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

Joseph A. Garcia, John E. Melton, Michael Schuh, Kevin D. James,
Kurt R. Long
NASA Ames Research Center

Dan D. Vicroy, Karen A. Deere, James M. Luckring,
Melissa B. Carter, Jeffrey D. Flamm
NASA Langley Research Center

Paul M. Stremel, Ben E. Nikaido,
Robert E. Childs
Science and Technology Corporation

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Outline

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

Overview

- 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

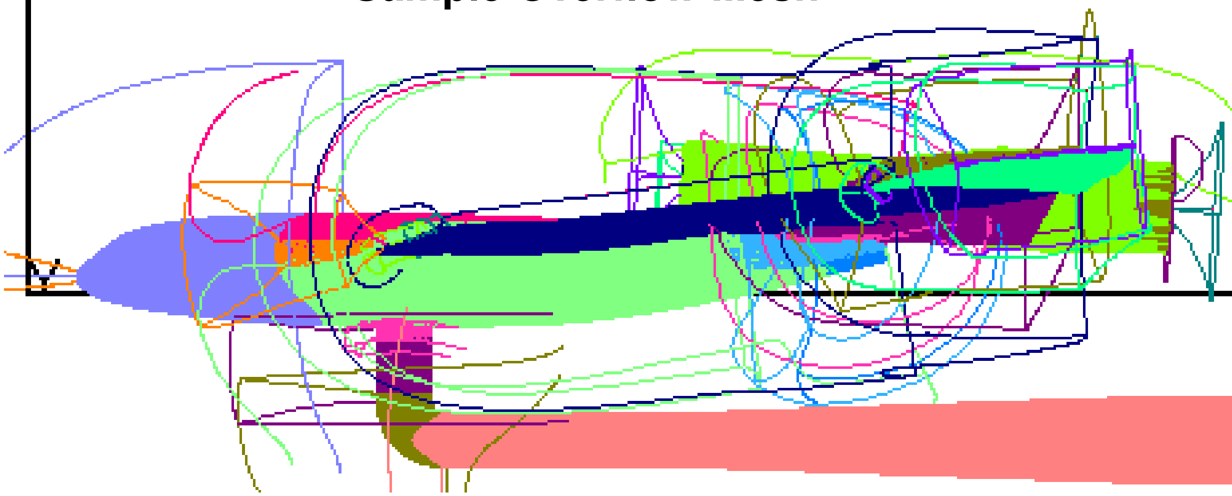
Efficient use of Multiple CFD Tools

- 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

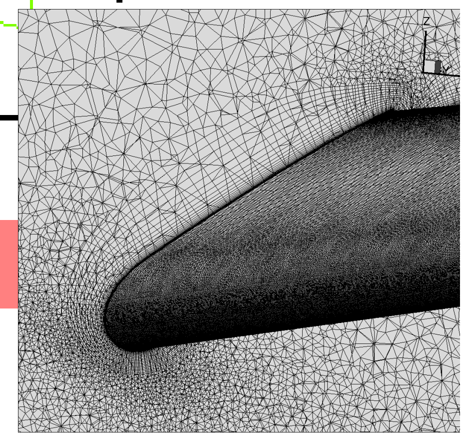
Geometry and Mesh Generation

Efficient use of Multiple CFD Tools

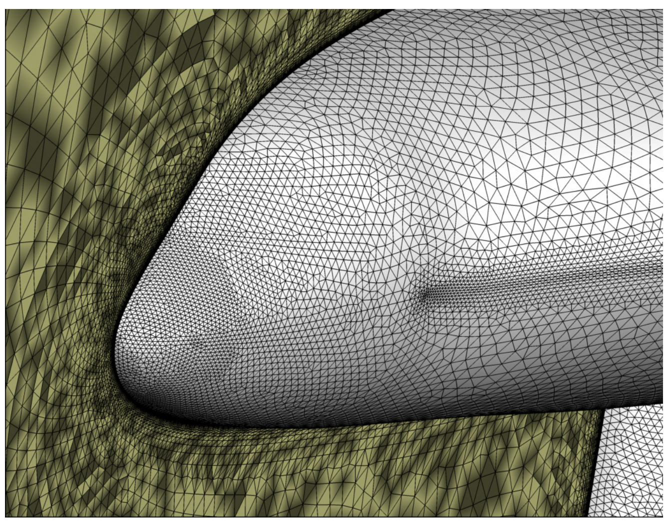
Sample Overflow Mesh



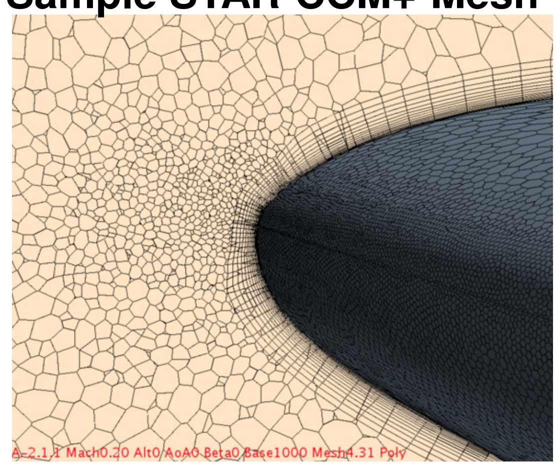
Sample FUN3D Mesh



Sample USM3D Mesh



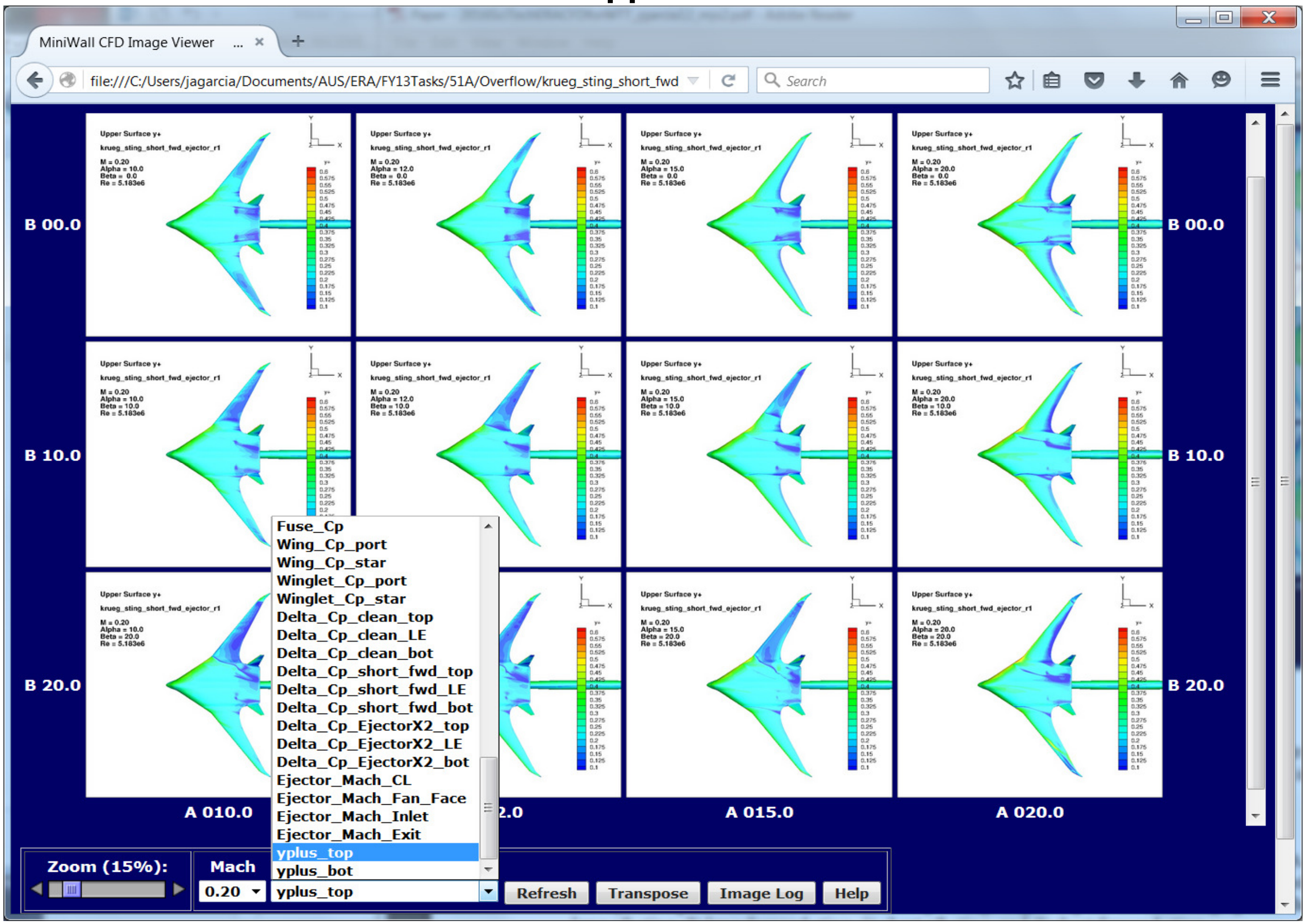
Sample STAR-CCM+ Mesh



CFD Quality Assessment

CFD Quality Assessment

'Miniwall' Application



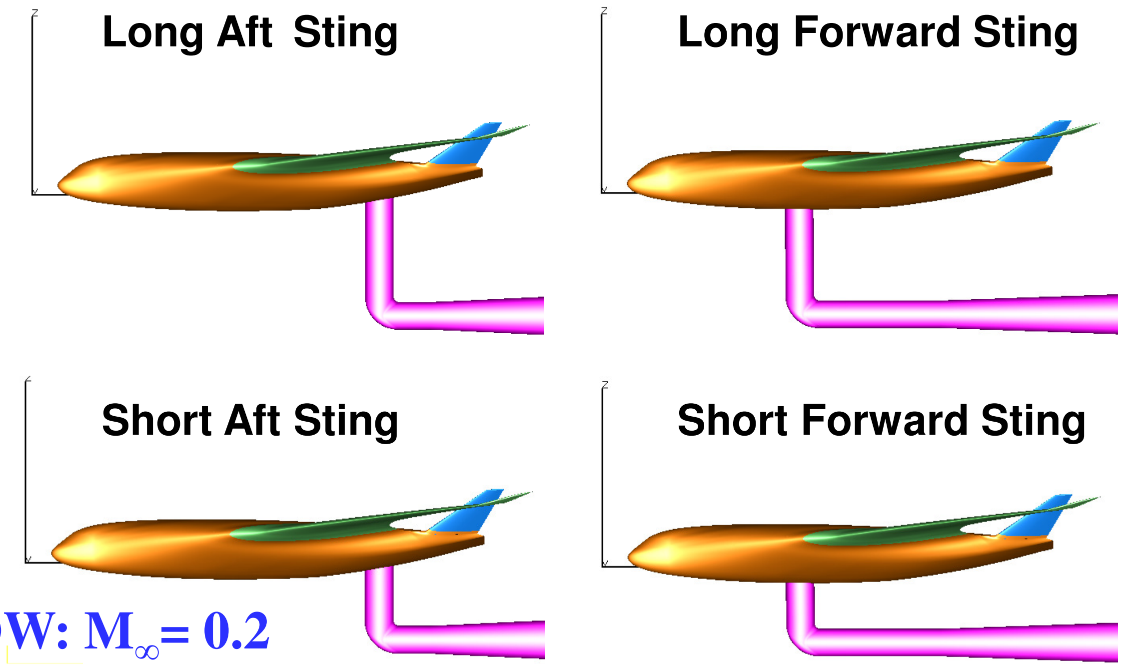
CFD Wind Tunnel Support

CFD was used to provide highest quality experimental testing

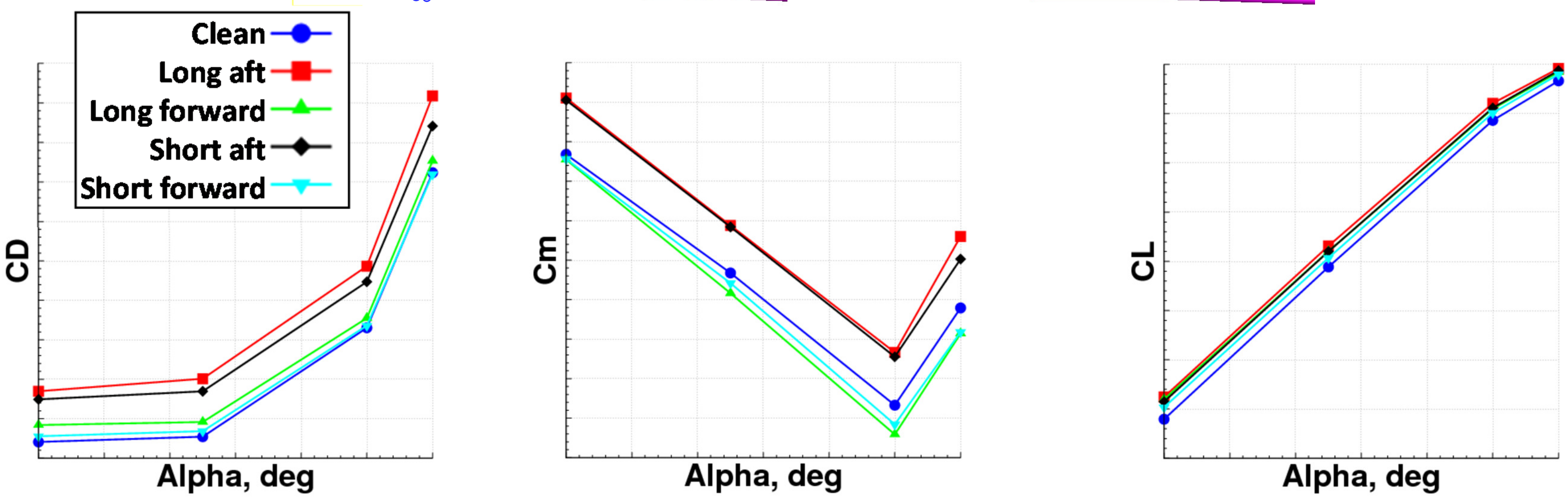
- Sting selection
- Ejector selection
- Acoustic array selection
- 40’x80’ sting installation

Sting Selection

CFD Wind Tunnel Support



OVERFLOW: $M_{\infty} = 0.2$



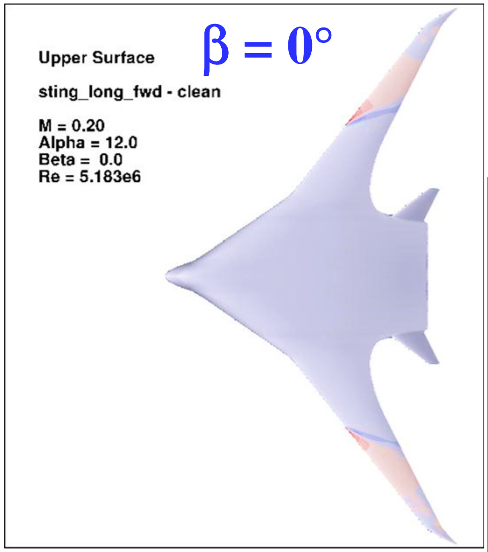
*Simulations run in free air

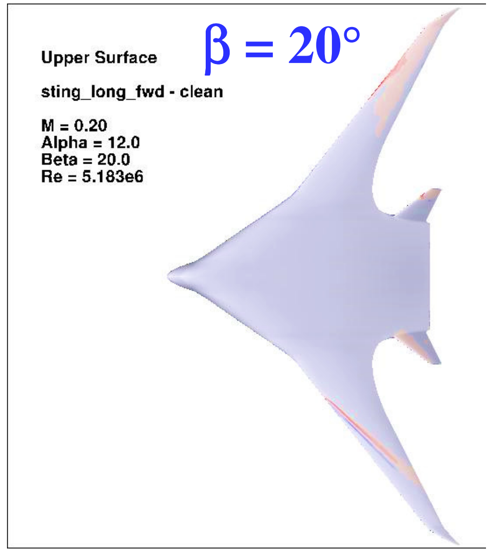
Sting Selection

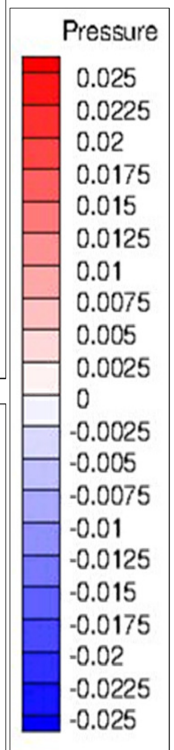
CFD Wind Tunnel Support

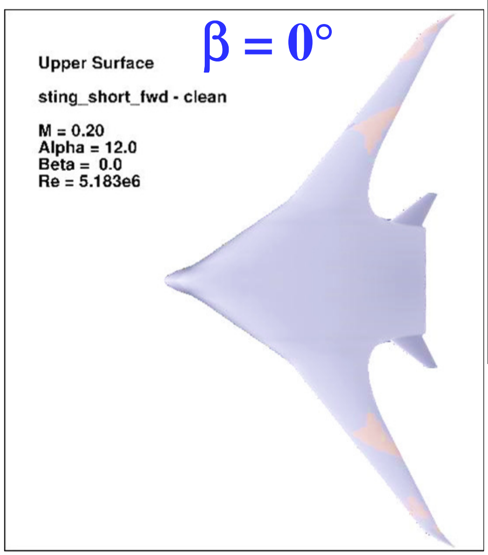
OVERFLOW: $M_\infty = 0.2$ $\alpha = 12°$

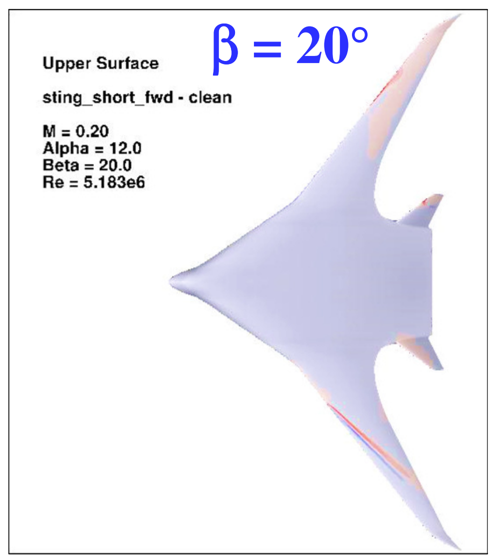
$\Delta Cp = (Cp_{Sting\_conf} - Cp_{Clean})$





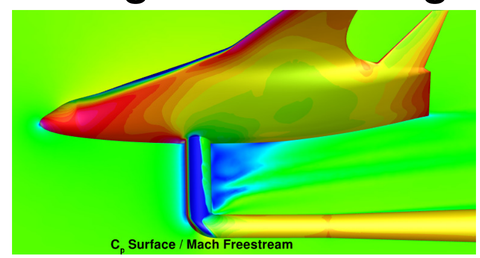




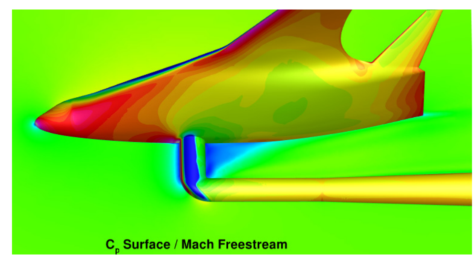


USM3D: $M_\infty = 0.2$ $\alpha = 20°$

Long Forward Sting



Short Forward Sting



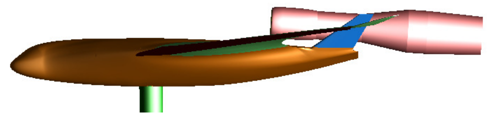
*Simulations run in free air

Ejector selection

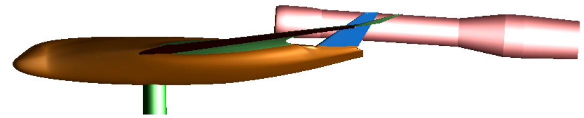
CFD Wind Tunnel Support

Overflow: $M_\infty = 0.2$ $\alpha = 20°$

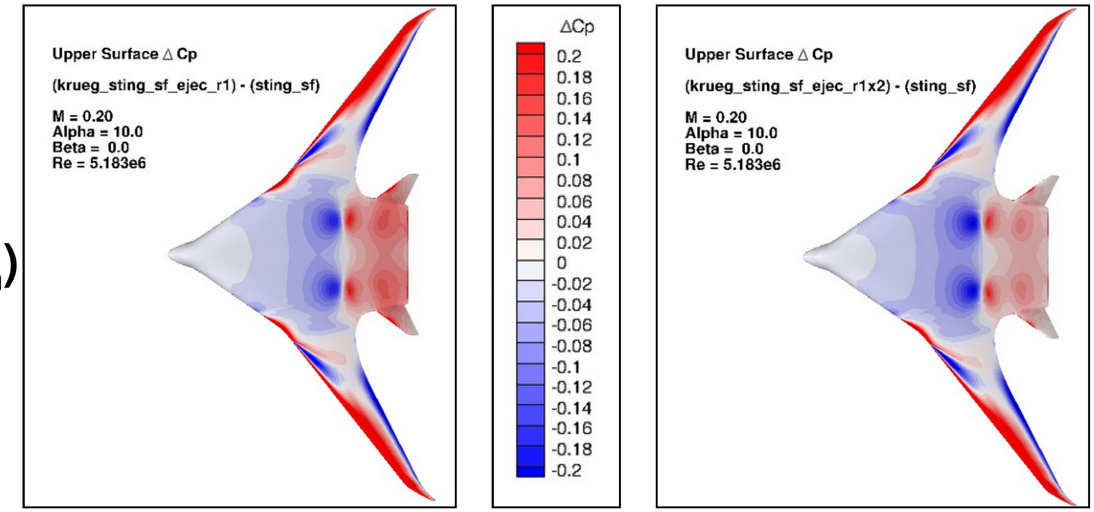
Short Ejector



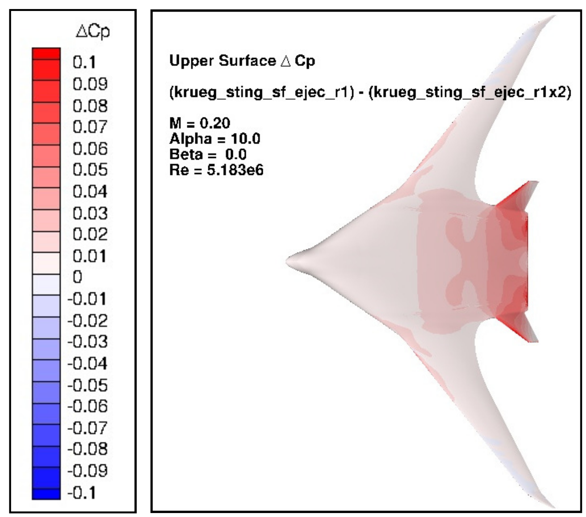
Long Ejector



$\Delta Cp = (Cp_{Ejector\_conf} - Cp_{Clean})$



$\Delta Cp = (Cp_{ShortEject} - Cp_{LongEject})$



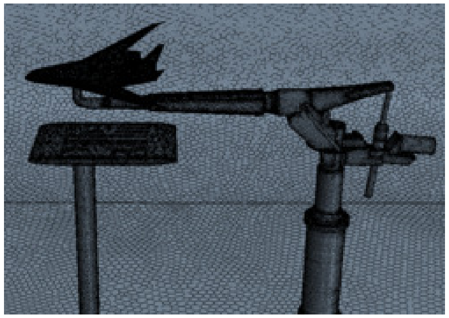
*Simulations run in free air

40’x80’ Acoustic array selection

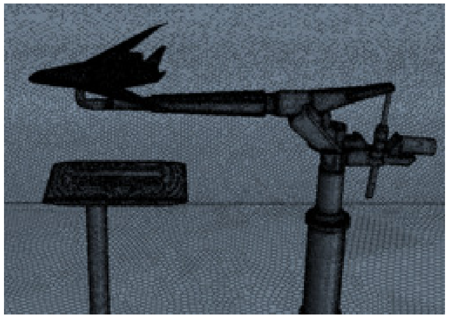
CFD Wind Tunnel Support

Vertical Placement

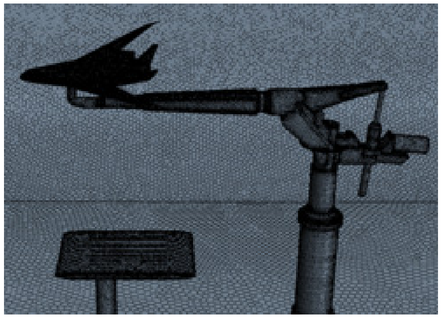
Array at 24” below



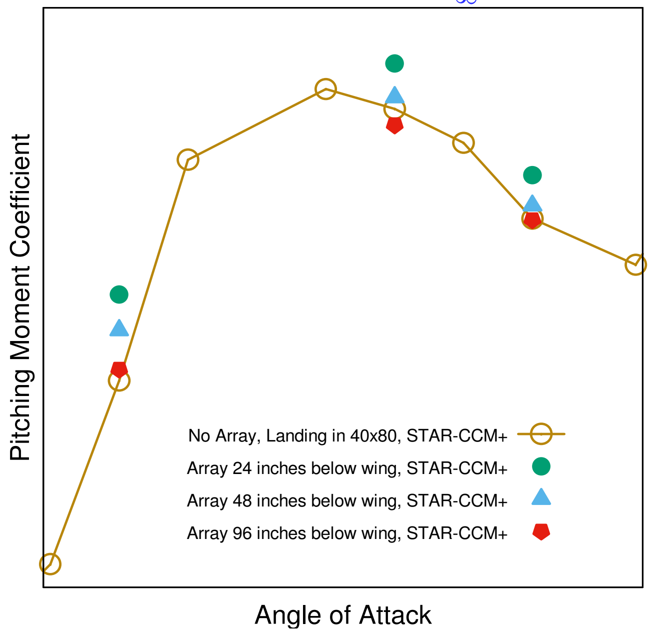
Array at 48” below



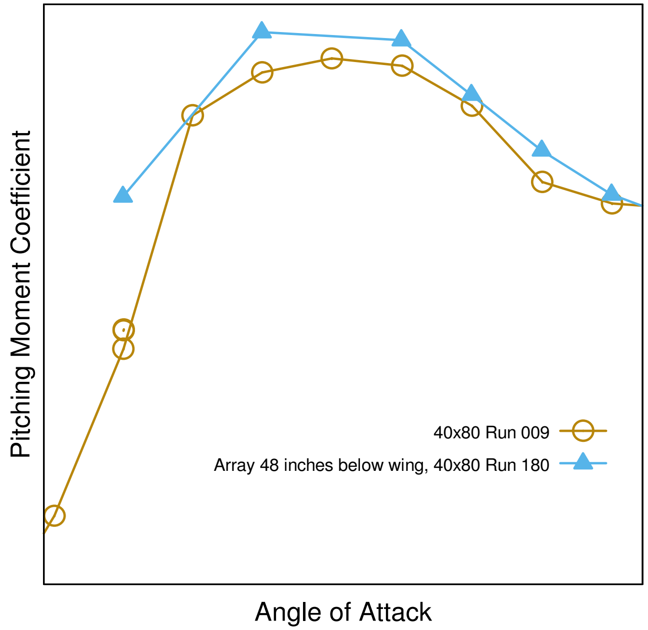
Array at 96” below



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



40’x80’ Wind tunnel data



* Simulations run with walls and supports

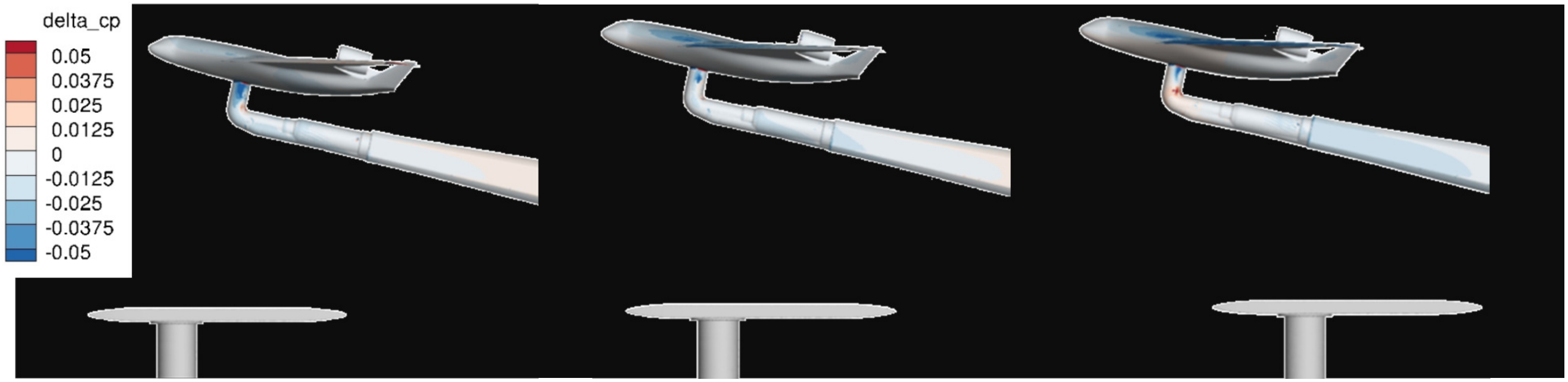
40’x80’ Acoustic array selection

CFD Wind Tunnel Support

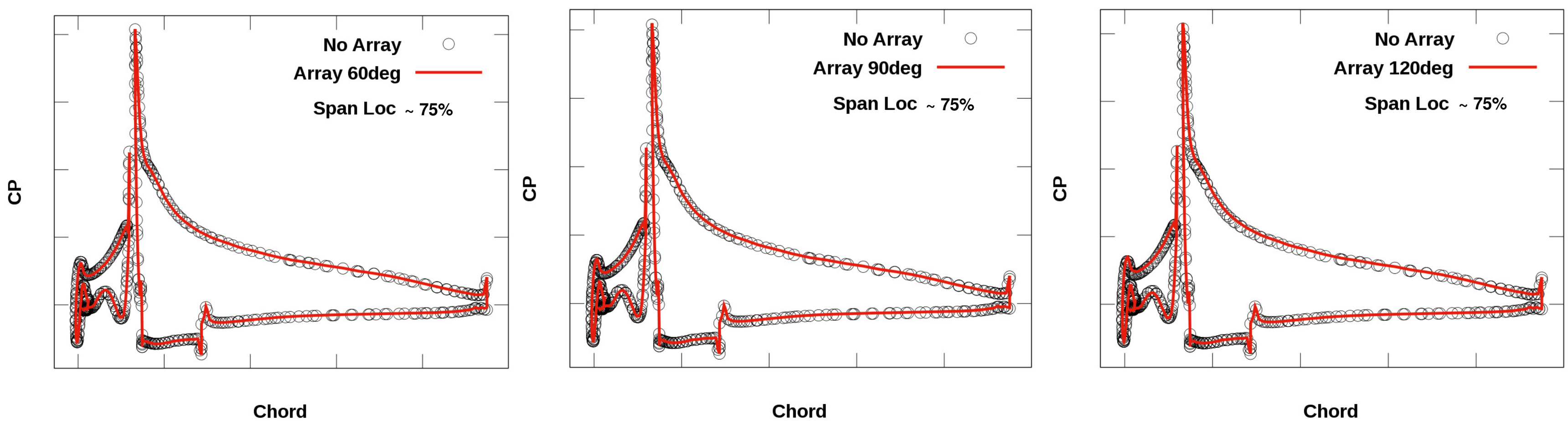
Horizontal Placement

60° Directivity   90° Directivity   120° Directivity

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



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

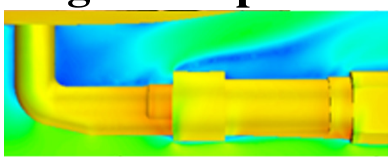


* Simulations run with walls and supports

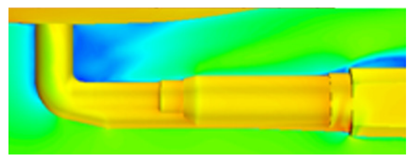
40’x80’ sting installation

CFD Wind Tunnel Support

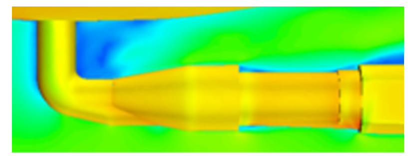
Original step collar



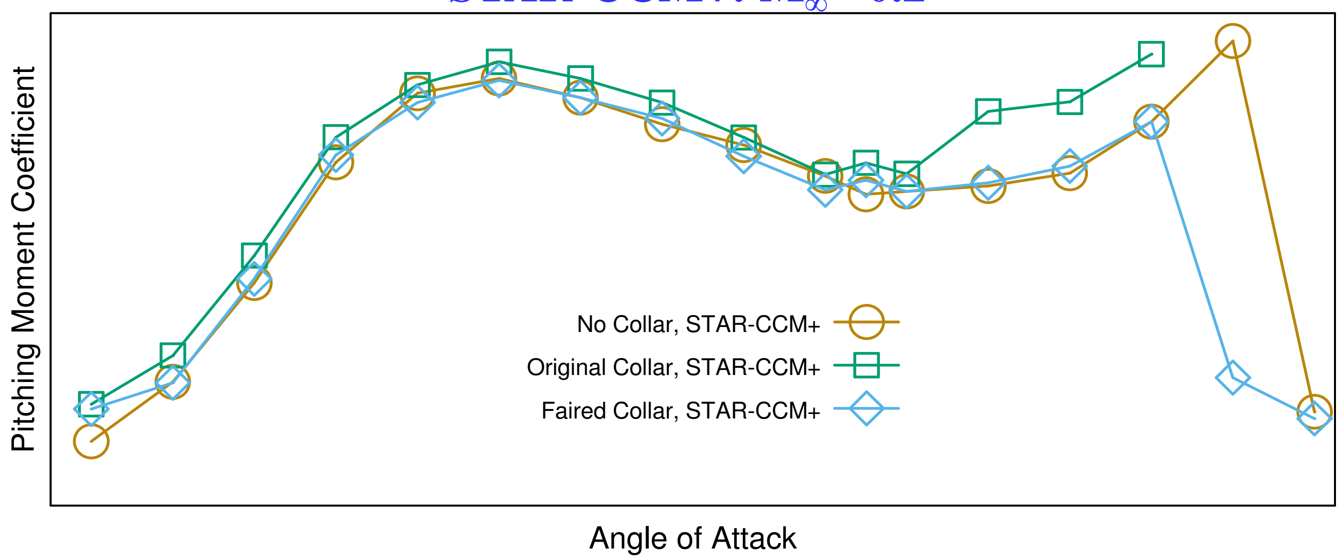
No collar



Faired collar



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



* Simulations run with walls and supports

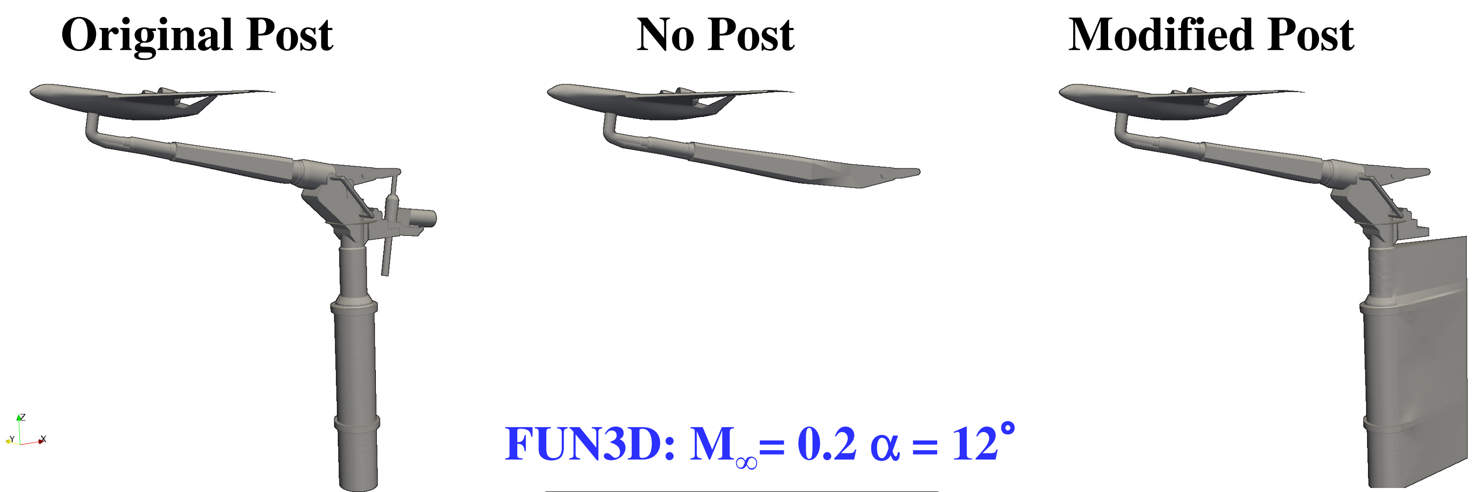
Lessons Learned & Simulation Guidelines

Lessons Learned

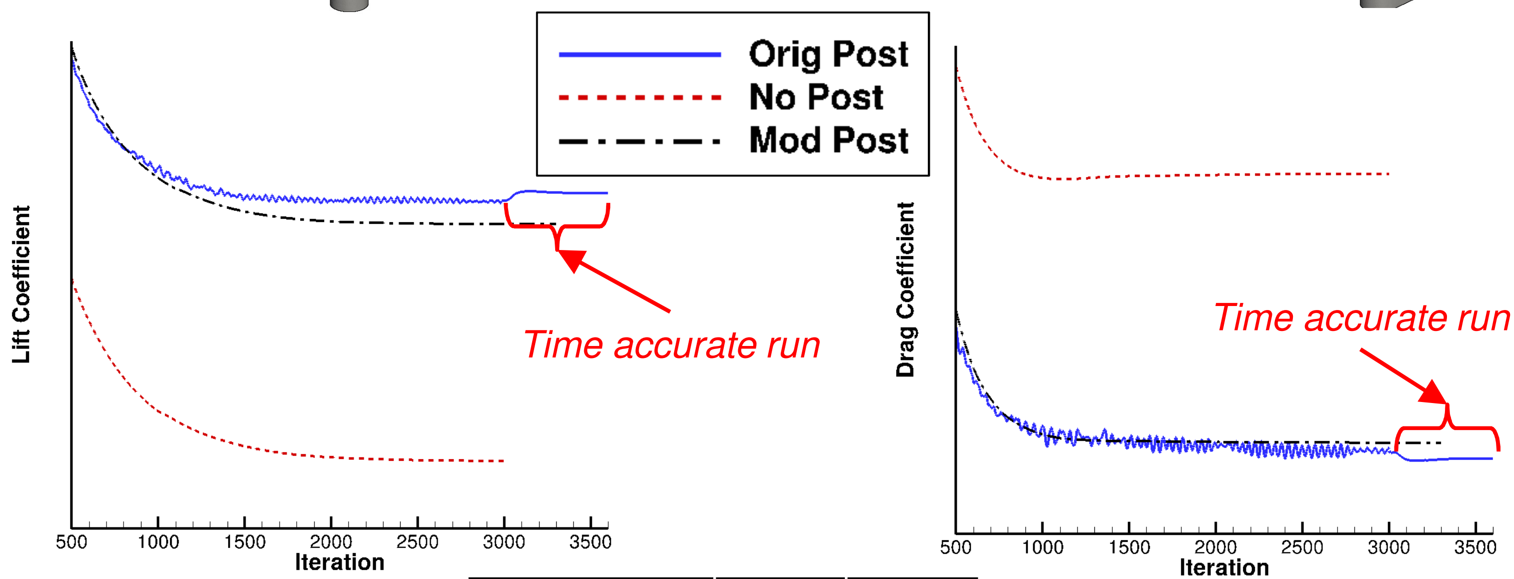
&

Simulation Guidelines

Support Post Unsteadiness



FUN3D: $M_\infty = 0.2$ $\alpha = 12°$



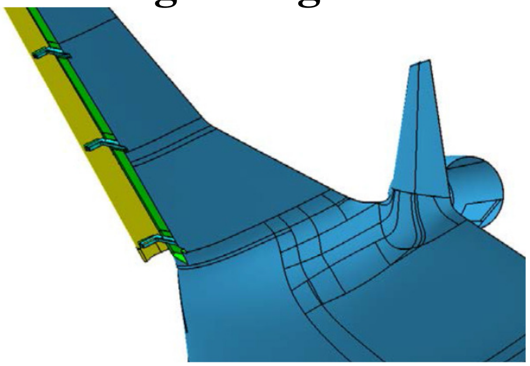
	ΔCL %	ΔCD%
no post	-4.6%	6.4%
modified post	-0.53%	0.35%

* Simulations run with walls

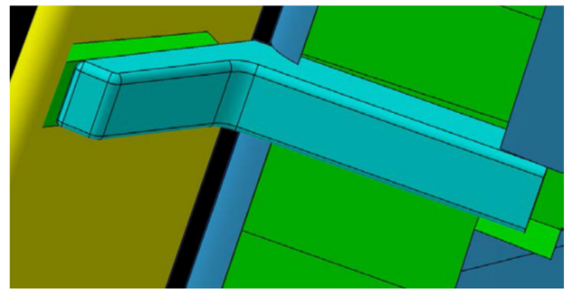
High Alpha CFD flow predictions

Dependency on time integration process

Landing Krueger

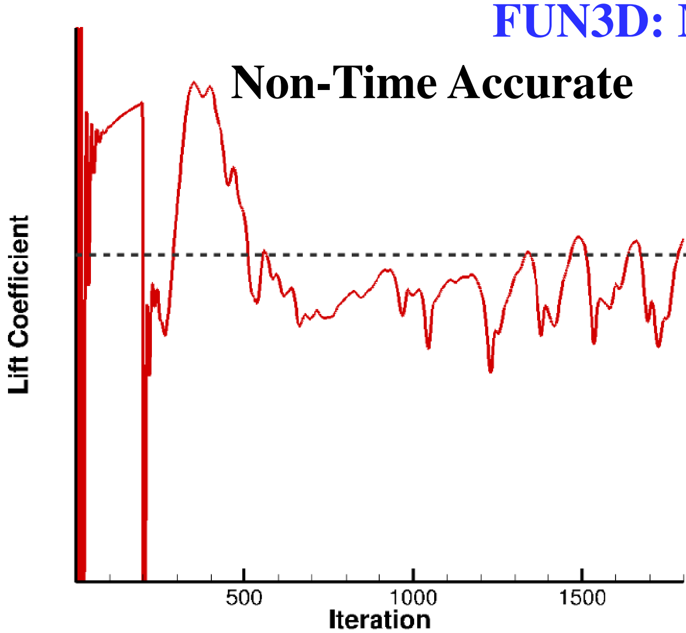


Krueger structural bracket



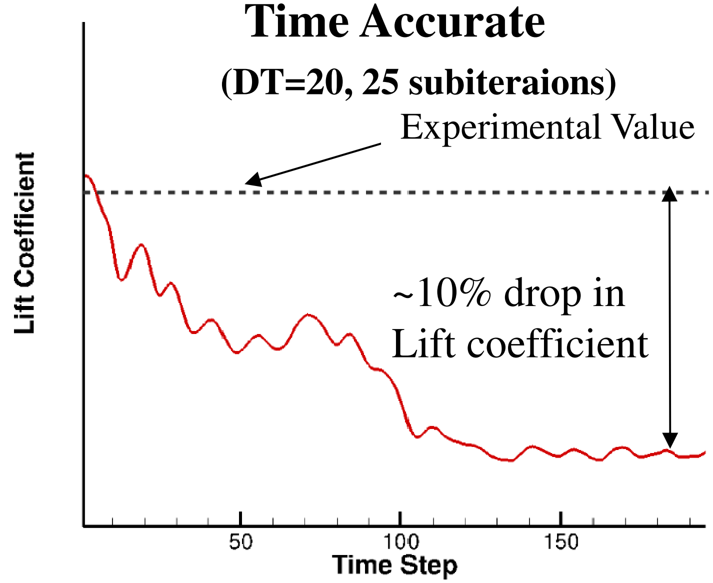
FUN3D: $M_\infty = 0.2$ $\alpha = 20^\circ$

Non-Time Accurate



Time Accurate

(DT=20, 25 subiteraions)

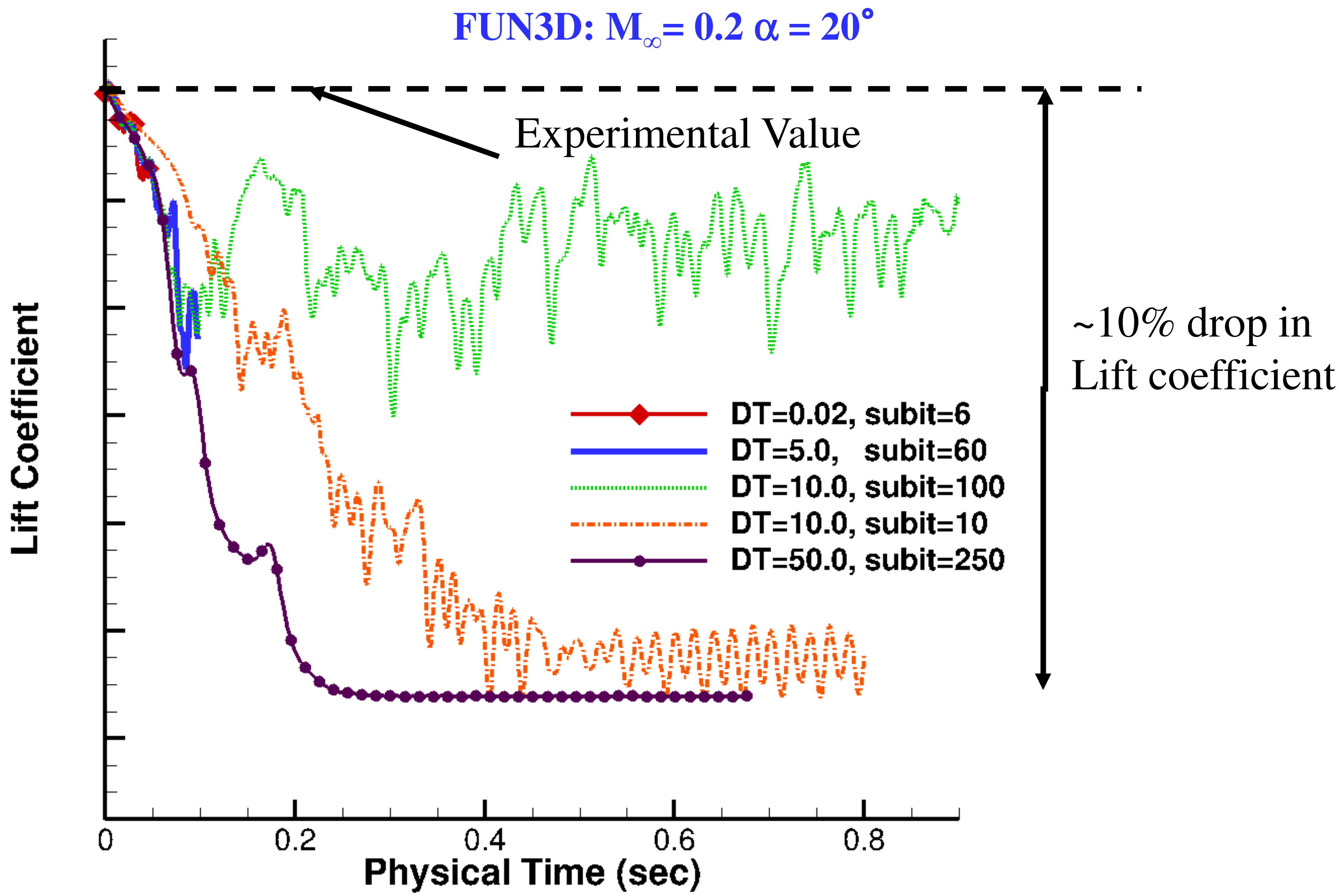


**similar results obtained with Star-CCM+ using the SST turbulence model and with OVERFLOW using SA model.*

High Alpha CFD flow predictions

Lessons Learned & Simulation Guidelines

Time accuracy study effect on HWB landing configuration

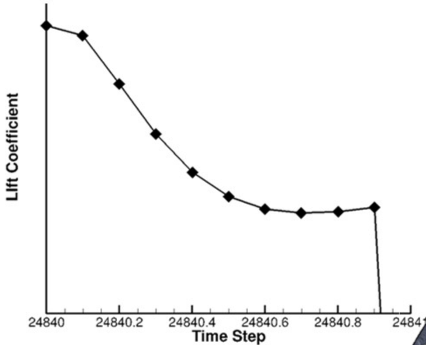


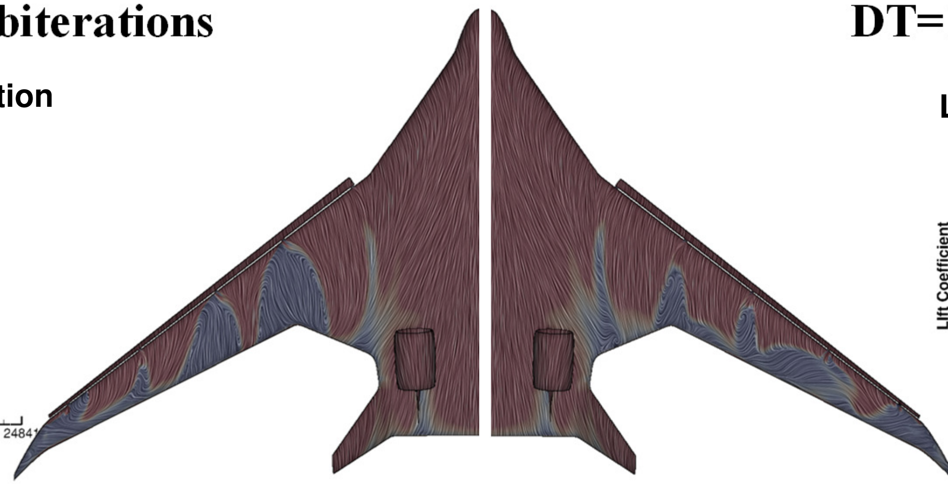
High Alpha CFD flow predictions

FUN3D: $M_\infty = 0.2$ $\alpha = 20°$

DT=10, 10 subiterations

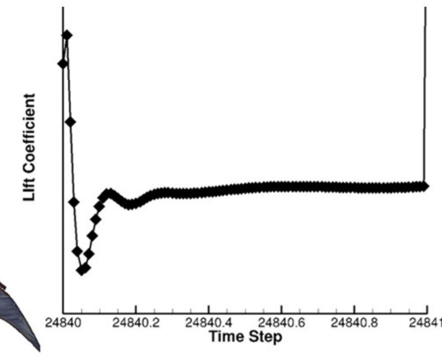
Lift coefficient subiteration



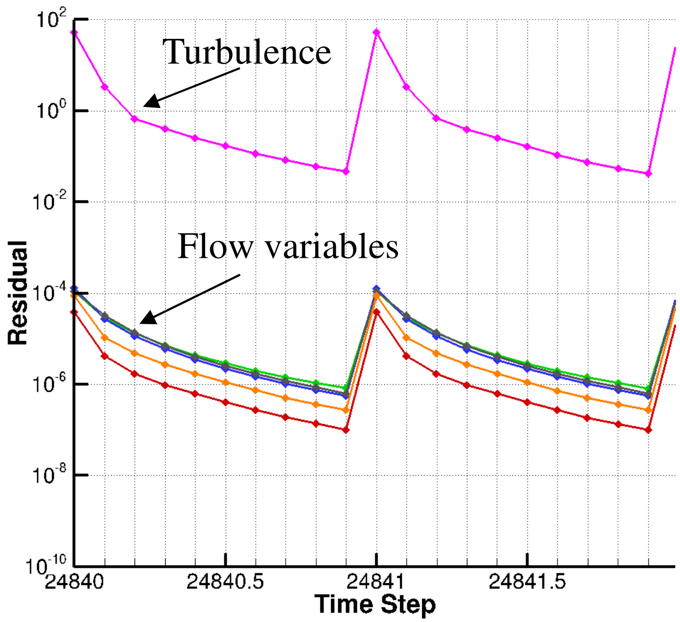


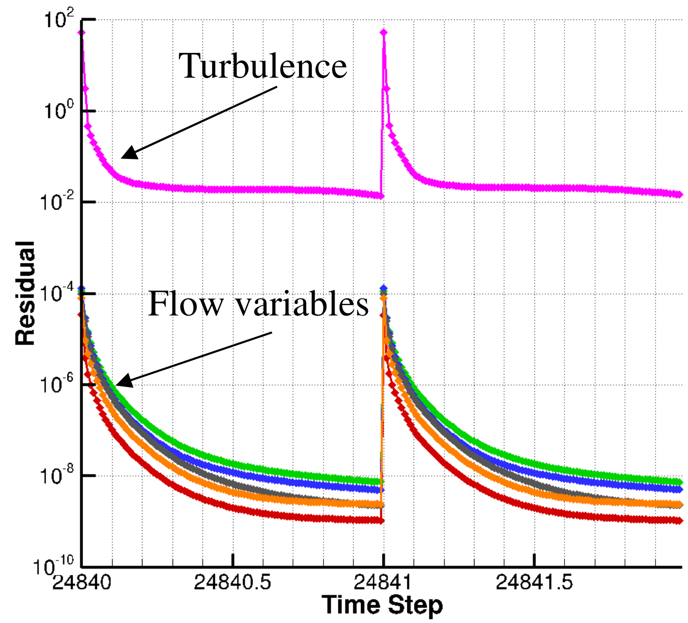
DT=10, 100 subiterations

Lift coefficient subiteration



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

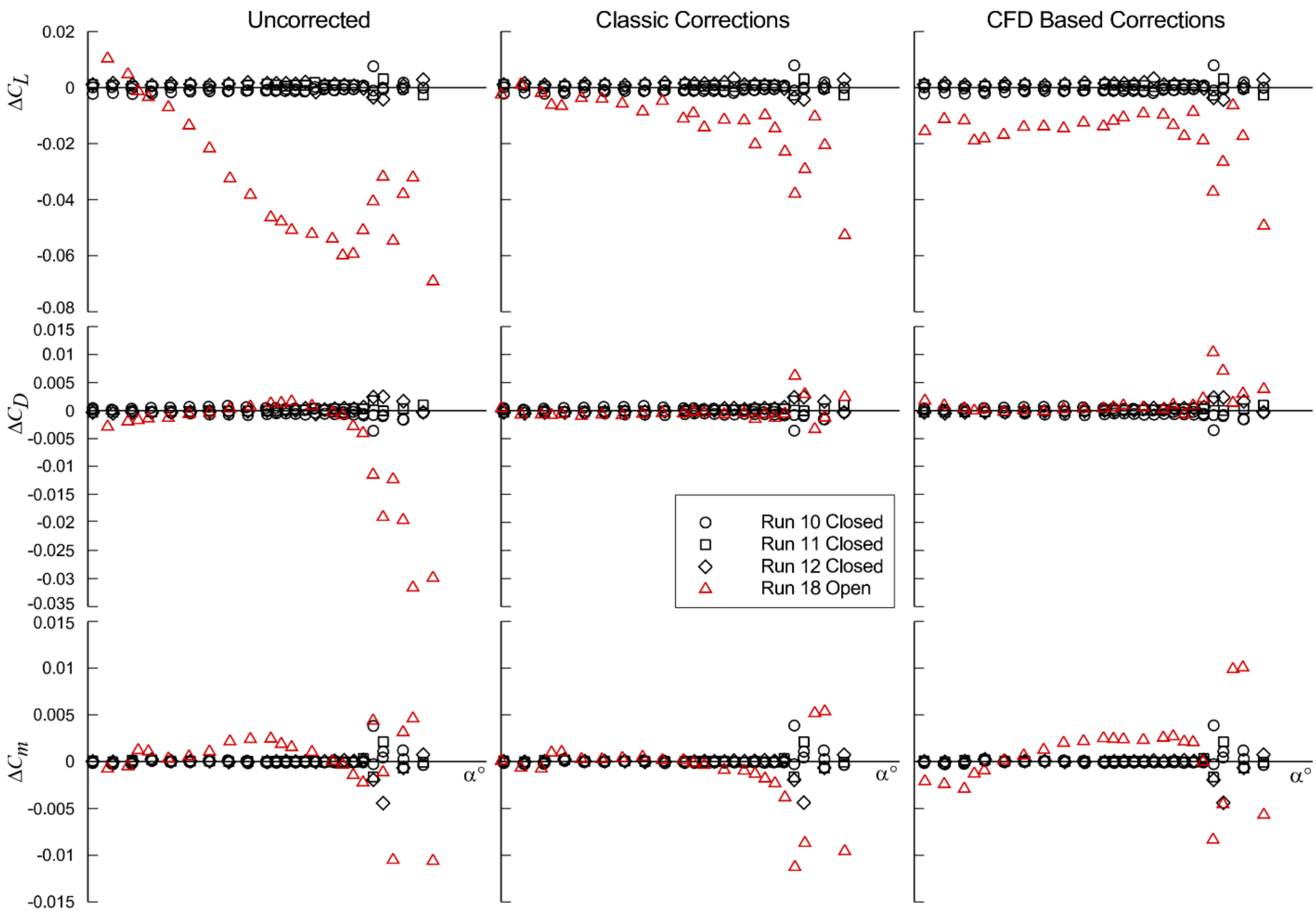
- The NASA ARMD Environmentally Responsible Aviation Project provided multi-year funding for both the wind tunnel testing and CFD analysis.
- Boeing support staff played an integral part in the success of the tests

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 mof 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_∞). 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*M_∞) 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.

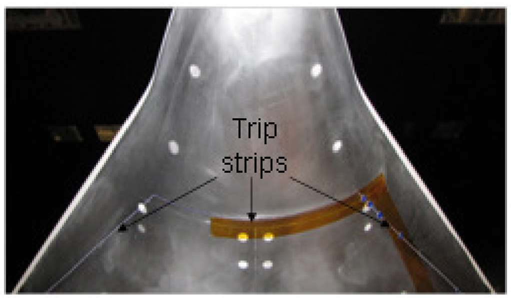
14'x22' Wind Tunnel Corrections

CFD Wind Tunnel Support

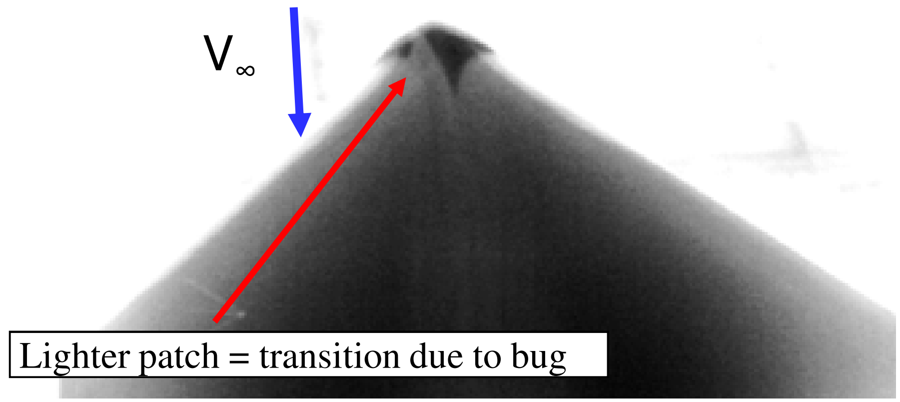


Trip dot selection

CFD Wind Tunnel Support



Upper Surface Thermal Imaging With Trip Dots



Upper Surface Thermal Imaging Without Trip Dots