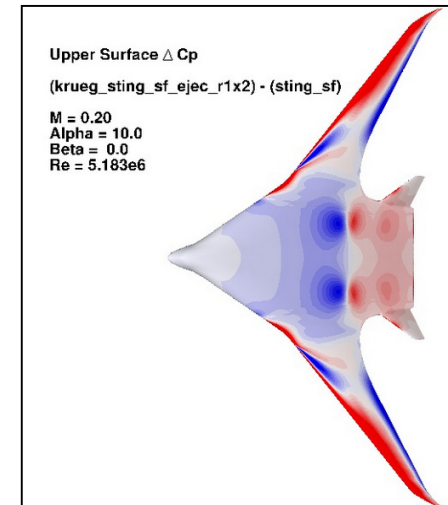
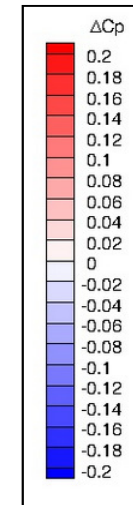
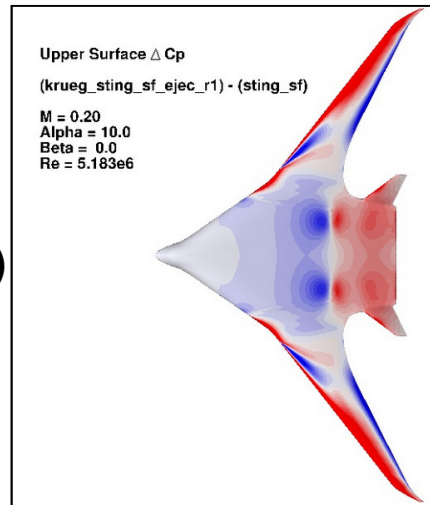
Short Ejector



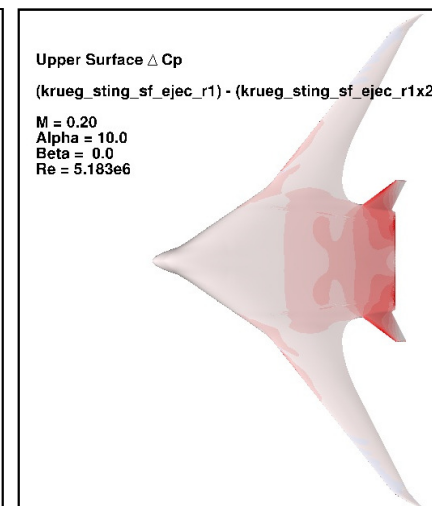
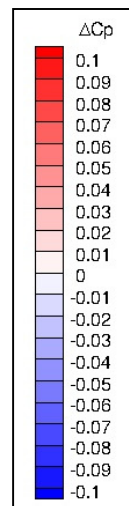
Long Ejector



$$\Delta C_p = (C_{p_{\text{Ejector\_conf}}} - C_{p_{\text{Clean}}})$$



$$\Delta C_p = (C_{p_{\text{ShortEject}}} - C_{p_{\text{LongEject}}})$$



\*Simulations run in free air

# 40'x80' Acoustic array selection



## Vertical Placement

Array at 24" below



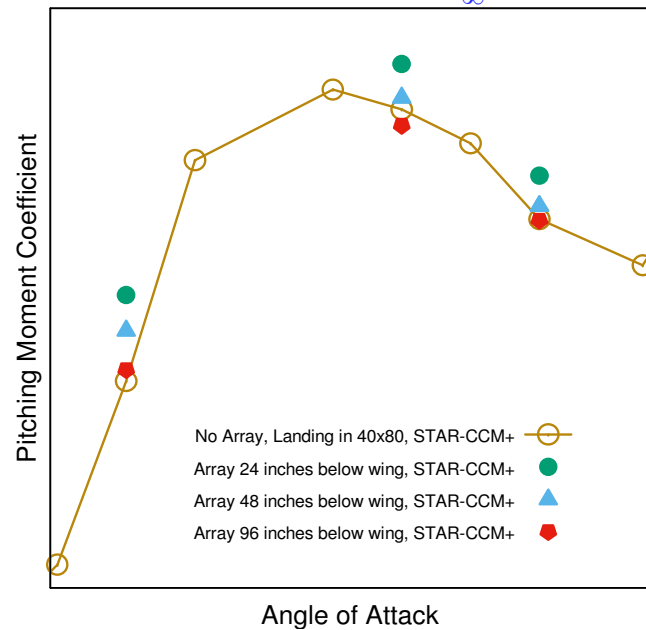
Array at 48" below



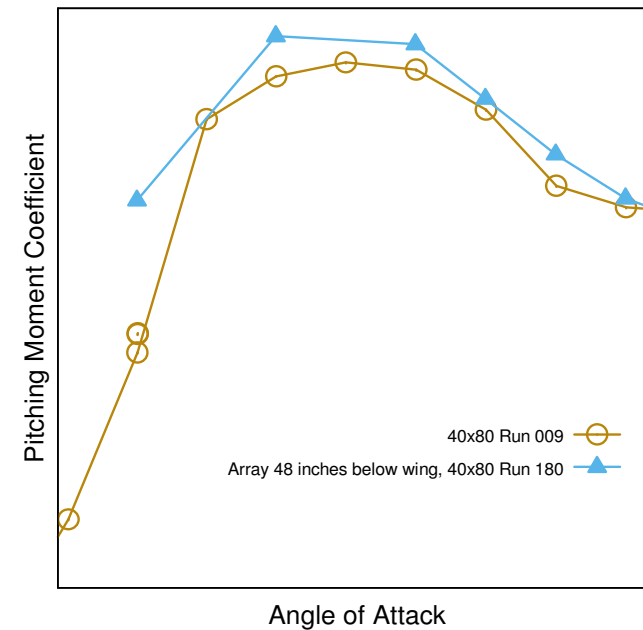
Array at 96" below



STAR-CCM+:  $M_\infty = 0.2$



40'x80' Wind tunnel data



# 40'x80' Acoustic array selection



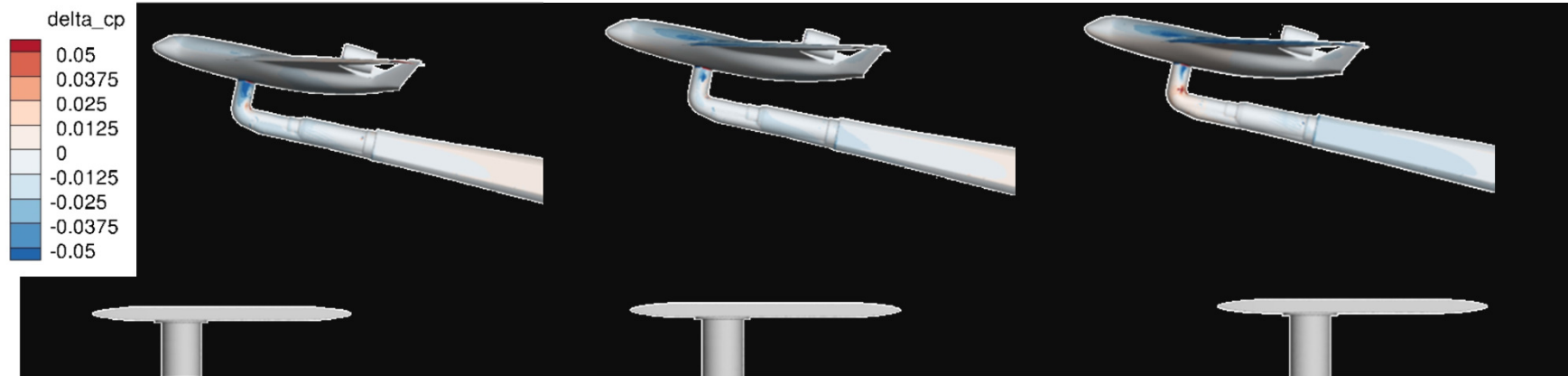
## Horizontal Placement

60° Directivity

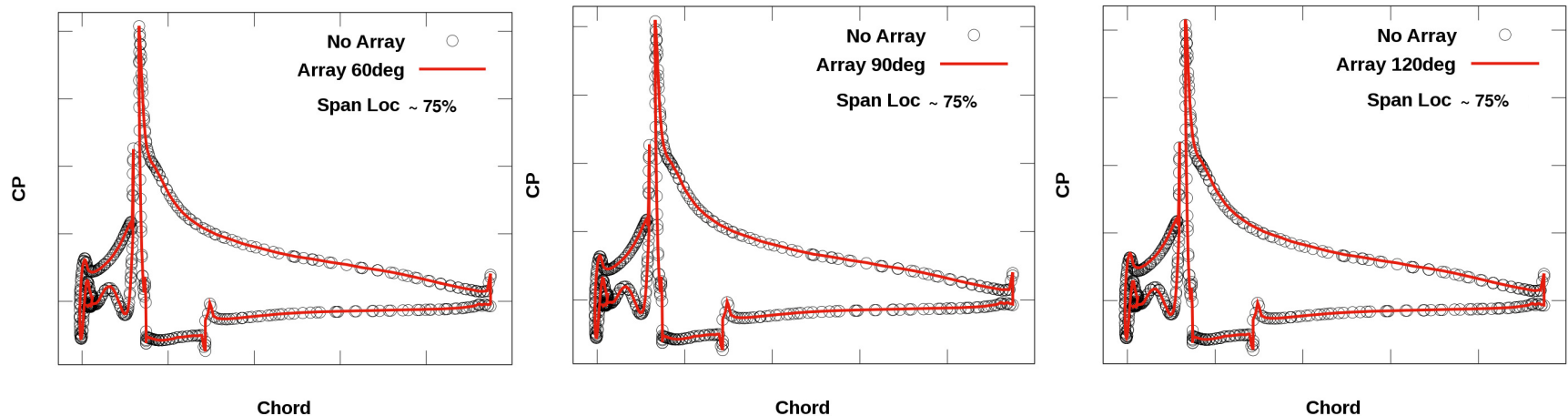
90° Directivity

120° Directivity

FUN3D:  $M_\infty = 0.2$   $\alpha = 12^\circ$



Cp comparison with and without Array at ~ 75% Span location



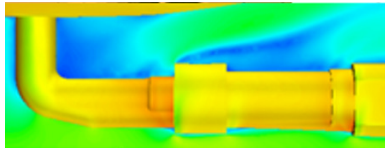
\* Simulations run with walls and supports 12



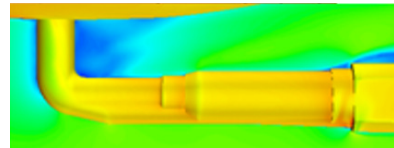
# 40'x80' sting installation



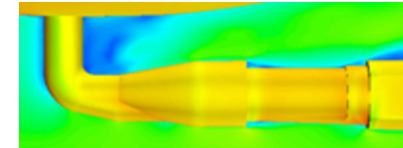
Original step collar



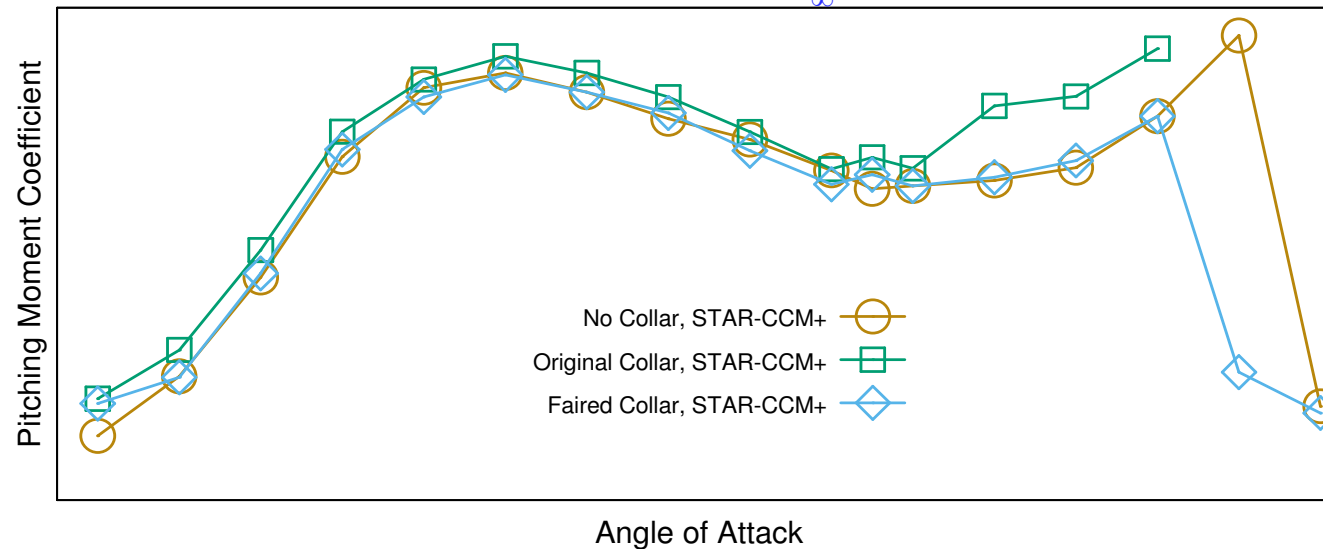
No collar



Faired collar



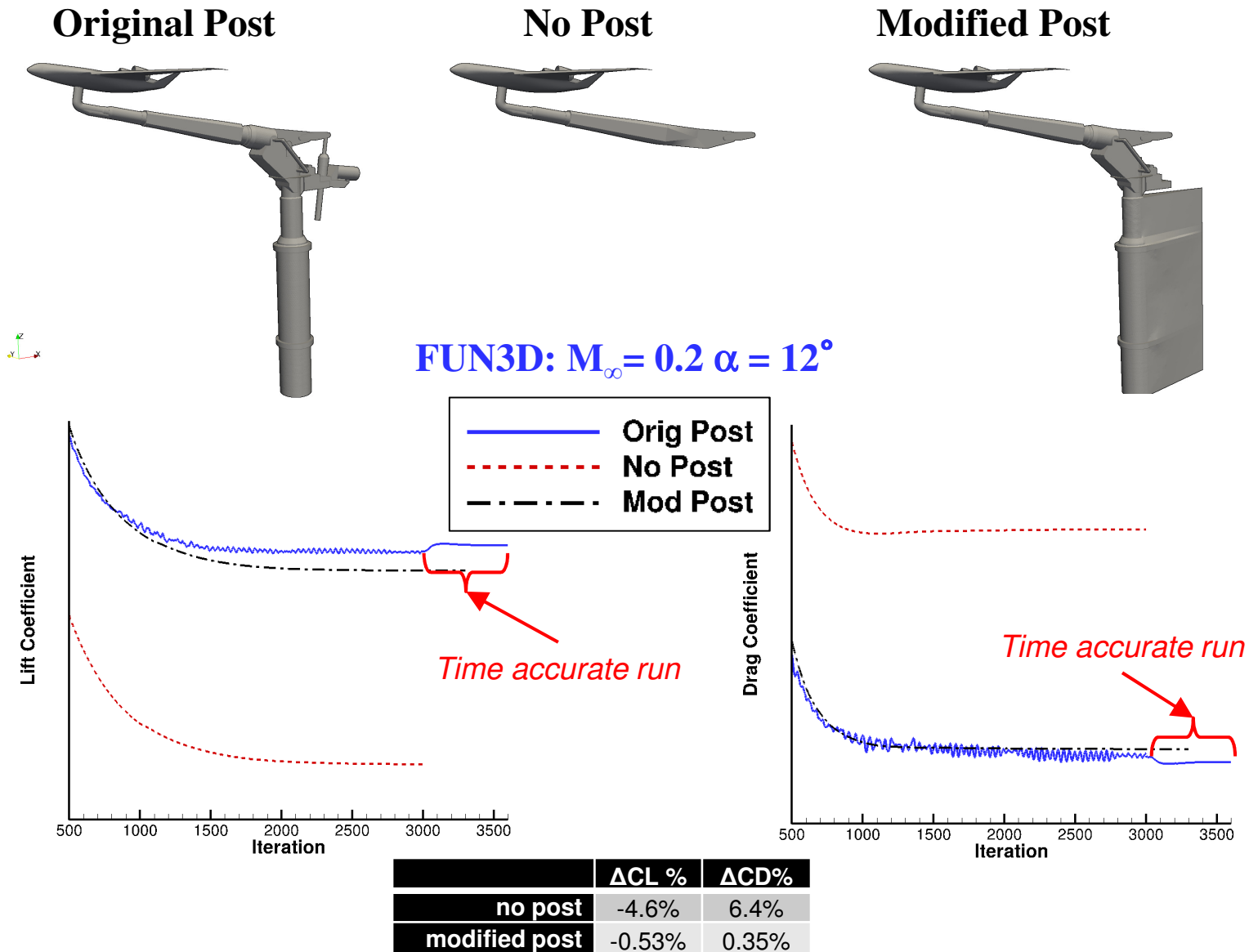
STAR-CCM+:  $M_\infty = 0.2$



\* Simulations run with walls and supports 13

# Lessons Learned & Simulation Guidelines

# Support Post Unsteadiness



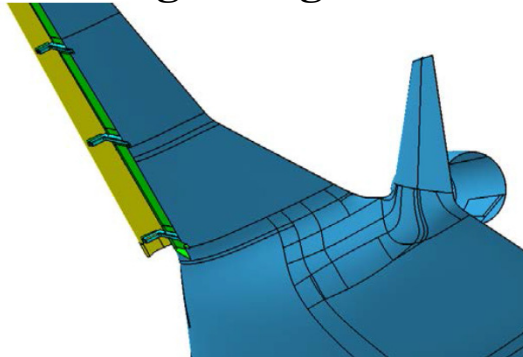
\* Simulations run with walls

# High Alpha CFD flow predictions

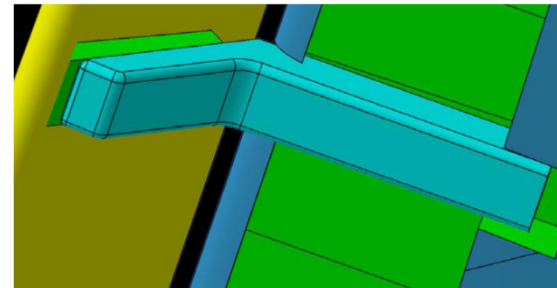


## Dependency on time integration process

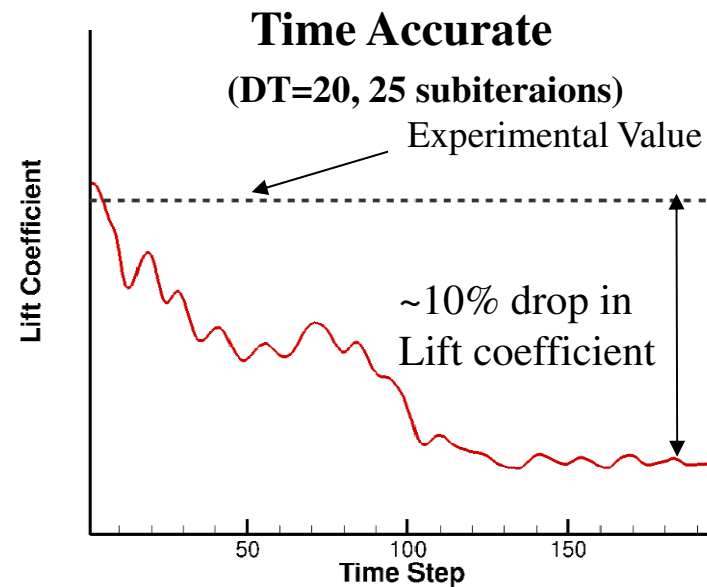
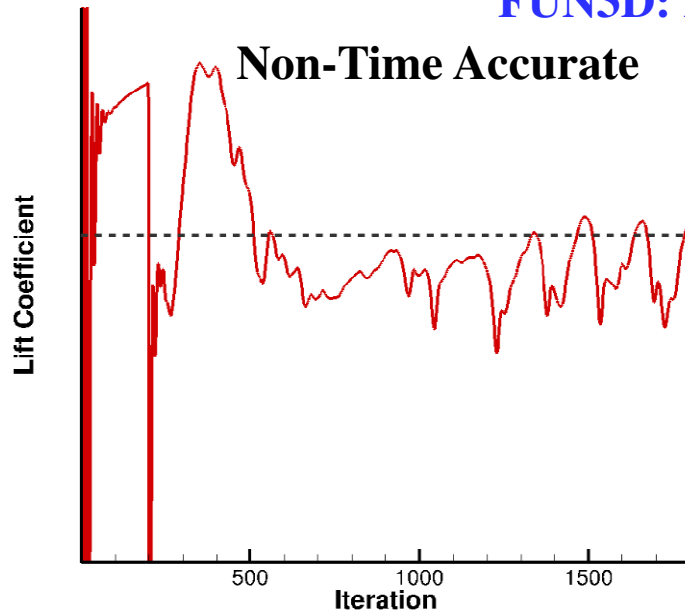
Landing Krueger



Krueger structural bracket



FUN3D:  $M_\infty = 0.2$   $\alpha = 20^\circ$



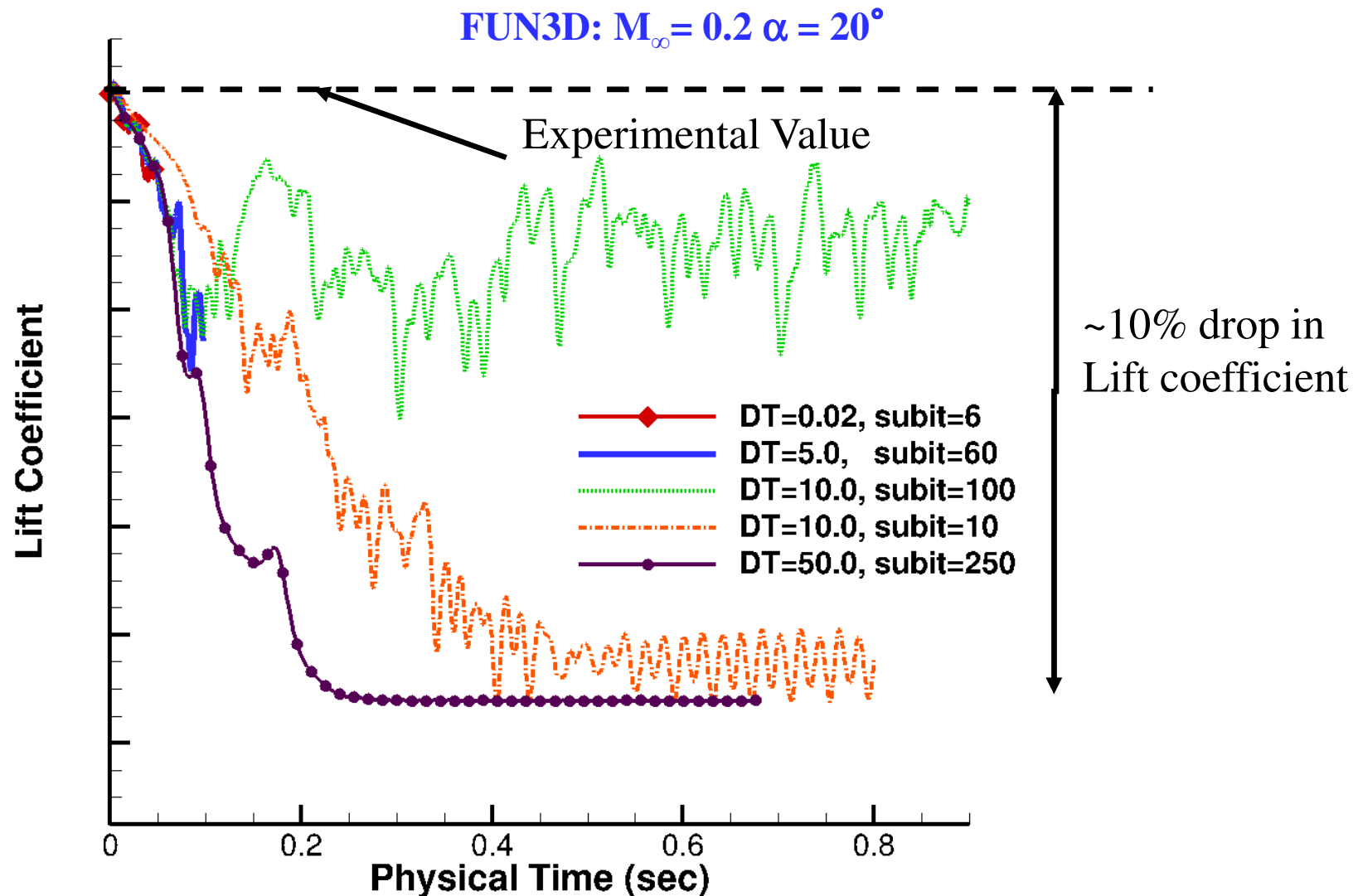
\*similar results obtained with Star-CCM+ using the SST turbulence model and with OVERFLOW using SA model.



# High Alpha CFD flow predictions



## Time accuracy study effect on HWB landing configuration

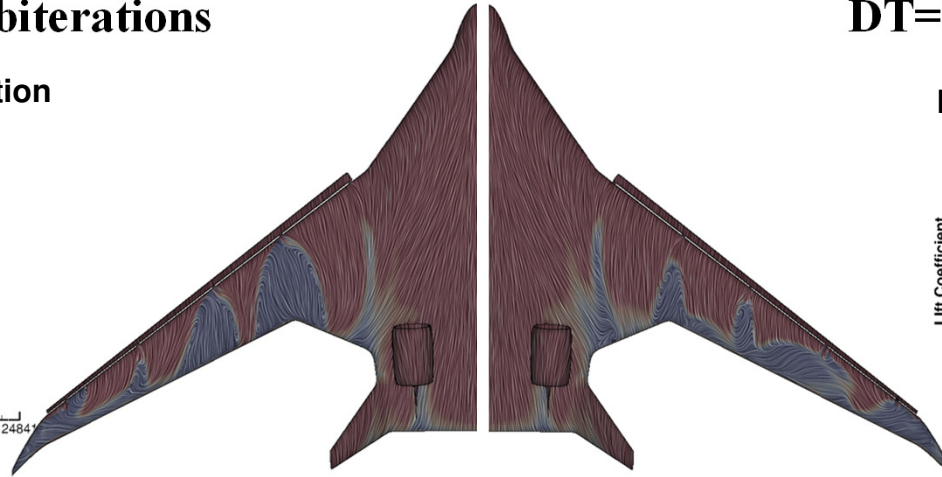
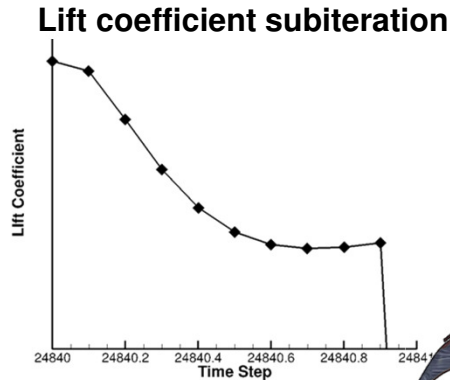


# High Alpha CFD flow predictions

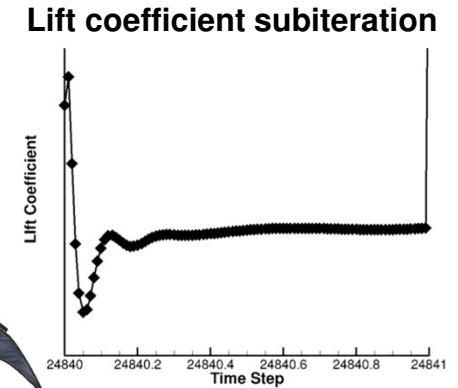


FUN3D:  $M_\infty = 0.2$   $\alpha = 20^\circ$

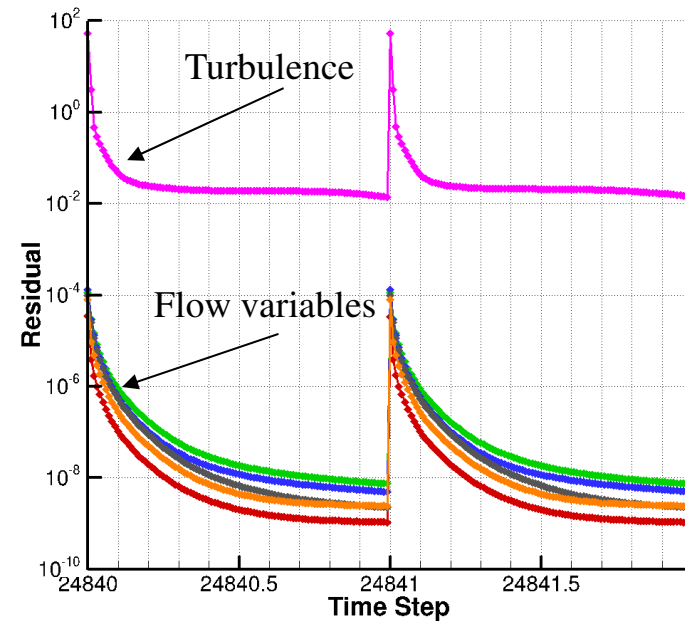
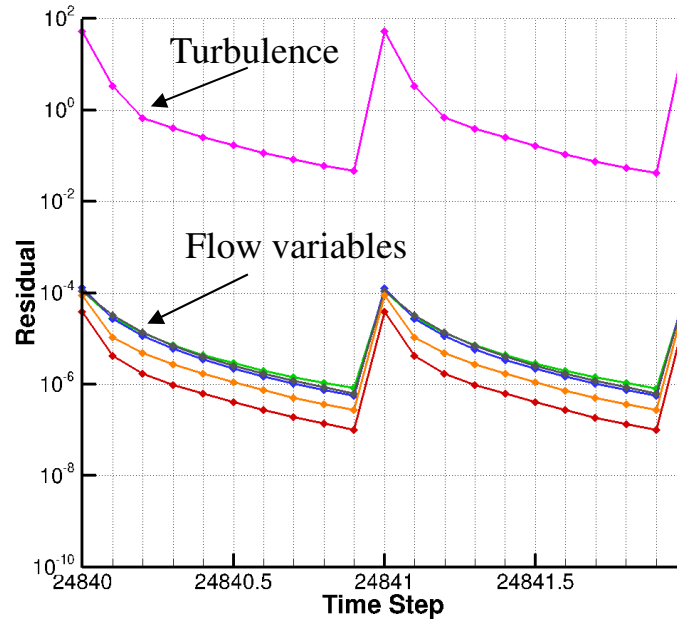
DT=10, 10 subiterations



DT=10, 100 subiterations



Residual subiteration Convergence



# Conclusions



- CFD was an integral part of NASA's ERA project.
  - Supported experimentalists in evaluating interference
  - Provided alternate support options to reduce unwanted effects
- Efficient use of multiple CFD solvers successfully used to provide timely insight.
  - NASA's CFD solvers: OVERFLOW, USM3D, and FUN3D
  - Commercial CFD solver STAR-CCM+
- CFD analyst worked side-by-side with wind tunnel experimentalists throughout entire project.
  - Enabled direct knowledge on specific testing setup
  - Provided key insight to how test data was measured and post-processed for later CFD analysis.
- Lessons Learned and CFD simulation guideline development possible due to available test data.

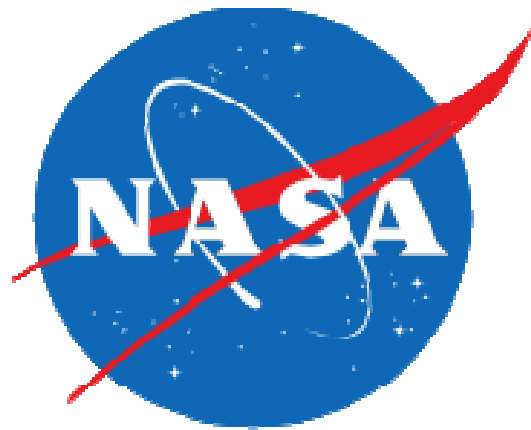
# Acknowledgements

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- The NASA ARMD Environmentally Responsible Aviation Project provided multi-year funding for both the wind tunnel testing and CFD analysis.
- Boeing support staff played an integral part in the success of the tests





# Time Step Selection Rationale

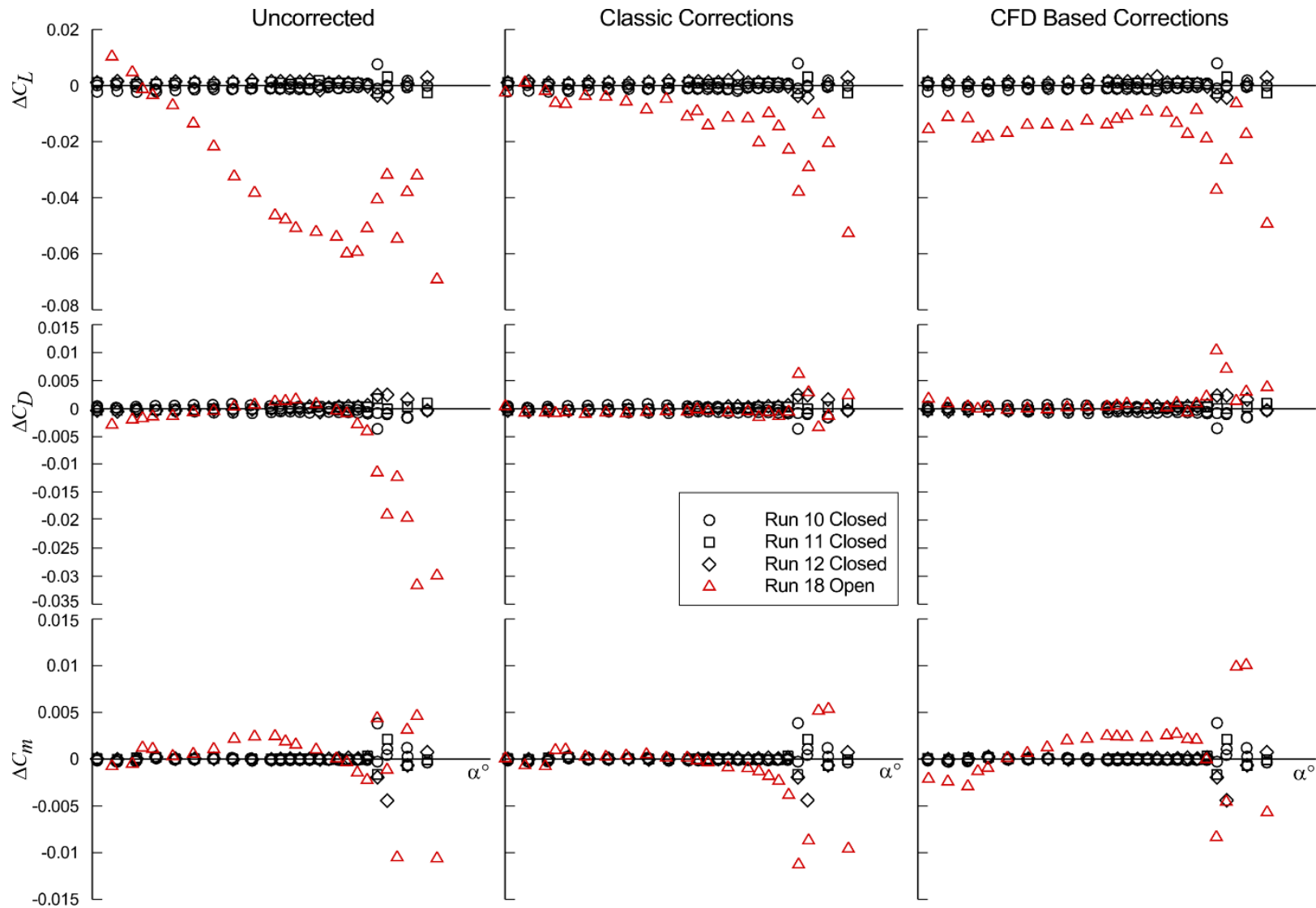


The rationale used to select these CFD time steps was to express them in terms of a physical vortex shedding Strouhal number ( $St$ ) of 0.25. This was done since the nominal Strouhal number of many unsteady separated wake flows tends to fall into a small range between 0.15 and 0.25. Further, the Strouhal number is defined as:  $St = fL/U$ . Where,  $f$  is the frequency,  $L$  is the relevant length scale, and  $U$  is the relevant velocity. In order to express  $St$  in terms of a CFD time step ( $DT$ ), the Strouhal number equation is rewritten such that the frequency  $f=1/DT$ , and the velocity  $U$  is set to freestream ( $U^\infty$ ). In FUN3D, the time step is normalized by the sound speed. This will then yield what is referred to as the time step based Strouhal number ( $StDT$ ) as follows:  $StDT = L/(DT \cdot M^\infty)$  in terms of the FUN3D grid units. Next, the ratio of the time step Strouhal number ( $StDT$ ) to the physical Strouhal number ( $St$ ) is used as a coarse measure of time integration accuracy. For good time accuracy, this Strouhal ratio,  $StDT/St$  must be at least 20, as the second-order backwards-difference time-integration scheme requires roughly that many points per period assuming a simple sinusoidal oscillation for high accuracy. An even higher ratio is needed if any part of the unsteady flow changes more rapidly than the gross features like integrated loads, and this is very common. Thus, the ratio of Strouhal numbers,  $StDT/St$  should be 20 or greater, by an unknown amount, to achieve good time accuracy.

# 14'x22' Wind Tunnel Corrections

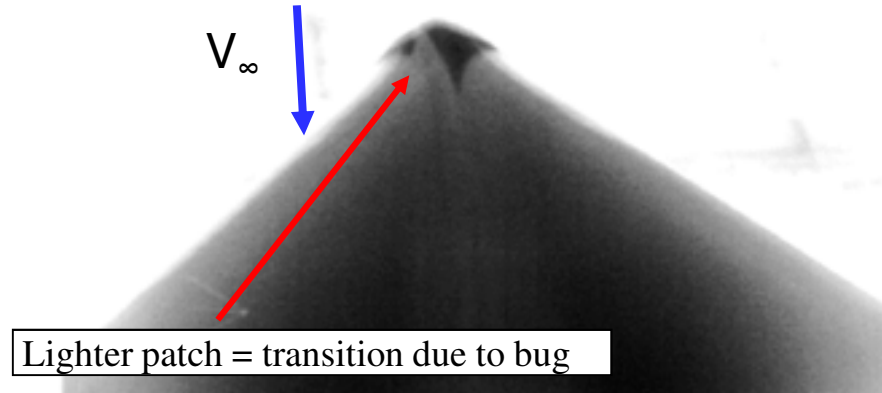
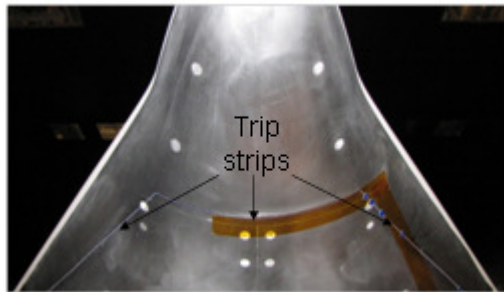


CFD Wind Tunnel Support



# Trip dot selection

## Upper Surface Thermal Imaging **With** Trip Dots



## Upper Surface Thermal Imaging **Without** Trip Dots

