CFL3D and FUN3D Analysis of HiLiftPW-1 Workshop Cases

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1st AIAA CFD High Lift Prediction Workshop (HiLiftPW-1)
Sponsored by the Applied Aerodynamics TC
Chicago, IL
June 27-27, 2010

CFD Code Descriptions

- CFL3D Structured-Grid Code
  - Thin-layer Navier-Stokes equations in all coordinate directions
  - Parallel 3D compressible cell-centered finite-volume RANS
  - Implicit local time-stepping using AF relaxation for linear system
  - Upwind Roe flux-difference splitting for inviscid fluxes
  - Spalart-Allmaras and SST turbulence models, fully-turbulent
- FUN3D Unstructured-Grid Code
  - Full Navier-Stokes equations-node centered
  - Parallel 3D compressible finite-volume RANS for mixed-element meshes
  - Implicit local time-stepping using multi-color point Gauss-Seidel relaxation for linear system
  - UMUSCL 0.5 scheme (Averaging + Upwind) for inviscid fluxes with Venkatakrishnan limiter
  - Combined Green-Gauss and edge-based gradients for viscous fluxes
  - Spalart-Allmaras turbulence model, fully-turbulent

Cases and Grids

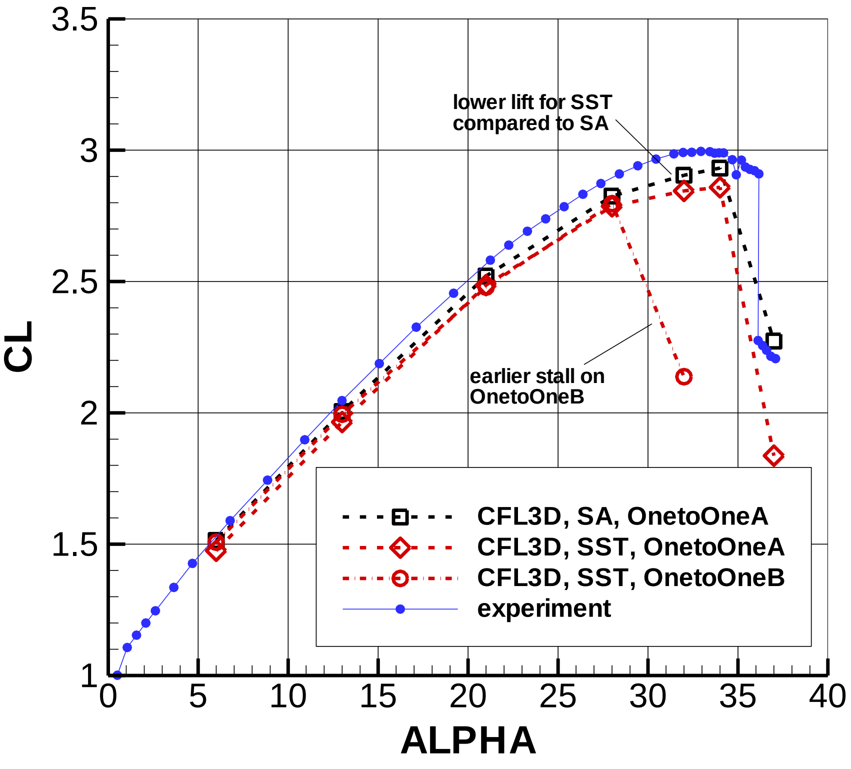
- Required Case 1 and Case 2
- Optional Case 3 not done

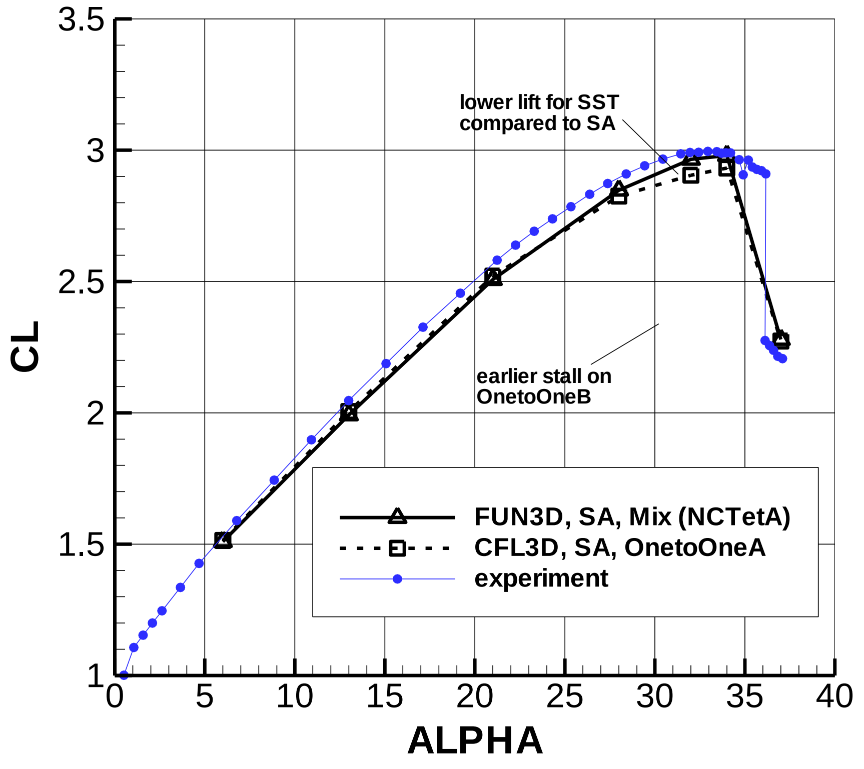
	Struct. 1 to 1 – A (Boeing)	Strut. 1 to 1 – B (Pointwise)	Unst. Tet NC - A (UWYO)	Unst. Mixed NC - B (DLR-Solar)
FUN3D			SA (Mixed)	SA (not finished)
CFL3D	SA SST	SST		

Comparison of Grid Sizes

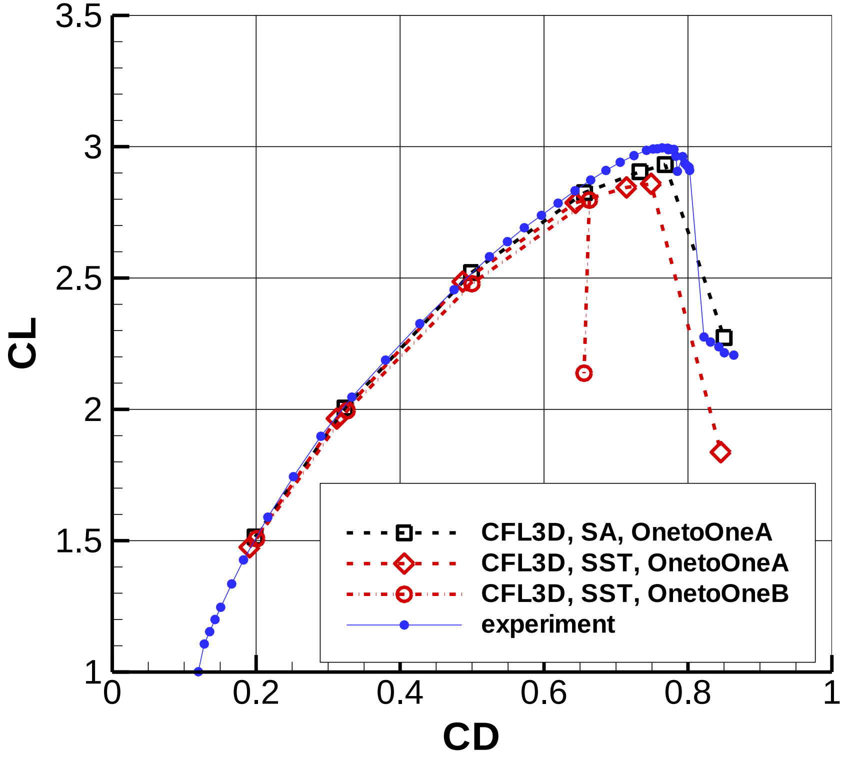
	Extra-Coarse	Coarse	Medium	Fine	Extra-Fine
Struct. 1-to-1 A Boeing	7.1M	22.6M	52.1M	171M	
Stuct. 1-to-1 B Pointwise	3.8M	11.2M	28.7M	85.5M	
Mixed ver. Unst. Tet. NC A VGRID		3.7M	11.0M	32.4M	
Mixed NC B Solar		12.3M	37.0M	111M	

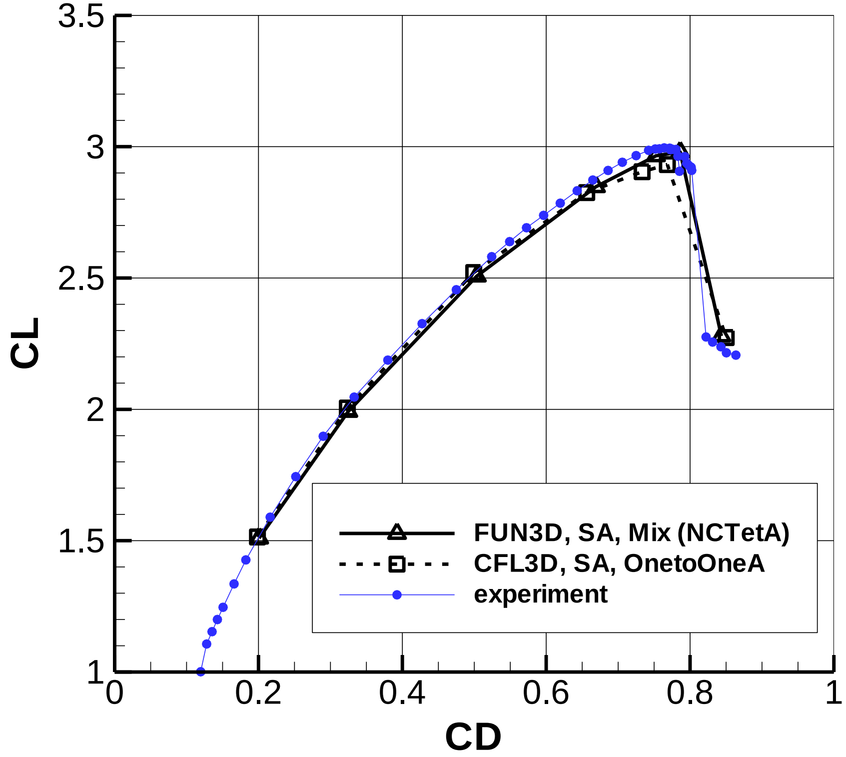
Configuration 1 – Lift Polar



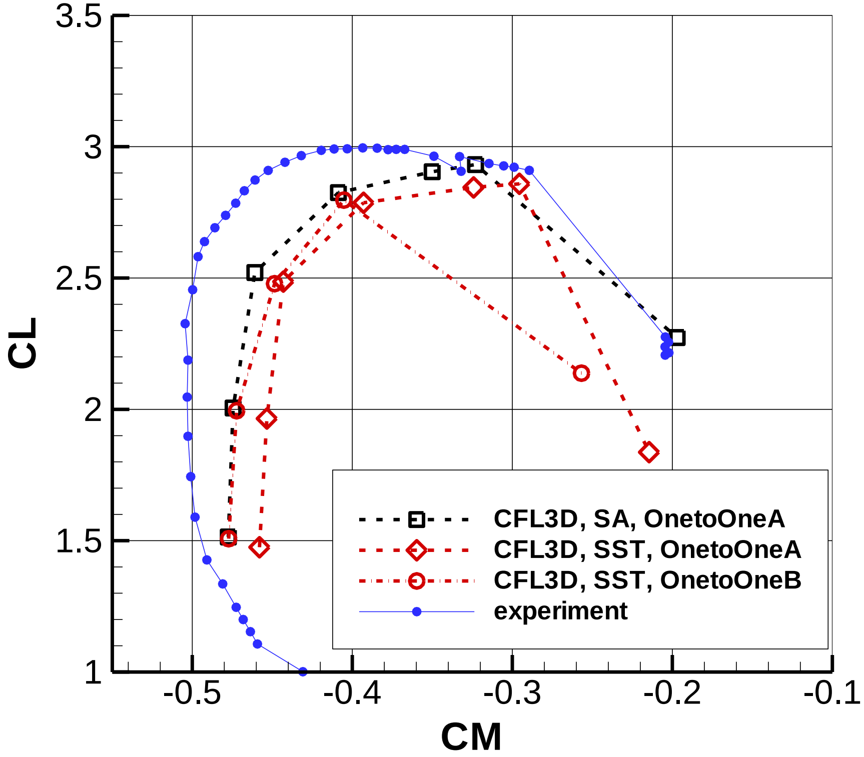


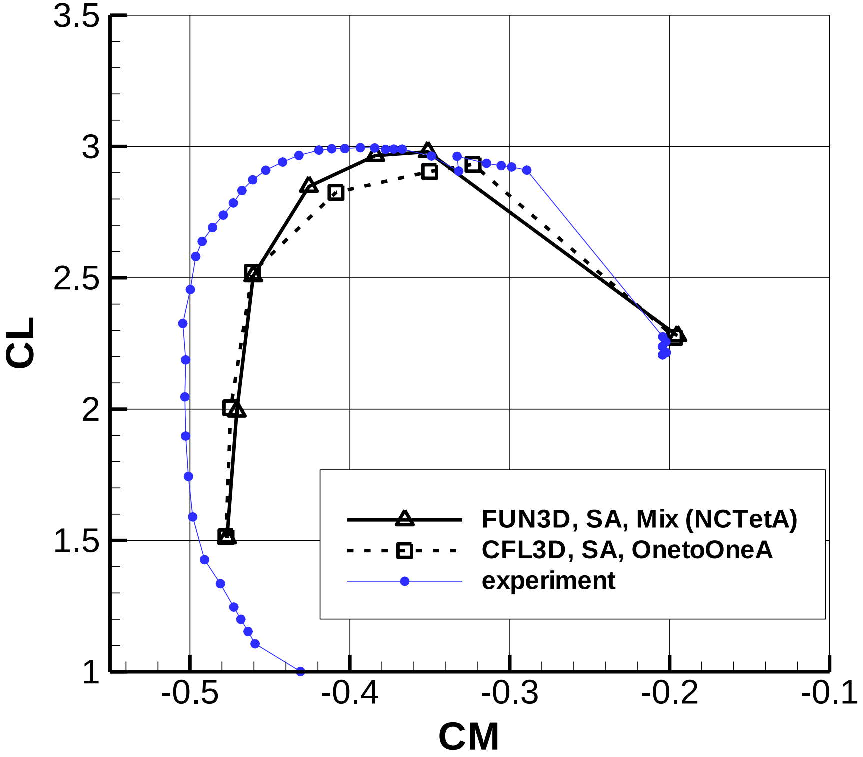
Configuration 1 – Drag Polar



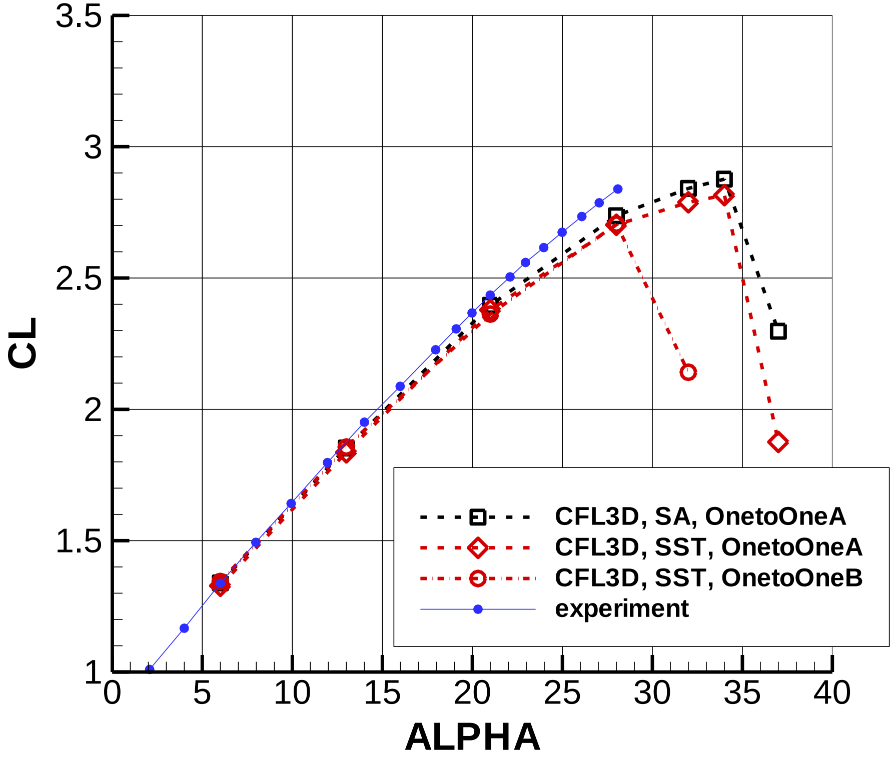


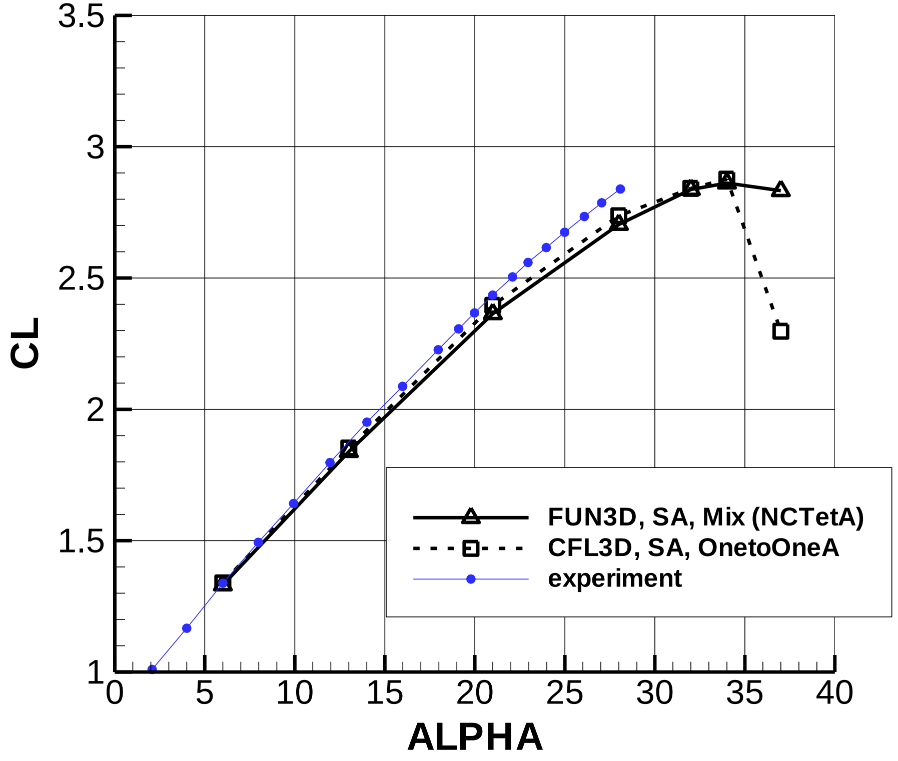
Config. 1 – Pitching Moment Polar



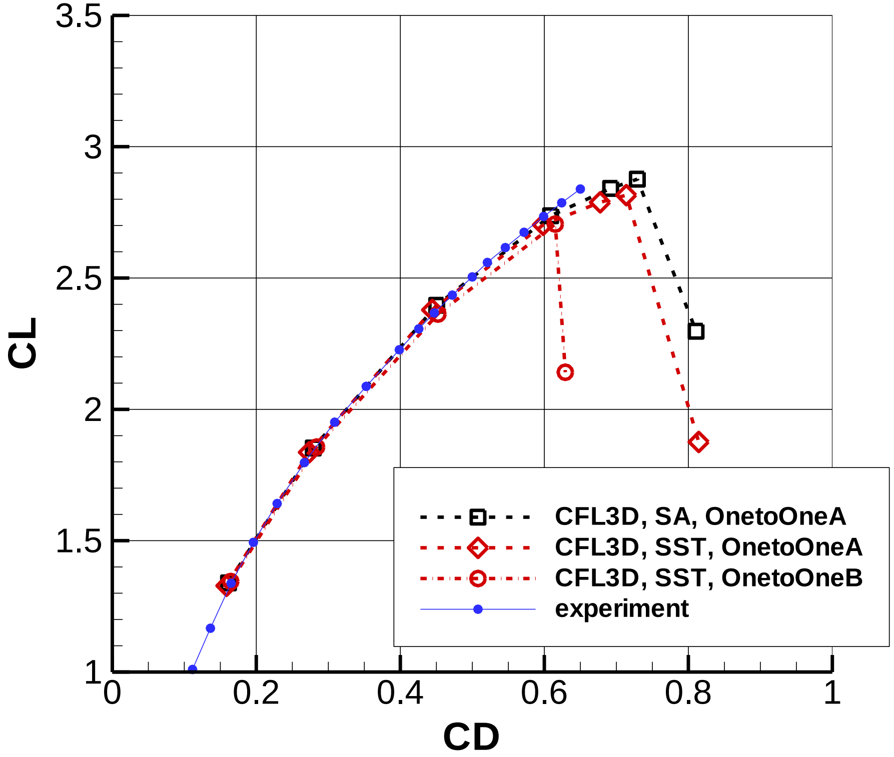


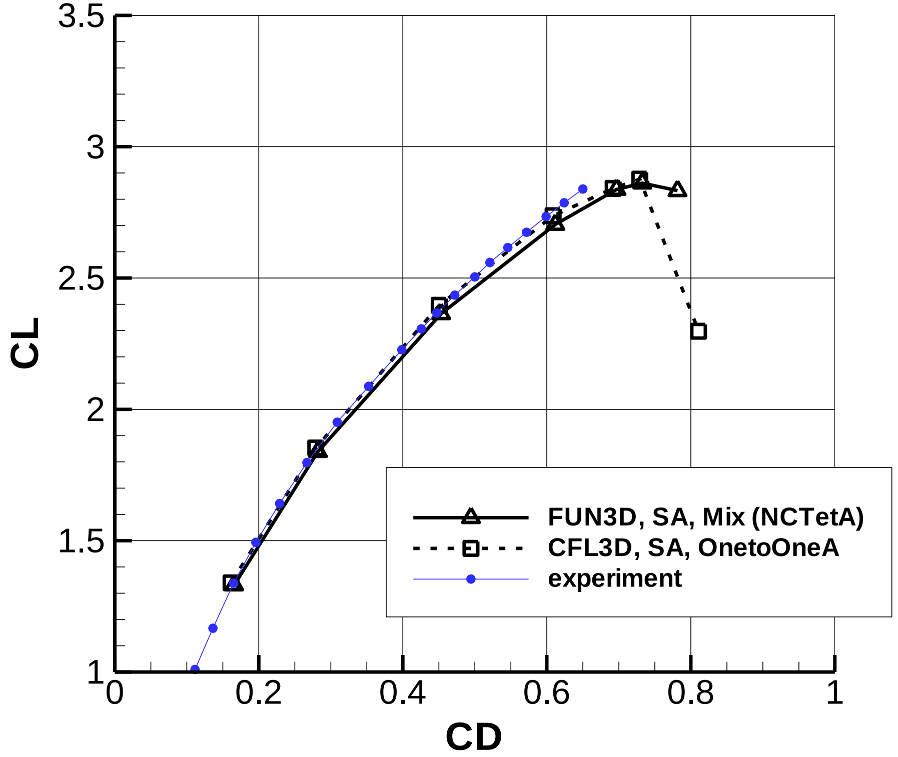
Configuration 8 – Lift Polar



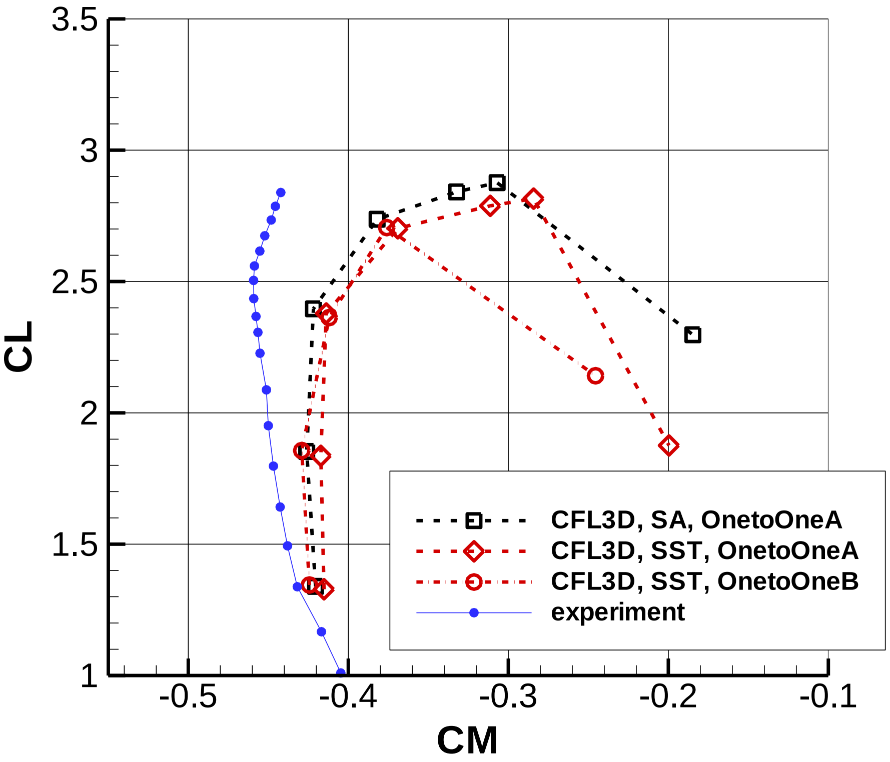


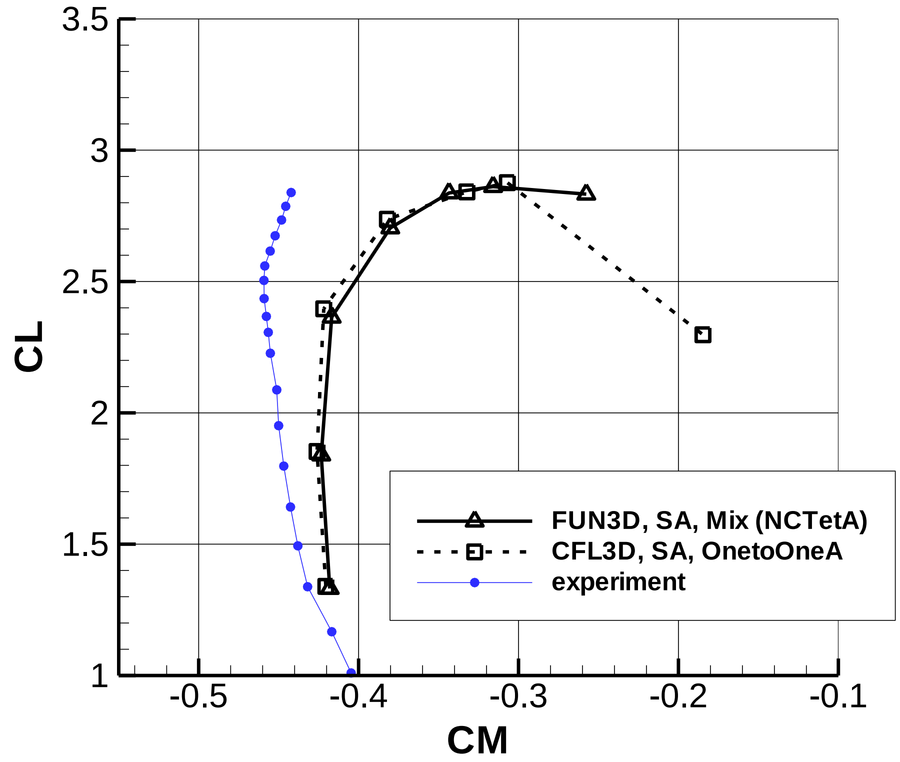
Configuration 8 – Drag Polar



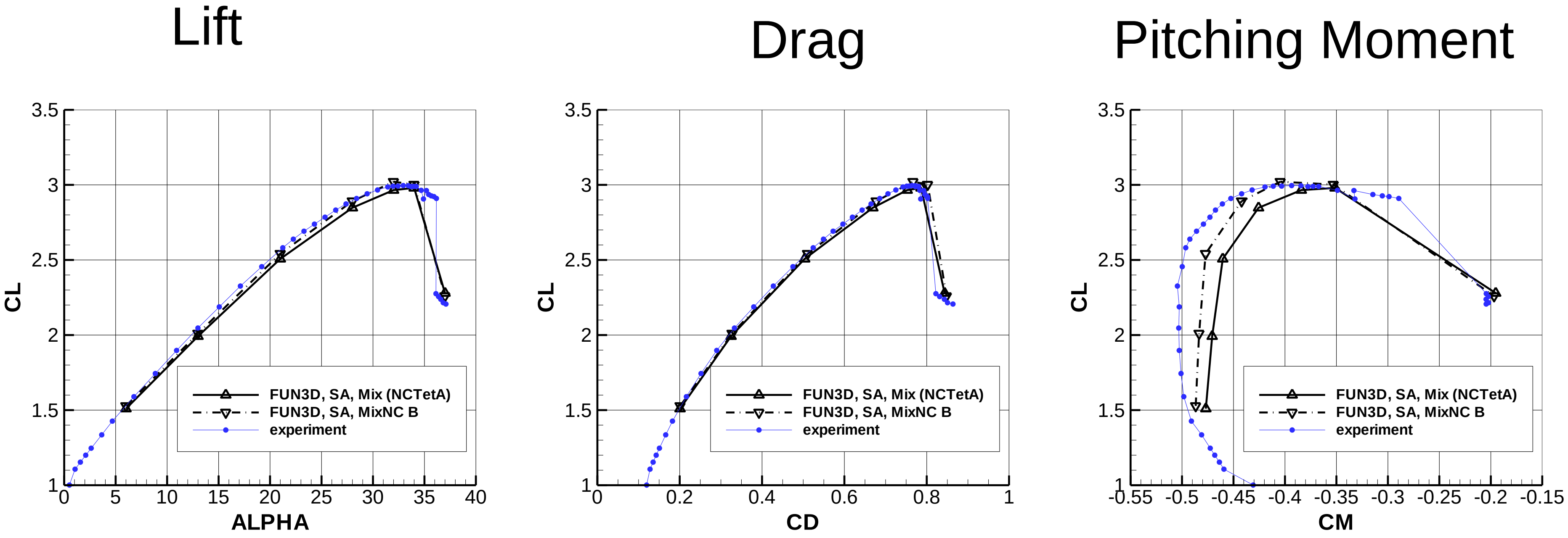


Config. 8 – Pitching Moment Polar





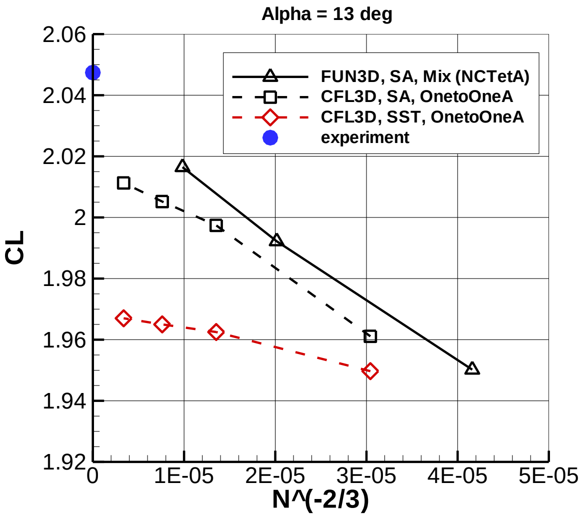
Configuration 1 – SOLAR Grids



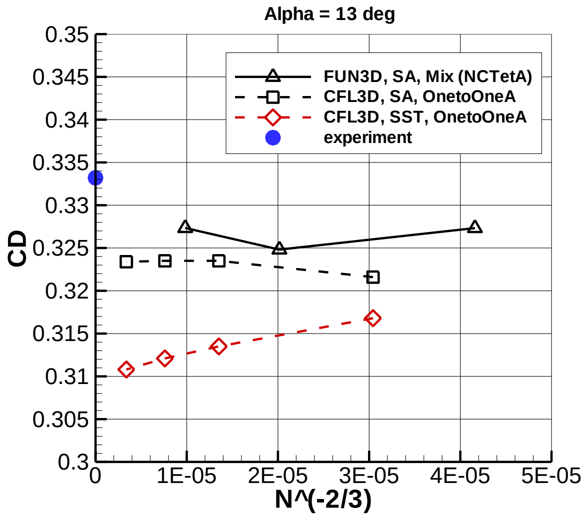
Grid Convergence – Config. 1

Angle of Attack 13 deg

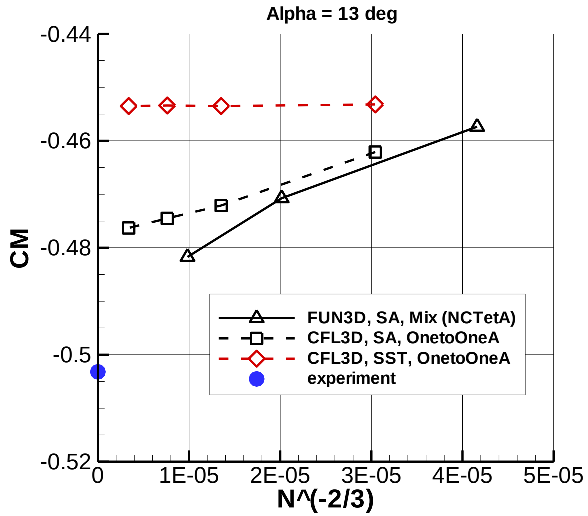
Lift



Drag



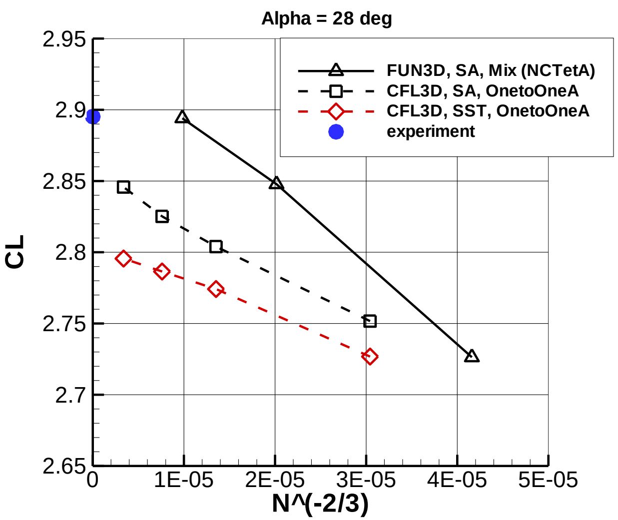
Pitching Moment



Grid Convergence – Config. 1

Angle of Attack 28 deg

Lift



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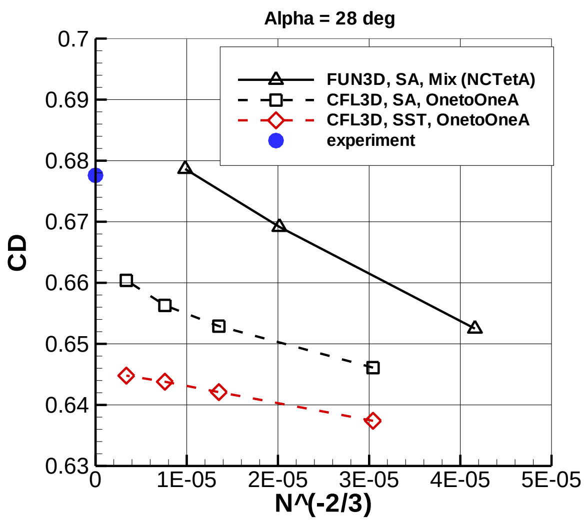
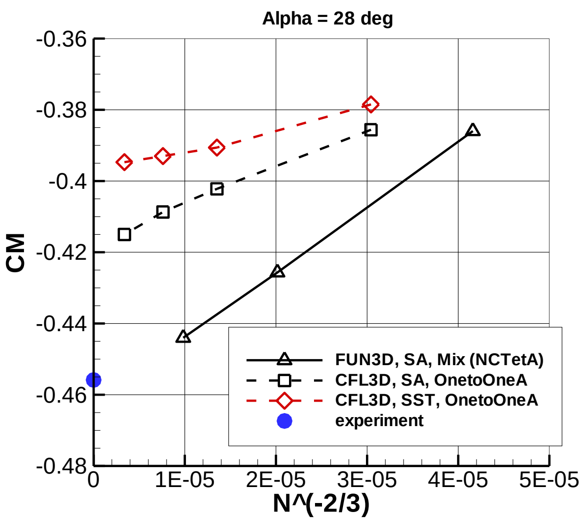
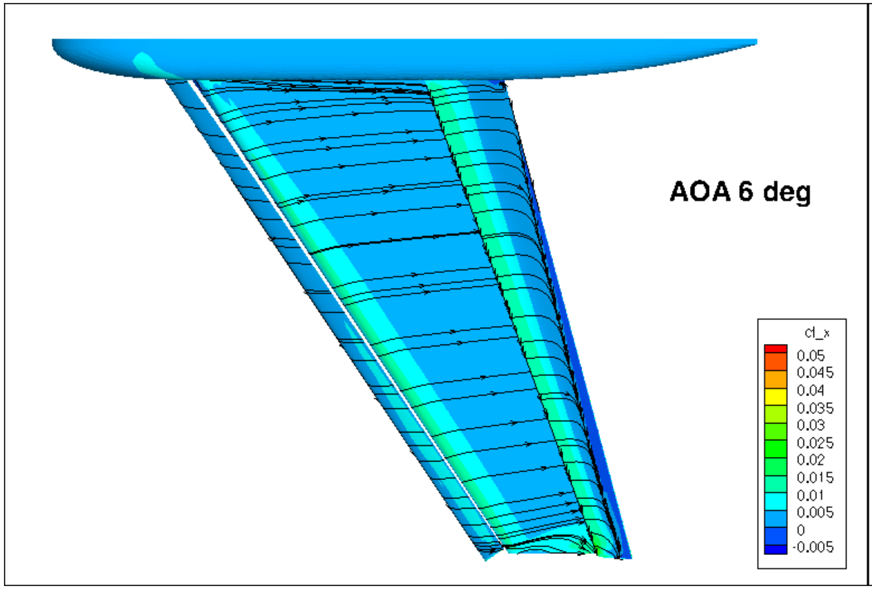
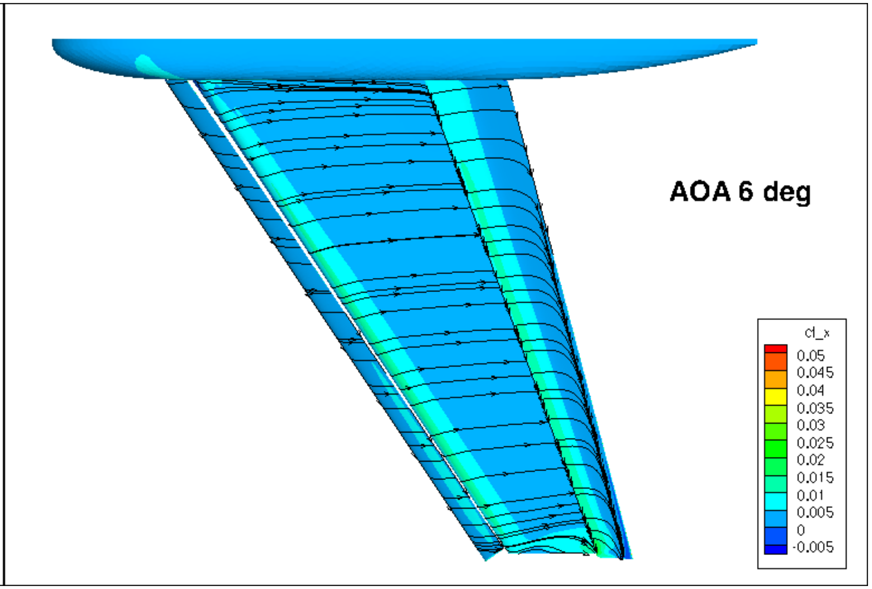


Pitching Moment



FUN3D Surface Restricted Streamlines



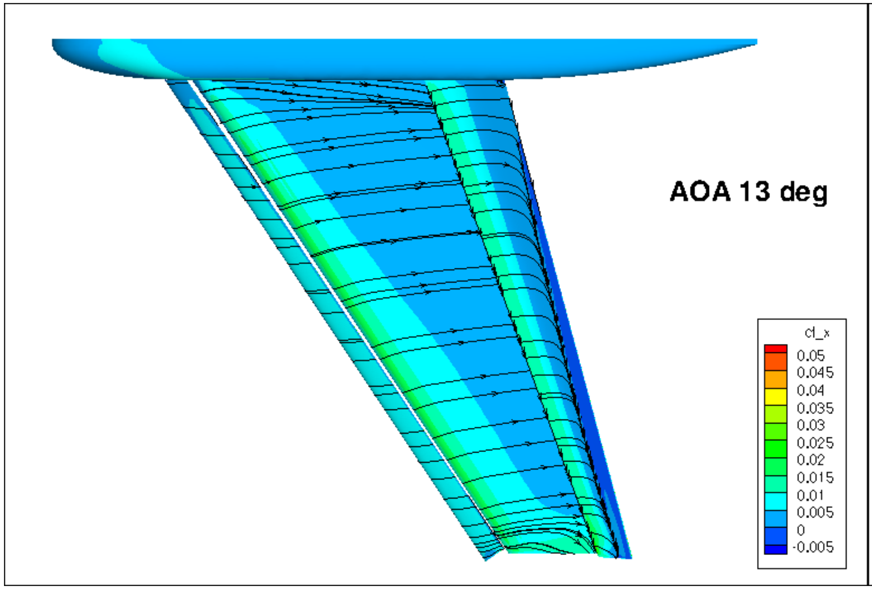


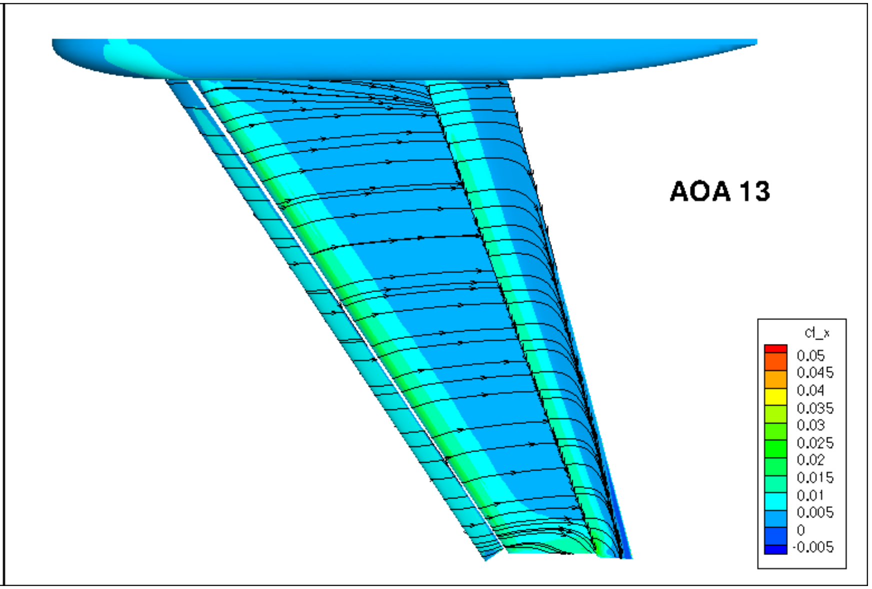
Config. 1

Config. 8

Medium Grid

FUN3D Surface Restricted Streamlines



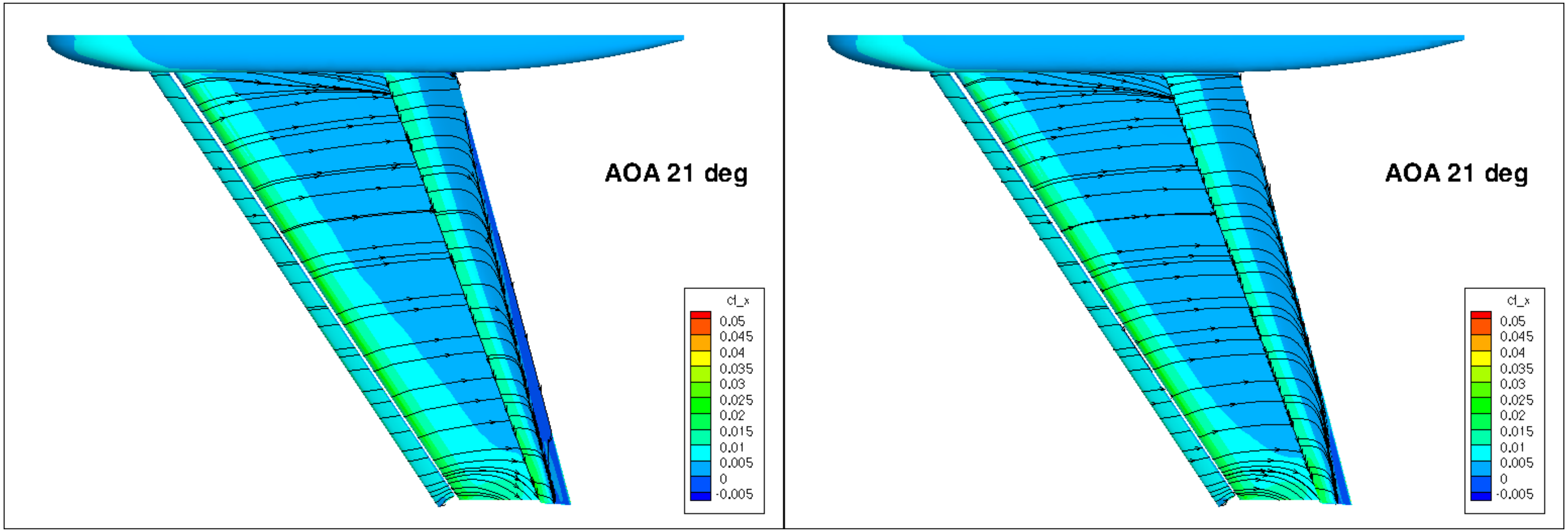


Config. 1

Config. 8

Medium Grid

FUN3D Surface Restricted Streamlines

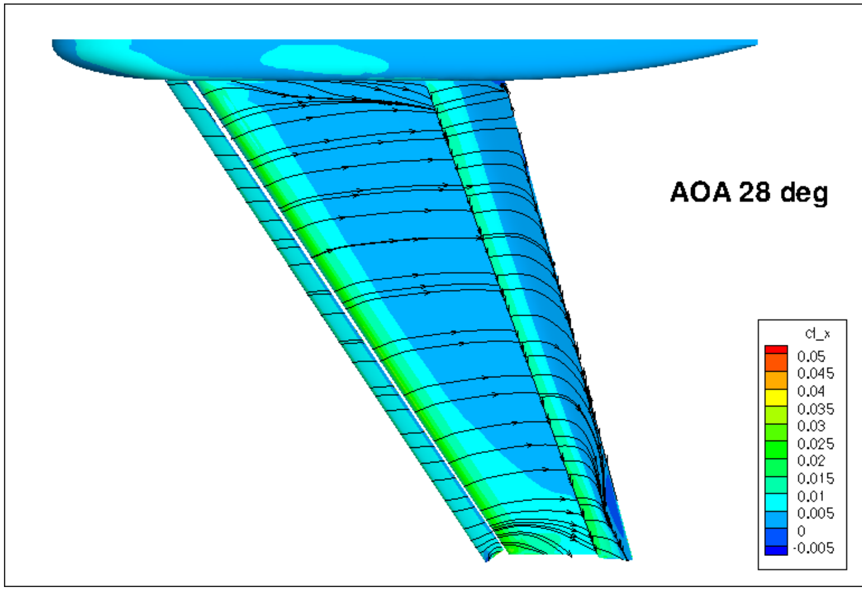


Config. 1

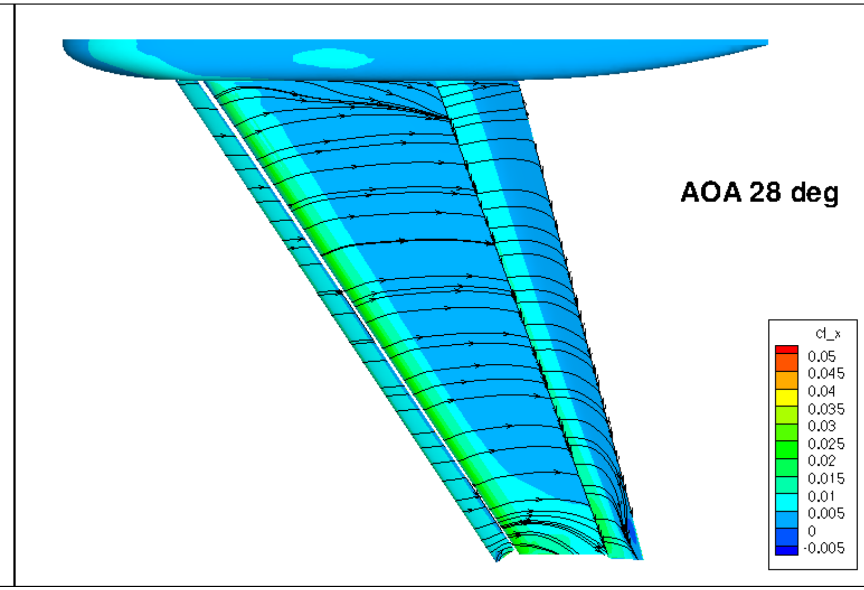
Config. 8

Medium Grid

FUN3D Surface Restricted Streamlines



Config. 1



Config. 8

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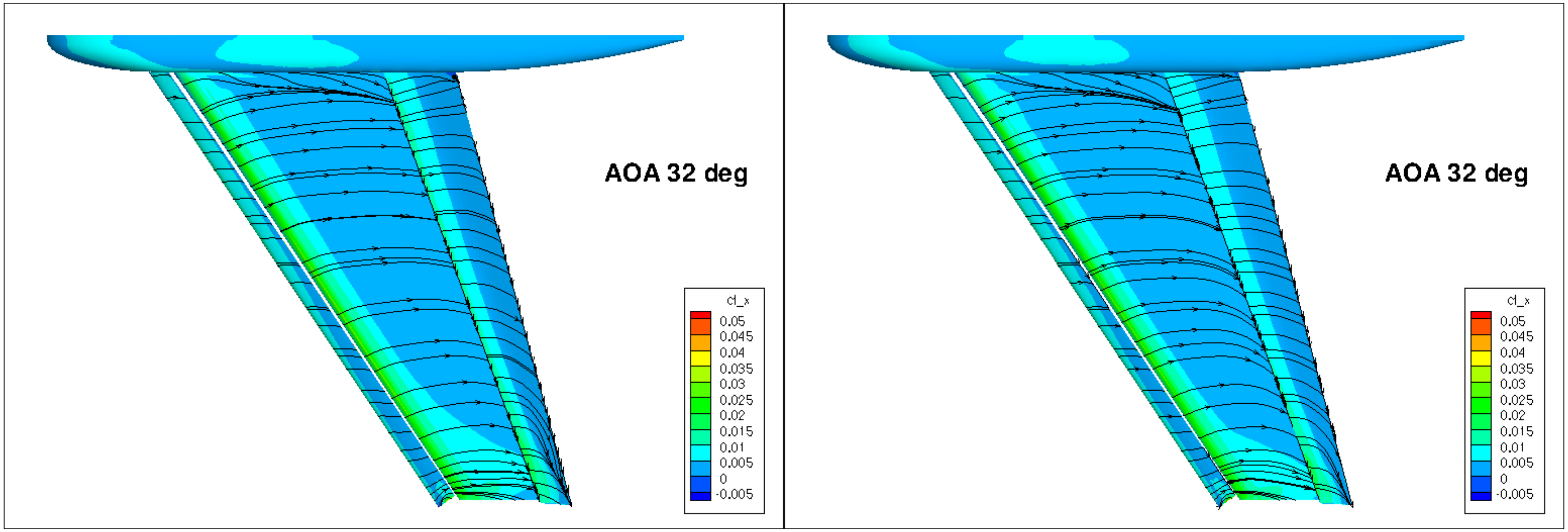
FUN3D Surface Restricted Streamlines

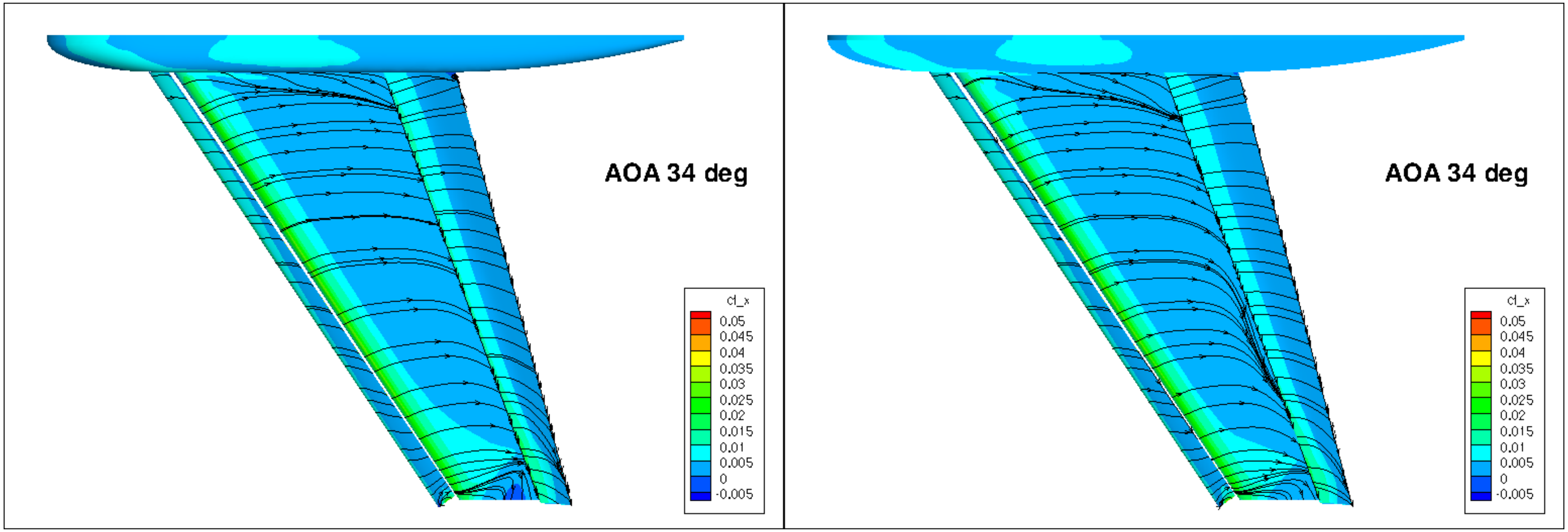


Config. 1

Config. 8

Medium Grid

FUN3D Surface Restricted Streamlines

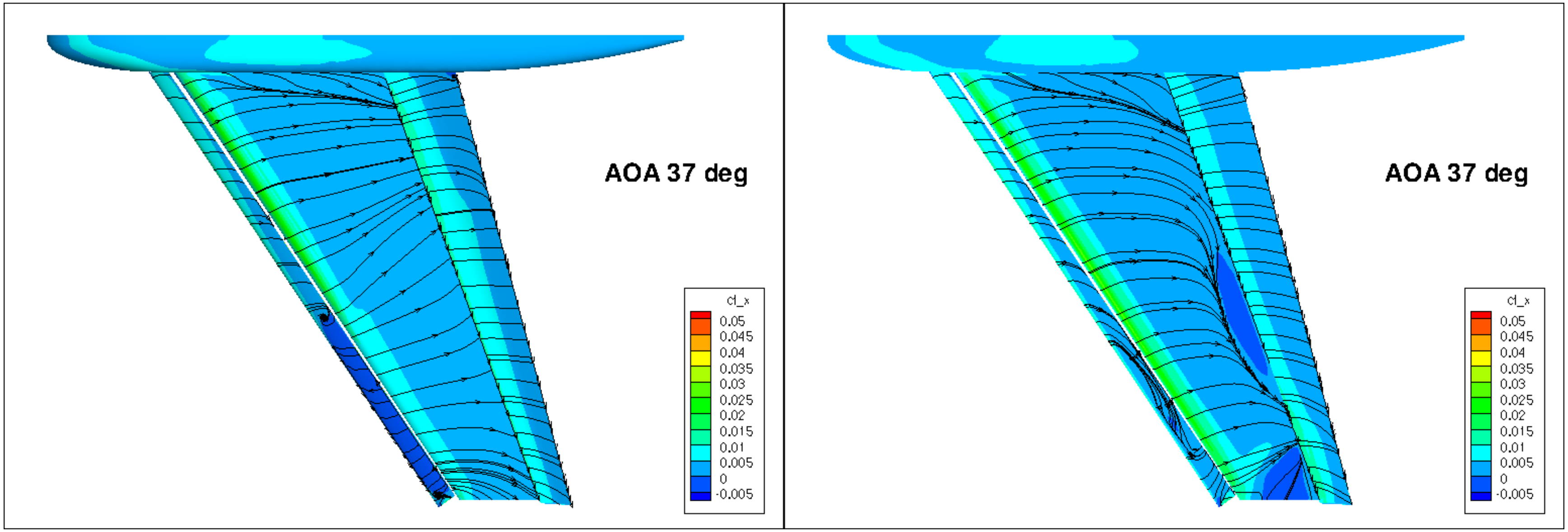


Config. 1

Config. 8

Medium Grid

FUN3D Surface Restricted Streamlines



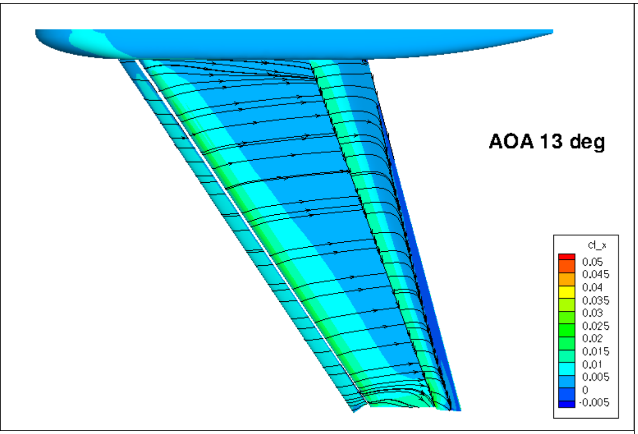
Config. 1

Config. 8

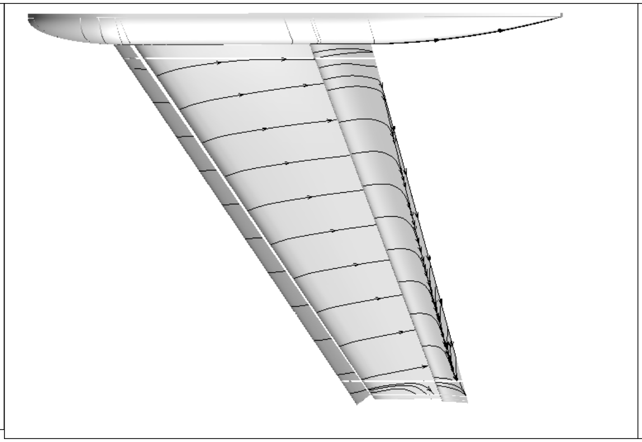
Medium Grid

FUN3D vs CFL3D Surface Flows –Config. 1

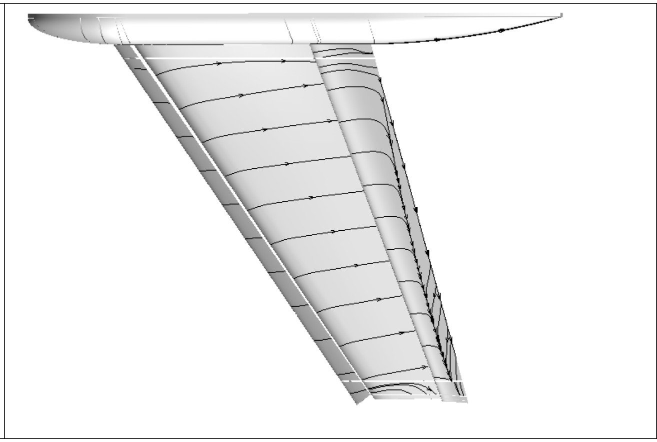
AOA 13 deg



FUN3D SA



CFL3D SA

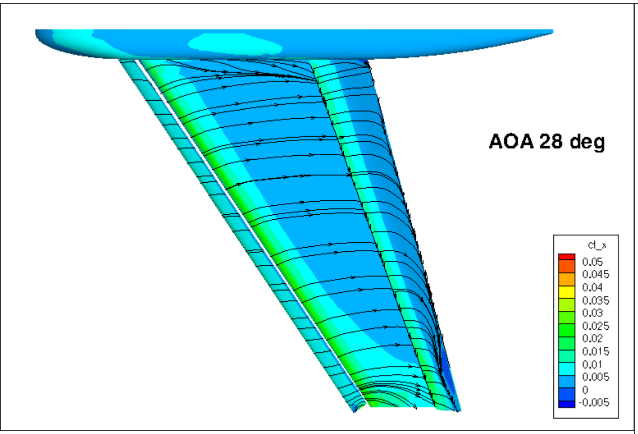


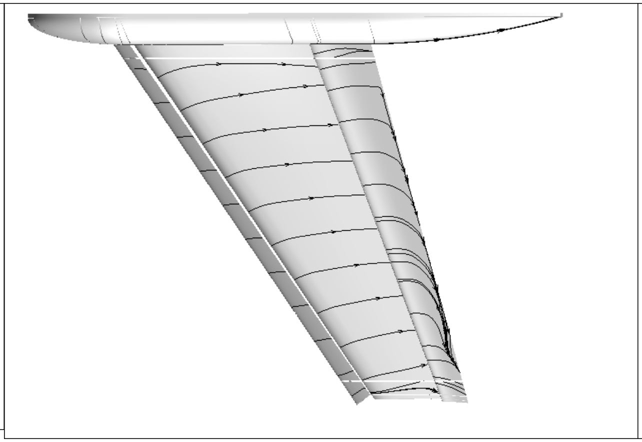
CFL3D SST

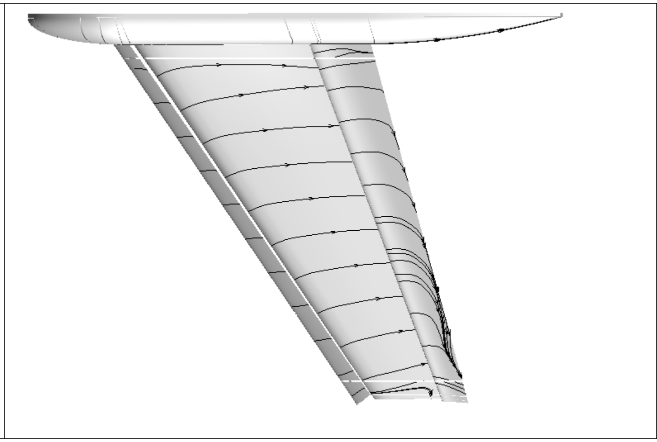
Medium Grid

FUN3D vs CFL3D Surface Flows –Config. 1

AOA 28 deg



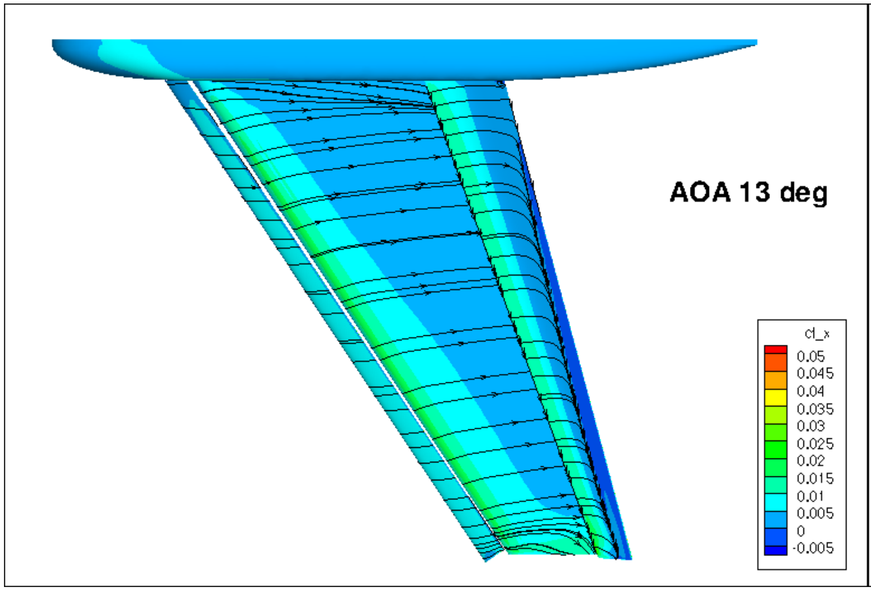


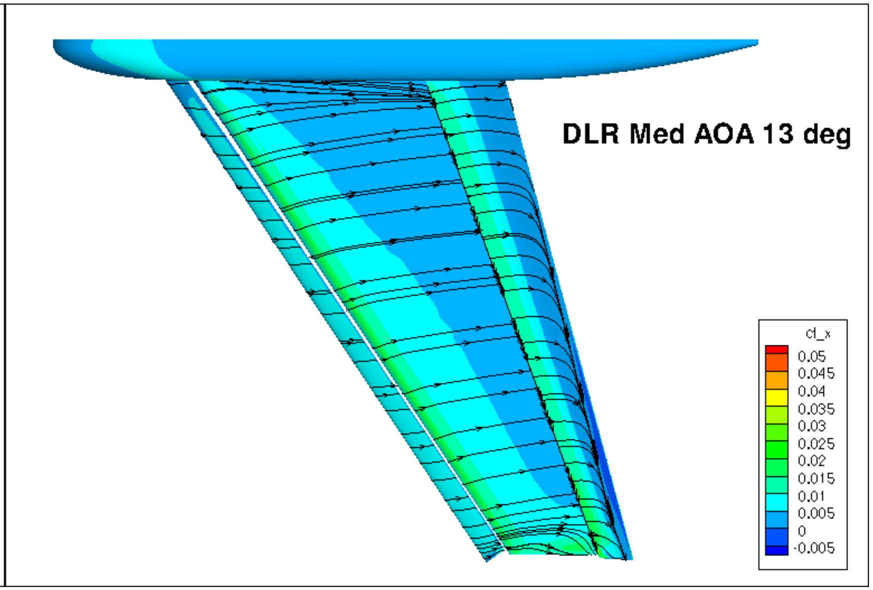


FUN3D SA CFL3D SA CFL3D SST

Medium Grid

FUN3D Config. 1





Tet NC A
(Mixed)

Mixed NC B

Medium Grid

Summary

- Grid convergence study
  - SST lower lift than SA (likely flap separation)
  - Struct. Grid and unst. Grid results with same turbulence model compare well
  - At higher alpha more difference between codes and more variation with grid refinement
- Flap study(medium grid)
  - Grid density/topology matters at highest AOA
    - One-to-one structured grid B seems to predict early stall
    - SOLAR grid results improved correlation at high AOA
  - Config. 1 has more flap separation than Config. 8
  - SST predicts more flap separation than SA
  - FUN3D predicts wing separation at highest AOA for Config. 8 (not seen in CFL3D solutions)

Acknowledgements

- Dr. Eric Nielsen, NASA LaRC
- Dana Hammond, NASA LaRC

HiLiftPW-1 - Rehearsal Background

Objectives

- Assess the numerical prediction capability (mesh, numerics, turbulence modeling, high-performance computing requirements, etc.) of current-generation CFD technology/codes for swept, medium/high-aspect ratio wings in landing/take-off (high-lift) configurations.
- Develop practical modeling guidelines for CFD prediction of high-lift flowfields.
- Advance the understanding of high-lift flow physics to enable development of more accurate prediction methods and tools.
- Enhance CFD prediction capability for practical high-lift aerodynamic design and optimization.
- Provide an impartial forum for evaluating the effectiveness of existing computer codes and modeling techniques.
- Identify areas needing additional research and development.

Focus

- The focus of this workshop will be on multi-element high-lift swept wing force, moment, and surface pressure prediction accuracy; a priori experimental data will be available for comparison.
- The NASA "Trap Wing" model will be studied.
- A statistical framework will be used to assess the CFD results.

HiLiftPW-1 – Trap Wing Model

HiLiftPW-1 - Rehearsal Background

- Case 1 : Grid convergence study (required)
  - Mach = 0.2
  - Angles-of-attack to be computed (deg) = 13 and 28
  - Reynolds number = 4.3 million based on mean aerodynamic chord (MAC)
  - Reference Temperature = 520 R
  - Trap Wing "Config 1" - Slat 30, Flap 25
  - Coarse, medium, fine and extra-fine (optional)
- Case 2: Flap deflection prediction study (required)
  - Mach = 0.2
  - Angles-of-attack to be computed (deg) = 6, 13, 21, 28, 32, 34, and 37
  - Reynolds number = 4.3 million based on MAC
  - Reference Temperature = 520 R
  - Medium Mesh from Grid Convergence Study
  - Trap Wing "Config 1" - Slat 30, Flap 25
  - Trap Wing "Config 8" - Slat 30, Flap 20
- Case 3: Flap and slat support effects study (optional)
  - Medium Mesh from Grid Convergence Study
  - Trap Wing "Config 1" - Slat 30, Flap 25

FUN3D Core Capabilities

- Solves 2D/3D steady and unsteady Euler and RANS equations on node-based mixed element grids for compressible and incompressible flows
- Used for numerous projects internal and external to NASA across the speed range
- General dynamic mesh capability: any combination of rigid/overset/morphing grids, including 6-DOF effects
- Aeroelastic modeling w/ mode shapes, full FEM, CC, etc
- Adjoint-based design optimization and mesh adaptation
- Linear scaling through 1000's of cores
- Capabilities fully integrated, large support team, online documentation, tutorials, etc